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**Hearing in various age groups of orchestral musicians and progression of hearing loss with increased number of years of music exposure**

**A thesis presented in partial fulfilment of the  
requirements for the degree of**

**Doctor of Philosophy**

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New Zealand**

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This project has been reviewed and approved by the Central Regional Ethics Committee- CEN/06/06/048. If you have any concerns about the conduct of this research, please contact Committee Administrator: Ms. Sonia Scott: C/- Ministry of Health, 1-3 The Terrace, POBox-5013, Wellington, T: (04) 4962405. Email to: [Sonia\\_Scott@moh.govt.nz](mailto:Sonia_Scott@moh.govt.nz)

## **Abstract**

In Orchestra musicians hearing plays a very important role, and slight alterations in their hearing will have a significant impact on their performance ability as musicians. Although the effect of orchestra music on hearing is documented, existing researches have several drawbacks, and in most studies measurement of musical sound exposure is not linked to audiological test results. Some variables that may have a significant influence on resulting hearing loss are not taken into consideration. The literature review shows a confusing picture, and some studies identify high-frequency notches suggestive of noise induced threshold shift while others suggest musicians' hearing levels are not significantly different from a non-exposed population. There are strict legal requirements for the daily noise exposure a worker can receive in workplace but nothing to regulate non-occupational noise and music exposure.

This research work sets out to study the effects of playing in an orchestra on various age groups of musicians, to identify important variables that may potentially contribute to resulting hearing loss, and how playing in an orchestra or a band affects children in particular. In this study 37 out of 61 adult musicians (61%), 19 out of 85 youth musicians (22%) and six out of 37 children musicians (16%) were found to have a hearing loss. The sound exposure measurements confirm that there is an increased risk for hearing loss of all ages and the majority of musicians are also exposed to high impulse noise with the peak level of above 140dB. There is a broad individual difference in sensitivity and vulnerability. It is often difficult to estimate total sound exposure for every musician. Individual susceptibility seems to depend on known and unknown factors and interaction between intrinsic and extrinsic factors. Personal ear protection devices are seldom used among the musicians. Hence this study stresses the importance of an individualised hearing conservation programme that includes identifying all potential variables/factors that may increase the risk.

This thesis addresses the development of hearing loss in orchestra musicians, audiological findings among players of different musical instruments, and methods of effective hearing conservation programmes for preventing hearing loss in musicians.

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# Glossary

## A

**Acoustics:** The science of sound, including its production transmission, reception and effects.

**Audiogram:** A standardised template or graph on which the hearing threshold of each ear is separately plotted as a function of frequency. Across the top horizontal axis the audible frequency bands are listed, and on the left axis, hearing threshold levels (in dB) in 10dB increments are listed (-10dB to 120dB hearing loss). The tracing is usually plotted by hand using the following convention: the red circles are joined by solid lines for the right ear and blue crosses are joined by dashed line for the left ear.

**Audiologist:** An audiologist is a healthcare professional specialising in identifying, diagnosing, treating and monitoring disorders of the auditory and vestibular system portions of the ear. Audiologists are trained to diagnose, manage and/or treat hearing or balance problems. They dispense hearing aids and recommend and map cochlear implants. They counsel families through a new diagnosis of hearing loss in infants, and help teach coping and compensation skills to late-deafened adults.

**Audiometry:** Pure tone audiometry is the measurement of the hearing threshold level of a person by a bilateral pure tone air conduction threshold test. The preferred method is based on the technique developed by Carhart and Jerker and later modified by Hughson and Westlake. The test is conducted by presenting a series of individual pure tones to the person (usually through headphones) in the audible frequency bands of 250, 500, 1000, 2,000, 4,000 and 8,000Hz. Tones are presented by a standardised procedure to determine the hearing threshold level in the particular frequency band. The results are presented in an audiogram.

**Asymmetry in hearing:** Significant difference in hearing between ears or significant inter-aural differences in hearing threshold sensitivity.

**Aural rehabilitation:** The process of identifying and diagnosing a hearing loss, providing different types of therapies to clients who are hearing impaired, and implementing different amplification devices to aid the client's hearing abilities. The goal of rehabilitation is to help the person to overcome the hearing handicap (disability).

**A-frequency weighting:** A network incorporated into a sound level meter to provide a simple measure of how loud a sound is perceived. A-frequency weighting has the response equal to the inverse of the equal loudness contour that passes through the 1000Hz at 30dB. Other frequency weightings such as B and C were developed, but now by international consensus and standardisation, A-frequency weighting is the weighting almost exclusively used for sound level measurement.

## C

**Cerumen or earwax:** It is a naturally occurring substance found in the human ear. Although there are subtle differences between the terms cerumen and earwax, they are used interchangeably. Specifically, when the ceruminous glands in the external ear secrete oils, the result is cerumen.

## D

**decibel:** The decibel (dB) is a unit used to measure sound intensity and other physical quantities. A decibel is one tenth of a bel (B). Its logarithmic scale is convenient to represent the entire range of human hearing.

**Dose:** The amount of noise exposure relative to the exposure limit for a working day and is stated as a percentage of the limit. In New Zealand, a noise dose of 100% is equivalent to 1 Pascal squared hour or an A-frequency weighted time-average level of 85dB over an 8-hour working day (LAeq 8h = 85dB).

**Dosimeter:** An integrating sound level meter of smaller size intended to be carried by the exposed person during the entire noise exposure period.

**Daily sound exposure:** The amount of sound energy a person receives in a day. For workers in industry it is the time integral of the squared instantaneous frequency weighted sound pressure over an 8-hour working day. The standard units are pascal squared seconds (Pa<sup>2</sup>s), but in industry it is more convenient to use pascal squared hours (Pa<sup>2</sup> h).

**Dips in the pure tone audiogram:** Exposure to broad band, steady noise, or noise with an impulsive component, the first sign was a dip or notch in the audiogram maximal at 4kHz with recovery at 6 and 8kHz. The notch broadens with increasing exposure, and may eventually become indistinguishable from the changes of aging (presbycusis), where the hearing shows a gradual deterioration at the high frequencies. Although 4kHz is the classic frequency affected, the notch may be noted elsewhere because the frequency range of the noise influences where the cochlear damage occurs.

## E

**Ear Infection:** An ear infection is usually defined as an inflammation of the middle ear, caused by bacteria, that occurs when fluid builds up behind the eardrum in the middle ear.

**Ear Protection Device (EPD):** Personal hearing protection devices are any type of ear protector that reduces the amount of volume perceived by the human ear, thereby preventing hearing damage in a loud environment. The three kinds of hearing protection are ear caps, earmuffs and ear plugs. The management of loud work environments, such as construction sites and shooting ranges, have a responsibility to ensure their employees are equipped with proper ear protection to prevent risk of hearing loss.

## F

**Frequency of sound:** As sound is generated by vibration of some sort, the frequency of sound is its number of vibrations per second. Frequency is measured in cycles per second, or Hertz (Hz). The higher the pitch of the sound, the higher the frequency. A low pitch such as a deep voice or a tuba makes fewer vibrations per second than a high voice or violin. Generally, noise induce hearing loss occurs at a pitch of about 2000-4000Hz.

## H

**Hair cells** are the sensory receptors of both the auditory system and the vestibular system in all vertebrates. In mammals the auditory hair cells are located within the organ of Corti on a thin basilar membrane in the cochlea of the inner ear. In mammals, cochlear hair cells come in two anatomically and functionally distinct types: the outer and inner hair cells. Damage to these hair cells results in decreased hearing sensitivity, which is called sensorineural hearing loss.

**Hearing loss:** Hearing loss is a reduced ability to hear sounds in comparison to normal hearing. Hearing loss ranges from slight to profound.

**Hearing threshold:** Hearing threshold is the sound level below which a person's ear is unable to detect any sound. For adults, 0dB is the reference level.

**Hearing Conservationist:** A certified occupational hearing conservationist "is a person who can conduct the practice of hearing conservation, including a pure-tone air conduction hearing evaluation and other associated duties under appropriate supervision, and who can function with other members of the occupational hearing conservation programme team."

**Hearing conservation programme:** It is a programme designed to prevent noise induced hearing loss. A written hearing conservation programme is required by New Zealand Health and Safety in employment whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level (TWA) of 80 decibels measured on the A scale (slow response) or, equivalently, a dose of 40 percent.

## I

**Individual susceptibility:** the marked variability in the manner in which individuals are affected by the same exposure to a toxic agent.

**Impulse Noise:** Impulse noise is often defined as noise consisting of single bursts with the duration of less than one tenth of a second.

**Integrating-averaging sound level meter:** An instrument that is used for measuring sound pressure level with standard frequency weighting components and a standard time averaging facility. These instruments are able to log, integrate and process data collected over a specified time period(s) to give values for a suite of standardised sound descriptors such as time-average level, peak level, maximum sound pressure level (in some instruments, exceedance levels and sound exposure levels depending

on usage) for the period sampled. In addition to giving numerical values for these parameters, many modern meters are produced with accompanying software to allow data to be downloaded to a computer for further processing and production of graphics such as time histories.

**Intensity of sound:** Intensity of sound is measured in decibels (dB). The scale runs from the faintest sound the human ear can detect, which is labelled 0dB, to over 180dB, the noise at a rocket pad during launch. Decibels are measured logarithmically, being 20 times the log of the ratio of a particular sound pressure to a reference value of  $20\mu\text{Pa}$ .

**ISO (International Organization for Standardization):** The world's largest developer and publisher of International Standards. It is a non-governmental organisation that forms a link between the public and private sectors. ISO is a network of the national standards institutes of 162 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system. It enables a consensus to be reached on solutions that meet both the requirements of business and the broader needs of society.

## L

**Leq:** See Time Average Level below.

**L<sub>avg</sub>:** A metric for monitoring noise proposed by US Occupational Safety and Health Administration (OSHA) standard. The  $L_{\text{avg}}$  is based on the premise that damage accrued in the ear during periods of high noise is partially repaired during intermittent low noise periods.

**L<sub>Peak</sub>:** peak sound pressure: The level of the highest instantaneous sound pressure, in decibels, that occurs during a given time period.

## M

**Maximum A-frequency weighted sound pressure level (L<sub>Amax</sub>):** This is 10 times the logarithm to the base 10 of the square of the ratio of the maximum sound pressure, to the reference value  $20\mu\text{Pa}$ . This is an RMS value and must not be confused with the peak level ( $L_{\text{peak}}$ ), a non-RMS value.

**Mismatch Negativity (MMN):** It is defined as a component of the event-related potential (ERP) to an odd stimulus in a sequence of stimuli. It arises from electrical activity in the brain and is studied within the field of cognitive neuroscience and psychology. It can occur in any sensory system, but has frequently been studied for audition and for vision.

**Music Induced Hearing loss (MIHL):** Hearing loss due to excessive, unprotected exposures to loud music. This includes listening to an MP3 player, attending a rock concert, or playing an instrument in an orchestra or band. Also refers to exposures to high volume of music over time that can cause permanent damage.

## N

**Noise:** In a narrow sense, noise can be considered as unwanted sound and refers to cases where the potentially affected person is not intentionally listening. In a broader sense, noise is often used as a synonym for sound.

**Noise Induced Hearing loss:** Noise induced hearing loss is a permanent hearing impairment resulting from prolonged exposure to high levels of noise. One in 10 people in New Zealand has a hearing loss that affects his or her ability to understand normal speech. Excessive noise exposure is the most common cause of hearing loss.

## O

**Occupational Safety and Health Administration (OSHA):** OSHA is an agency of the US government (under the Department of Labour) with the responsibility of ensuring safety at work and a healthful work environment.

**Octave bands:** The division of the audible frequency range into a standardised series of adjacent frequency bands where the upper frequency is twice the lower frequency. Each of these bands can be further divided into one-third octave band frequencies.

**Orchestra:** Is a group of instrumental ensemble that contains sections of string, brass, woodwind and percussion instruments. The orchestra grew by accretion throughout the 18th and 19th centuries, but changed little in composition during the course of the 20th century.

**Orchestra pit:** Is the area that is located in a lowered area in front of or under the stage, in which musicians perform. The conductor is typically positioned at the front of the orchestral pit facing the stage.

**Oto-acoustic emissions (OAEs):** Sounds made by our inner ear as it works to extract the information from sound to pass on to the brain. These biological sounds are a natural by-product of this energetic biological process and their existence provides us with a valuable 'window' on the mechanism of hearing, allowing us to detect the first signs of deafness – even in newborn babies. Distortion Product Oto-acoustic Emission or dual-tone evoked distortion product is produced from an ear during the non-linear amplification of sound energy in the cochlea.

**Otolaryngology:** Study of medical and surgical management and treatment of patients with diseases and disorders of the ear, nose, throat (ENT), and related structures of the head and neck. They are commonly referred to as ENT department.

**Otoscopy:** It is a visual inspection of the ear drum and the auditory canal.

## P

**Patho-Psychology:** It is a study of the biological and physical manifestations of disease as they correlate with the underlying abnormalities and physiological disturbances.

**Peak level ( $L_{\text{peak}}$ ):** The peak level, expressed in decibels, is 10 times the logarithm, to base 10 of the square of the ratio of the peak sound pressure to the reference value  $20\mu\text{Pa}$ . It is a non-RMS value and should not be confused with  $L_{\text{Amax}}$ . It has no frequency weighting, but to limit the measurement to sound in the audio-frequency range, a 'Z' weighting is used to provide a cut off at high and at low frequencies. A 'C' weighting is often used if no 'Z' weighting is provided on the sound level meter and is stipulated in some standards. In New Zealand it is measured according to NZS 6801:1999 Acoustics – the measurement of sound.

**Perilymph:** The fluid between the bony and membranous labyrinths of the ear.

**Presbycusis:** The sensorineural hearing deterioration associated with age.

**Permanent threshold shift:** Permanent threshold shift is a permanent loss of hearing and can occur with regular exposure to excessive noise for long periods of time. It can also occur with exposure to very high sound levels for a short period of time. This type of hearing loss will normally continue to increase for up to five years after exposure to the noise.

## S

**Signal-to-noise ratio (SNR):** The signal level minus the noise level (dB).

**Sound exposure:** The time integral of the squared instantaneous frequency weighted sound pressure over a specified time interval or event. The standard units are in pascal squared seconds ( $\text{Pa}^2\text{s}$ ) but can also be quoted in pascal squared hours ( $\text{Pa}^2\text{h}$ ).

**Sound level meter:** An instrument to measure the sound pressure level in decibels (dB), and complying with either or both IEC 60651 or IEC 61672.

**Sound pressure level ( $L_{\text{p}}$ ):** Expressed in decibels is ten times the logarithm of the square of the ratio of the frequency weighted and time weighted sound pressure level to the reference value  $20\mu\text{Pa}$ .

**Standard deviation (SD):** It is a statistical value used to determine how spread out the data in a sample is, and how close individual data points are to the mean, or average value of the sample.

## T

**Tone:** Sound that has a definite pitch. Any given tone is characterised by length, loudness, timbre, and a characteristic pattern of onset and decay.

**Tinnitus:** Tinnitus is a condition in which a person hears a ringing, buzzing or hissing sound which is caused by the hearing system itself and not by any external sources. Tinnitus can be temporary or persistent and is relatively widespread. It is often associated with hearing impairment, ageing or exposure to loud sounds, and generally involves the part of the nervous system that deals with hearing.

**Threshold of hearing:** This is the minimum sound pressure level for a specific sound that can evoke an auditory response.

**Time-average level ( $L_{Aeq\ t}$ ):** The value of the A-frequency weighted sound pressure level of a continuous steady sound that, within a measurement sample time (t), has the same mean square sound pressure as the sound under investigation whose level varies with time. The time period for every LAeq measurement should be stated.

**Temporary threshold shift (TTS):** The temporary raising of the hearing threshold level after exposure to loud sound.

**Threshold of pain:** The minimum sound pressure level of a specified sound, which will give a definite sensation of pain (for a given individual).

**Transient oto-acoustic emissions (TOAEs):** Sounds emitted in response to an acoustic stimulus of very short duration; usually these are clicks, but they can be tone-bursts.

**Tympanometry:** A technique designed to measure the response of the middle ear to sound energy and provides quantitative information on the function and presence of fluid in the middle ear.

## W

**Weighting:** This refers to the effect on a signal of electronic circuits that modify the signal in a standardised manner. Frequency weighting refers to modifiers of frequency response. Time weighting refers to modifiers of the integration time.

**WHO:** The World Health Organization.

## **Chapter 1 : Introduction**

Noise is an inescapable part of modern life. The World Health Organization has already identified it as a serious health issue (WHO-PDH, (1997). Noise and music induced hearing loss is a global phenomenon. One's ears seem to age faster with noise exposure, and many who are so exposed are likely to lose their hearing in their thirties instead of their sixties (Shafer, 2006). My team of audiologists is seeing in younger people the kind of hearing loss that was typically found in aging adults. Given the serious health and social consequences of hearing impairment, its increasing prevalence is cause for concern (Wallhagen, Strawbridge, Cohen, & Kaplan, 1997). The NIOSH Committee to Review Hearing Loss Research Program (ISO, 2006) recommended that there should be greater funding and effort allocated in prevention of hearing loss than waiting for people to lose their hearing and then provide rehabilitation.

According to National Institute on Deafness and Communication Disorder (NIDCD 2008), individuals of all ages, including children, adolescents, young adults, and older people, can develop Noise Induced Hearing loss (NIHL) while exposed to intense sounds in the workplace, in recreational settings, or at home. Among the working population who could be affected by NIHL, members of professional symphony orchestras are a specific group (Jansen, Helleman, Dreschler, & de Laat, 2008). Although it is assumed that amplified musical performances are loud, musical instruments and voices also reach high intensity levels. A soprano can sing at 115dBA, a tuba or violin can reach 110dBA, and a trumpet 111dBA. Maximum sound levels in student practice rooms have been measured at 110dBA and higher (Phillips, Shoemaker, Mace & Hodges, 2008).

Gradual hearing loss caused by continuous loud music exposure is called music induced hearing loss (MIHL) (Einhorn, 2006). Review of the audiological literature clearly indicates that noise/music induced hearing loss occurs among musicians (Axelsson & Lindgren, 1978; Royster, J., Royster, L. H., & Killion, 1991; Mikl, 1995; Eaton & Gillis (2002); Kahari, Zachau, Eklöf, & Mölle, 2004; and Emmerich<sup>1</sup>, Rohmann<sup>1</sup>, Bormann<sup>1</sup>, Richter<sup>1</sup>, & Huonker, 2006) with varying incidences ranging

up to 58% in classical musicians and up to 30% in rock/pop musicians. In addition, studies show that musicians are exposed to sound levels in potentially hazardous ranges, extending up to 120-130dBA only three feet from the speaker in amplified rock/pop bands (Axelsson & Lindgren, 1978), 83-112dBA on stage in various orchestras (Ostri, Eller, Dahlin, & Skylv, 1989) and 80-101dBA, on stage in jazz, blues, and country and western bands (Kahari, Zachau, Eklof, Sandsjo & Moller, 2003). According to Einhorn (2006), these levels, and the fact that many musicians practise or perform 4-8 hours a day, suggest a strong causal relationship between their chronic loud music exposure and music induced hearing loss. The implications of hearing loss are important for all of us, but they are of particular importance to musicians. Musicians' hearing requirements, as related to their livelihoods, are much greater than those of other professions, and their hearing-related injuries can become severe disabilities, or even career-ending.

Musicians and non-musicians alike are susceptible to work-related hearing damage from sound, but unlike other professions (Backus, Bradford & Williamon, 2009), the sound musicians innovatively create is not a by-product of their own occupation – it is their product (Chasin, 1996). Although studies have detailed noise exposure in the workplace for many professions (Taylor, Pearson, Mair & Burns, 1965), relatively little is known about the sound exposure in musicians receive or the effect this “noise” has on musicians' hearing (Fearn, 1976; Royster et al, 1991; Lee, Behar, Kunov & Wong, 2003).

Musicians in orchestras are exposed to high sound levels that depend on the specific location and instrumental group within the orchestra. Noise induced hearing loss strongly relates to the average daily sound exposure influenced by different circumstances. Besides hearing loss, annoyance and functional limitations due to high sound exposure for certain orchestra members, caused by instruments of colleagues, is an important practical issue (Boasson, 2002).

The issue of whether musicians tend to have NIHL has been debated for a long time. There is a continued general debate about possible hearing loss and tinnitus among musicians. It has been argued that hearing loss and tinnitus are the natural and inevitable results of playing in an orchestra. Investigations from the literature show

that as no clear hearing loss risk is seen (Bremmelgaard & Obeling, 1996). Some investigations show a risk of hearing loss (Axelsson & Lindgren, 1981; Karlsson, Lundquist & Olausson, 1983; Johnson, Sherman, Aldridge & Lorraine, 1985, Royster et al., 1991), while others do not show a risk (Lipscomb, 1976; Axelsson & Lindgren (1981), Axelsson, Eliasson & Israelsson, 1995). The risk is partly dependent on the type of orchestra (symphony or rock band). Generally, it seems that the noise limits that are set for noise in industry may not be correct in relation to the risk of hearing loss from music (Obeling & Poulsen, 1999).

The risk of orchestra musicians' hearing depends on many factors, but more importantly, it depends on their instrument, the composition being played, seating arrangements and physical location within their orchestras, involvement in other music groups, and other types of noise exposure (Schmidt et al., 2011). Typical sound levels in string sections are 86-91dBA, 90-94dBA in woodwind sections, 83-94dBA in brass sections, and up to 98dBA in percussion sections (Lataye, Campo & Loquet, 2000; Lebo & Oliphant, 1968). Musicians are also exposed to very high sound levels during personal and group rehearsals, and are likely to spend considerably more time during rehearsals (individual and group) than in performances. The total amount of noise exposure indicates the likelihood of an elevated risk of noise induced hearing loss (Laitinen, Toppila, Olkinuora, & Kuisma, 2003).

There is a difference between noise and sound. For example, people consider loud music to be 'good' sound, where more volume adds to the enjoyment (Serra et al., 2005). This is in contrast to, say, industrial noise, which is generally seen as a 'bad' sound where more volume is undesirable (Crandell, Mills & Gauthier, 2004).

According Behar, Wong and Kunov (2006), the very nature of music is not frequently found in the industrial environment, where frequency and sound levels change constantly in a non-cyclical manner; the duration of the exposure changes from day to day. A performance programme is rehearsed a number of times, with frequent interruptions and repetitions, and then the piece is performed once, twice (in the case of a symphonic orchestra), or several times (in the case of an opera or ballet). The cycle of rehearsals and performances is then repeated with a completely different

programme. Therefore, the very concept of a sound exposure, repeated day after day, (as commonly found in industry) cannot be easily applied to this case.

Despite a high level of sound exposure and a fairly large selection of earplugs available, musicians have been reported to seldom use personal hearing protectors. The support and determination to get musicians accustomed to using hearing protectors are important factors in hearing conservation (Huttunen, Sivonen & Poyykko, 2011).

With the increased risk of hearing loss, tinnitus, and other symptoms with increased music exposure, the use of hearing protectors would seem to be justified. Musicians have reported that the main reason for using hearing protection is a fear of hearing loss and tinnitus (Laitinen et al., 2003). They have also indicated that they used them to avoid pain, to protect their ears from fatigue, to decrease stress, irritation, and due to existing hearing loss and tinnitus (Toppila, Pyykko & Stark, 2011). However, it seems that for many of the musicians, the reported problems created by wearing hearing-protection devices, e.g. their having a significant effect on the musicians' performances and making errors, were worse than their fears of hearing loss, a factor which limits their usage of such devices (Laitinen 2005). Musicians have reported that having existing hearing loss makes the use of hearing protectors especially difficult (Toppila et al., 2011).

Hearing losses are critical to a musician who must correctly perceive and produce the accurate pitch, loudness, timbre, tempo and style of a musical piece (Phillips et al., 2008). While for non-musicians the critical frequency range for speech perception is 250 to 4000Hz, musicians must be able to discriminate specific frequencies over a much broader frequency range. The range for a piano is 16 to 8000Hz, and for the pipe organ, up to 17,000Hz (Phillips et al., 2008). Psychological issues related to hearing difficulties may also be present (McBride, Gill, Proops, Harrington, Gardiner, & Attwell, 1992; Chasin, 1999; Zembower, 2000; and Kahari, Axelsson, Hellstrom & Zachau, 2001).

Hearing is vital for musicians in performance, and significant hearing loss could be very distressing for anyone in this situation, particularly if it has the potential to affect

their livelihood. Musicians are fully dependent on their hearing for their profession, and they are frequently exposed to loud music. Besides, they have a complicated relation to preventive measures, such as wearing ear muffs or using protective screens, as these may be accompanied by the loss of subtle effects that are necessary to play music and interact with fellow musicians (Jansen et al., 2008). Given that the musician's ear is the most valuable instrument for every musician, every effort to preserve their hearing is vital.

## **1.1 Aims**

The aim of this study is to examine all we know about musicians' hearing loss and what we do not know about it. This research project has a broad aim of providing greater understanding of the effects of music on hearing health of musicians, and that will in turn help in planning preventive measures and strategies to minimise hearing damage. For this purpose we have performed analysis of information obtained from case history, complete audiological evaluation, and sound level measurements during rehearsal and performance along with personal sound exposures received by the musicians, and we performed analysis of hearing loss development with increased number of years to music exposure.

The aims of this study include:

- 1) Detailed comparative analysis of various audiological findings in various age groups of orchestral musicians.
- 2) Music survey, which was planned for the purpose of risk analysis by measuring sound exposure of various age groups of orchestral musicians in comparison to the damage risk criteria and existing research findings. The measured sound exposure could then be compared with the damage risk criterion.
- 3) For the purpose of assessing the effect of long-term exposure of the orchestra music on musicians' hearing, and to study the hearing loss development in musicians with increased music exposure, there would be analysis of audiological evaluation performed over a number of years, and hearing loss development or progression assessed in different instrumental musicians.

- 4) In order to find the factors that may have influence on increasing the risk of hearing loss among musicians, it was planned to investigate other factors such as: family history of hearing loss, history of ear infections, usage of personal stereos history of other noise exposure, regular visits to loud music venues and school discos, and general awareness of music induced hearing loss.
- 5) Also planned was detailed analysis of the usage of ear protecting devices among various age group of orchestral musicians, and the reasons for not using the ear protecting devices on a regular basis.
- 6) This research project was also designed with the aim to identify various strategies and measures that can be taken to prevent noise levels, and their effects on musicians' hearing.

## **1.2 Thesis Outline**

The thesis is presented in the subsequent 13 chapters, and the references and appendices are included at the end. They are as follows:

**1 Introduction:** This chapter gives a brief outline on the important issues of noise induced hearing loss in musicians. This chapter also includes aims of the study.

**2 Hearing loss-Overview:** A brief outline on hearing loss, and issues surrounding hearing problems in the general population.

**3 Anatomy and Physiology of Human Ear:** The anatomy and physiology of the human ear and hearing mechanisms are discussed in detail. This chapter also includes the patho-physiology of the auditory system, and conditions and disorders that give rise to noise induced hearing loss.

**4 Studies on noise and hearing loss in musicians – A literature review:** This chapter presents a comprehensive review of key literature involving musicians and their hearing, with key material from international studies so that comparison could be made with this work.

**5 Studies on factors that influence music induced hearing loss in orchestra musicians:** A comprehensive review of literature on various factors that have been identified to have influence on initiation and progression of noise induced hearing loss, and also the factors that are reported to have influence on music induced hearing loss.

**6 Rationale/Justification of the Research Project, Conceptual Framework, Study Design and Unanswered/Research Questions:** This chapter includes a number of unanswered questions that have been identified after the review of literature. It also includes the conceptual frame work provided with the rationale/justification of the research project. The chapter also includes the study design.

**7 Research methods:** This chapter presents the experimental investigations undertaken, the equipment and/or tools used, and the noise descriptors/criteria measured.

**8 Results – audiological evaluations performed on various age groups of musicians:** This chapter presents the results of various types of audiological evaluations performed on various age groups of musicians, and the results are presented in various sections.

**9 Results – longitudinal analysis of hearing loss development:** This chapter reports on the analysis of audiological evaluation performed over a number of years and hearing loss development or progression or deterioration with increasing number of years to music exposure.

**10 Results of personal sound exposures of musicians and fixed time-average levels taken:** This chapter reports on sound pressure levels measured during rehearsal and concert performance by fixed sound level meters and personal sound exposure meters (doseBadges) fitted to the clothing of individual musicians.

**11 Discussion:** The results of the full study are summarised and discussed. Pertinent findings are highlighted with recommendations suggested for further consideration.

There is also a section on original contribution to knowledge and limitation to this study.

**12 Conclusions:** This chapter summarises all the findings from this study.

**13 Recommendations:** This chapter summarises various recommendations that could be used to mitigate hearing loss among musicians.

**References:** This section includes all the references cited in this thesis. They are listed in alphabetical order.

**Appendices:** In appendices A to K, the special conditions and requirements of the Central Regional Ethics Committee are listed. This also includes case history forms used on adults and children, and information sheets used in this study to obtain approvals from various group of musicians, the development of a noise measurement plan, and sample monitoring reports.

## **Chapter 2 : Hearing loss – Overview**

### **2.1 Introduction**

Communication skills are central to a successful life for all individuals. Communication difficulties caused by hearing loss greatly affect education, employment, and the well-being of many individuals. Each day is a challenge for many individuals with a hearing loss – and also for their families (National Institute on Deafness and Other Communication Disorders, 2003). According to the Hearing Health Progress Review (Health People, 2010), every year numerous deaf or hearing-impaired newborns, children, teenagers, adults, and older individuals must adjust their lives so they can successfully live in a world that depends upon hearing. Causes of deafness or hearing loss include: genetics, noise or trauma, sensitivity to certain drugs or medications, aging, and viral or bacterial infections. The impact of hearing loss, however, needlessly reduces the productivity and quality of life of those affected, as well as all of society.

After World War II, the significant effect of noise upon the inner ear became more seriously recognised. After that, the information and documentation increased, resulting in the passing of the major regulations/standards e.g., Occupational Safety and Health Act (OSHA) in 1971. This act has had a major impact upon industrial control of noise levels, and indeed, on society's interest in compensation. Even today, the adverse effects of noise and music upon hearing remain a major and serious problem. This is mainly due to the following factors:

- The very nature of noise/music induced hearing loss (hearing loss happens gradually and the signs are subtle at first).
- Our own built-in defences and ability to adapt make it difficult to self-diagnose.
- Ever-increasing popularity of amplified and un-amplified music.
- Lack of legislation governing non-occupational noise/music exposure.
- The lack of use of individual ear protection.
- The popularity of personal stereos and,

- Music being an aspect of today's youth culture, and its being a means of creating an identity for many young people.

Hearing loss is one of the leading and fastest growing serious disabilities in our modern society. Today, hearing loss is a common problem due to the combined effects of noise, aging, disease, and heredity. According to estimates by the World Health Organization (WHO, 2002), 278 million people worldwide have moderate to profound hearing loss in both ears. The incidence of hearing loss is reported to be increasing with age. Approximately 31.4% of people over age 65, and 40% to 50% of people 75 and older, have a hearing loss. Only one out of five people who could benefit from hearing aids actually wears one (Natalizia et al., 2010). According to the American Speech, Language and Hearing Association in October 2006, the number of Americans with a hearing loss has doubled during the past 30 years.

Hearing experts believe that the average level of human ear sensitivity is being altered because of noise exposure (Concha-Barrientos, Campbell-Lendrum & Steenland, 2004). According to the Royal National Institute for the Deaf in the UK (RNID) in 2003, hearing loss is on the increase and younger people are becoming hard of hearing. The New Zealand Ministry of Social Development document prepared in 2002 indicates that hearing loss greatly affects education, social, employment, and the well-being of many New Zealanders. However, each day is a challenge for many who have a hearing loss. Most people are quite unconcerned about their hearing. Even a minimal hearing loss is not inconsequential (Kochkin, 2005).

According to the Hearing Health Progress Review (Health People, 2010), deaf or hearing-impaired individuals can function with their hearing peers, making untold contributions to the nation's economy and well-being. However, the key to success for these individuals is early identification, evaluation, and appropriate intervention and rehabilitation.

## **2.2 Hearing Evaluation and Rehabilitation**

Increasing numbers of New Zealanders are experiencing a gradual reduction in hearing during their adult years. There are many studies indicating that men are more frequently affected in the 35 to 60 year old age group now, as compared to previous decades (Wallhagen et al., 1997). Because the change is often gradual and subtle, few are aware of the hearing loss until it becomes difficult to manage (Stoffel & Hatch, 2011).

According to US National Center for Health Statistics 2010, only 29 percent of adults in the age range of 20 to 69 years of age have had their hearing tested in five years. According to Health Hearing 2010, regular hearing testing would likely improve identification, intervention, productivity, and quality of life of an individual. The American Speech, Language and Hearing Association (1997) recommends adult hearing screening at least every decade until age 50, with more frequent monitoring after 50 years of age.

The nation's elderly are especially vulnerable to hearing impairment. Presbycusis, the loss of hearing associated with aging, affects about 30 percent of adults who are age 65 years or older and about half of those over age 75 (Gates, Cooper, Kannel & Miller, 1990), and (Cruickshanks, Wiley, Tweed, Klein & Klein, 1998). As the population ages and lives longer, the number of people with hearing impairment will increase considerably. According to National Center for Health Statistics (2010), hearing loss associated with aging usually affects the high frequency speech discrimination – the sounds necessary for understanding speech. The isolation created by difficulty in conversing with families and friends can be enormous for individuals with hearing loss. According to Wallhagen et al., (1997), only 37 percent of people aged 70 years or older have had their hearing tested in the past five years in the US.

Once hearing impairment is identified, the goal is to provide appropriate treatment. Strategies for intervention or rehabilitation depend upon the kind of hearing loss, age of onset, services available, and family preferences. Treatment often includes mechanical devices, such as hearing aids, cochlear implants, and augmentative and assistive devices that are designed to enhance residual hearing, allowing the

individual to function better in the hearing world. Unfortunately, only a small number of adults with hearing impairment use these devices (Garstecki & Eler, 1998). According to Wallhagen et al., (1997), only 211 per 1,000 adults identified with hearing impairment ever used a hearing aid, and approximately 2 per 1,000 deaf or very hard-of-hearing adults had a cochlear implant. Approximately, only about 25% of adults who are 70 years of age and older, who could benefit from a hearing aid, actually use one. Many who could benefit from assistive listening devices i.e. instruments that improve hearing in specific situations such as talking on the telephone, do not know about or use these devices.

### **2.3 Types of hearing loss**

Hearing loss can be categorised by which part of the auditory system is damaged. There are two basic types of hearing loss: conductive hearing loss and sensorineural hearing loss, and sometimes there are elements of both conductive and sensorineural hearing loss – a mixed hearing loss. Conductive hearing loss occurs when sound is not conducted efficiently through the outer ear canal to the eardrum and the small bones of the middle ear. The most prevalent causes of conductive hearing loss are: fluid in the middle ear from colds, allergies, Eustachian tube dysfunction, ear infection, otosclerosis, perforated eardrum, and impacted earwax.

Sensorineural hearing loss occurs when there is damage to the inner ear (cochlea), or to the nerve pathways from the inner ear to the brain. Most of the time, it cannot be medically or surgically corrected. This is the most common type of permanent hearing loss. Sensorineural hearing loss reduces the ability to hear faint sounds. Even when speech is loud enough to hear, the speech may not be clear. Some possible causes are illnesses, medications that are toxic to hearing, hearing impairment that runs in the family (genetic or hereditary), aging, head trauma, malformation of the inner ear, and exposure to loud noise/music.

Sensorineural hearing loss can be further classified as cochlear and central loss. Central Auditory Processing Disorder is a broader term for a number of disorders that affect the way the brain processes auditory information. This disorder can affect both children and adults. It is reported that approximately 2-3% of children and 17-20% of adults have this disorder. Males are twice more likely to be affected by the disorder

than females (Musiek & Chermak, 2007). Individuals with auditory processing disorder most often have normal peripheral hearing ability but have difficulty processing the information they hear or receive, which leads to difficulties in recognising and interpreting sounds, especially the sounds composing speech.

## **2.4 Incidence and prevalence of hearing loss**

About 20 percent of the total adult population (18 years and over) of the UK has a hearing loss of 25dB or greater in the better hearing ear (Davis, 1989). In terms of self-reported disability, 26 percent of the population said that they had great difficulty hearing what was said against a background noise, whereas only 10 percent reported some difficulty in quiet on the better ear, with 19 percent reporting some difficulty in quiet on their worse ear (Cochrane, 1971; and Hinchcliffe, 1961).

According to Greville (2001), in New Zealand, 10.3% of the population (390,600) report having a hearing loss of some degree. In the non-industrialised population, 9.8% (368,600) report having a hearing loss of some degree, and 6.6% of the population (250,300) report having a disability caused by hearing loss. In the non-industrial adult population, 0.7% (2,620) report disability attributed to deafness. One third of all types of hearing loss can be attributable to noise and music exposure. In the last three decades we have created noisier equipment without much in the way of regulation to control it.

The relationship between exposure to loud noise and hearing loss has been recognised for over a century. However, it is only in the past 30-40 years that leisure noise, particularly music, has attracted attention as a possible cause of hearing loss. Apart from the standards, there are psychological aspects such as attitudes towards noisy musical settings and the individual's behaviour regarding the use of hearing protection, which may be considered as important factors in the understanding of why the prevalence of hearing related problems has increased significantly. According to a recent study (Callahan, et al., 2011), a majority of musicians showed a casual attitude about hearing protection despite the elevated risks of hearing loss.

According to The World Health Organization (2002), hearing loss caused by noise exposure is a significant occupational health problem. Throughout the world,

exposure to excessive noise/music is the major preventable cause of permanent hearing impairment. The total population of the world is approximately 7 billion and the majority of the population (approximately 5 billion) live in developing countries. In developing countries, occupational noise and urban environmental noise are increasing risk factors for hearing impairment. Most of these nations have rapidly expanding economies with occupational noise exposure increasing in all types of industry. In a developed country, this is at least partially the cause in more than one third of those with hearing problems. (Nelson, Nelson, Concha-Barrientos & Fingerhut, 2005) estimated that the prevalence of noise induced hearing loss is about 7% of the population in developed countries and 21% in developing countries.

In many industrial nations, noise induced hearing loss remains the biggest compensational occupational hazard worldwide. Though it has been estimated that the risk from occupational noise begins to decrease in developed countries, according to Thorne et al., (2008), in New Zealand there has been a substantial increase in the number of new NIHL claims annually, rising from 2823 in July 1995–June 1996 to 5580 in July 2005–June 2006. Together with ongoing claims, the overall costs of NIHL claims increased by an average of 20% each year (a six-fold increase over the decade), resulting in a total cost to the New Zealand Government's Accident Compensation Corporation of \$193.82M over the review period. Thorne concluded that the substantial and increasing societal costs, despite decades of NIHL control legislation, suggest that current strategies addressing this problem are not effective, inadequately implemented, or both, and that the hearing loss caused by recreational noise is on the increase.

In Berglund, Lindvall & Schwela (1999), many of the workers in the developing world are neither concerned with nor aware of the need for using the ear protection, and in many countries legislation is not in effect or enforced. Hence there is a worldwide increase in occupational and non-occupational noise induced hearing loss, and today it is a global phenomenon. The risk from occupational noise is beginning to decrease in developed countries, but globally there is a significant increase in social/recreational noise.

According to WHO-PDH (1997) document, the substantial increase in longevity has stemmed from the medical profession's improved success in controlling infectious and chronic diseases. As people are living longer and industrialisation spreads so rapidly, noise induced hearing loss started to add substantially to the global burden of health and social disability. So as mentioned before, hearing loss has taken a public health priority.

Understandably, given the serious health and social consequences of hearing impairment, its increasing prevalence is cause for concern, and it is very important that prevention of preventable hearing loss should become a national health priority. In Wallhagen et al., (1997), for example, according to New Zealand's Department of Labour's key facts on NIHL, the Accident Compensation Scheme (ACC) spends about \$40 million per year (double that of five years ago), and noise induced hearing loss appears in the top five of all claims. Hearing losses from different causes are additive and interaction can occur between noise exposure and chemicals such as toluene, or antibiotics such as the amino glycosides. In the elderly, NIHL may add to the hearing loss of presbycusis to produce a hearing handicap sooner and worse than would occur from age alone (WHO-PDH, 1997).

## **2.5 Attitudes towards hearing loss**

Although the importance of good hearing can hardly be overstated, it is not often appreciated by the public, and many are still quite unconcerned about losing their hearing. There is still a stigma attached to hearing loss. Even today, it is often considered to be an embarrassing problem, and for many it is a sign of aging and senility. Many people do not seek any help, of their own accord, for their hearing loss for many years. Even today, significant proportions of people live with denying their disability, or just tolerate it. People accept the need for eye glasses very easily, but you may hurt someone's feeling by saying that he or she doesn't hear well. This is as true for someone who is aged as it is for teenagers.

Generally, most young adults feel "loud" is fun. One young adult said during audiological consultation in a response to a question, that the reason for his not using the earplugs was that he did not want to be identified as soft, vulnerable, over-

protected, and a good guy rather preferring to be identified as a guy who is strong but cool, careless, dashing and who can withstand any type of threat. There seems to be a significant challenge ahead – to bring a change in the attitude of this younger generation and to get the message across on prevention of hearing loss. According to Rawool and Colligon-Wayne (2008), in a survey of university students, very few showed any concern regarding potential risks of hearing loss. The majority (75%) of them reported awareness of noise exposure and associated hearing loss; however, half of the surveyed students reported potentially harmful exposure to loud music.

The “Wellington Hearing Expo” held on 28-30 Sep 2007 was conducted in Wellington as a part of a preventive strategy. The Massey University noise experts arranged a facility to measure the volume levels on people’s personal stereos. It was very surprising to learn that a significant number of the young ones preferred a volume setting 15-20dB higher than the required volume. Although they could enjoy the music at a lower volume setting, the majority preferred it much louder (Wellington Hearing Expo, 2007).

## **2.6 Impact of hearing loss in social life**

According to Arlinger (2003), untreated hearing loss can lead to significant social isolation and other psychological issues such as depression. When hearing loss occurs in an adult, more subtle manifestations of the same problem may be found. Most people with age or noise induced hearing loss lose hearing in the high frequencies first, making it difficult for them to distinguish consonants, especially s, f, t and z. This makes a person strain to understand what is being said in everyday conversation. Adults with high frequency loss know that there is speech because they can hear the vowels, but cannot discriminate speech sounds, particularly in the presence of background noise or in group/meeting situations. Although these sounds are not responsible for the acoustic power of speech, they are very important to the intelligibility of speech (Dobie, 1995; Suter & Gierke, 1987). Commonly, a person with noise induced hearing loss will complain of tinnitus, which according to Baguley, Axon, Winter and Moffat (2002) is the phantom perception of sound in the absence of any physical sound. For many in the early stages of noise induced hearing loss, tinnitus is the most distressing symptom (Axelsson & Sandh, 1985; Neuberger,

Korper, Raber, Schwetz, & Bauer, 1992). This makes talking to one's spouse, going to movies, church and other pleasures, that most of us take for granted, more and more stressful. It is also unrecognised that hearing loss significantly impacts personal relationships, according to a survey conducted by Harris Interactive (R) on behalf of Cochlear Americas in 2007, a global leader in hearing technologies, which commissioned the survey to shine a light on the realities of hearing loss during "Better Hearing and Speech Month". One in four adults (23%) says they have either a spouse or family member, or know someone, with hearing loss. Of the 27 million U.S. adults with hearing loss, the number one cited relationship that suffered was the one with their romantic partner (35%), followed by friends, family members and co-workers. They can lose self-esteem through a fear of being characterised as 'deaf' or 'handicapped', or through feeling like a burden to their family or loved ones (Jubb-Toohy, 1994). The concern that one may be missing out on important verbal communications can cause stress, particularly in environments with high background noise, and also a tendency to avoid situations, where one may have trouble hearing, which can lead to a feeling of isolation and reduced social contact (Jubb-Toohy, 1994).

The high frequency loss associated with difficulty in perceiving high pitched sounds and the inability to discriminate speech sounds in difficult-to hear environments such as group situations or in the presence of background noise, results in major communication problems for an individual (Hetu & Getty, 2001). In a new study, Brandeis University researchers conclude that adults with mild-to-moderate hearing loss may use so much cognitive energy on hearing accurately that their ability to remember spoken language suffers as a result. "There are subtle effects of hearing loss on memory and cognitive function in older adults," said Arthur Wingfield (2005), the Nancy Lurie Marks Professor of Neuroscience at the Volen National Center for Complex Systems at Brandeis University. "The effect of expending extra effort in comprehending words means there are fewer cognitive resources for a higher level of comprehension." The study showed that even when older adults could hear words well enough to repeat them, their ability to memorise and remember these words was poorer in comparison to other individuals of the same age with good hearing (Wingfield, McCoy, Peelle, Tun, & Cox, 2006). Close family members, particularly spouses, may also experience irritation with the need to constantly repeat verbal

communication or talk loudly (Arlinger, 2003). Likewise, the desire of a deafened individual to avoid certain social situations can affect the spouse's social life. Deafness also impacts greatly upon an individual's leisure and entertainment choices, potentially rendering music, films, television and theatre less enjoyable or inaccessible. It also disconnects the affected person from the simple sounds of nature and daily life (Trevithick, 1995).

## **2.7 Hearing loss in children**

According to a (New Zealand) National Audiology Centre report, about 8% of children start school with hearing loss (Greville, 2001). The highest rate of hearing loss among school entrants is among Pacific Island children (15%), closely followed by Maori children (13.5%), and 0.24% of children (2,800) wear hearing aids. Maori children are more likely than others to have permanent hearing loss, requiring them to use hearing aids. The cause of this difference is possibly due to a genetic origin.

According to American Speech-Language-Hearing Association's public education information, hearing is critical to speech and language development, communication, and learning. The earlier hearing loss occurs in a child's life, the more serious the effects are on the child's development. Similarly, the earlier the problem is identified and intervention begun, the less serious the ultimate impact is. Hearing loss causes delay in the development of receptive and expressive communication skills. The language deficit causes learning problems that result in reduced academic achievement. Communication difficulties often lead to social isolation and poor self-concept. It may have an impact on their vocational choices as well

Newborns can be easily and cost-effectively screened for hearing impairment. The Ministry of Health has systematically introduced Universal Newborn Hearing Screening and Early Intervention Programme (UNHSEIP) in New Zealand, and the babies and children are identified early and are being rehabilitated successfully. It is a mandate that hospitals screen all children before they are discharged from the newborn nursery or within the first three months of life. According to the American Academy of Paediatrics (1999), in the past, the average age of diagnosis of hearing loss in infants and young children ranged from 14 months to around three years of

age. This delay in diagnosis is significant in terms of time lost during unique opportunities in brain development for language acquisition, spoken or signed (National Institute on Deafness and Other Communication Disorders, 1997). Yoshinaga-Itano and Apuzzo (1998) suggested that to optimise this critical intensive period of language development, intervention must start as close to birth as possible, preferably before six months of age.

Hearing loss in early childhood has very many devastating effects. A substantial hearing loss in infancy affects child's speech-language development and learning, also significantly impairs the child's expression of needs, and often results in alienation from the child's family, sometimes to a permanent deficit in his ability to establish relationships. Severe hearing loss also leads to frustration and isolation because of the difficulty in communication (Bade, 2011).

Even mild hearing loss can cause significant emotional and social problems. It also has a negative impact on verbal language, reading, writing and academic performance (Bess, 1985).

## **2.8 Rehabilitation**

Although several advances have been made to treat various types of conductive hearing loss that are surgically curable, sensorineural hearing loss can be cured only in very few conditions. Our understanding of hearing loss and the improvement in hearing aid technology has made it possible to help to improve almost every patient with hearing loss, but prevention of hearing loss remains the best cure.

According to Sataloff and Sataloff (2006), in the past decade there has been improvement in our understanding of the function of the ear and related structures, and this has opened some possibilities for prevention of damage and some possibilities of restoration of hearing function. Among the preventive measures are some ototoxic drugs that often prevent hearing loss. The possibility of a thorough and comprehensive assessment may reveal underlying causative factors. Today, as our knowledge increases, there is a genuine increase in the number of patients successfully treated. Although not all hearing loss can be cured completely, almost every patient with hearing loss can be helped through accurate diagnosis,

understanding of the condition, education, medication, aural rehabilitation, amplification, and/or cochlear implantation. In the past few decades there have been major advancements, and even more can be expected as our exploration continues with the possibilities of more and more understanding of complex inner ear structures and the ear and brain interface.

Apart from this, there are issues related to currently existing services to people with hearing loss. A significant number of hearing impaired people in New Zealand have unfulfilled needs in relation to their hearing loss. The current levels of funding for hearing aids is inadequate; as a consequence, untreated hearing loss will cause significant costs to the country, mainly because of reduced productivity. This situation is only likely to worsen over time as the country's workforce ages. Not only does this greatly have influential effects on the quality of the affected individual's life through limiting social communication, entertainment and employment opportunities, but it also translates into a handicap for the individual's immediate family and friends (Williams, 2005a).

Though there has been a significant growth in hearing aid technology and hearing aid fitting methods, even today many individuals with hearing loss are dissatisfied with their hearing aids. Though the new technology has made these hearing aids remarkably discreet, the hearing instruments don't enjoy the fashion status of a pair of glasses.

Hearing aids have continuously evolved over the past 50 years, in term of styles and technology. Technological advances in hearing aids and rehabilitation services have expanded the range of options available to improve the success of modern devices. Today's hearing aids differ significantly from their analogue predecessors because the application of digital signal processing has permitted many adaptive and/or automatic features. Included in the benefits of digital hearing aids are: improved sound quality, multiple listening programmes for different listening environments, advanced noise reduction strategies, acoustic feedback reduction, compatibility with remote control options, and flexibility in manipulation of the frequency, compression and gain of the hearing aid (Natalizia et al., 2010).

## **2.9 Prevention of hearing loss – challenges**

According to (WHO-PDH 1997) document on the prevention of noise induced hearing loss, the best-known and easiest prevention of NIHL is ear protection, although its disadvantages (discomfort, poor sound quality and low-frequency discrimination) often result in poor fitting and use. Better awareness and motivation for prevention of NIHL during recreational activities is needed, although scare tactics may not be the best means of prevention; many people, particularly young men, are opposed to preventive measures, since they are considered to decrease the enjoyment of the activity. Further, many developing countries apparently have greater need for many health care improvements other than prevention of NIHL.

Consequently, it is an important and challenging issue to improve awareness about the wonderful sense of hearing. Good hearing is often taken for granted, and a possible hearing loss is not taken seriously by young people. In comparison to research on the anatomy and physiology of the ear, as well as our comparatively good understanding of NIHL, our knowledge of the best ways to influence attitudes about noise and recreational habits is quite poor. Much more emphasis should be given to improving people's appreciation of the value of good hearing, their attitudes to noise, and knowledge about NIHL and its consequences and prevention. This is an important challenge for primary health care.

Environmental strategies for preventing noise induced hearing loss encompass all the areas, since it can be argued that all exposures containing sufficient acoustic energy to cause injury should be included in the category of environmental noise. Occupational noise exposure, by this definition, is just one example of an environment – the workplace – where a person may be exposed to hazardous noise. Listening to amplified music through earphones may be another form of noise exposure.

There is concern but little data regarding the types and quantities of noise to which children are routinely exposed during school hours. Hearing ability declines with age, starting in infancy, but it is not certain how much of the decline is due to ageing and how much is due to excessive noise. Recent studies suggest that during school activities children are routinely exposed to noise levels above those recommended

standards, and that children may receive more noise at school than from an eight-hour work day at a factory. The school environment may be excessively noisy during a bus ride to and from school, at assembly, shop or music classes, and in the classroom itself. It also seems more research is needed on the non-occupational noise exposure of young people.

In a survey by the Central Institute for the Deaf (William, 1991) of daily noise exposure in 110 children age 6-14 years, each child wore a personal noise dosimeter from rising until bedtime on a school day. Noise exposures have also been measured during hockey games, at summer day camps and during swim meets. There was widespread exposure to loud sounds. Sound pressure levels above 90 decibels were commonly encountered in the lunchroom and gym; the average sound pressure level measured over a 24-hour day ( $L_{Aeq,24h}$ ) for all children was 87.4dB and, during recess, some exposures exceeded 115dB ( $L_{Aeq,1min}$ ). Thus, it is possible for children to suffer permanent hearing loss due to school activities, and steps need to be taken to quieten the typical child's environment.

It is recommended that to deal more effectively with NIHL, key information and messages on prevention and control of harmful noise exposure and hearing conservation should be widely disseminated in the local community (Berglund et al., (1999).

## **2.10 Current standards relationship between noise exposure and NIHL**

It is understandable that current standards on hearing loss prevention are a compromise between what is practically possible to reduce the noise level in industry and what is needed to protect the hearing of those exposed to the noise. (Lutman & Davis, 1996). It does not account for many factors that may have a significant number of variables, some of which will have a positive influence and others a negative influence on the hearing status of a given individual. Hence the current standards and regulations are not sufficient enough to protect everyone's hearing ability. For workers in the music and entertainment industry the noise exposure is a

potential occupational hazard, and it often exceeds the action values or exposure limit values given in regulations as the European Directive 2003/10/EC (Brockt, 2010).

Our current knowledge regarding the relationship between noise exposure and hearing impairment is far from complete (Sataloff & Sataloff, 2006). Current standards regarding the relationship between noise exposure and NIHL is based on cross-sectional studies of people exposed to noise, a vast majority of which were conducted several decades ago and concentrated on people exposed continuously to high levels of noise that were more commonplace in the 1950s and 1960s. The majority of the studies suffered from a lack of appropriate non-exposed control subjects, and longitudinal studies are almost entirely lacking (Lutman & Davis, 1996). Another possible problem is that the instrumentation that was often used could measure only instantaneous levels and was not up to the quality of what is available today – so the results are not directly comparable (Dickinson, 2007). The damage risk criteria are primarily based on population statistics and not individual data. Authoritative reports have involved large primary studies or have synthesised data from several large primary studies. The study done by Burns and Robinson (1970) created the basis of the first edition of the international standard ISO 1999 in 1975. Even today, the tables created by the UK National Physical Laboratory (NPL) are used widely for the prediction of NIHL in populations exposed to noise. The later version of ISO 1999:1990 included various results from studies in the US as well as from the studies of Burns and Robinson to derive formula for predicting NIHL. ISO 1999:1990 allows the user to add different values to account for the effects of age-induced hearing loss. But even today our understanding about influence of each factor in a given individual is very limited. Hence our approach to hearing loss prevention should go beyond the standard and criteria.

This research project was carried out in order to improve our knowledge of the relationship between exposure to noise/music and its relationship to the noise induced hearing loss that may result that will in turn help in planning effective preventive measures and strategies to minimise hearing damage.

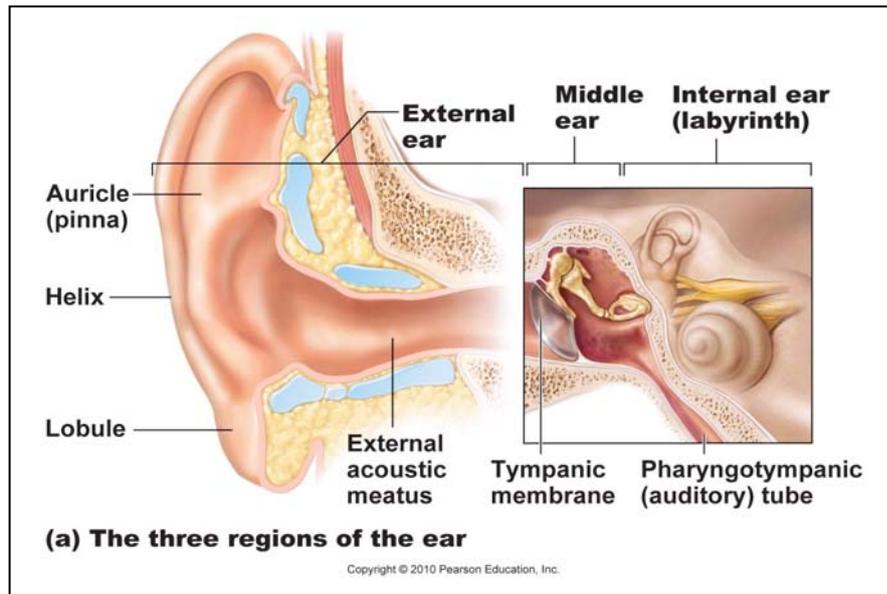
## **Chapter 3 : Anatomy and Physiology of Human Ear**

### **3.1 Introduction**

Hearing is the process by which the ear transforms sound vibrations in the external environment into nerve impulses that are conveyed to the brain, where they are interpreted as sounds.

The auditory mechanism is responsible for processing the acoustic signal. Auditory stimuli can arrive at the ear with an amazingly wide range of sound pressures, from the whisper of a leaf blowing in the breeze to the pressures associated with painfully loud sound. The human auditory mechanism has a frequency range of approximately 10 octaves, spanning 20 to 20,000Hz. Within these broad requirements are much finer tasks, including differentiating small increments in frequency and intensity. Sounds are produced when vibrating objects, such as the plucked string of a guitar, produce pressure pulses of vibrating air molecules, better known as sound waves. The ear can distinguish different subjective aspects of a sound, such as its loudness and pitch, by detecting and analysing different physical characteristics of the waves. Pitch is the perception of the frequency of sound waves.

The human ear is composed of external, middle and inner ears (Figure: 3-1). Each part has a specific function in the hearing process.



**Figure 3-1: Structure of the human ear**

Source: Marieb & Hoehn (2007)

### 3.2 External Ear

The outer ear is composed of the pinna, or ear lobe, and the external auditory meatus or ear canal. Both structures funnel sound waves towards the ear drum or tympanic membrane, allowing it to vibrate. The pinna is also responsible for protecting the ear drum from damage. The pinna collects sounds and channels them to the canal. The meatus serves as a conduit for sound waves to travel to its innermost end, which terminates at the tympanic membrane, or eardrum.

The auricle is the visible part located on the side of the head, and it is a cartilaginous structure. It is thought to enhance reception and provide some indication of location of sound. The soft cartilage of the outer ear is thought to provide some cushioning effect of sound waves on impact and may mitigate the effects of loud noises. The pine forms the opening of the oval shaped ear canal, which extends approximately 25mm to terminate at the eardrum (or tympanic membrane). The ear canal has a natural resonant frequency of around 3000Hz, which increases the sensitivity in this region. This could perhaps be explained as analogous to an organ pipe closed at one end; closing the other end will create a new resonant frequency. For example, when

the ear is closed by application of headphones, a new resonant frequency will occur in the order of 6000Hz.

The external auditory meatus is approximately 7mm in diameter and 2.5cm long, and this contributes to hearing as a resonating cavity; the resonant frequency depends to a large part on the length of the cavity. The lateral third of the canal is comprised of cartilage and is about 8mm long; the medial two-third is the bony meatus of the temporal bone. This is slightly S-shaped. Within the canal are small hairs and a waxy substance called cerumen (wax); they both serve as a protective function by filtering out particulates and keeping the canal healthy and free of infection.

The outer ear can be seen primarily as a collector of sound. The pinna, with its ridges, grooves, and dished-out regions, is an excellent funnel for information directed towards the head and from the front or side, although less effective for sound arising from behind the head. Because the outer ear has no active (movable) elements, it can have a passive effect on the input stimulus. The pinna acts as a “sound funnel,” focusing acoustic energy into the external auditory meatus, and the external auditory meatus funnels sound to the tympanic membrane. However, both these structures have shapes that boost the relative strength of the signal through resonance, with the result being relatively enhanced signal intensity that is between 1,500Hz and 8,000Hz. The components of the pinna contribute a relatively small amount to the overall gain as compared with that of the external auditory meatus. However, the contribution of the entire system results in a net gain reaching 20dB at approximately 2,000Hz.

The tympanic membrane, which is made up of three layers of tissue, is a slightly oval structure, approximately 10mm in diameter in the superior-inferior dimension. The anterior-posterior dimension is slightly smaller (about 9mm in diameter), and the entire membrane is placed within the canal at a 55 degree angle with the floor.

The tympanic membrane or the ear drum, which is  $55\text{mm}^2$  in area, marks the boundary between the outer and middle ears. It completely separates the two spaces, being an extremely thin three-layered sheet of tissue. In summary, the outer ear is

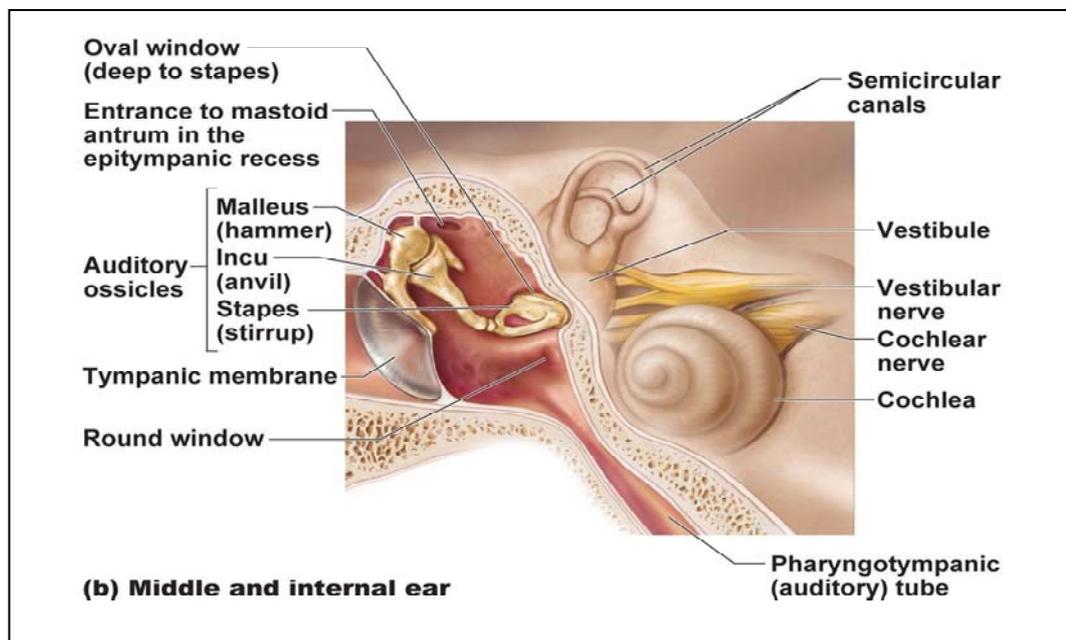
composed of the pinna, the structures that serve primarily as a sound collector, and the external meatus or the ear canal terminating at the tympanic membrane, which separates the outer ear from the middle ear.

### 3.3 Middle Ear

The middle ear is an air filled cavity of about  $2\text{cm}^3$  and contains a chain of three articulated bones known as the ossicular chain or auditory ossicles, which transmit acoustic energy impinging on the tympanic membrane to the cochlea in the inner ear (Figure 3.2). This ossicular chain is a semi-rigid set of three articulated bones that provides the means for transmission of acoustic energy impinging on the tympanic membrane to the inner ear. The malleus is the largest of the ossicles, providing attachment with the tympanic membrane. Although the malleus is the largest of the ossicles, it is only 9mm long and weighs a mere 25mg.

**Figure: 3-2 Middle ear bones**

Source: Marieb & Hoehn (2007)



The incus (shaped like an anvil) provides the intermediate communicating link of the ossicular chain. The body of the incus articulates with the head of the malleus. The incus weighs approximately 30mg, and its longest process is approximately 7mm. The malleus and incus articulate by means of saddle joint, although it appears that the movement at the joint is quite limited. Rather, the malleus and incus appear to move as a unit upon movement of the tympanic membrane. The stapes, or “stirrup,” is the third bone of this chain. The head of the stapes articulates with the lenticular process of the incus. The footplate of the stapes rests in the oval window of the temporal bone, held in place by the annular ligament. This is the smallest of the ossicles, weighing approximately 4mg, with the area of the stapes being about  $3.5\text{mm}^2$ . The articulation of the incus and stapes (the incudo stapedial joint) is of the ball and socket type. The ossicular chain is held in place by a series of strategically placed ligaments that suspend the ossicles from the walls of the middle ear cavity.

These three effects combined (the area, lever, and buckling effects) result in a signal gain of about 31dB, from the tympanic membrane to cochlea, depending on the stimulus frequency. Again, if the middle ear was removed, a signal would have to be 31dB more intense to be heard. The middle ear transformer action is very important to audition, and any process that reduces the effectiveness of the function (middle ear diseases) can have a serious impact on conduction of sound to the inner ear.

The tympanic membrane has an effective area of about  $55\text{mm}^2$ , while that of the oval window is only about  $3.2\text{mm}^2$ , making the tympanic membrane 17 times as large, depending on species size. Sound energy reaching the tympanic membrane is funnelled to a much smaller area of the oval window, so there is an increase in gain of 17:1, which translates to an increase of about 25dB. The second impedance-matching is achieved by a lever difference. The length of the manubrium (the long part of the malleus) is approximately 9mm, while that of the long process of the stapes is about 7mm, giving an overall gain of about 1.2dB. The lever effect arising from this is nearly 2dB.

The third effect arises from buckling of the tympanic membrane is that as it moves in response to sound, the tympanic membrane buckles somewhat, so that the arm of the

malleus moves a shorter distance than the surface of the tympanic membrane. This results in a reduction in velocity of the malleus, with resulting increase of force that provides a 4 to 6dB increase in effective signal.

### **3.3.1 The Eustachian Tube**

The Eustachian tube is an integral part of the middle ear mechanism in that it links the middle ear with the nasopharynx. The tube is, in adults, about 36mm long with the lateral, which is the body part connected to the middle ear, being approximately 12mm long. The medial, cartilaginous portion is 24mm long, which is connected to the nasopharynx. The middle ear pressure is approximately equal to outside pressure. This helps to equalise the pressure if the middle ear pressure is less. The Eustachian tube is normally closed and opens when swallowing or yawning. In children, it does not function as efficiently as in adults. The support provided by the cartilage and bone is poor and the tensor veli palatini muscle, which opens the Eustachian tube, is weaker than in adults. As the child develops, the Eustachian tube function improves, resulting in fewer middle ear infections in older children and adults. It performs the following functions: to ventilate and equalise air pressure with that experienced by the outer ear, drain any secretions from the middle ear to the nose, and prevents reflux of fluid into the middle ear. The Eustachian tube is normally closed and opens when swallowing or yawning.

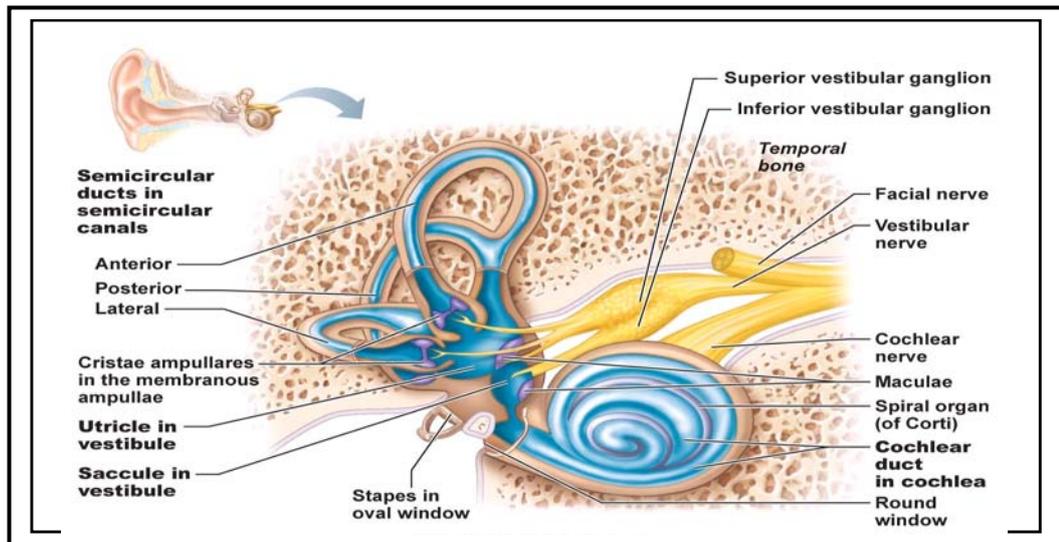
### **3.3.2 The acoustic reflex**

There are two important muscles of the middle ear attached to the ossicles i.e. the Tensor Stapedius and Tensor Tympani. These are the smallest muscles of the human body. The Stapedial muscle is 6mm long and is embedded in the posterior wall of the middle ear. The muscle inserts into the posterior neck of the stapes, so that when it contracts, the stapes is rotated posteriorly. The Tensor Tympani is approximately 25mm in length, arising from the anterior wall of the middle ear space. Contraction of this muscle pulls the malleus antero-medially, thereby reducing the range of movement of the tympanic membrane by placing indirect tension on it. Indeed, both the tensor tympani and the stapedial muscles stiffen the middle ear transmission system, thereby reducing transmission of acoustical information in the lower

frequencies. That is, contraction of these muscles reduces the strength of the signal reaching the cochlea, potentially protecting it from damage due to high signal intensity. This reaction is known as the acoustic or aural reflex. Sometimes it is also known as the stapedial reflex. It is triggered by loud sounds, typically greater than 85dB SPL. The neural circuit for the acoustic reflex is such that stimulation of either ear results in response by both the ears, although attenuation of the signal by the ipsilateral ear is stronger than the attenuation in the contralateral ear. Unfortunately, the protective function is compromised, in that the stiffening of the ossicular chain provides little barrier to transmission of the high-frequency sound so dominant in modern industrial societies. The aural reflex will not provide protection for instantaneous sounds (peak levels), such as gunshot blasts, as it takes a fraction of a second for activation.

### **3.4 Inner Ear**

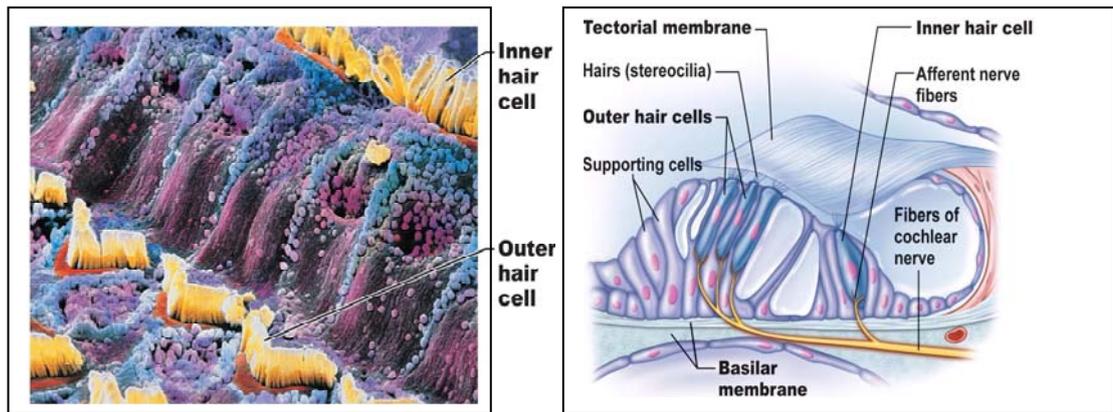
The inner ear (also called the labyrinth due to its complicated shape) is comprised of a complex system of fluid filled cavities positioned deep in the temporal bone (Figure 3.3) and located behind the eye socket. The bony labyrinth is a system of channels winding their way through the bone with distinct regions or cavities including the cochlea and three semicircular canals positioned at right angles to each other. The semicircular canals are part of the body's balancing system. The bony labyrinth is filled with perilymph, which is connected to and similar in composition to the cerebrospinal fluid. The membranous labyrinth is a continuous series of membrane sacs contained within the bony labyrinth and floats in the perilymph. It bounds an extracellular fluid space, called the endolymphatic space (ELS), which contains the endolymph, a fluid of unique ionic composition. Unlike some other non-mammalian species, the endolymphatic space is entirely bounded by cells, with no form of direct communication with the perilymph. The cochlea is a snail-like configuration with  $2\frac{1}{2}$  turns.



**Figure: 3-3 Bony labyrinth**

Source: Marieb & Hoehn (2007)

In the cochlea the scala vestibuli is part of the bony labyrinth and filled with perilymph. It lies superior to the scala media and the oval window is located at its base. The scala media is also known as the cochlear duct and endolymphatic space as it is filled with endolymph. The two chambers are separated by Reissner's (or the vestibular) membrane. The external wall of the scala media, the stria vascularis, is made up of rich vascularised mucosa that secretes endolymph. The scala media contains the organ of Corti. The scala tympani are part of the bony labyrinth (like the scala vestibuli). It contains perilymph and lies inferior to the cochlear duct. The scala tympani and scala vestibuli are in contact (or in communication) through the region known as the helicotrema, which is located at the cochlear apex. The basilar membrane of the organ of Corti separates this chamber from the scala media. (Figure 3.4)



**Figure 3-4: Organ of Corti**

Source: Marieb & Hoehn (2007)

The membranous labyrinth of the cochlea, the cochlea duct, resides between the scala vestibuli and tympani, making up the intermediate scala media. This structure houses the sensory apparatus for hearing. The basilar membrane forms the floor of the scala media, separating the scala media and scala tympani. It is on this membrane that the organ of hearing is found. The organ of Corti (Figure 3-4) is grossly similar to the design of the vestibular organs (described later). There are four rows of hair cells resting on a bed of Deiters' cells for support. The outer three rows of hair cells, known as outer hair cells, are separated from single row of inner hair cells by the tunnel of Corti. The superior surface of the outer hair cells and the phalangeal processes of Deiters' cells form a matrix termed the reticular lamina, through which the cilia protrude. The tectorial membrane overlays the hair cells, and has functional significance in the processing of acoustic stimuli. The outer hair cells are clearly embedded in this membrane, but the inner hair cells do not make physical contact with tectorial membrane, although its proximity to the hair cell is an important contributor to hair cell excitation.

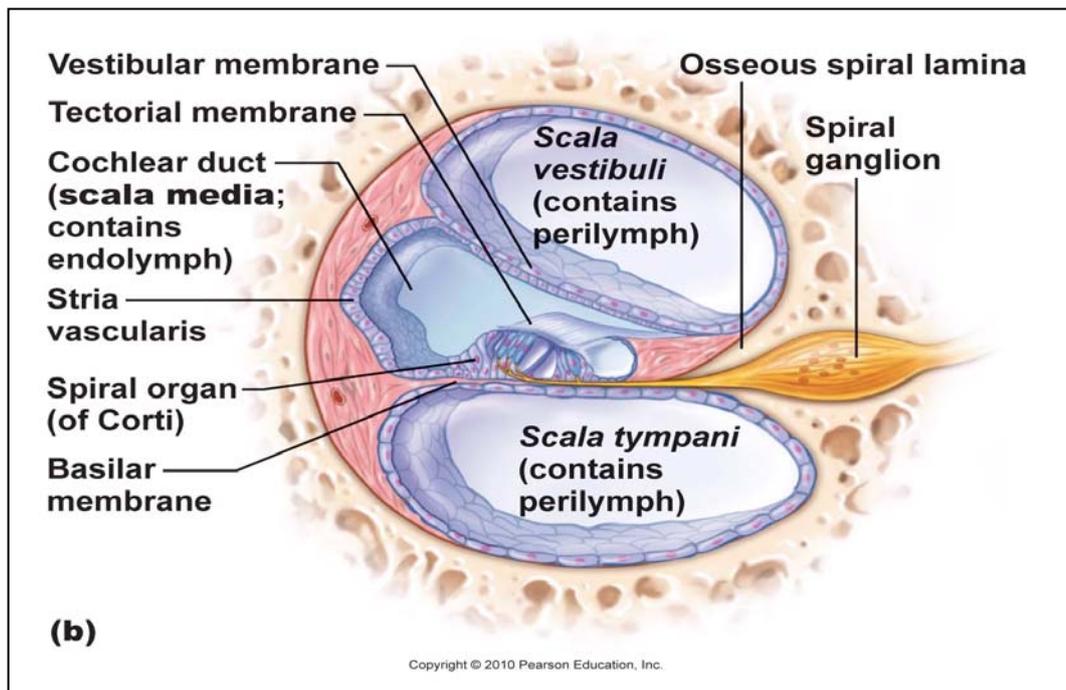
The inner and outer hair cells differ markedly in number. The 3,500 inner hair cells form a single row stretching from the base to apex. The upper surface of each hair cell is graced with the series of approximately 50 stereocilia forming a slight 'U' pattern. There are three rows of inner hair cells, broadening to four rows in the apical end, and numbering approximately 12,000. As with the inner cells, the stereocilia protrude from the surface of each outer hair cell, but with a W or V

shaped pattern formed by 150 stereocilia. The Cilia of a hair cell are connected by thin, filamentous link.

Shorter cilia are connected to the taller cilia by “tip link” and cilia are also linked laterally, thus ensuring that movement of one cilia involves disturbance of adjacent cilia on a hair cell. Stereocilia found in the apex are longer than those found in the base.

The morphology of the hair cells differs markedly. The inner hair cells are teardrop or gourd shaped, with the broad base and narrowed neck. The outer hair cells, in contrast, are shaped like a test tube. One simply must be awed by the cochlea; the structure would neatly fit on the eraser of a pencil, and the fluid within it would be a drop on your table top.

The structures are astoundingly small and delicate. The inner ear is responsible for performing spectral and temporal acoustic analyses of the incoming signal. Spectral analysis refers to the process of extracting or defining the various frequency components of a given signal. The frequency and intensity of vibration define the psychological correlates of pitch and loudness.



**Figure 3-5: Cross section of the Cochlea**

Source: Marieb & Hoehn (2007)

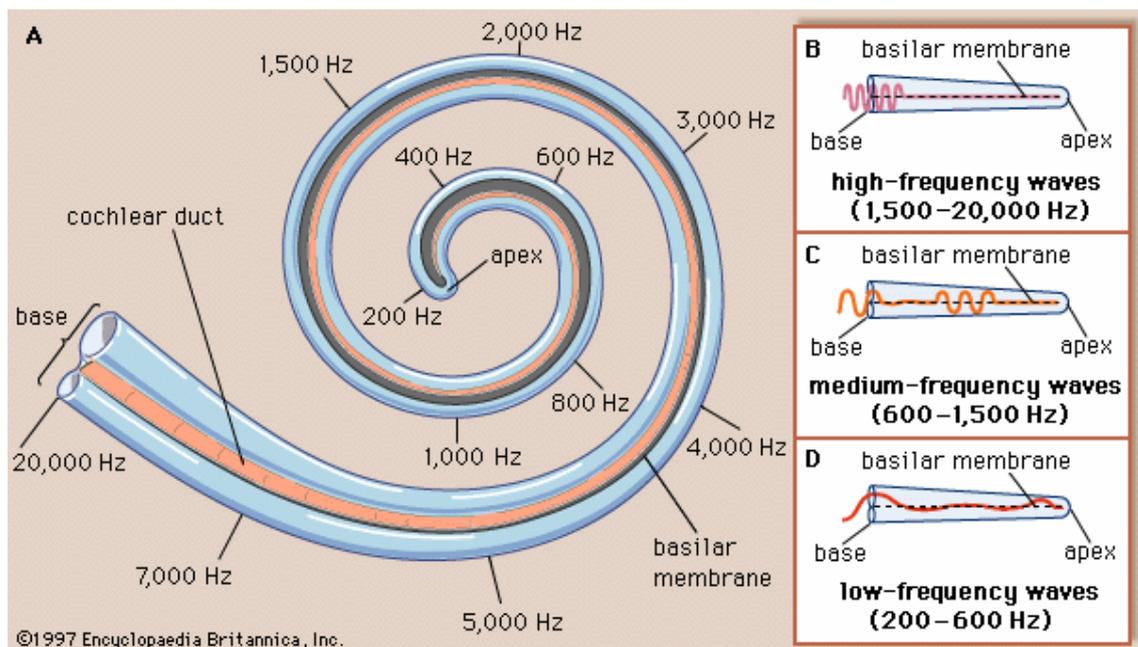
A cross section (Figure 3-5) through one of the turns of the cochlea (inset) showing the scala tympani and scala vestibuli, which contain perilymph, and the cochlear duct, which is filled with endolymph.

Figure 3-5 shows the cochlear duct and spiral lamina divide the cavity of the bony cochlea into three separate scala (chambers): the scala vestibuli, the scala media and scala tympani.

The cochlea is specially designed to sort out the frequency components of an incoming signal, determine their amplitude, and even identify basic temporal aspects of that signal. Subsequently, processing occurs as the signal works its way rapidly along the auditory pathway, ultimately reaching the brain.

The outer hair cells in the cochlea are able to produce low intensity sounds called otoacoustic emissions (OAEs). Otoacoustic emissions are acoustic signals generated by the normal inner ear, either in the absence of acoustic stimulation (spontaneous emissions) or in response to acoustic stimulation (acoustically-evoked emissions) or

electrical stimulation (electrically-evoked emissions). There are three types of Otoacoustic emission testing: Spontaneous, Transient, and Distortion Product. The Spontaneous oto-acoustic emissions (SOAE) are sounds emitted without an acoustic stimulus. The Transient (evoked) otoacoustic emissions (TOAE) are sounds emitted due to acoustic stimuli of very short duration. Distortion product otoacoustic emissions (DPOAE) are the sounds emitted due to a stimulus by sounds of different frequencies. While the response is emitted from the cochlea, the middle and outer ear must be able to transmit the sound (in reverse) back to the OAE recording microphone, and so OAEs can only measure the peripheral auditory system (outer, middle and inner ear). OAEs are often used as a neonatal screening tool to test the presence/absence of cochlear function. In addition, this technique is used for children too young to participate in conventional hearing tests, and also, otoacoustic emission testing is used routinely in an audiology clinic for early identification of noise induced hearing loss.



**Figure 3-6 Basilar membrane: analysis of sound frequencies**

Source: Marieb & Hoehn (2007)

The analysis of sound frequencies by the basilar membrane reveals that:

(A) The fibres of the basilar membrane become progressively wider and more flexible from the base of the cochlea to the apex. As a result, each area of the basilar membrane vibrates preferentially to a particular sound frequency.

(B) High-frequency sound waves cause maximum vibration of the area of the basilar membrane nearest to the base of the cochlea.

(C) Medium-frequency waves affect the centre of the membrane.

(D) Low-frequency waves preferentially stimulate the apex of the basilar membrane.

The locations of cochlear frequencies along the basilar membrane shown are a composite drawn from different sources. (Figure 3-6)

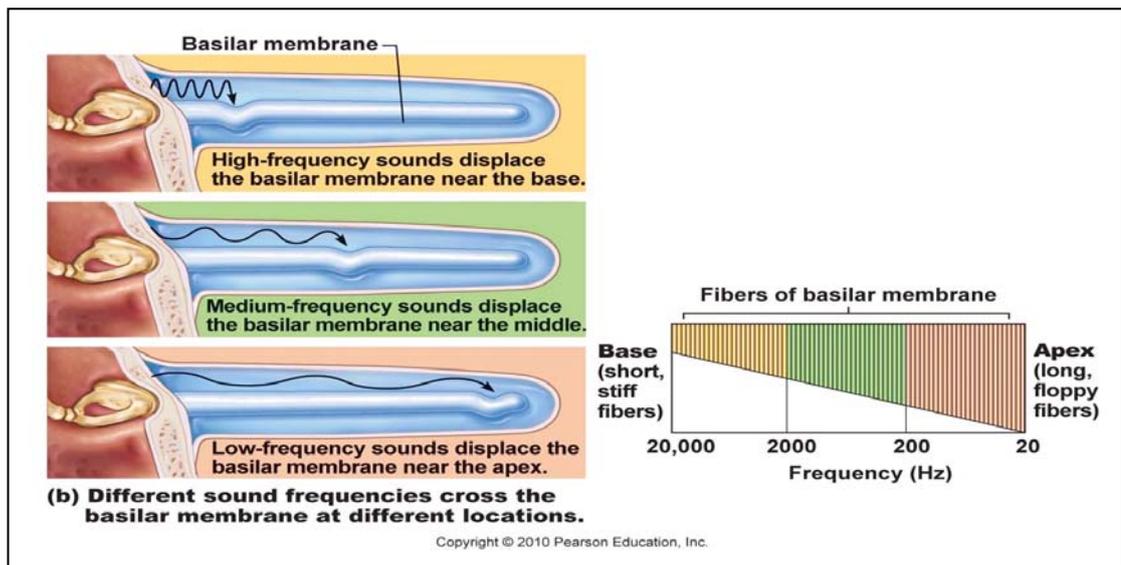
### **3.4.1 Inner ear fluids**

The inner ear is comprised of two main sections. The semi-circular canals, utricle and saccule, make up the vestibular system and are involved in balance. The scala tympani, scala media and scala vestibule make up the cochlea which is involved in hearing. They are filled with fluid – Perilymph and Endolymph – which are of very different chemical composition. Under normal conditions they occupy separate compartments and therefore do not mix. The distribution of these fluids with respect to the receptor cells may play an important role in inner ear transduction and thus may be a major factor in governing the great sensitivity of the mechanoreceptors of the inner ear.

The perilymphatic chamber of the vestibular system has a wide connection to scala vestibuli, which in turn connects to the scala tympani by an opening called the helicotrema at the apex of the cochlea. The scala tympani is then connected to the cerebrospinal fluid of the subarachnoid space by the cochlear aqueduct. The endolymphatic system of the cochlea (scala media) is connected to the saccule by the ductus reunions, and from there it connects to the endolymphatic sac, which lies in a bony niche within the cranium. The endolymph of the utricle and semi-circular canals also connects to the endolymphatic sac.

The existence of the many ducts connecting different parts of the inner ear has led to the idea that the cochlear fluids are flowing through the ear. However, unlike other body fluids, such as saliva or lacrymal fluid (tears), the fluids of the inner ear are not secreted and reabsorbed in volume. This is a widespread misconception, based on old studies that used poor experimental techniques. Maintenance of the chemical composition of both fluids is dominated by ion transport processes that are localised in each region.

Compression in the fluid of the scala vestibuli is translated directly to the basilar membrane, and the disturbance at the basilar membrane initiates travelling wave. The cochlea has a tonotopic arrangement, with high-frequency sounds resolved at the base and low-frequency sounds processed at the apex, and the point of maximum excursion of the basilar membrane determines the frequency information transmitted to the brain.



**Figure 3-7 Hair cell activation in the Cochlea**

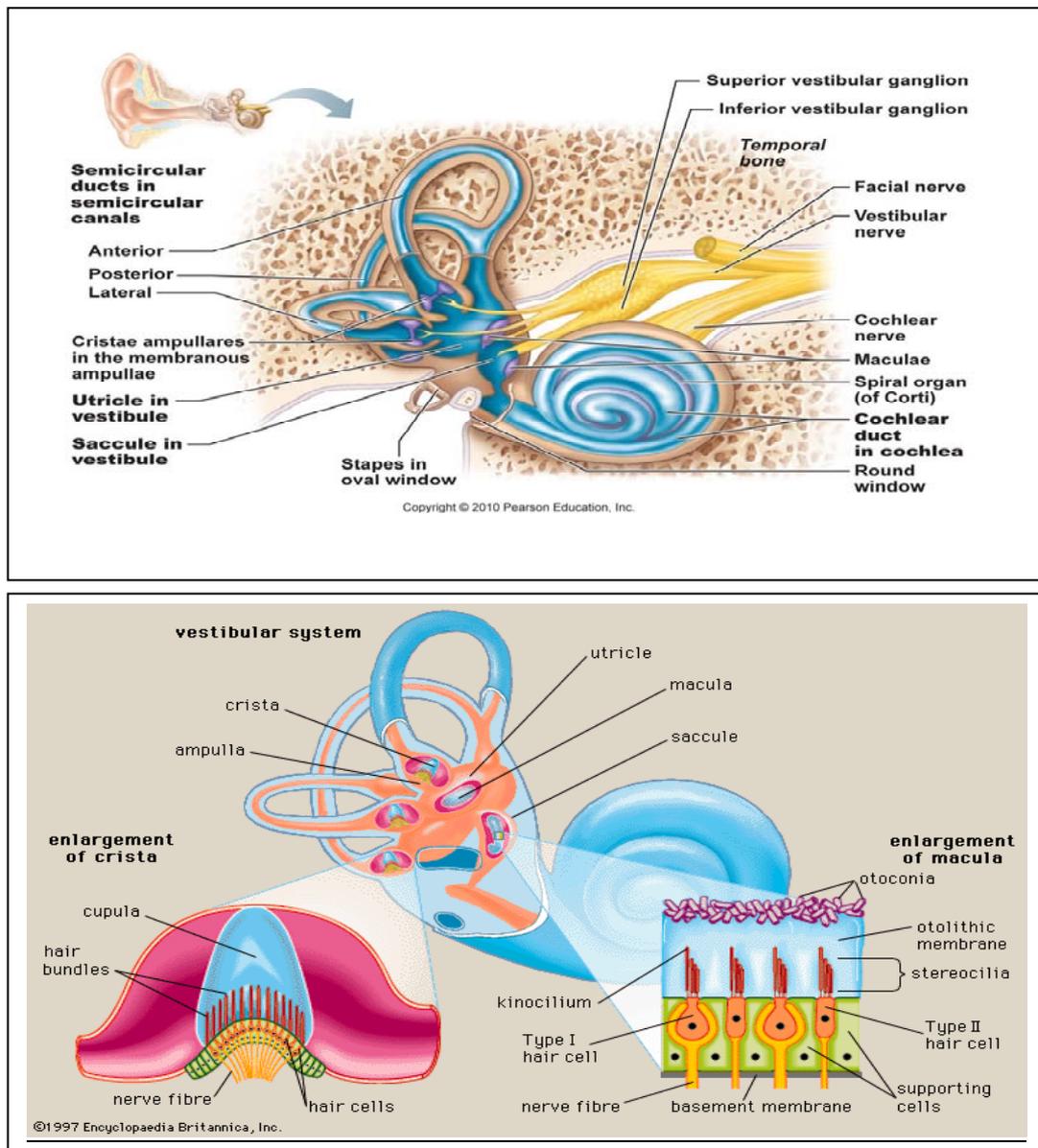
Source: Marieb & Hoehn (2007)

The tonotopic array of the cochlea is relayed to the auditory nervous system in the form of individual nerve fibre activation. The travelling wave quickly damps after reaching its point of maximum excursion. The frequency analysis ability of the basilar membrane is determined by graded stiffness, thickness and width. The basilar membrane is stiffer, thinner, and narrower at the base than at the apex. Excitation of the outer hair cells occurs primarily as the result of shearing effect on the cilia. The excitation of the inner hair cells is produced by the effect of fluid flow and turbulence of endolymph. When the basilar membrane is displaced upward, the hair cells are activated, resulting in electrical potentials. Resting potentials are those voltage potential differences that can be measured from the cochlea at rest. The scala vestibuli is 5mV more positive than the scala tympani, but the scala media is 80mV more positive.

The intercellular resting potential in the hair cell reveals a negative potential difference between the hair cells and the basilar membrane of 70 mV, giving a 150 mV difference between the hair cells and the surrounding fluid. Stimulus-related potentials include the alternating current cochlear microphonic, generated by the outer hair cells; the summing potential, a direct current shift in the endocochlear potential; and the whole-nerve action potential, arising directly from stimulation of large number of hair cells simultaneously. There are two basic types of neurons (low-threshold neurons and high -threshold neurons) in the V111<sup>th</sup> nerve, and specific techniques have been developed for assessing their function. High-threshold requires a higher intensity for response and encompasses the higher end of our auditory range of signal intensity. Low-threshold fibres respond at very low signal levels and display random firing, even when no stimulus is present. Low-threshold neurons may process near threshold sounds, whereas high-threshold fibres process high-level sounds. Temporal and tonotopical arrayed information progresses to higher centres for further extraction of information.

The cochlear nucleus reveals tonotopic representation with the wide variety of neuron responses. The superior olivary complex is the primary site of localisation of sound in space. Contralateral stimulation of the superior olivary complex by high-frequency information results in excitation related to stimulus intensity. Low-frequency stimuli presented binaurally to the superior olivary complex result in interaural time difference detection. A wide array of responses is seen at the inferior colliculus, including neuron inhibitory responses, onset and pause responses, intensity-sensitive units, interaural time-and intensity-sensitive neurons. The medial geniculate body is a relay of the thalamus. The cerebral cortex receives input primarily from the contralateral ear via the ipsilateral medial geniculata body. The auditory reception area is organised into columns, having a similar characteristic frequency. Different neurons within the columns respond to different stimulus parameters, such as frequency up-glides, down-glides, intensity up-and down-glides, and so on.

### 3. 5 Vestibular Mechanism

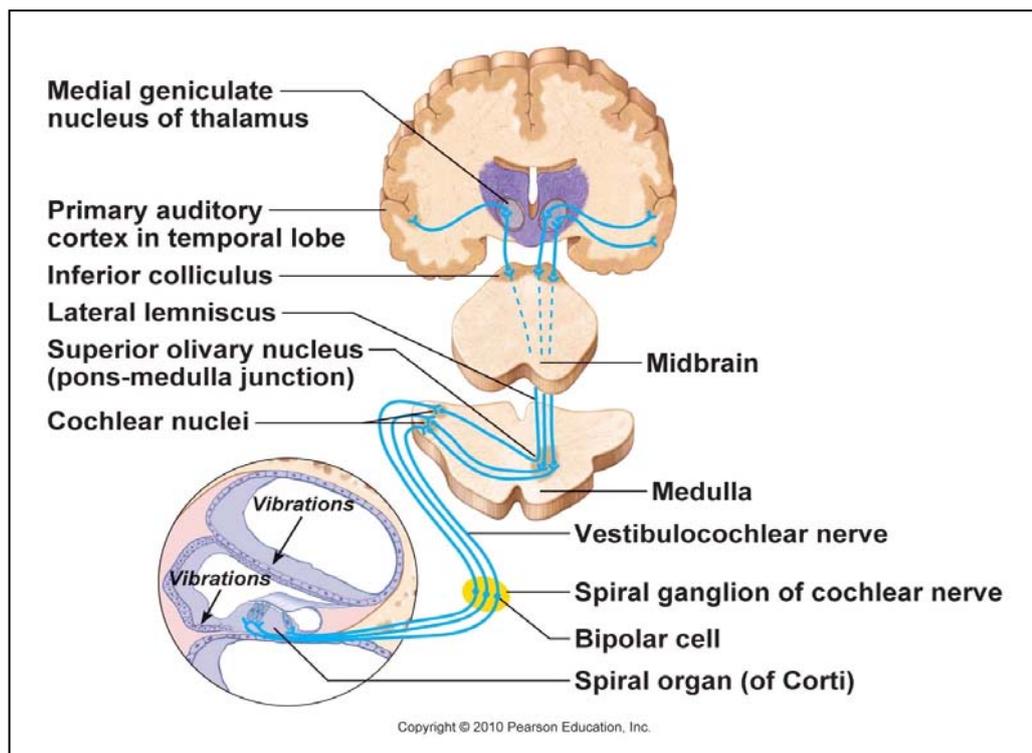


**Figure 3-8: Vestibular system**

Source: Marieb & Hoehn (2007)

Figure 3-8 shows that the membranous labyrinth of the vestibular system (centre), which contains the organs of balance, and (lower left) the cristae of the semicircular ducts and (lower right) the maculae of the utricle and saccule.

The semicircular canals are uniquely designed to respond to rotatory movement of the body. By virtue of their orientation, each canal is at right angles to one other canal, so that all movements of the head can be mapped by combination of outputs of the sensory components, the cristae ampullares. Activation of the sensory element arises from inertia; as the head rotates, the fluid in the semicircular canals tends to remain in the same location. The result of this is that the cilia is simulated by relative movement of the head during rotation. The utricle and saccule sense acceleration of the head during body or head movement, rather than rotation. Taken together, the vestibular mechanism provides the major input to the proprioceptive system serving the sense of one's body in space. This information is integrated with joints sense, muscle spindle afferents and visual input to form the perception of body position.



**Figure 3-9 Auditory pathway (Neural) from the organ of Corti to the auditory cortex in the brain**

Source: Marieb & Hoehn (2007)

There are many ascending auditory pathways to the brain involving various brain stem nuclei, but the most important pathway for the impulses produced by the organ of Corti ascend via the spiral ganglion (Figure 3-9) to the cochlear nuclei in the

medulla. From here the impulses pass to the superior olivary nucleus and through the lateral lemniscal tract to the auditory reflex centre of the midbrain known as the inferior colliculus. From there the impulses pass to the auditory cortex in the temporal lobe through relays in the medial geniculate body in the thalamus. Impulses also pass from the inferior colliculus to the superior colliculus in the midbrain. These colliculus acting together produce the reflexes to sound such as the startle reflex and head turning.

### **3.6 Processing of auditory signals**

Even beyond these tasks are the everyday requirement of listening to a signal embedded in a background of noise and listening to extremely rapid sequences of sounds. The outer ear collects sound and shapes its frequency components somewhat; the middle ear matches the airborne acoustic signal with the fluid mechanism of the cochlea; the inner ear performs temporal and spectral analysis on the ongoing acoustic signal; the auditory pathway conveys and further processes that signal. The cerebral cortex interprets the signal.

Auditory processing is the ability to distinguish important sounds from what can be described as auditory jumble of extraneous sound. If the discrimination of sound waves is sufficient, distinct tones can be heard. The analytical power of the auditory cortex is so great that it allows listeners to detect single instruments in an orchestra. Auditory processing is a complex function with some cortical cells depolarising at the beginning of a tone sounding with others depolarising at the tone end. There are cells which seem to depolarise continuously, with some having higher thresholds than others. Figure 3-9 shows the pathway from the right ear where the signal is processed by both sides of the auditory cortex of the brain, but the signal processing in this case will be stronger in the left side of the cortex (described as the contralateral auditory pathway).

### **3.7 Ear development**

There appears some uncertainty over the time periods of development during gestation although the development of the cochlea is usually complete by the end of

the second trimester of gestation. Lerner (2006) indicates that while a newborn's ear looks like that of a fully developed adult, research is continuing to determine when the ear completes development and takes on a full adult-like function. As this could extend into puberty, it would be prudent to limit a child's exposure to noise well below that considered an acceptable risk for adults.

### **3.8 Hearing through air conduction**

This is the usual process by which the auditory function occurs. The sound waves travel to the ear via the pinna and travel down the ear canal to move the eardrum. This sets the ossicular chain (middle ear bones) to move and then transfers the vibrations to the cochlea, which converts these into neural impulses via the auditory nerve to the brain and for processing.

### **3.9 Hearing through bone conduction hearing**

The sound energy can also be transmitted by the cranial bones to the inner ear in a process known as bone conduction. The person's own voice is partly heard by this method. When the sound is sufficiently loud, a part of sound energy in the air is converted to solid-bone vibration in the skull. The acoustic energy may also be received by the bone conduction through the bone structure from other parts of the body. The same patterns of vibration as in air conduction are set up along the basilar membrane. Hearing through bone conduction is important aspect to be considered in evaluating the effectiveness of hearing protecting devices.

### **3.10 Thresholds of discomfort and pain**

The level at which sound becomes painful for a listener is the pain threshold for that person at that time. The threshold pressure for sound varies only slightly with frequency and can be age-dependent. Additionally, people who have been exposed to more noise usually have a higher threshold pressure. A threshold shift can also cause threshold pressure to vary. Prolonged exposure to sound at levels evoking pain can cause physical damage, potentially leading to hearing impairment. At sound pressure levels above 120dB, the average listener experiences discomfort. At about

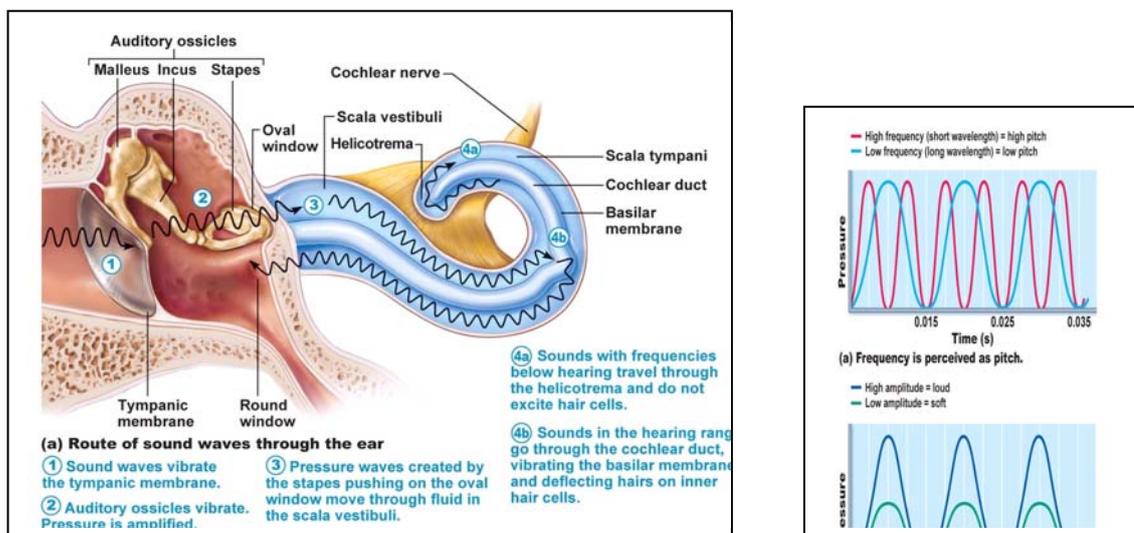
140dB, the listener experiences pain. It is likely that children will experience discomfort and pain at lower levels than adults. The World Health Organization recommended that in the case of children, sound pressure levels should never exceed 120dB (Berglund et al., 1999). A study by Freeman, Khvoles, Cherny & Sohmer, (1999) examined long term noise exposure on the developing and developed ear in laboratory rats. The study was based on the auditory development of the rat and designed to model the human foetal development of the ear. Anaesthetised young rat pups and mature adults were exposed to long-term continuous white noise (15 days at 12 hours daily continual exposure) of varying intensity. The effects were measured by electrophysiological and histological examinations. The authors observed greater histological damage to the cochlea of young immature rats (especially in the apical region of the basilar membrane) when compared to adult rats. They did not find a lower threshold function or greater susceptibility for noise-induced hearing loss in young rats when compared to adult rats by electrophysiological examination (otoacoustic emissions, and auditory brain stem evaluation). The observed histological damage could suggest long term rather than immediate effects on auditory function, as the onset of noise-induced hearing loss typically occurs gradually. A study on the long-term effects of such observed histological damage to the developing ear would be beneficial.

### **3.11 Types of Noise Induced Hearing Loss and Mechanisms of Injury**

There are two types of hearing damage that can occur from noise. The first type, called acoustic trauma, is an immediate, severe, and permanent hearing loss resulting from a sudden blast of extremely intense or loud sound (eg, gunshot or explosion) causing physical disruption of the inner ear structures. The second type, what we typically refer to as NIHL, is a gradual hearing loss that results from chronic loud noise exposure. Temporary threshold shift refers to NIHL of brief duration, lasting several hours to days. Irreversible NIHL, termed permanent threshold shift, may develop after many years of exposure. The degree of NIHL is determined by intensity, duration of exposure, spectral characteristics of the noise, and individual susceptibility. NIHL is the leading occupational disorder.

There are two general theories about the mechanism of injury in NIHL within the cochlea. The first proposes the concept of accumulated microtrauma and physical damage to the hair cells and/or their supporting structures. The second attributes the injury to metabolic exhaustion, causing an accumulation of damaging free radicals and oxidants which, in turn, overwhelm the antioxidant buffering capacity of the cells, leading to cell death.

### 3.12 Physiology, Pathophysiology and Histopathology



**Figure 3-10: Physiology of human ear**  
Source: Marieb & Hoehn (2007)

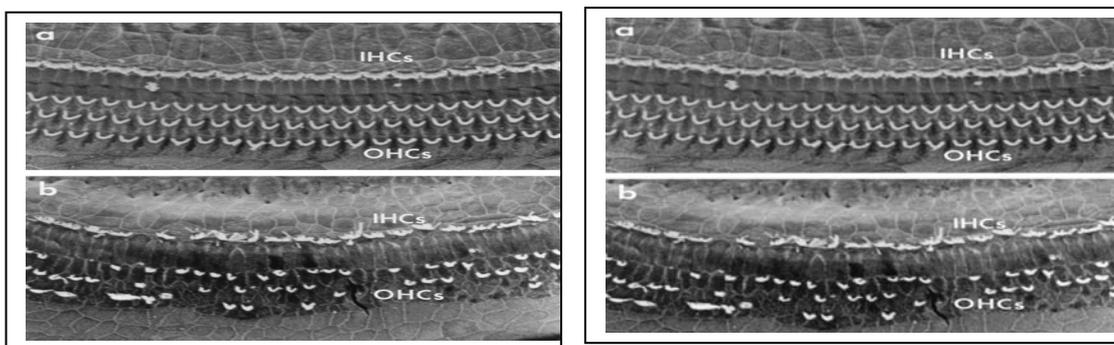
Although the histopathologic correlate to chronic NIHL is injury to the cells of the inner ear, the pathogenesis involves interactions between all three divisions of the auditory system – the external, middle and inner ears. The importance of the external ear centres on the resonant characteristics of the external auditory canal. Tubes that are open at one end have an inherent resonant frequency that is determined primarily by the length of the tube. The average human ear canal is 25mm in length. Using this value in the formula: resonant frequency = speed of sound/4 x ear canal length, means the average resonant frequency of the human ear is 3200Hz. Additionally, the configuration of the ear canal can serve to amplify mid-frequency sounds by as much as 20dB. The clinical importance of these characteristics is twofold. Studies have shown that the most severe hearing loss is demonstrated to be ½-1 octave higher than the offending noise. The broadband noise seen in industry is converted by the fundamental resonance of the ear canal to a 3Hz

noise. This leads to the characteristic 4Hz notch seen on the audiogram in noise-exposed individuals. Secondly, as mentioned previously, significant variability exists in different individual's response to similar noise exposure. One explanation for this variability could be differences in ear canal configuration and inherent resonance (Dobie, 1995; Henderson & Hamernik, 1995).

The contribution of the middle ear to the response to noise is the action of the acoustic reflex. The middle ear structures involved in this reflex are the tensor tympani muscle, which is attached to the head of the malleus, and the stapedius muscle, which is attached to the head of the stapes. Two cranial nerves – the trigeminal (V<sup>th</sup> nerve) and facial (VII<sup>th</sup> nerve) – participate in the reflex. Stimulation of the reflex by a sudden intense sound causes muscle contraction. As explained above, the action of the tensor tympani is to tense the tympanic membrane by pulling the malleus medially while the tensor stapedius pulls the stapes perpendicular to its axis on the oval window. The combined action of these muscles is to stiffen the middle ear structures, thereby reducing the sound energy reaching the inner ear. This system is most effective in attenuating low frequency sounds (<2kHz). Also, as reported above, human and animal studies have shown that malfunction of the acoustic reflex is related to more temporary and permanent hearing threshold shifts. Specifically, patients with Bell's palsy developed more TTS on the side of the facial paralysis when exposed to moderate noise. Additionally, differences in reflex latency, threshold, strength of muscle contraction and resistance to adaptation have been found and may help to explain inter-individual differences in NIHL (Dobie, 1995; Henderson, Subramaniam & Boettcher, 1993; Henderson & Hamernik, 1995).

The injurious action of noise is believed to affect not only the sensory cells of the inner ear but also the supporting cells, nervous structures and blood vessels. The outer hair cells are more vulnerable to noise injury than the inner hair cells (IHC). This is likely secondary to several characteristics, including the location of the outer hair cells, which is close to the point of maximal basilar membrane displacement, the direct shearing forces on the stereocilia of the outer hair cells against the tectorial membrane, and the relative lack of supporting cells around the outer hair cells. Early noise-induced injury involves alterations in hair cell membranes that eventually lead to a failure in the regulation of intracellular ionic composition. A chain of events is

set off that involves cell swelling or an increased number of lysosomes and changes in essentially all cellular organelles. The hair cell cilia may become floppy, disordered, splayed, fractured or fused. Some of these changes seen in the cilia are reversible – this may be seen clinically as a temporary threshold shift. However, at some point the cell is unable to recover from these injuries and degenerates – causing a permanent threshold shift. With prolonged noise exposure, supporting cells and inner hair cells undergo similar changes and eventual loss. After inner hair cell loss, retrograde degeneration of cochlear nerve fibres may also be seen. Noise exposure has also been found to cause changes in the vascular system of the cochlea. Reductions in the number of capillaries, evidence of vessel occlusion, and alterations of red blood cells packing density have all been demonstrated in noise-damaged ears. Although all of these pathologic changes have been well documented in both animal and human studies, a clear relationship between the degree of hearing loss and cochlear pathology has not been documented. Histological study of ears that demonstrate identical audiograms may reveal markedly different pathology. Not only does this, once again, point to differences in susceptibility to NIHL, but it also has implications regarding differences in successful rehabilitation of hearing loss (Seikel, King & Drumlight, 2005; Marieb & Hoehn, 2007).



**Figure 3-11: Damage to Cochlea hair cells**

**These are electron micrographs of cochlear hair cells. The ones on the left are healthy. Portion of a healthy organ of Corti from a guinea pig showing the characteristic three rows of outer hair cells and single row of inner hair cells.**

Source: Keithley, Mien-Chi & Fred (1993).

Figure 3.11 shows the normal cochlea, the stereocilia of a single row of inner hair cells (Ices), and three rows of outer hair cells (Ohms care present in an orderly array. In the damaged cochlea, hair cells are missing, and stereocilia are abnormal, leading to hearing loss.

Exposure to excessive sound dulls hearing and may damage the ear. If the sound is moderate, it produces a temporary threshold shift (TTS), which, if the ear is allowed to rest, recovers from. Anyone who has visited a disco or been close to loud machinery has experienced this phenomenon; this mechanism is metabolic exhaustion and recovery. If the sound is sufficiently intense, it produces a much more severe TTS, which may go on to become a permanent threshold shift (PTS).

There is a critical point at which the level of sound correlates well with anatomical damage to the outer hair cells, a process of damage and scarring or repair. The threshold for temporary threshold shift is somewhere between 78 and 85dB, and the point at which it changes from mid-term to long-term is about 140dB. The spectrum of the sound and the length of exposure are critical.

Cilia of the outer hair cells are attached to each other near their tips by linking filaments, and each cilium has a little rootlet that passes through the ciliary's plate. If the mechanical disturbance produced by sound is sufficient to fracture the rootlet or to disturb the linkage (those often happen together), the anatomical correlates of sound exposure is to produce a floppy cilium. These only partly recover, and frequently the cilia are destroyed by pharyngeal scarring. By contrast moderate sound excursion produces much less distortion of the cilia, and they do recover. Noise characteristically damages the outer hair cells of the basilar turn. If the sound is intense enough, there is a physical disruption of the cochlea and other structures such as the stria vascularis, and the supporting cells may also be damaged. Some time after hair cell death there is also neural degeneration of the first order neurons. Very intense sound has been shown to produce damage to the vestibular epithelium of guinea pigs, and this has also been convincingly demonstrated in humans.

### 3.12.1 Tuning Curve

Each auditory nerve fibre is most responsive to a specific frequency, but as the intensity of sound increases, it becomes progressively sensitive to adjacent frequencies. With outer hair cell loss, the most sensitive finely tuned part of the response is lost. It is generally assumed that the sharp tuning of these curves at low intensity is the result of active mechanisms in the outer hair cells and associated efferent nerve pathways. Those losses may be correlated with the clinical findings of poor sound discrimination, a common complaint in NIHL.

Hearing loss from loud noise exposure happens because of damage to structures in the cochlea. Excessive exposure to high-intensity sound causes damage to the outer hair cells of the organ of Corti, in the cochlea. These cells are responsible for the enhancement of hearing sensitivity and tuning. The outer hair cells have a motor component that amplifies soft sounds at specific frequency points in the cochlea and are responsible for the sharpness of pitch perception as well as amplifying soft sounds (Henderson & Hamernik, 1995). Damage also causes a widening of the auditory filtering system, which reduces the accuracy of pitch perception (Seikel et al., 2005). This can occur with even a small amount of hearing loss.

The damage mainly occurs to the hair cells and their nerves fibres. Hair cells in the cochlea respond to different frequencies of sound. A different group of hair cells respond to different frequency (pitch) sounds. Some respond to low frequency sounds, a group of hair cells respond to mid frequency sounds, and some of them respond only to high frequency sounds. When hair cells in the cochlea are repeatedly exposed to excessive or over-stimulation from loud sound, they become fatigued and fail to respond effectively to the sound stimuli. This causes temporary dullness in hearing or temporary threshold shift (TTS). If there is no further noise exposure the temporary damage recovers approximately within 16-24 hours of the exposure. If the loud noise/music exposure is repeated for prolonged periods the hair cells will become permanently damaged and the hearing loss becomes permanent.

Figure 3-11 shows a portion of a noise-damaged organ of Corti from a guinea pig exposed to sound at 120dB (Keithley et al., 1993). This is similar to that experienced

at a heavy metal rock concert. The ones on the right have been damaged by noise exposure, showing “scars” that have replaced many of the outer hair cells and showing the remaining stereocilia in disarray. Hearing is permanently damaged because lost hair cells will not be replaced, and injured cells may be dying.

This image on the left shows healthy/normal cochlea. The figure shows three rows of healthy/undamaged outer hair cells and the single row of inner hair cells. The image on the right shows the permanently damaged outer hair cells. Unfortunately, as of today, no proven treatment has been identified to help damaged cochlear hair cells to regenerate or be replaced.

Damage from noise in occupational settings mostly occurs to those cells that detect higher frequencies of sound. Thus the characteristic noise-induced hearing loss is a loss of high frequency hearing, particularly between 3 and 6kHz (Dobie, 1995). As each group of hair cells in the cochlea is responsible for a particular frequency of sound, the frequency of the intense sound influences the frequencies in the hearing loss. However, the hair cells that are responsible for detecting high frequency sounds are the most affected.

Exposure to excessive sound dulls hearing and may damage the ear. If the sound is moderate it produces a temporary threshold shift, which, if the ear is allowed to rest, recovers from. Anyone who has visited a discothèque or been close to loud machinery has experienced this phenomenon of metabolic exhaustion and recovery. If the sound is sufficiently intense, it produces a much more severe temporary threshold shift, which may go on to become a permanent threshold shift.

There is a critical point at which correlates well with anatomical damage to the outer hair cells, a process of damage and scarring or repair. The threshold for TTS is somewhere between 78 and 85dB, and the point at which it changes to from mid-term to long-term is about 140dB. The spectrum of the sound and the length of exposure are critical.

### **3.12.2 Relationship-Temporary Threshold Shift and Permanent Threshold Shift**

The amount of temporary threshold shift depends upon the frequency of sound and individual susceptibility. It recovers after a period of relative quiet, with the speed of recovery depending upon the amount of noise – the greater the exposure, the longer the recovery time. This has importance in terms of administrative controls related to length of work shifts. If the sound levels are high enough, they produce long-term temporary threshold shift and recovery takes much longer. For example, people exposed to an explosion may partially lose their hearing, and recovery may continue for several days or even weeks. Recovery in these circumstances is rarely complete. The threshold for long-term temporary threshold shift marks the upper limit of safe working conditions.

Although temporary threshold shift is not a good predictor of permanent threshold shift (Henderson et al., 1993), its measurement still represents the only ethical method with sufficient control for developing information regarding the effects of noise on human hearing (Melnick, 1991). A noise-induced permanent threshold shift occurs when there is a less than a full recovery from a noise-induced temporary threshold shift. This may be a fairly common occurrence, with small amounts of permanent damage taking place after multiple temporary threshold shift experiences (Feuerstein, 2002).

According to the experts, a temporary threshold shift refers to the temporary hearing impairment that usually occurring after exposure to intense noise, the threshold being the quietest sound distinguished by the subject. It is now widely accepted that repeated temporary threshold shifts can lead to accumulated cellular damage which can cause a permanent threshold shift (Henderson & Hamernik, 1995). The precise relationship between temporary and permanent threshold shifts has not yet been elucidated, and temporary threshold shift cannot be used to predict the magnitude of permanent threshold shift. According to an animal study, however, (Luz, Fletcher, Fravel & Mosko, 1973) a TTS is considered to be a good predictor of early development of permanent threshold shift. A temporary threshold shift is known to increase in constant noise in direct proportion to the logarithm of exposure time and to decay in inverse proportion to the logarithm of recovery time (Botsford, 1971).

### 3.12.2.1 Equal energy Hypothesis

The total amount of acoustic energy to which the ear is exposed is important because damage appears to be dose dependent: the 'equal energy' concept. This states that between the threshold of damage – about 80dB – and an upper limit above which physical disruption takes place, similar total amounts of sound energy produce similar damage no matter whether the sound is of high intensity for a short period or a low intensity for a longer period. That is, double the sound level, half the safe time and vice versa. As the decibel scale is logarithmic, a doubling or halving of intensity is a change of 3dB. Thus, if one knows the safe level of sound exposure for an eight hour work day, one can compute the safe exposure time for differing intensities of sound. If 85dB is assumed to be safe for eight hours, then 88dB is safe for four hours and 91dB safe for two hours et cetera. If the intensity of a sound and the length of exposure are known, one can compute the eight hour time weighted average (LAeq, 8hr).

The equal energy concept is valid if the individual is exposed to the sound continuously; if the sound exposure is intermittent, as is the case with much industrial noise, this may be considered too severe a rule. As a result, in North America a 5dB trading relationship was adopted. The international standard ISO 1999 was established, based on the equal energy concept. It also provided a correction factor for ageing and other ear disease. As the North Americans saw the sense of this and started changing their regulations, some of the European advocates of the 3dB rule recognised the possible protective effect of intermittent noise exposure and at one time considered moving in the opposite direction (Robinson, 1987). There appears to be no single correct figure; it depends upon the nature of the sound exposure. The use of a time average level is a conservative approach as it protects more people; in truth for most industrial sound exposure the real exchange rate probably lies near 4dB per halving or doubling. There is also controversy about the base value. Most countries and some jurisdictions in the United States have adopted 85dB, others 87dB, but most in the United States still use a 90dB. The upper limit above which no ear should be exposed to appears to be about 115dB.

## **Chapter 4 : Studies of noise and hearing loss in musicians – A literature review**

### **4.1 Introduction**

This chapter includes various studies on hearing and hearing loss in orchestral musicians. It starts with the brief information on difference between music and noise. The studies are divided into various categories: studies finding that hearing loss is not a major issue among orchestra musicians and include longitudinal analysis of hearing loss development or progressive hearing loss with increased years of music exposure; studies finding better hearing with orchestra musicians than normal population; studies explaining sound power of various instrument groups; studies finding that hearing loss is a major issue among orchestra musicians; studies of young musicians, musicians and ear protection; and also studies on usage of ear plugs among musicians.

### **4.2 Difference between music and noise**

In the industrial population, the researchers are mostly comparing measures of standard noise exposure measurement with well-defined models of hearing loss. This is possible because many sources of noise in the industry have similar physical properties, such as spectrum shape, spectrum level, and even peak-to-average intensity (or crest factor) features. Music, by contrast, has very highly variable spectral shapes, differing spectral levels, varying ‘on-off times’ (between intense and quiet), and is played in very many environments from garages to concert halls; hence it is more difficult to make predictions concerning the damage-risk criteria for music than for noise exposure. This factor also makes it an even harder task to determine the total noise exposure of a musician.

The very nature of music is intermittent and has both quiet and intense passages. This variability in sound pressure levels in music has been considered to reduce the risk of hearing loss in musicians when compared to an industrial noise exposure where it is constant (Chasin, 1996). It is also proposed that the very nature of music, where frequency and sound level change constantly in a non-cyclical manner

(Behar et al., 2006), enables the ear to rest and reduces the potential risk compared to the noise in the industry where the noise is relatively continuous (Chasin, 1996).

Hearing loss in a musician is often asymmetric, unlike noise-induced hearing loss (except for an industrial worker where the machine is on one particular side). For the musician, this probably relates to the position of their musical instrument (or others' instruments) in relation to their ears. In the percussionist, for instance, it tends to be worse in close proximity to the high-hat cymbals. It also tends to be worse in the left ear of violinists and worse in the right ear of flute and piccolo players. Because of this imbalance, it is not unusual for these musicians to complain of distortion even in their better ear.

As mentioned above, there is a difference between noise and sound. Though the two relate to the same physical phenomenon and mostly affect the ear in the same way, people consider loud music to be 'good' sound, where more volume adds to the enjoyment (Serra et al., 2005). This is in contrast, to say, industrial noise, which is generally seen as a 'bad' sound where more volume is undesirable, (Crandell et al., 2004; Ologe, Akande & Olajide, 2005).

Unlike occupational noise exposure, musicians in a big orchestra are exposed to more than various type of sound source from their fellow musicians who are seated next to them, as well as playing their own instruments.

Music is much different in terms of frequency and intensity which constantly change, unlike an occupational noise. The classical music contains higher un-weighted peak levels than most industrial noise. The sound exposure from classical music to a large extent consists of sine-shaped time signals (a single note is represented by a sinusoidal oscillation of a single frequency and certain of its harmonics, depending on the musical instrument) while the chord is represented by several simultaneous tones (notes) whose ratio to each other are whole numbers.

In industrial practice, the first step in noise control is to reduce emission at the source – obviously not an option for a symphony orchestra.

Unlike industrial noise exposure, musicians work in highly variable venues where their acoustic characteristics can have significant effects on hearing (garages to concert halls) and have ‘exposure schedules’ that are almost impossible to predict.

The sound musicians innovatively produce is not a by-product of their job – it is their product, and good hearing is so important to produce music well. This particular difference makes musicians a special case. Musicians are very much dependent on their hearing for their profession, and they are frequently exposed to loud music. Besides, they have a complicating aversion to preventive measures, such as wearing ear muffs or using protective screens, as they may be accompanied by the loss of subtle effects that are necessary to play music and interact with fellow musicians.

### **4.3 Studies finding that hearing loss is not a major issue among orchestra musicians**

There are several studies that found that the hearing loss in musicians is not a major issue. Some studies even found that the musicians hearing loss is better than in the normal populations (Kahari, Axelsson, Hellstrom & Zachau, 2001).

Westmore and Eversden (1981), after performing audiometry and recording sound pressure levels within orchestras during performances, concluded that preventing hearing loss in musicians is not entirely possible, and also reported that there is no threat to the players’ continued livelihood though age-induced hearing loss poses a problem later in life. Short-lasting bursts of sound of high amplitude were found to occur, and some players had audiometric changes consistent with NIHL. Karlsson et al., (1983) found that the average threshold levels for symphony musicians were within the range expected for their age and therefore concluded that performing with a symphony orchestra was not a risk to hearing. According to Williams (1995), the orchestra musicians do not have a major noise exposure – the noise levels in the orchestra pit is not a major issue – but concluded that the noise levels in the pit environment will always be louder than in the open area. This was following a large study encompassing both hall and pit players from Australian Broadcasting

Corporation. Measurements were performed using a number of sound level meters during a variety of activities including rehearsals and performances.

After performing audiometric tests and taking sound level measurements on the musicians from four Danish orchestras, Obeling and Poulsen (1999) arrived at a conclusion that musicians are not expected to suffer significant hearing loss compared to the median audiogram from ISO 7029 for the same age and gender from industrial noise exposure.

Kahari et al., (2001) used sound level meters placed in various instrument groups to calculate the sound exposure of the musicians in four Danish symphony orchestras. They reported the average audiogram showed a decrease at higher frequencies, similar to an age-related hearing loss. The audiograms of 57 musicians were corrected for the age of the person by means of the median from ISO 7029, and the average audiogram from these age-corrected individual audiograms showed no signs of hearing loss. The audiograms were also compared to the expected audiograms from ISO 1999, which takes account of the number of years at work, the number of playing hours per week, and the average sound level in the orchestra for the instrument groups. In almost all cases the measured audiograms looked better than the predictions from ISO 1999. This study predicted that the musicians as a group, not as individual musicians, are not expected to get pronounced audiometric hearing losses from playing in a symphony orchestra. But the study noted that the data material is limited, and that the subjects have not been selected in a systematically or representative way.

Beale (2002) measured sound exposure levels on musicians from the Sydney Opera House after noise doses (%) were measured, having as a base 1 DND (daily noise dose) equivalent to LAeq, 8hs = 85dBA. He used Larson Davis, Bruel and Kjaer, and CEL noise dosimeters mounted on tripods located at 0.3 m from the ears of chosen musicians. Data was obtained during the performances of 18 operas. The report included only data from some wind instruments, and no mention was made as to whether the data was from a single performance or an average of several performances. The summary data indicated that the 1 DND had been slightly exceeded by only the trumpet section (103%) and horns (107%). The author

claimed that musicians in the pit had higher noise exposure than their colleagues on stage, although it did not mention by how much. This conclusion in theory appears to be true, but was not by his data.

After conducting a study with Netherlands Ballet Orchestra, Boasson (2002) concluded that, with the exception of the horns, all groups' music exposures were at or below the limit of 85dBA after sound level measurements. This orchestra performs yearly at about 18 different venues. Depending of the size of the venue, the size of the orchestra varies between 65 to 80 musicians. The measurements, such as instrumentation used, microphone location, and duration of the measurement were not included in the research paper. From the measurement data, the author found the sound exposure per type of performance (so-called "project") per year. This he calls LEX, PROJECT, and it is the noise exposure average over 260 days (the implicit duration of the musicians' annual activities). From the calculated data, the author predicted the hearing loss at 2, 3, 4, and 6kHz among the different groups of musicians will incur deterioration in hearing after playing for 30 years in the same environment. This was calculated using the ISO 1999 standard.

Lee, Behar, Kunov, & Wong (2005) concluded that playing for the orchestra does not pose risk of hearing loss for the musicians after comparing the sound levels to ISO 1999 standard. The music exposures of Canadian Opera Company orchestra players were measured to assess the risk of hearing loss of players in orchestra pits. This was done during 18 sessions that included rehearsals, dress rehearsals and actual performances of two operas. Seventy-three noise exposures on musicians were measured using five dosimeters for the entire duration (three hours) of each event. From this data he estimated the time average sound level received by its musicians and also calculated the total sound exposure for an entire year.

Toppila et al., (2011) concluded that orchestra musicians' hearing loss corresponds to that of the non-noise-exposed population after performing music level measurement and hearing evaluation on 63 musicians from four Helsinki classical orchestras. He also assessed some individual susceptibility factors with a questionnaire and also tested their blood pressure and cholesterol levels, and then compared their hearing loss to ISO 1999-1990's predictions. He found that

musicians' hearing loss distribution corresponded to that of the general population, but highly exposed musicians had greater hearing loss at frequencies over 3kHz than less-exposed. Toppila et al., (2011) stated that music deteriorates hearing, but by less than what ISO 1999-1990 predicted.

A survey conducted by Qian, Behar and Wong (2011) concluded that the noise exposure levels from only the orchestra's activities do not present risk of hearing loss. In this study, exposure to other musical activities was not included. They conducted sound level measurement on a 70-strong orchestra which plays an average of 360 hours/year (rehearsals and performances), and also conducted a survey using five dosimeters Quest model 300 during 10 performances of the ballet *Romeo and Juliet* by Sergei Prokofiev, deemed as the noisiest in the whole repertoire.

#### **4.4 Longitudinal study or progressive hearing loss with increased music exposure**

The only longitudinal follow-up study found in the literature was on progressive hearing loss from Sweden. Kahari et al., (2001), using pure-tone audiometry, undertook hearing reassessment of 56 classical musicians who participated in Axelsson & Lindgren's study 16 years earlier, in 1995. This study was on progressive hearing loss in these classical orchestra musicians after 16 years of music exposure. The main conclusions drawn from this study were that the male musicians, compared to the female musicians, showed a tendency toward a more pronounced, although not significant, hearing reduction in the high frequency region and higher threshold distribution within the 90th percentile than the female musicians. This was found most often in the left ear. The median audiogram for all females showed a notch configuration at 6kHz, compared to the males who had a high-tone sloping configuration. When comparing high frequency pure-tone average (HFPTA) values with ISO 7029, the females are distributed around the ISO 7029 median and well within the 90th percentile. The average hearing threshold of the males was equal with the median. This follow-up study showed no progressive hearing loss in pure-tone hearing threshold values in spite of an additional 16 years of musical noise exposure.

#### **4.5 Studies finding better hearing than normal population**

Fleischer and Muller (2005) examined the hearing of 187 orchestra musicians aged between 21 and 70 years with average of 44 years. They found that the hearing of 83.4% of the musicians was better than that predicted by the ISO 1999 standard. On this basis, the authors supported the theory that a high noise level may indeed build resistance to hearing loss, something that could explain their findings (Jansen et al., 2008). Relative auditory thresholds were generally better than the normal-hearing reference group of ISO 7029 (2000) standard, except at 6kHz.

#### **4.6 Studies explaining sound power of various instrument groups**

In another study, Mikl (1995) attempted to assess the risk of hearing loss in musicians by calculating the sound power from different instrument groups in the orchestra. He used 10 microphones located on a hemisphere around selected groups, each with three musicians, all located within 3m from the centre of the hemisphere. For each instrument group, representative segments of the opera *Tosca* by Puccini were selected by the conductor and designated as ‘soft’, ‘medium’, and ‘loud’. The musicians were also asked to play the ‘loud’ selections at the maximum possible level. The sound power of each group of instruments was measured and corrected for the reverberation time of the room and the number of players within the group. The overall sound power was then calculated using the total number of players in each group. This study concluded that the highest overall noise power comes from the brass and percussion sections. The aim of this study was to calculate the sound power of groups of instruments, and therefore cannot be used to assess the risk to hearing loss in musicians.

#### **4.7 Studies finding that hearing loss is a major issue among orchestra musicians**

There are some studies that have concluded that the hearing loss is a major issue among orchestra musicians. The incidence of hearing loss among musicians varies across studies, depending on the definition of hearing loss and the specific subgroup

studied. Axelsson and Lindgren (1978) studied 83 pop musicians with an average of nine years of music exposure and a mean age of 30 years, and concluded that the incidence of hearing loss in musicians to be 30%. Royster et al., (1991) found that the audiograms are presented with notches, but additional increased high frequency threshold attributed to age-related hearing loss. In this study measurements of music exposure and hearing thresholds among orchestral musicians were carried out at the Royal College of Music (RCM) on 19 staff members (mean age=45.7, SD=11.0).

McBride et al., (1992) found that some musicians are exposed to sound levels in excess of the recommended limit and are therefore at risk after measuring sound levels during five rehearsals and two concert performances of the Symphony Orchestra of the City of Birmingham. The data collected was time average level ( $L_{eq}$ ), Peak level ( $L_{peak}$ ), duration, and music dosage. Musicians were subjected to the audiometric test to determine the presence of hearing loss. For that purpose, 18 'high-risk' musicians were matched for age and sex to 'low-risk' musicians. The authors stated that they cannot estimate the total noise exposure due to the fact that most professional musicians have other commitments, such as teaching. This study drew conclusions after applying paired t-test to the results of both groups failed to show significant differences in hearing thresholds at high frequencies (2, 4, and 8kHz) but did at low frequencies (0.25, 1, and 2kHz), but no explanation of this effect was provided in this study.

Mikl (1995) found that the placement of the performers in the orchestra, coupled with a tight schedule, contributes to a significant risk of noise-induced hearing loss for orchestra musicians, but concert patrons and the conductor are not at risk after performing a series of music measurements during rehearsals and performances of the Australian Opera and Ballet Orchestra. In this study, measurements were taken between four and six positions using a Larson Davis integrating sound level meter and dosimeters, and the microphones were suspended from the ceiling at a distance of less than a meter from the monitored ear.

Eaton and Gillis (2002) reported on three studies of musicians' noise exposures. On analysis mean equivalent sound level,  $L_{eq}$  of 146 symphony musicians was 90dBA.

Brass and woodwind players have higher  $L_{eq}$  values than stringed instrumentalists. In addition, elevated hearing levels for certain instrument groups (woodwind, percussion and brass) were observed.

This study concluded that most musicians are overexposed. Laitinen et al., (2003) used dosimeters to measure noise exposure levels of players, singers, dancers, and auxiliary personnel of the Finnish National Opera. From their results, annual noise exposure levels of different groups of musicians were calculated, assuming that the total duration of the exposure (individual and group rehearsals and performances) was 1500 hours.

Kahari et al., (2004) concluded that rock musicians showed slightly worse hearing thresholds compared to classic musicians. In musicians' hearing loss, tinnitus and hyperacusis were the most common problems and were significantly more frequent compared to the reference group. In this study they performed hearing tests on 140 classical musicians and 139 rock musicians, and compared their hearing test results to age appropriate reference materials. The hearing thresholds showed notched configurations in both classical and rock musicians but overall well preserved hearing thresholds. Female musicians had significantly better hearing thresholds in the high frequency region than males.

According to Emmerich et al., (2006), professional musicians often suffer from occupational hearing loss. He assumed that changes in the central processing of auditory signals reflect a functional reorganisation following a peripheral (cochlear) damage. In order to assess the hearing ability in musicians they assessed sound emissions in the orchestras and recorded hearing levels by audiometry and otoacoustic emissions (TEOAE/DPOAE) as well as mismatch negativity (MMN) to auditory stimuli by using EEG and MEG. Data was obtained from 172 professional musicians aged 11-69 years from a music school and three major German orchestras. The orchestral musicians are exposed to sound pressure levels up to 120dB SPL. After 12 years of musical performance, 52% of the musicians suffer from hearing damage, and the MMN 200 ms after the stimulus was significantly larger in musicians vs. non-musicians regardless of pure-tone or out of tune chords. Among the strings, the data differed between right and left ears. The author

concluded that to assess the mechanisms of occupational hearing loss and to diagnose the damage, we need to assess the hearing threshold shifts, and also, the influenced parameters of central auditory processing have to be investigated. The author assumed that changes in the central processing of auditory signals reflect a functional reorganisation following a peripheral (cochlear) damage.

A study performed by Emmerich, Rudel and Richter (2008) found that more than 50% of the musicians had a hearing loss of 15dB and more after assessing the hearing status of professional musicians at different ages to look for a coherence of declined hearing ability and the sound emissions in order to provide advice for hearing protection and occupational medicine in musicians. Audiometric data and amplitudes of OAE were evaluated from 109 professional musicians aged 30–69 years from three major German orchestras and from 110 students of an academy of music (aged 11–19 years). The sound emissions of the whole orchestra and the single instruments group were measured at the orchestra stages and pits during rehearsals and performances. The highest losses were found among the strings and the brass players. DPOAE amplitudes were reported to decline with the duration of performing music in the orchestras. The professional musicians aged older than 60 years had a significantly greater hearing loss at 4 and 6kHz than those aged 30–39 years. Among the strings in one orchestra, a dominant hearing deficit in the left ears was observed. This study concluded that orchestral musicians hearing level becomes poorer and OAE amplitudes significantly decline with the length of time of being a professional musician, and the music levels during practice and performances exceed those allowed in industry.

Schmuziger, Patscheke and Probst (2007): in this exploratory study, pure-tone thresholds from 0.5 to 14kHz were measured in both ears of 16 non-professional pop/rock musicians (mean age, 35 years; range, 27 to 49 years) before and after a 90-minute rehearsal session. All the musicians experienced repeated exposures to intense sound levels during at least five years of their musical careers. This study concluded that after the rehearsal, median threshold levels were found to be significantly poorer for frequencies from 0.5 to 8kHz.

Jansen et al., (2008) assessed the hearing status of musicians of professional symphony orchestras; 241 professional musicians, aged 23-64 years participated in this study. A brief medical history and a subjective judgment of their hearing and hearing problems were assessed. Musicians were subjected to an extensive audiological test battery, testing of audiometric thresholds, loudness perception, diplacusis, tinnitus, speech perception in noise, and oto-acoustic emissions. Musicians show more noise induced hearing loss than could be expected on the basis of age and gender. Their audiograms show notches at 6kHz, a frequency that is associated with NIHL. Musicians often complained about tinnitus and hyperacusis while diplacusis was generally not reported as a problem. Tinnitus was most often localised in the left ear and this could not be related to the instrument. It was usually perceived in high frequency areas, associated with NIHL.

O'Brien, Wilson and Bradley (2008) found that the principal trumpet, first and third horn and principal trombone are at the greatest risk of exposure to excessive sustained noise levels, and that the percussion and timpani are at greatest risk of excessive peak noise levels. However, the findings also strongly support the notion that the true nature of orchestral noise is a great deal more complex than this simple statement would imply. This study recorded music levels in the Queensland Orchestra in Australia over a period of three years. The study recorded time average and peak level.

#### **4.8 Studies in young musicians**

In certain animal models there is evidence of heightened susceptibility to noise exposure shortly after birth--a "critical period" (possibly following the time when fluids fill the middle ear but before complete development of the cochlear structures). However, it is not clear that data from such animal models can be generalised to full-term normal human infants. Premature infants in noisy environments (e.g. neonatal intensive care units), however, may be at risk.

As there has been an existing controversy about hearing loss in orchestra musicians, student musicians are not defined as an 'at risk' population according to the Occupational Safety and Health Administration. Previous studies have shown that

all tested student musicians, regardless of instrument type, were exposed to daily noise doses that exceeded both OSHA and NIOSH (National Institute for Occupational Safety and Health) standards.

Student musicians enter college level intensive music programmes of study to begin a life-long professional career in music. Many music students spend many more hours practising their musical instruments in small practice rooms, where measured music levels may exceed levels at which an industry would be required to mandate a hearing conservation programme (Phillips & Mace, 2008).

It has been generally accepted that prolonged exposure to loud music causes various hearing symptoms (e.g. tinnitus) and consequently leads to a risk of permanent hearing damage, known as music-induced hearing loss (MIHL). Such potential risk of MIHL due to loud music exposure has been widely investigated in musicians and people working in music venues. With advancements in sound technology and rapid developments in the music industry, increasing numbers of people, particularly adolescents and young adults, are exposing themselves to music on a voluntary basis at potentially harmful levels, and over a substantial period of time, which can also cause MIHL.

Niskar et al., (2001) conducted a survey of US children 6 to 19 years old, from 1988 to 1994. This was a national population-based cross-sectional survey with a household interview, audiometric testing at 0.5 to 8kHz, and compliance testing. A total of 5249 children aged 6 to 19 years completed audiometry and compliance testing for both ears. The criteria used to assess NITS included audiometry, indicating a noise notch in at least one ear. The results are suggestive that 12.5% (approximately 5.2 million) are estimated to have noise induced threshold shift in one or both ears. In the majority of the children meeting Noise Induced Threshold Shift (NITS) criteria, only one ear and only one frequency are affected.

A large survey conducted by WorkSafeBC (Workers Compensation Board of British Columbia) on young workers entering the workforce reported that over 20% have some early signs of hearing loss. This report includes all causes of hearing loss. Canadian data (Statistic Canada) shows that 13% of children (up to 14 years of age) have some hearing loss, but this statistical data does not separate out the cause.

In a Scandinavian study (Axelsson & Lingren, 1981), a hearing test on 538 teenage boys revealed a 15% of the children had hearing loss (greater than 15 decibels [dB]). The loss indicated that the majority of hearing loss was related to noise exposure. Zenner (1999), a German review of clinical data, estimated that one in 10 adolescents had some degree of noise-induced hearing loss from 'leisure time noise'. Meyer-Bisch (1996), an epidemiological evaluation of audiometric survey of 1364 young subjects conducted in France, found evidence of hearing problems in 12% of the general population, and in a subgroup that often attended rock concerts or used 'personal cassette players' (more than seven hours per week), 66% had hearing loss.

National Institutes of Health (NIH) in surveys have found that school-age children are the fastest growing population of noise-exposed individuals suffering permanent hearing loss (Blair, Hardegree & Benson, 1996). Palmer (2009) stressed the importance of targeting the life-long habits of school-age music instrumental students and their teachers through an education and hearing protection programme and encouraging life-long healthy hearing habits in them. This is a group of individuals who are known to have potentially damaging levels of sound exposure through a school activity, and a group of individuals who are using their hearing for a specific purpose (i.e., making music).

On a study of hearing acuity of undergraduate music students, Fearn (1993) reported that 33% of student orchestral musicians had elevated thresholds, 75% of which were at 6000Hz and 50% in only one ear. Royster et al., (1991) recorded exposure data over a one week period using personal noise dosimeters attached to 10 RCM orchestra students during rehearsals and during a performance. Noise levels (and compliance with the UK's noise at work regulations) depended upon the type of instrument being played and where musicians were seated; for example, the average 8-hour time average level for the trumpet was 88.4dB(A), while it was only 77.1dB(A) for the double bass. The author suggests that different hearing protection strategies may be appropriate for different musicians. Audiogram data taken from 37 students showed that the students (mean age=24.2, SD=4.0) had statistically significant bilateral notches at 6kHz, indicative of noise-induced hearing loss.

Schmidt, Verschuure and Brocaar (1994) concluded, after assessing hearing of students at the Rotterdam conservatory, that the exposure of conservatory students to the practice of music has as yet had no effect on their hearing. However, they noted that high percentages of audiometric noise dips (16%) and high-frequency losses (20%) were found in students of the conservatory, as well as a high percentage (72%) of extended high-frequency losses relative to the reference curves. An equally large (and in the high-frequency region an even higher) percentage of hearing losses was found in the control group of medical students with the same median age.

Miller, Stewart and Lehman (2007) concluded that music measurement criteria OSHA (1983) and NIOSH (1998) yielded values that exceeded a 100% daily noise dose for all subjects. The results indicated that university student directors and musicians appear to be at high risk for permanent noise-induced hearing loss, secondary to excessive exposure to loud music. Twenty-seven student musicians were surveyed regarding musical practice and playing habits, knowledge of hearing conservation practices, use of hearing protective devices (HPD), and the occurrence of tinnitus after exposure to loud music. In addition, noise exposure levels during practice and sporting events (football and basketball games) at which they played were monitored with a dosimeter simultaneously set to measure noise levels. Forty-eight percent of the subjects reported practising or playing their instrument >10 hours a week. Most musicians (74%) reported having been taught about the effects of noise on hearing and health; however, less than a third used ear protection while playing their instruments and those who did used it inconsistently. Sixty-three percent of subjects reported experiencing tinnitus after exposure to loud music. These results support the need for on-going hearing conservation programmes to educate student musicians and student directors about the dangers of excessive exposure to loud music.

Phillips, Henrich and Mace (2010) analysed hearing threshold and survey data collected over three years in a university school of music. These indicate that 52% of undergraduate music students show a decline in high frequency hearing at 6000Hz consistent with acoustic overexposure. Declines at 4kHz have grown in number over the past three years, from 2% in the first year to 30% in the third year.

These 'noise notches' are seen in all instrument groups, including voice, and are seen more in the right ear than the left ear in all groups. Exposure to outside noise appears to be a determining factor in who develops these declines. It is also concluded that a genetic predisposition factor is a likely risk factor (Phillips et al., (2010).

Backus and Williamon (2009) found that a statistically significant notch at 6kHz in the left ear, indicative of noise-induced hearing loss (NIHL), but no significant notch was found in the right. He concluded that the earliest audiometric indicator of impending NIHL for musicians may be a developing hearing threshold notch at 6kHz in the left ear. An assessment of hearing thresholds among student orchestral musicians was carried out at the University College London Ear Institute in conjunction with the Royal College of Music (RCM). Audiogram data taken from 162 students (86 F, 76 M; mean age=23.7 years, SD=4.8) showed noise exposure asymmetry did not appear to account for notch asymmetry as trombone and trumpet players showed evidence of the same left notch trend as lateralised instrument players such as violin and viola players.

In a study by Callahan et al., (2011), the students were also asked about their participation in 14 other activities involving potential noise exposure, including concerts (95 percent attended), use of personal stereo players (92 percent), and going to restaurants and bars with loud music (87 percent), as well as machine use (15 percent), target shooting (14 percent), hunting (11 percent), and construction work (6 percent). This author concluded that as young musicians they don't really think about hearing loss being a factor for them now.

Barlow (2010) found an extremely high hazard of excessive noise exposure in both their social and study-based music activities after evaluating 100 music students across a range of university popular music courses. These were surveyed using a 30-point questionnaire regarding their musical habits both within and external to their university courses and also using sound level measurements. The responses showed 76% of student musicians reported having experienced symptoms associated with hearing loss. Rehearsals averaged 11.5 hours/week with a mean duration 2 hrs 13 mins plus a mean level of 98dB  $L_{Aeq}$ . Ninety-four percent of

subjects reported attending concerts or nightclubs at least once per week, and measured exposure in two of these venues ranged from 98 to 112dB  $L_{Aeq}$  with a mean of 98.9dB  $L_{Aeq}$  over a 4.5-hr period.

## **4.9 Musicians and ear protection**

### **4.9.1 Introduction**

Standard hearing protectors provide more reduction in the higher frequency sound energy than in the low frequency energy. Such sound reduction is not suitable for musicians' needs, as they cut down the high frequency energy in the music and distort the music quality. These standard hearing protectors do not provide uniform attenuation. Most available hearing protectors not only muffle the high frequencies, but may also provide too much protection. As a result, many musicians who are required to wear hearing protectors put them in only part way, or alter the plugs so they can still hear speech and environmental sounds.

For many professional orchestras, the acoustical environment during practice or performance is far from optimal with respect to avoiding or at least minimising the risks for hearing damage. Historically, the usage of hearing protection by musicians has been undesirable or even somewhat of a taboo (Chasin & Chong, 1992). The main reasons are: 1) The occlusion effect, which causes the user to feel echoey, blocked-up, and stuffed-up; 2) The stronger attenuation in the high frequency region relative to low frequency (Killion, DeVilbiss & Stewart, 1988; Chasin & Chong, 1991); and 3) It has been considered taboo because a musician doesn't want their peers or their audience to perceive them as having less-than-perfect hearing (Ostri et al., 1989). The developments in the hearing protection devices (earplugs) have come a long way, and now there are several commercially available models specially designed for use by musicians.

## **4.9.2 Musicians' plugs with varied attenuation**

### **4.9.2.1 Custom made musician ear plugs**

Based on the earlier work by Elmer Carlson (Chasin, 1996; Killion et al., 1988), manufacturers made ear impressions and prepared custom made earplugs with approximately 15dB of attenuation over a range of frequencies. The earplug, named the ER-15<sup>TM</sup>, was manufactured by Etymotic Research Inc. This has become more popular and accepted widely by the musicians as it provides uniform attenuation.

The most popular musician ear plugs are ER-9 ER-15 and ER-25 ear plugs, which, as the name suggests, provide uniform attenuation of 9dB, 15dB and 25dB respectively. Etymotic Research (ER) makes 'filter buttons' that fit into custom made ear plugs (Figure 4-1) that are made by ear mould labs and/or audiology clinics. Therefore, it is easy to substitute a button that provides a different amount of attenuation if the musician requires it. ER filters are specially manufactured; the attenuation value is constant. The ear mould laboratories use a 'mass meter' to verify that the custom made ear mould has the correct volume of air in the sound bore in order to establish an essentially flat attenuation pattern. As it is a custom made product, the deeper the end of the ear mould in the ear canal, the less the occlusion effect is. According to Chasin and Chong (1994), this can be achieved if the ear mould impression terminates 2-3 mm inside the bony portion of the ear canal. Currently, ER makes buttons (filters) with 9, 15, and 25dB uniform attenuation, as well as their non-custom ER-20. These musician ear plugs are useful for musicians who play various musical instruments that have a broad band energy spectrum, or those who perform in an environment with significant broad band sound energy. The ER-20 is another low cost alternative standard musician plug available commercially as Hi-Fi earplugs.

Custom-fit uniform attenuation musician earplugs consist of a button-sized filter attached to the outer end of a silicone earplug moulded to the shape of the ear canal. Musicians Earplugs<sup>TM</sup> buttons have a diaphragm which functions as an acoustic compliance, while the volume of air in the sound bore of the custom ear mould acts as an acoustic mass. The combination of the two produces a resonance at

approximately 2700Hz (as in the normal ear), which results in a smooth, flat attenuation.

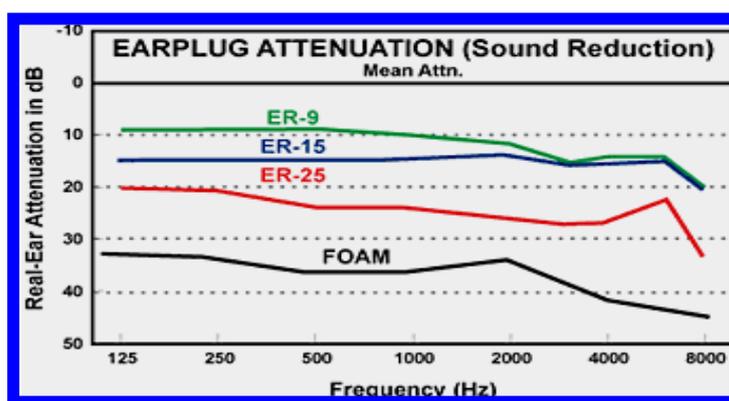


**Figure 4-1: Custom-made musician plugs with attenuation filters**

(from [www.sensaphonics.com](http://www.sensaphonics.com))

#### 4.9.2.2 Special filters with various levels of sound reduction (attenuation)

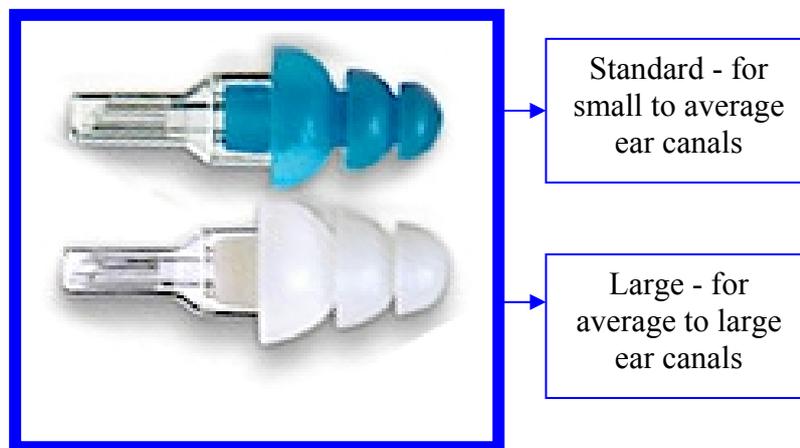
Unlike the standard ear plugs which are used for protecting the ears from loud noise exposure, these musicians' plugs have special filters with various sound reduction capabilities. Figure 4-2 shows that custom made musician plugs with ER-9 filters provides flat 9-dB sound reduction through the mid range and 15dB in the highs. ER-15 provides uniform 15-dB sound reduction across frequencies. ER-25 provides 25-dB relatively flat sound reduction across frequencies.



**Figure 4-2: Musician plugs (with various attenuation filters) and foam ear plug: mean attenuation (sound reduction) characteristics**

#### 4.9.2.3 Non-custom made or standard musician plugs

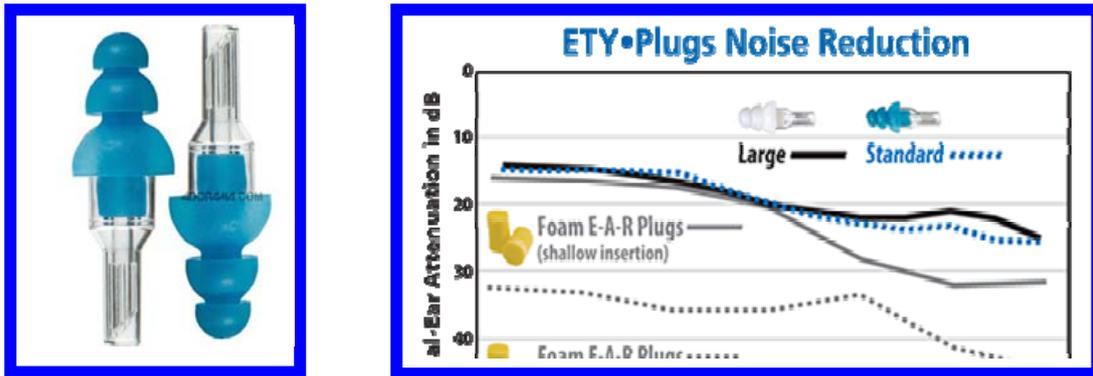
This is a non-custom (one-size-fits-most) earplug (Figure 4-3) that aims to match the fundamental and harmonic structure of music at the ear, only at a sound pressure level of about 20dB lower than at the unprotected ear (Chasin & Chong, 1991). ETY Plugs come in two sizes to fit almost all sizes of ear canals. For average to small ear canals, there is standard ER-20 (formerly called Baby Blues), and for average to large ear canal size large size ER-20 is suitable.



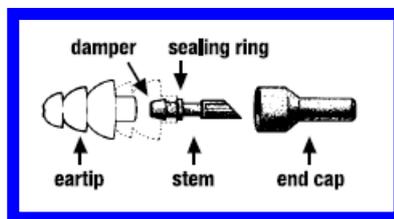
**Figure 4-3: ETY Plugs in two sizes**

(<http://www.etymotic.com/pdf/erme-er20-fittingguide.pdf>)

This plug uses a folded horn concept to enhance the high frequencies and thereby compensate for high frequency attenuation. The folded horn concept is a modification of the acoustic transformer effect, where the flaring tube is folded onto itself because of space limitations but the high frequency enhancement is maintained. However, because of the non-custom fit, there is a slightly higher attenuation at higher frequencies (called “roll-off”). The ER-20 is a lower-cost alternative to the ER-15, and works well for percussionists whose highest-risk sound exposure comes from the high-hat cymbals. The slight high-frequency roll-off helps to prevent damage at a frequency of 6000Hz (mostly from the cymbals). The sound attenuation provided by the ER-20 is shown in Figure 3-4, as compared to two common foam earplugs. If required, it is possible to make a custom version of the ER-20 with the help of an ear mould lab.



**Figure 4-4: ETY Plugs and noise attenuation (reduction) in various frequencies**



**Figure 4-5: Diagram of the ER-20/Hi-Fi earplug**  
(from <http://www.etyotic.com/pdf/erme-er20-fittingguide.pdf>)

Standard ETY Plugs provide approximately 20dB sound reduction across frequencies when used correctly. The NRR for ETY Plugs is 12dB, which underestimates the true effectiveness of these earplugs. Clinical measurements show that properly inserted ETY Plugs provide an average of 20dB sound reduction across frequencies in real ears.

#### 4.9.2.4 Noise Reduction Rating (NRR)

NRR is required by the US Environmental Protection Agency for all non-custom earplugs. Single number rating is in use in many countries. In Canada, they use an ABC scheme where hearing protectors are classified according to a standard (Z94.2-94) into class A, B, or C, depending on the octave band attenuation values and the measured time weighted average (Behar & Desormeaux, 1995). The most commonly used scheme in the United States is the Noise Reduction Rating. The NRR is based on a formula that estimates the minimum amount of noise reduction achieved by 98% of laboratory subjects. The NRR formula includes a numerical

adjustment for individual variability and for persons who do not wear hearing protection as instructed.

The EPA requires manufacturers to print a noise reduction rating (NRR) on all non-custom earplugs. The NRR for ER-20s is 12dB, but actual clinical measurements of properly inserted ER-20s indicate that these earplugs provide an almost equal sound reduction (20dB) at all frequencies in real ears. The required formula used to determine NRR includes an adjustment for individual variability and for those persons who do not wear ear protection as instructed. Many investigators have found no consistent rank order correlation between the real-world NRRs and labelled NRRs. NRR is computed from laboratory data that are not representative of the values attained in the real world by actual users.

Table 4-1 gives a recommended earplug by instrument type (Chasin, (1996). Musicians practise and perform in a variety of different settings, and they are exposed to high levels of sound, sometimes for long periods. They require different amounts of protection, depending on the sound levels they encounter during rehearsals and performances. Some musicians use different filters in each ear (e.g., ER-9 in one ear and an ER-25 in the other), depending on the location of the sound source.

**Table 4-1 Recommended musician ear plugs by musical instrument type**

<b>Musical Instruments</b>	<b>ER•9</b>	<b>ER•15</b>	<b>ER•25</b>	<b>Harmful Sound Comes From:</b>
Small strings	•	•		Own instrument, other strings
Large strings	•	•		Brass
Woodwinds		•		Brass, percussion
Brass		•	•	Own instrument, other brass
Flutes		•		Percussion
Percussion		•	•	Own instruments, other percussion
Vocalists	•	•		Own voice, speakers, monitors
Acoustic guitar	•	•		Drums, speakers, monitors
Amplified instruments		•	•	Speakers, monitors
Marching bands		•		Multiple sources
Music teachers		•		Multiple sources
Recording engineers		•		Speakers, monitors
Sound crews		•		Speakers, monitors

**The above table was adapted from: Chasin, M. (1996). *Musicians and the prevention of hearing loss*. San Diego, CA: Singular Publishing Group.**

#### **4.9.3 Studies on usage of musicians' ear plugs**

As there are really no options for music reduction at the sound source and on the transmission path of the musician, the use of suitable personal hearing protection becomes important for musicians. But musicians often refuse even ear plugs with flat frequency attenuation (Brockt, 2010). It is often an unsatisfactory sound impression; it is restrictions in the music instrument control and the interaction within the orchestra that are the frequent complaints. These problems predominantly result from the occlusion effect that influences the perception of bone conduction and thus changes the sound of their own instruments for the players. Brass, woodwind and players of other instruments that induce a lot of structure-borne sound into the jaw or skull are highly affected. Consequently, hearing protection should be a topic in musician's education as a matter of course (Brockt, 2010).

McBride et al., (1992) acknowledged the issues that arose in the provision of hearing protection but felt that harmful levels of sound exposure may not occur often enough in an orchestra to warrant the provision of personal hearing protection such as foam inserts; and indeed, this would not be acceptable to some musicians.

Eaton and Gillis (2002) evaluated the hearing test results for 53 members of the Vancouver Symphony Orchestra (VSO) and reported that less than half of the musicians reported regular use of hearing protection, and 47% of VSO musicians reported regular use of hearing protection, with most using CSA Class A earplugs. Interestingly, musicians in the instrument group with the highest estimated noise exposure (horn, trumpet and trombone) reported the lowest percentage (10%) regular use of hearing protection and confirmed that conventional hearing protectors are unsuitable for musicians. Specialised hearing protectors with uniform attenuation may be appropriate for certain situations. An educational programme to inform musicians about the effects of sound exposure, risk of hearing loss, and exposure control options is warranted.

According to Laitinen et al., (2003), classical musicians are often exposed to sound levels that exceed the Finnish national action limit value of 85dB(A). Still, the use of hearing protectors is uncommon among musicians. The purpose of this study was to find out musicians' attitudes towards hearing protectors, and under which conditions hearing protectors are used. The study group consisted of five major classical orchestras in the Helsinki region. The players were asked to fill out a questionnaire with questions on hearing protection and ear symptoms, including tinnitus, hearing loss, pain in the ears, and temporary ringing in the ears. Also, questions concerning stress and working environments were asked. Of those who responded, 94% were concerned about their hearing to some degree. Only 6% of the musicians always used hearing protector devices (HPDs). Hearing protectors were used more often among musicians having ear symptoms (20%) than those reporting no symptoms (6%). The study shows that musicians seldom use hearing protectors before symptoms begin. The ear symptoms increased usage rate, but the usage levels are still far from ideal. Laitinen et al., (2003) stressed the importance of motivation, and training is needed to improve hearing protector use among musicians.

Zander, Spahn and Richter (2008) conducted a study by distributing a questionnaire to 429 musicians in nine orchestras in order to obtain information on the use of hearing protection and the musicians' hearing sensitivity. Hearing protectors were found to be seldom used by orchestral musicians. During orchestral rehearsals, < 1/6 of the test persons used Type 1 (individually fitted) hearing protectors although > 80% of the respondents indicated that they knew about them. This study concluded that the subject of hearing protection in orchestral musicians should be investigated with a multidimensional approach, which considers the following in equal measure: legal regulations, the requirements and limits of the music sector, and the individual characteristics of the musicians involved.

In the West Virginia study on student musicians, Callahan et al., (2011) reported that the students played their primary instruments from five to 17 hours a week, and 79 percent said they never wear hearing protection (like foam or wax plugs, or sound-blocking headsets) during practice or rehearsal. Ninety percent did not wear hearing protection during ensemble performances. Fifty-three percent said they didn't think hearing protection was needed. Lesser percentages said they didn't wear hearing protection because it hindered them from hearing environmental sounds, was uncomfortable, made communication difficult, was a hassle, or looked strange. Very few respondents reported using hearing protection while practising their instrument; according to the paper, the majority of them showed a casual attitude about hearing protection despite musicians' elevated risks of hearing loss. The researcher supports the need for continuing efforts to raise awareness in student musicians about the risks of excessive noise/music exposure.

## **Chapter 5 : Factors that influence music induced hearing loss in orchestra musicians**

### **5.1 Introduction**

According to Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Commission (2008), several research studies have been carried out during the past 50 years to understand the physiological changes in the auditory system induced by excessive noise exposure. At least for the past 10 years, new and promising data has uncovered several series of factors that have a significant effect on the occurrence and further progression of noise induced hearing loss. Though primarily the loudness and the duration of noise are the two important factors that have been identified to have significant influence on noise induced hearing loss, these factors are considered to be having a significant influence on the initiation and progression of hearing loss (Abbate et al., 2005). One thoroughly established characteristic of NIHL is that, on average, more intense and longer-duration noise exposures cause more severe hearing loss. A second finding is that there is a remarkably broad range of individual differences in sensitivity to any given noise exposure. Several factors have been proposed to explain differences in NIHL among individuals; others may be associated with differences over time within the same individual. It is important to distinguish those factors, whose roles in determining susceptibility are supported by a consistent body of theory and empirical evidence, from other factors whose roles have been proposed but for which theory and/or data are less conclusive.

#### **5.1.1 Complex interaction of various factors**

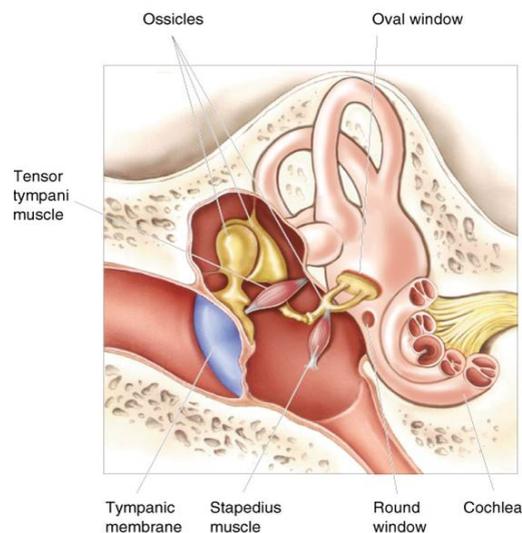
The exposure to noise cannot be viewed in isolation. Also, it is difficult assess the effects of each individual variable separately. Apart from noise exposure, many of the individuals may also be exposed to vibration, extreme temperature and humidity, and a variety of atmospheric pollutants such as volatile chemicals; moreover they all age as well. We have not yet completely understood how these factors interact with one another. Some of the people may be exposed to a mixture of steady-state and impulse noise, and the interactions of these factors are not yet completely understood either.

## 5.2 Middle ear problems and NIHL

### 5.2.1 Acoustic Reflex

The Acoustic Reflex (AR) is an involuntary muscle contraction in response to loud sound stimuli that occurs in the middle ear of mammals.

When presented with a very loud sound stimulus, the tensor stapedius and tensor tympani muscles of the ossicles (middle ear bones) contract. The tensor stapedius pulls the stapes (stirrup) of the middle ear away from the oval window of the cochlea, and the tensor tympani pulls the malleus (hammer) away from the ear drum. The reflex decreases the transmission of sound energy to the cochlea, where the sound energy is converted into electrical impulses to be processed by the brain. The acoustic reflex normally only occurs at relatively loud sound levels, and absence of acoustic reflex can indicate neural hearing loss.



**Figure 5-1 Middle ear muscles**

Source: Zemlin, W. R. (1988). *Speech and hearing science: Anatomy & physiology* (3<sup>rd</sup> ed.). New Jersey: Prentice Hall

### **5.2.2 Acoustic reflex threshold and protective factor**

In order for the acoustic reflex to be an important protective factor, its reduction is of great importance. At the same time, it is probably the parameter that is difficult to evaluate. In animals, the effect of the middle ear muscles on sound transmission in the middle ear has been studied using direct methods (Borg, 1972). It has been found that frequencies up to 2-4kHz are reduced by 20dB in cats and rabbits. In humans, however, the reduction has been investigated mostly by using indirect methods. Borg (1968) studied AR in patients who had one-sided acute facial palsy. AR response was determined on the contralateral side before and after recovery from the paralysis. At 500Hz, the reduction was 20dB. At higher frequencies, the reduction was lower, and at 1.5kHz, only a small reduction could be observed at maximum muscle contraction. Similar results have been reported by Rabinowitz (1979) and Zakrission (1979). All of the studies agree that AR does not give any reduction at high frequencies in the range where noise injury is most pronounced.

### **5.2.3 Acoustic reflex and time pattern**

The long latency time in AR is a characteristic that has caused many authors to consider AR to be of no importance in the case of impulse sound exposure. Fletcher and Riopelle (1960) succeeded in obtaining a significant reduction in the TTS after exposure to impulse sound. They introduced a 'protective tone' 200 ms prior to the impulse, sufficient to activate the AR during the course of the impulse; hence a single impulse can pass through the middle ear without any activation or with a delayed activation of the AR. They observed that the AR cannot bring about any protective effect for the inner ear.

### **5.2.4 Fatigability**

A great deal of interest has been focused on the stability and fatigability of the acoustic reflex using constant, pure-tones and noise signals. Many of the studies show very rapid fatigability in the acoustic reflex. The obvious conclusion from the basis of several studies is that for durations that commonly occur in industrial noise exposure

(e.g. a typical 8-hour working day), the actual protective function of the AR is insignificant because of fatigability. It has also been known that the AR can be reactivated after a short pause or after a change in intensity and frequency of the sound (Gjaevenes & Söhoel, 1966).

### **5.2.5 Protective effect**

It appears that the acoustic reflex under special conditions can reduce injury to the inner ear. On the other hand, it is questionable whether the hearing loss caused by industrial noise is really affected by the acoustic reflex. Arguments which have been presented against the AR as a protective function are: a) The AR is quickly fatigued at high noise levels. b) The AR reduces only low-frequency sound whereas the injuries are primarily in the high-frequency region. c) The AR reduction is too small to have a protective effect, even at low frequencies. d) The reaction time in AR is too long to affect impulse noise if the impulse noise is the main cause of impaired hearing; the AR, consequently, would have a negligible effect.

Temporary Threshold Shift experiments have been performed on people (Zakrisson, Borg, Linden & Nilsson, 1980) and Permanent Threshold Shift (PTS) experiments on rabbits (Borg, Nilsson & Engström, 1983) in order to evaluate the protective effect of acoustic reflexes during exposure to industrial noise. The human subjects had acute one sided facial paresis (Bell's palsy). Thus the patient had no middle ear reflex in the affected ear. On the affected side, the ipsilateral reflex threshold was normal. The Temporary Threshold Shift (TTS) was greatest in ears which lacked the middle ear reflex. The frequency of maximum TTS reduction shifted from about 3750Hz to 2075Hz – the important speech frequency range. TTS became broader, with an expansion primarily toward the low frequencies.

Borg et al., (1983) found that TTS increases and expands downward in frequency after exposure to shipyard noise when there is no acoustic reflex. Borge et al (1983) performed PTS studies on a total of seven rabbits. In all cases, the permanent threshold was greater in ears without the AR than those with the intact AR. At higher noise exposure levels, the difference was pronounced. The permanent threshold shift results in trial animals were similar to the temporary threshold shift in humans. PTS appears

in the frequency range that corresponds to the energy distribution of the noise exposure in individuals who lack a normal AR.

### **5.3 Conductive hearing loss and individual vulnerability**

One factor that may be associated with decreased susceptibility to Noise Induced Hearing Loss (NIHL) is conductive hearing loss; the cochlear structures protected by any form of acoustic attenuation. For similar reasons, middle ear muscles, which normally serve a protective function by contracting in response to intense sound, when inoperative, can result in increased susceptibility. Among the other factors that are theoretically associated with differences in susceptibility are: (a) unusually efficient acoustic transfer through the external and middle ear, as a determinant of the amount of energy coupled to the inner ear structures; and (b) pre-existing hearing loss, which could imply that less additional loss would occur if the sensitive structures have already been damaged. Support for these hypotheses has been modest; in the case of the transfer function this is because little empirical work has been done to test that hypothesis, and, in the case of reduced sensitivity, it is because several studies disagree. In general, when there is a difference in average loss to a given noise exposure, those ears with previous Permanent Threshold Shift or Temporary Threshold Shift have shown somewhat less additional loss than those not previously exposed.

Transmission losses caused by damage to the middle ear provide an example of a sound reduction which may reduce the degree of noise injury. Observations have also shown that persons with chronic conductive loss have received a certain protective effect. Results to the contrary have also been reported; the sensorineural component has been reported as greater in ears with conductive hearing loss: (1) a complicating factor is that acute and chronic infections in the middle ear, as well as otosclerosis, by themselves, can cause sensorineural loss; (2) it also seems that ears with chronic purulent otitismedia or otosclerosis are more vulnerable to noise than non-infected ears.

Borg et al., (1983) conducted a retrospective study of shipyard workers, carried out on using individuals with one-sided transmission loss. Eight persons were selected from a large population of workers who had been exposed to noise. The persons selected had one-sided conductive loss, established prior to noise exposure. In the left ear where

there is no transmission loss, there was a pronounced sensorineural reduction, while the bone conduction of the right ear was rather insignificantly affected. All the eight subjects showed similar results, with the pronounced sensorineural loss at 4kHz in ears with the normal middle ear function. Thus the results show that a transmission loss could be regarded as protection against noise injury. The chronic conductive loss constitutes a static reduction in the energy transmission.

Job, Raynal and Rondet (1999) investigated the effects of personal stereo use in young adults and found that hearing threshold elevations could be demonstrated only in subjects with a history of recurrent otitis media in childhood.

## **5.4 Aging and noise induced hearing loss**

### **5.4.1 Presbycusis**

Presbycusis is the scientific name for age-related sensorineural ear hearing loss. It is loss of hearing that occurs naturally with age because of gradual changes in the inner or middle ear structures in individuals as they grow older. It is defined as a progressive bilateral symmetrical age-related sensorineural ear hearing loss. The hearing loss is most marked at higher frequencies.

### **5.4.2 Interaction between various aging and noise exposure**

Chronic noise exposure can interact with other factors to produce a hearing loss that may differ from that expected if each factor was delivered separately. Aging and noise exposure are the two most common causes of hearing loss. Chronic NIHL occurs over years of exposure, and many individuals will experience some degree of age induced hearing loss (AIHL) in addition to NIHL. The interaction between Age Induced Hearing loss (AIHL) and NIHL seems to be additive up to a cumulative loss of approximately 40dB. This concept predicts that the normal progression of hearing loss associated with aging will occur in subjects with NIHL from an early age.

There is considerable variation among individuals. Some have had significant loss of hearing since age 50, while others have no hearing problems into their 90s. One explanation for this difference may be the person's occupations and noise exposure. In general, men seem to experience hearing loss more often and more severely than women. Noise induced hearing loss is often assessed in workers only in their fifties

and sixties, by which time age-induced hearing loss also occurs. The exact relationship between the two is still not clearly understood. Is it additive, synergistic or protective? It is the same outer hair cells that are affected by both. Noise damage is important early in the worker's life; presbycusis is dominant in later years. Current opinion suggests that at the most, the two are additive, but in more severe NIHL the effect of presbycusis is less.

NIHL classically produces a notch based at 3, 4 or 6kHz with industrial noise exposure. This begins in the first year or two, but the loss continues to grow for about 10 years at these frequencies. Beyond 10 years the hearing loss may spread into lower frequencies and high frequency recovery disappears; the loss at the initial frequencies may also continue to grow, but a lesser rate. Thus, after many years in noise, there is no characteristic notch and the lower frequencies – 1 and 2kHz are gradually involved. Later in life it becomes difficult to disentangle presbycusis from NIHL. There are several studies that have found that chronic noise exposure can interact with other factors to produce a hearing loss that may differ from that expected if each factor was delivered separately. Aging and noise exposure are the two most common causes of hearing loss. Since we know that chronic NIHL occurs over years of exposure, many patients will experience some degree of age-induced hearing loss (AIHL) in addition to NIHL. Similarly, subjects with pre-existent AIHL will experience the same degree of NIHL with any given noise exposure, as will those without AIHL. Once the total loss exceeds 40dB then one must factor in a 'compression term' which takes into account that both AIHL and NIHL occur via the same mechanism – hair cell loss – such that when a number of hair cells have been previously damaged by one factor, there exists less chance for the other factor to cause further damage, and the total loss will not simply be the sum of the two individual losses.

#### **5.4.3 Changes in middle ear transmission with aging and the critical period for noise vulnerability**

Middle ear motion decreases with age (Doan, Erulkar & Saunders, 1996; Rosowski, Brinsko, Tempel & Kujawa, 2003), and less efficient transfer through the middle ear could decrease NIHL susceptibility. Direct measurements of sound transmission through the aging middle ear in CBA/CaJ (Rosowski et al., 2003) show that

transmission losses may account for part of the sensitivity reduction (<6dB) at frequencies above 16kHz in old, unexposed ears.

There are several studies of cochlear function that have suggested a period of heightened sensitivity to injury from noise or ototoxic drugs during maturation (Bock & Saunders, 1977; Bock & Seifter, 1978; Lenoir, Bock & Pujol, 1979); Henley & Rybak, 1993) and beyond (Henry, 1982; and Pujol, 1992) periods of obvious structural and functional maturation of the cochlea. In mice, age-related shifts in NIHL susceptibility are well documented.

#### **5.4.4 ISO Standards**

In many individuals, hearing ability deteriorates with increasing age. Numerous studies have quantified this phenomenon to the extent that it is specified in international standard ISO 7029:2000. The standard models the distribution of hearing threshold levels in males and females separately in terms of deviations from a baseline set at the age of 18 years. The distributions are semi-normal, defined by mean values and standard deviations representing the upper and lower parts of the distribution. The mean (equal to median) values rise gradually with age at first, and then accelerate for older people. The standard deviations also increase with age, giving a wide spread for older people. Hearing deteriorates more with age in men than in women. The standard only specifies the distributions up to the age of 80 years, due to limitations in the source data.

In young adults, ISO 7029 shows little change over the age range from 18-25 years. For example, at the median there is an increase of less than 1dB at any frequency from age 18 to 25 years in either males or females. There has been substantial debate about the baseline value used to represent hearing threshold level for 18-year-olds. The original standard implied that a value of 0dB should be assumed; this was based on numerous studies of highly screened populations of young adults. However, those studies involved participants who were not representative of the population at large and had thresholds that are slightly better than the whole population. The studies in the UK have shown that a baseline in the range 2-7dB is more representative of the otologically normal UK population (Lutman & Davis, 1994).

#### **5.4.5 Aging and individual susceptibility**

Increasing age has been hypothesised to be associated with decreasing susceptibility. This contention is based on the existence of presbycusis i.e., hearing loss that increases with age and is not known to be attributable to excessive noise exposure or other known etiology. The typical levels of presbycusis at various ages have recently been incorporated as Annex A in ISO 1999-2:1989. That standard may be used to estimate the portion of overall hearing loss that is attributable to exposure to excessive noise. There are some studies that have suggested the very long term effects of noise as possibly emerging only at an old age, but this has been refuted by contradictory evidence from several other epidemiologic studies (Ferrite & Santana, 2005; Lee et al., 2005; Rosenhall (2003); Gates, Schmid, Kujawa, Nam & D'Agostino, 2000). More recent experimental data (Kujawa & Liberman, 2006) suggest that early noise exposure can render the inner ear more vulnerable to aging. Unnoticeable effects can also occur over years as indicated by small instabilities in cochlear functioning which were observed in students exposed to noise in their leisure-times (Rosanowski, Eysholdt & Hoppe, 2006).

Gates et al., (2000), in a review of longitudinal hearing loss data from a large cohort of men, observed that in ears with presumed cochlear damage from previous noise exposure, subsequent hearing loss progression with age was exacerbated at frequencies outside the original NIHL. This observation suggests that ears with noise damage age differently from those without. Hearing losses in noise-exposed and/or aging ears are highly variable (Gates & Mills, 2005).

Age-related and noise induced hearing losses in humans are mostly multifactorial, with contributions from, and potential interactions among, numerous variables that are known and unknown, and can shape the final outcome. A recent retrospective clinical study suggests an age–noise interaction that exacerbates age-related hearing loss in previously noise-damaged ears (Gates et al., 2000). This issue of noise and age induced hearing loss interaction has a significance public health importance (Gates et al., (2000); Rosenhall, 2003; Lee et al., 2005), given the high prevalence of noise exposure in, and the aging of, our society.

The issue of ear aging faster with noise exposure has been an issue for many years as it has a significance public importance. Kujawa and Liberman (2006), in an animal model, compared noise-induced and age-related hearing loss (NIHL; AHL) in groups of CBA/CaJ mice exposed identically (8–16kHz noise band at 100dB sound pressure level for two hours but at different ages (4–124 weeks) with unexposed cohorts for different post exposure times (2–96 weeks). When evaluated two weeks after exposure, maximum threshold shifts in young-exposed animals (4–8 weeks) were 40–50dB; older-exposed animals (16 weeks) showed essentially no shift at the same post exposure time. However, when held for long post exposure times, animals with previous exposure demonstrated AHL and histopathology fundamentally unlike unexposed, aging animals or old-exposed animals held for two weeks only. Specifically, they showed substantial, ongoing deterioration of cochlear neural responses, without additional change in preneural responses, and corresponding histological evidence of primary neural degeneration throughout the cochlea. This was true particularly for young-exposed animals; however, delayed neuropathy was observed in all noise-exposed animals held 96 weeks after exposure, even in those that showed no NIHL two weeks after exposure. Data suggest that pathologic but sublethal changes initiated by early noise exposure render the inner ears significantly more vulnerable to aging.

Progressive age-related changes in the noise-damaged ear involve the inner hair cell and/or the auditory nerve to a greater degree than the outer hair cells or other structures contributing to the cochlear amplifier. It is reported that hearing thresholds deteriorate after noise exposure more dramatically than in age-matched, unexposed counterparts. Early noise exposure increases AHL, especially at frequencies below the region of maximum damage (e.g., 5.6 and 8.0kHz), in which initial post exposure threshold shift was minimal.

### **5.5 Gender and noise induced hearing loss**

The gender of an individual has been often considered as a possible influencing factor with men appearing somewhat more affected than women. The difference however seems minimal if present (Müller & Richartz, 1989).

There is little difference in hearing thresholds between young male and female children. Between ages 10 and 20, males begin to show reduced high-frequency auditory sensitivity relative to females. Women continue to demonstrate better hearing than men into advanced age. These gender differences are probably due to greater exposure of males to noise rather than to their inherent susceptibility to its effects.

Firth, Herbison, McBride and Feyer, (2001), and McBride, Firth and Herbison, (2003) conducted occupational health survey of 381 farmers in Southland and reported that 11.6% had noise induced hearing loss – that was 17.1% of the men and 1.5% of the women. A paper by Pearson et al., (1995) presents the results from the largest and longest longitudinal study reported to date of changes in pure-tone hearing thresholds in men and women screened for otological disorders and noise induced hearing loss, to estimate longitudinal patterns of change in hearing thresholds in 681 men and 416 women with no evidence of otological disease, unilateral hearing loss, or noise induced hearing loss. The results show: (1) hearing sensitivity declines more than twice as fast in men as in women at most ages and frequencies; (2) hearing sensitivity declines over time and is detectable at all frequencies among men by age 30, but the age of onset of decline is later in women, at most frequencies, and varies by frequency in women; (3) women have more sensitive hearing than men at frequencies above 1000Hz, but men have more sensitive hearing than women at lower frequencies; and (4) hearing levels and longitudinal patterns of change are highly variable, even in this highly selected group. These longitudinal findings document gender differences in hearing levels and show that age-associated hearing loss occurs even in a group with relatively low-noise occupations and with no evidence of noise induced hearing loss.

## **5.6 Risk factors and noise induced hearing loss**

There are several known and unknown risk factors that may not by themselves be harmful to the auditory system, but it has been shown that when they are associated with an extended noise exposure, they increase the risk of hearing loss. However, when noise exposure is paired with other factors that may not be physically recognisable as damaging, their individual effect is not accountable or measurable.

### **5.6.1 Work load and noise exposure**

It has been found that individuals exposed to 95dB and above with significant workload have been shown to have increased temporary threshold shift (Cheng, Cunningham & Rubel, 2005). They also found that the workload on a given day is an important determining factor in the amount of recovery time required to return to the original baseline hearing level.

### **5.6.2 Vibration and exercise**

According to Chen, Dai, Sun, Lin and Juang (2007), individuals can decrease their susceptibility to temporary threshold shift (TTS) by improving their cardiovascular fitness. Whole body vibration or extensive exercise during noise exposure puts ears at greater risk.

It is also reported that people who are exposed to vibration and loud noise exposure develop worse hearing loss than non-affected fellow workers. It is not unusual for significant vibration to accompany noisy environments. Although vibration alone is not known to cause hearing loss, it is not known if vibration has any influence on NIHL. Animal studies conducted by Phaneuf and Hetu (1990) have found more severe hearing loss and hair cell loss in animals exposed to both vibration and noise compared to those exposed to noise alone. According to Dobie (1993), in humans, vibration causes a larger TTS after a noise exposure; however, it is not clear if this can be translated to larger PTS. In studies by Lindgren and Axelsson (1988) and Miani, Bertino, Francescato, di Prampero and Staffieri (1996), noise exposure during highly physical activities was shown to produce a greater TTS than just the noise exposure alone.

Vibration-induced hearing loss may be developed in patients after temporal bone surgery or in subjects working with vibrating tools. In such cases, combined exposure to noise and vibration can increase hearing threshold shift compared to noise-only exposure. Other studies concerning association of body vibration with sound trauma brought contradictory and inconclusive results (Palmer et al., 2002a; Silva & Mendes, 2005).

### **5.6.3 Smoking and noise induced hearing loss**

There are several studies that have found adverse effects of smoking on hearing among the working population (Barone, Peters, Garabrant, Bernstein & Krebsbach, 1987; Virokannas & Anttonen, 1995; Noorhassim & Rampal (1998); Nakanishi, N., Okamoto, M., Nakamura, K., Suzuki, K., & Tatara, K. (2000); Hong & Kim, (2001); Mizoue, Miyamoto & Shimizu, (2003); and Ferrite & Santanna, 2005). There are other studies that haven't found any association between smoking and hearing loss (Karlslose, Lauritzen & Engberg, 2000).

According to Pouryaghoub, Mehrdad and Mohammadi (2007), smoking can accelerate noise induced hearing loss, but they stated that more research work is required to understand the underlying mechanisms. This was a cross-sectional study that was designed to study the effect of smoking on NIHL in 206 male smoker workers and 206 male non-smoker workers in a large food-producing factory, in which workers were exposed to noise levels exceeding 85dBA. The percentage of workers with a hearing threshold of greater than 25dB at 4000Hz in the better ear was 63.6%, and 18.4% in smoker and non smoker groups respectively. This difference was statistically significant after adjustment for age and exposure duration. Another cross-sectional study conducted by Mohammadi, Mazhari, Mehrparvar and Attarchi (2010) surveyed the effect of smoking on NIHL in 504 workers in a large wagon manufacturing company who were exposed to noise >85dBA. This study concluded that the frequency of hearing loss in smokers was higher than non-smokers. The possible explanation for the underlying pathogenic mechanism may be the well-known vascular changes and the consequent cochlear hypoxia related to both smoking and long-term intense noise exposure (Hawkins, 1971; Starck, Toppila & Pyykko, (1999); and Chen, 2002).

### **5.6.4 Heat exposure and Noise Induced Hearing Loss**

There are studies that have found that heat exposure causes increased temporary threshold shift (TTS). A study conducted by Chen et al., (2007) found that increased temporary threshold shift (TTS) is observed with increased high-frequency noise exposure when this is paired with increased blood temperature.

It has been believed that as blood temperature increases, the hair cells for high-frequency transduction require a greater oxygen supply than others, and the two simultaneous metabolic processes can deplete any oxygen reserves of the cochlea (Miller, Ren, Dengerink & Nuttall, 1996). It is also believed that the auditory system goes through a temporary changes caused by a decrease in the oxygen and the pressure in the cochlear endolymph that leads to vasoconstriction of the local vessels.

### **5.6.5 Ototoxic drugs and noise exposure**

It is reported that commonly-used drugs can produce a hearing loss that has many of the same physiological and psychophysical features as hearing loss induced by exposure to intense noise.

According to Fausti et al., (1999), extended high-frequency audiometry is a useful tool in detecting ototoxicity from aminoglycosides and cisplatin before there is an effect on the frequency range that typically occurs in conversational speech. A similar mechanism may be operating when the cochlea is affected by noise exposure. It has been demonstrated that the mechanisms of sensory hair cell degeneration in response to noise and aminoglycosides share a final common pathway (Cheng et al., 2005). It has been found that simultaneous exposure to noise and ototoxic medications may have an amplifying affect on individual's hearing loss, and may also produce more threshold elevation than with either factor alone. This combined effect has been studied and demonstrated in noise-exposed animals given aminoglycoside antibiotics. A common chemotherapy drug cisplatin was not found to cause hearing loss alone, but in animals, when the drug was given first and then the animals exposed to noise, the hearing was worse than in animals exposed to noise alone. Although the diuretic furosemide is potentially ototoxic when given intravenously to patients with altered renal function, oral administration in people with normal kidneys has not been associated with hearing loss. The review of literature on the combined effect of salicylates and noise seems to be contradictory. Some of the studies have demonstrated a potentiating effect, while others have not found a similar effect. Two separate studies done in the mid 1980s found that in noise exposed individuals, if higher doses of aspirin (1.9 gr/day) were taken, their temporary threshold shift with noise exposure was of greater magnitude and slower to recover. It is important and reasonable to counsel every individual with

significant noise exposure to avoid high dose aspirin therapy (Dobie, 1993; and Henderson, Spogr, Subramaniam & Campo, 1994).

#### **5.6.6 Noise and exposure to chemicals**

Recently there has been considerable interest in the effect of chemical solvents on hearing. Solvents are widely used in industry. Carbon disulphide in the manufacture of rayon and use of paint, and styrene used to make plastics. Among all these chemicals, toluene is probably the most widely used. It has been found, in animal experiments and in human epidemiological studies, that exposure to these chemicals produces hearing loss not found in control subjects and that the hearing loss is found to be worse when there is also exposure to noise. The effect may be synergistic. Toluene is known to be cochleotoxic, others may also be neurotoxic; but the exact mechanism is not very clear yet.

Individuals' exposure to several chemicals, together with lowered levels of breathed oxygen, was found to increase the severity of noise induced hearing loss. It has been observed that chemical asphyxiants increased the risk of NIHL; chemicals such as hydrogen cyanide (Fechter, Chen & Johnson, 2002) and acrylonitrile, one of the 50 most commonly produced industrial chemicals (Fechter, Klis, Shirwany, Moore & Rao, 2003). According to Chen and Liu (2005), reduced intake of oxygen (Hypoxia), was found to extend NIHL to other frequencies beyond the noise induced damage. Smoking on a regular basis was also found to be a significant risk factor increasing the severity of NIHL in epidemiologic surveys conducted (Burr, Lund, Sperling, Kristensen & Poulsen, 2005; Ferrite & Santana, 2005; Wild, Brewster & Banerjee, 2005).

It is also reported that for individuals who are exposed to hazardous noise, certain chemical pollutants may have an additive effect on hearing loss. It has been found that toluene, carbon monoxide and carbon disulphide in combination with noise exposure are found to cause a more severe high frequency hearing loss than noise exposure alone (Campo et al., 1998). There are other agents such as lead, mercury, xylene and trimethyltin that are suspected to either worsen noise induced hearing loss or alter susceptibility to noise induced damage (Chou, Lai & Kuo, 2009).

### **5.6.7 Influence of loud noise exposure during post noise exposure**

It had been found that the presence of loud sounds during the post noise exposure has an influence on the amount of recovery from temporary threshold shift (TTS) caused by the original noise exposure. There are only a few studies that were devoted to study these influences, and the effective parameters are poorly known (Niu, Tahera & Canlon, 2004; Norena & Eggermont, 2005). The beneficial effects of these post-trauma environmental sounds can be quite large, and as they are easy to control in humans, they have very high potential clinical implications. Even the epidemiologic data also point to similar significant effects in humans (Abbate et al., 2005).

### **5.6.8 Noise exposure and efferent and sympathetic innervations**

It has been found that efferent and sympathetic innervations of the cochlea (a retro control from the brain to the cochlea) have almost no influence on the normal functioning of the cochlea as their suppression does not lead to noticeable changes, but this system is reported have an influence on cochlear reactivity in adverse conditions, and this influence has been particularly well observed with noise induced hearing loss. The protective role of the efferent system upon noise induced hearing loss was studied by Cody and Johnstone (1982). A remarkable development was made regarding exposure parameters leading or not leading to protection (Rajan, 2001; Rajan, 2003). The predictive value of an efferent response to assess susceptibility to NHIL still remains controversial (Maison, Luebke, Liberman & Zuo, 2002); Luebke & Foster, 2002; Wagner et al., 2005). Niu and Canlon (2002) have shown the efferent and sympathetic innervations involvement in sound conditioning. The influence of the sympathetic cochlear innervations on NIHL was discovered many years ago by Borg (1982). The experiments conducted by Horner, Giraudet, Lucciano and Cazals (2001), and Giraudet, Horner and Cazals (2002) further extended such findings. The experiments pointed to an interaction with the efferent innervations. They also showed modification of cochlear sensitivity to acoustic trauma by anaesthesia or even sedation.

### **5.6.9 Anti-inflammatory drugs and its protective effects from noise induced damage**

Salicylates have been found to facilitate recovery from acoustic trauma (Yu, Li & Hu, 1999). Another study found that salicylates in combination with trolox (an anti-oxidant) decreases noise induced damage (Yamashita, Jiang, Le Prell, Schacht & Miller, 2005). The steroids and non-steroids anti-inflammatory drugs were found to provide protection against noise induced damage. It is also found that corticoids combined with hyperbaric oxygenation can help to rescue post-trauma effect in animal experiments (D'Aldin, Cherny, Devriere & Dancer, 1996; Lamm & Arnold, 1999); this was also confirmed by another experiment conducted by Fakhry, Rostain and Cazals, (2007). Wang and Liberman (2002) studied the role of stress and corticosterone in protecting against NIHL. Other studies found the beneficial action of dexamethasone on NIHL (Takemura et al., 2004; Tahera et al., 2006; Sendowski, Abamrane, Raffin, Cros & Clarencon, 2006a).

### **5.6.10 Drugs giving some protection from noise induced damage**

There are no known medical options for noise induced hearing loss. There is some research work being undertaken for drug and genetic therapies (National Institute on Deafness and Other Communication Disorders, 2006).

There is some evidence that noise induced hearing loss can be minimised by taking mega doses of magnesium for a few days, starting as soon as possible after exposure to the loud noise (Gordin, Goldenberg Golz & Netzer, 2002). There are studies that have found there are a few new drugs that are proven experimentally to have special protective and repairing properties relating to noise induced hearing loss. A magnesium-high diet reported to be helpful as a preventive measure if taken before exposure to loud noises (Scheibe, Haupt, Mazurek & Konig, 2001; Haupt, Scheibe & Mazurek, 2003; Attias, Bresloff, Haupt, Scheibe & Ising, 2003; Sendowski, 2006). Consuming sizable amounts of magnesium can be potentially harmful, so this treatment should be followed with caution (Ford & Mokdad, 2003).

The real pharmacological changes that produce these protective effects and the metabolic effects of these drugs are not completely understood yet.

### **5.6.11 Neurological factors and protective effects from noise exposure**

A number of studies have identified that administration of some of the neurotrophic agents or modulators of neurotransmission were found to have protective effects against noise induced damage. They are NMDA blocking agents (Chen, Duan, Lee, Ruan, & Ulfendahl, 2003; Diao, Zhang, Liu, Han & Gao, 2005; and Ruel et al., 2005) and noradrenergic related compounds (Horner et al., 1998; and Giraudet et al., 2002). The ciliary neurotrophic factor was studied by Zhou, Zhai and Yang, (1999). The protective effects of basic fibroblast growth factor were also investigated (Zhai et al., 2002; and Zhai, Wang, Han & Yang, 2004).

### **5.6.12 Drugs and anti-apoptotic effects on noise induced hearing loss**

There are at least five different drugs that have been identified to have protective effects against noise induced hearing loss, but usage of these drugs is not possible or seen to be a viable option because of the required high dose level and availability of these drugs. These drugs are calcineurin inhibitors (Minami, Yamashita, Schacht & Miller, 2004), Src-PTK inhibitors (Harris, Hu, Hangauer & Henderson, 2005), riluzole (Wang & Liberman, 2002), a peptide inhibitor of c-Jun N-terminal kinase (Wang et al., 2007) and all-trans retinoic acid, an active metabolite of vitamin A (Ahn, Kang, Kim & Chung, 2005). These drugs are reported to have anti-apoptotic effects.

### **5.6.13 Various other factors**

There are some other factors that have been identified to have a protective effect on noise induced hearing loss: Hypothermia (Henry, 2003), a calcium pump activator (Liu, Yu, Han, Yang & Li, 2002), prior heat acclimatising (Paz, Freeman, Horowitz & Sohmer, 2004), and a heat shock protein inducer (Mikuriya et al., 2005).

#### **5.6.14 Impulse noise**

Impulse noise is often defined as noise consisting of single bursts, with the duration of less than one second and the peak levels at least 15dB higher than background noise. Impulse noise differs from steady state noise by the properties in the time domain. Impulse noise contains rapid sound pressure transients. The physical properties of impulse noise are characterised by peak level, rise and decay time, duration and number of impulses, spectral content, and level distribution (Starck Pekkarinen & Pyykko, 1988; Pekkarinen, Iki, Starck & Pyykko, 1993; Hamernik & Hsueh, 1991). The criteria presented for impulse noise are based on the repetition rate of peaks of sound pressures. According to Levine, Hofstetter, Zheng and Henderson, (1998) and Henderson et al., (1998), the Equal Energy Hypothesis (EEH) is based on the assumption that hearing loss from a given exposure is proportional to the total energy of the exposure. A corollary of this assumption is that the power of the exposure and the duration of the exposure are interchangeable. Studies of impulse and impact noise show that hearing loss does not follow the prediction of the EEH (Ward, 1986). In France the maximum A-weighted peak level is 135dB, and in the United Kingdom the C-weighted peak sound pressure is limited to 200Pa (140dB). This criterion of unweighted 200Pa (140dB) is used in the European Union (EU) directive 86/188, and in ISO 1999-1990 regardless of the number of impulses. The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended that no exposure in excess of C-weighted peak sound pressure level of 140dB should be permitted. In several occupations the impulses are so rapid that they contribute only a minimal amount to the energy content of noise. These impulses can cause damage even though there may be no awareness of the hazard. The hearing protectors attenuate impulse noise effectively because of the high frequency content of the most impulsive sound.

# **Chapter 6 : Rationale/Justification of the Research Project, Conceptual Framework, Study Design and Unanswered/Research Questions**

## **6.1 Rationale/Justification of the Research Project**

### **6.1.1 Noise induced hearing loss and prevention**

Hearing loss is one of the leading and fastest growing disabilities in our modern society, and exposure to loud music or noise is one of the leading causes. Although this type of hearing loss is 100% preventable, very little is being done to prevent it, and most people are quite unconcerned about their hearing. It is on the increase, and more and more young people are becoming hard of hearing. A National Audiology Centre (Greville, 1997) survey found that more than 10% of the population has some degree of hearing loss. And according to research by the Royal National Institute for the Deaf in the UK (RNID) in 2003, nearly half of young people experience hearing problems after being exposed to loud music.

Noise induced hearing loss (NIHL) is the most prevalent sensorineural hearing loss after presbycusis (Rabinowitz, 2000). Prevalence of NIHL increases with continued exposure and advancing age. The prevention of NIHL will require a better understanding of its prevalence in the population and contributing exposure factors (Phillips et al., 2010).

According to NIOSH recommendations for the prevention of Noise Induced Hearing Loss (NIHL), high intensity sound exposure involves a time-intensity trade-off that begins with an allowable eight-hour exposure at 85dBA and decreasing the time exposed by half for every 3dB increase in intensity. Sound exposure measurements in music students and music teachers document exposure levels over 85dBA (Behar et al., 2006; Phillips, & Mace, 2008). For workers in the music and entertainment industry, the noise exposure is a potential occupational hazard, and it often exceeds the action values or exposure limit values given in regulations as the European Directive 2003/10/EC (Brockt, 2010).

### **6.1.2 Noise induced hearing loss and individual variability**

Noise induced hearing loss is reported to have varied impact on individuals, suggesting that there is influence of susceptibility (Henderson et al., 1993; Lu, Cheng, Li, Zeng & Zhao, 2005). There are number of researchers have associated several genetic variants with NIHL (Konings et al., 2007; Sliwinska-Kowalska, Noben-Trauth, Pawelczyk & Kowalski, 2008; Van Laer et al., 2006; Yang et al., 2006).

There are several medical factors that have been identified as a potential contributor to noise induced hearing loss susceptibility that includes cardiovascular disease, diabetes, kidney failure and immune function impairment, and poor cholesterol reading (Phillips et al., 2010), and some other factors such as chemical exposures (Morata & Campo, 2002; Fuente & McPherson, 2006); ototoxic medications (Tan et al., 2001; Toppila et al., 2001), and smoking (Pouryaghoub et al., 2007).

### **6.1.3 Music induced hearing loss**

NIHL can be caused by a single traumatic impulse sound but is more typically caused by repeated exposures to high intensity sound. It was assumed that only amplified musical performances are loud. It was thought that unamplified music does not cause hearing loss, but musical instruments and voices also can reach high intensity levels (Phillips et al., 2008).

Musicians use the hearing mechanism for various purposes: (a) performing accurately relative to pitch, timbre, dynamics, and duration; and (b) studying musical scores and listening to recordings to determine accepted performance practices for specific musical genres and styles. Additionally, musicians rehearse and perform with various music groups in recital and concert situations. Any reduction in acute sense of hearing would likely impair one's abilities as a musician (Walter, Mace & Phillips, 2008).

According to Davis (1950), as professional musicians, hearing health will be vital to their success. High-intensity levels in performance and practice can cause hearing loss that will threaten pitch, timing, and loudness perception. Excessive exposure to high-intensity sound causes damage to the outer hair cells of the organ of Corti in the

cochlea. These cells are responsible for the enhancement of hearing sensitivity and tuning. The outer hair cells have a motor component that amplifies soft sounds at specific frequency points in the cochlea and are responsible for the sharpness of pitch perception as well as amplifying soft sounds (Kiang, Liberman, Sewell & Guinan, 1986). Therefore, damage also causes a widening of the auditory filtering system, which reduces the accuracy of pitch perception (Axelsson & Lindgren, 1981). This can occur with even a small amount of hearing loss.

The loss of hearing brings with it problems with loudness, frequency, and temporal perception, and often includes ringing in the ears, or tinnitus. These losses are critical to a musician who must correctly perceive and produce the accurate pitch, loudness, timbre, tempo, and style of a musical piece. While for non-musicians the critical frequency range for speech perception is 250 to 4000Hz, musicians must be able to discriminate specific frequencies over a much broader frequency range. The range for a piano is 16 to 8000Hz, and for the pipe organ, up to 16,744Hz. Psychological issues related to hearing difficulties also may be present (McBride et al., 1992; Chasin, 1999; Zembower, 2000; Kahari et al., 2001).

A notch in the audiogram/audiometric configuration is defined as a drop in hearing sensitivity mostly observed between 3000-6000Hz, which characterises noise induced hearing loss. The hearing loss in musician is often asymmetric, usually with more loss in the left ear than the right ear (McBride & Williams, 2001; Nageris, Raveh, Zilberberg & Attias, 2007; Phillips & Mace, 2008).

There seem to be large variations in operational definitions of noise induced hearing loss reported in different prevalence studies. Most of the studies reporting prevalence of NIHL in children have fairly consistently defined NIHL as a notch at 3000–6000Hz, which is 15dB in depth and relative to the thresholds at lower frequencies (Niskar et al., 2001; Renick, Crawford & Wilkins, 2009). Studies of NIHL prevalence in adults have defined NIHL in terms of absolute thresholds at a level poorer than 20dB HL (Agrawal, Platz & Niparko, 2008).

#### **6.1.4 Noise induced hearing loss in children**

There are only a few studies on NIHL in children. These studies have shown that the prevalence of noise induced hearing loss increases steadily over childhood and adolescence. In most of the studies, the frequency of greatest loss was 6000Hz. Niskar et al., (2001) reported data obtained from children aged 6–19 years, which showed that overall prevalence of NIHL was 12.5%, with 1.8% of all subjects showing a bilateral loss. NIHL prevalence increased with age; 8.5% of 6–11 year-olds and 15.5% of 12–19 year-olds showed a notch. In Finnish children, Haapanemi (1995) found the prevalence to be 8.3%; prevalence was lower in younger children (6.4%) than in older children (11.5%). Renick et al., (2009) studied Ohio farm children with high exposure levels, with 3.9% of children showing a bilateral loss, and found a prevalence rate of 22.5%. Again, the prevalence was lower for younger children (17.1%) than for older children (26.5%).

According to Phillips et al., (2010), consistency in the use of a single definition of NIHL would benefit research in this area. A comparison of reports of NIHL in young adults reflects the issue of notch definition. Agrawal and colleagues (2008) reported a prevalence of 8.5% in adults aged 20–29 years in the NHANES database. They used a definition of a high-frequency pure-tone average at 3000, 4000, and 6000Hz of 25dB HL or more. On the other hand, using a criterion of only 10dB notch depth, Lees, Roberts and Wald (1985) found that 40% of the 60 students (aged 16–25 years) they tested had a notch of 10dB depth, mainly at 6000Hz.

Student musicians practise both individually and in ensembles, but usually they do not experience the 8-hour days of exposure to industrial noise which is reported to be more harmful than music exposure (Strasser, Irle & Legger, 2003). Nevertheless, their exposure levels are high enough to put their hearing at risk (Phillips & Mace, 2008).

### **6.1.5 Industrial population and professional musicians**

In the prevalence figures for both industrial populations and for professional musicians, the global prevalence of NIHL was estimated to be 29% for 20–29 year-olds in a review of 17 studies worldwide (Nelson et al., 2005). Most of the prevalence studies on industrial noise workers report the notch to be at 4000Hz. The reported adult prevalence figures for professional musicians (38–50%) are similar, with notches mainly at 6000Hz (Emmerich et al., 2008; Kahari et al., 2004; Jansen et al., 2008). It is reported that the prevalence of NIHL in industrial populations varies by industry (electrical workers, sand and gravel workers, and construction workers) between 37–59.7% (McBride & Williams, 2001; Landen, Wilkins, Stephenson & McWilliams, 2004; Dement, Ringen, Welch, Bingham & Quinn, 2005; Rachiotis, Alexopoulos & Drivas, 2006).

### **6.1.6 Controversies in hearing loss in musicians**

The review of literature shows that there is a controversy about the presence of hearing loss in musicians. There has been a long lasting dispute/confusion on music induced hearing loss or of other factors to the hearing loss. Until now the problem has not been resolved. About 50 years ago Arnold and Miskolczy-Fodor (1960) conducted a first study on hearing abilities in orchestral musicians which opened long-lasting discussions and studies. The thorough literature review regarding hearing loss among orchestral musicians shows a confusing picture.

The discussions about tinnitus and hearing loss among musicians are argued that hearing loss and tinnitus are the natural and inevitable results of playing in an orchestra (Obeling & Poulsen, 1999).

Most studies suggest musicians' hearing levels are not significantly different than a non-exposed population. However, several studies identified high-frequency notches suggestive of a noise induced threshold shift. Some investigations concentrate on audiogram determinations (Kahari et al., 2001; Karlsson et al., 1983) and others on sound level measurements (Williams, 1995). Behar et al., (2006) reported after reviewing 13 papers on noise exposure of orchestral musicians that the question of whether orchestra musicians are overexposed does not appear to have a clear answer. Although studies have detailed noise exposure in the workplace, for many professions it

is relatively less clear about the noise exposure musicians receive or the effect this 'noise' has on musicians' hearing (Royster et al., 1991; Fearn, 1993; Lee et al., 2005).

Generally, studies can be divided into three groups: the studies where only music exposure is measured, studies where only hearing thresholds are measured, and studies where music measurement and hearing assessment are also taken. The assessment of risk of hearing loss has been varied and is confusing because of contradictory conclusions obtained by different researchers (Jansen et al., 2009). The findings range from better hearing by Fleischer and Muller (2005), who found that the hearing of 83.4% of the musicians was better than was predicted by the ISO 1999 standards; these findings support the theory that a high noise level may indeed build resistance to hearing loss (Behar et al., 2006). There are several other studies that have found minimal hearing loss (Bremmelgaard & Obeling, 1996; Obeling & Poulsen, 1999; Kahari, Axelsson, Hellstrom & Zachau, 2001a; Beale, 2002; Lee et al., 2005). And some studies have also shown a risk of hearing loss (Axelsson & Lindgren (1978); Karlsson et al., 1983; Johnson et al., 1985; Ostri et al., 1989; Royster et al., 1991) while others do not show a risk (Lipscomb, 1976; Axelsson & Lindgren (1978); Axelsson et al., 1995; Lee et al., 2005).

Many factors contribute to the risk of hearing loss in musicians besides the frequency range and intensity level of the music. Reverberation within rehearsal rooms and rehearsal halls, placement within an ensemble, genetic predisposition, and duration of exposure each day, as well as accumulated years of exposure, are contributing factors (Axelsson & Lingren, 1981; and Fearn, 1993). According to Lindgren and Axelsson (1983), and Swanson, Dengerink, Kondrick and Miller, (1987), stress and whether or not the musician likes the piece of music both play a part in temporary shifts in the hearing threshold.

#### **6.1.7 Analysis of hearing loss development with increased years of music exposure**

There is no much of information on hearing loss development in musicians except one longitudinal follow-up Swedish study, Kahari et al., (2001). Using pure-tone audiometry, Kahari and colleagues conducted a hearing reassessment of 56 classical musicians who had participated in Axelsson and Lindgren's study 16 years earlier, in

1995. This study was on progressive hearing loss in these classical orchestra musicians after 16 years of music exposure. The average hearing threshold of the males was equal with the median. This follow-up study showed no progressive hearing loss in pure-tone hearing threshold values in spite of an additional 16 years of musical noise exposure.

#### **6.1.8 Usage of ear protection among musicians**

Though the developments in the hearing protection devices (earplugs) have come a long way and there now are several commercially available models especially designed for use by musicians, for many professional orchestras the acoustical environment during practice or performance is far from optimal with respect to avoiding or at least minimising the risks of hearing damage. Historically, the usage of hearing protection by musicians has been undesirable or even somewhat of a taboo (Chasin & Chong, 1992). The main reasons are: 1) The occlusion effect, which causes the user to feel echoey, blocked-up, and stuffed-up; 2) The stronger attenuation in the high frequency region relative to low frequency (Killion et al., 1988; Chasin & Chong, 1991); 3) It has been considered taboo because a musician does not want their peers or their audience to perceive them as having less-than-perfect hearing (Ostri et al., 1989).

As there are really no options for music reduction at the sound source and on the transmission path of the musician, the use of suitable personal hearing protection becomes important for musicians. But musicians often refuse even ear plugs with flat frequency attenuation (Brockt, 2010). McBride et al., (1992) acknowledged the issues that arise in the provision of hearing protection but felt that harmful levels of sound exposure may not occur often enough in an orchestra to warrant the provision of personal hearing protection such as foam inserts; and indeed this would not be acceptable to some musicians.

#### **6.1.9 Possible reasons for confusing results on presence of hearing loss in musicians**

The reasons for confusing results stems from very many factors and they are: basic study designs; variables that have not been taken into consideration; definition of hearing loss and the age group of musicians being analysed; risk analysis; the type of music being played; seating arrangements the size of the orchestra; the background of the researcher who conducts the study; and equating the measured music exposure

(Leq) to music exposure normalised for eight hours per day. It is also very confusing to learn that the studies that have measured the music levels reported excessive music exposure (more than 85dBA, which is considered to be a safe limit), and on the other side, the studies where hearing was assessed, showed that the hearing of the classical musicians is similar or slightly affected when compared to non-exposed population (Bremmelgaard & Obeling, 1996; Obeling & Poulsen, 1999; Kahari et al., (2001a); Beale, 2002).

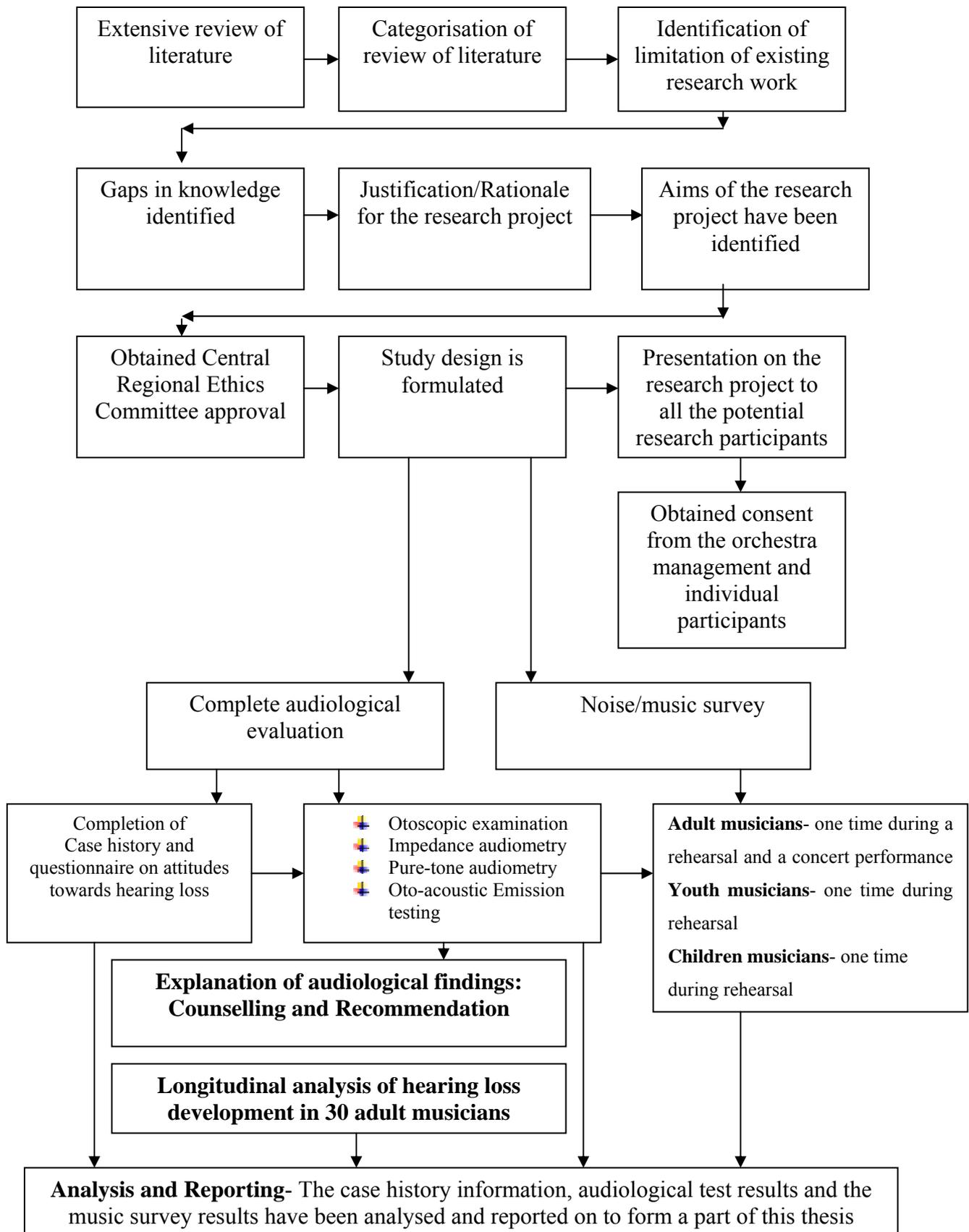
#### **6.1.10 Drawbacks of the currently existing studies**

The drawbacks of the currently existing studies that contribute to knowledge on hearing loss in orchestra musicians are a) some of the research studies have not identified all the factors that might have influenced the risk of acquired hearing loss in musicians, hence the concluding comments are mostly drawn from inconsistent analysis of data; for example, there are variations between the noise levels from the different pieces being played and changes in the exposure from surrounding instruments due to seating arrangement (Mikl, 1995; Kahari et al., 2001). b) Several studies have not provided measurement details, nor have they mentioned sound level measurement details; placement/location of the microphone (Beale, 2002). c) Some of the researchers did not provide adequate information about the data and the calculations (Behar, 2006). d) Sometimes the researcher has only performed sound measurement and not linked them to audiological test findings (Williams, 1995; Karlsson et al., 1983). e) Some of the studies have not taken into account the other music and noise exposure in musicians apart from regular music exposure. f) There are many studies where the possibility of individual vulnerability has not been mentioned. g) There are many variables that are involved and their influence is difficult to assess. For example, there are variations between the noise levels from the different pieces being played and changes in the exposure from surrounding instruments due to seating arrangement (Behar et al., 2006). Contrary to the recommendations of any hearing conservation programme, there are several studies where noise measurement is not linked to audiological test results (Suter, 2002). Some of the studies have not taken into account the other noise exposure in musicians apart from music exposure. Hearing loss is the result of long-term exposure to high noise levels. Whenever possible, measurement results should be linked to the musicians' audiometric tests (ISO 1999).

Given this extensive debate, there are drawbacks with the existing research work, and there are gaps in our current understanding/knowledge on music induced hearing loss. So this research project was justified and was carried with the following conceptual framework, and the study design was formulated to gain greater understanding of music induced hearing loss.

## 6.2 Conceptual Framework

After the review of literature, the conceptual framework was decided to outline possible courses of action in this research project.



## 6.3 Study Design

**1) Review of literature:** A thorough review of literature was collected in order to understand the current knowledge on hearing loss in musicians, and the studies are divided into various categories: Studies finding that hearing loss is not a major issue among orchestra musicians; Longitudinal study or progressive hearing loss with increased music exposure; Studies finding better hearing than in the normal population; Studies explaining sound power of various instrument groups; Studies finding that hearing loss is a major issue among orchestra musicians; Studies on young musicians; and musicians and ear protection, including studies on musicians' use of ear plugs.

**2) Identification of limitations of existing studies:** After the review of literature, the limitations of existing research work have been identified, and so has the list of possible variables that might have influenced the results.

**3) Gaps in our knowledge:** The analysis of current literature available shows that the studies on children musician's hearing loss is limited; there is no comprehensive study on hearing loss in orchestra musicians of various age groups, and often the noise survey is not linked to audiological test results. There is only one study on hearing loss development in musicians; most studies suggest musicians' hearing levels are not significantly different than in a non-exposed population, and there is controversy about the presence of hearing loss in musicians.

**4) Justification/Rationale and aims of the research project:** Based on the limitation of existing research work and the gaps in our current knowledge on hearing loss in orchestral musicians, the rationale/justification is formulated and the aims of this research project was identified.

**5) Central Regional Ethics Committee approval:** As the project involved the direct participation of children, youth and adult musicians, full Central Regional Ethics Committee Approval was required. Approval was given (CEN/06/06/048). The special conditions and requirements of the committee were met in full.

**6) Study Design:** After the Ethics Committee approval, conceptual framework was decided upon to outline possible courses of action, and the study design was formulated to form a basic guideline for this research work.

**7) Presentation of the research project:** The orchestra management and the music teachers organised a meeting to make a formal announcement of the research projects to adult and youth orchestra musicians and the parents of children musicians, in order to discuss the details of the research project. A question and answer session was used to clarify the doubts. All participants were provided with the written information on the research project along with the consent forms to be signed and sent.

**8) Audiological evaluation:** Although all the musicians were encouraged to participate, the participation in the research study was voluntary. All the consented musicians have undergone complete audiological evaluation. The audiological evaluation included: an initial interview, held separately with each participant. The interview was aimed at obtaining relevant case history and also included a questionnaire on attitudes towards Hearing Loss, Otoscopic Examination, Impedance audiometry, Pure-tone audiometry and Distortion Product Otoacoustic emission testing (DPOAE). The summary of the test findings was made available to individual musicians on request.

**9) Noise Survey:** The researcher explained the test procedure to the client concerned and explained how exposure to loud sound may cause a temporary/ permanent change in hearing status. The researcher explained to the client that the study involves a complete hearing test and wearing a doseBadge to measure the sound to which they have been exposed during rehearsal and performance. The doseBadges are a new light weight tool to measure sound exposure in industrial settings. They are small and lightweight enough not to interfere with normal playing of music and are pinned to clothing near the ear. They can also be pinned to a music stand if wearing them is not a good option. These doseBadges are certified intrinsically safe and have been previously approved for use in two Massey University Studies on Noise in early Childhood Centres (Massey University Human Ethics Committee Wellington Protocol 03/120 and 05/34).

**11) Counselling and Recommendation:** The audiological test results would be explained to each musician after the completion of the hearing evaluation. If the musician was found to have a hearing loss, the researcher explained the hearing test findings and the treatment options available, offered advice on measures that can be taken to prevent further deterioration to their hearing, and also offered to refer musicians to private audiologists or to the hospital audiological services for further treatment if required.

**12) Analysis of hearing loss development with increased years of music exposure (longitudinal analysis):** This part of the research work was performed to assess the effect of long-term exposure of the orchestral music on musician's hearing, and to study hearing loss development in musicians with increased music exposure. For this purpose, we analysed the pure-tone audiometry (which was performed as part of the hearing conservation programme) of 30 adult musicians who have been undergoing regular audiometric testing for the past 10-20 years.

**13) Analysis and Reporting:** The information obtained from case history, information obtained from questionnaires on attitudes towards hearing loss, audiological test results and music survey results was analysed and forms part of this thesis. It is also intended that a scientific paper will be prepared and presented at the international scientific meeting to give the findings of the research and recommending measures to be taken (including public education) to prevent music induced hearing loss.

## **6.4 Research questions**

After a complete review of the literature, there were still many unanswered questions regarding hearing loss in orchestral musicians in the literature that contributes to our current understanding of the subject. This research project will try to find answers to a number of the following unanswered questions:

### **6.4.1 Hearing status of various group of musicians**

- a) Is every professional musician (music instrument player) at risk for acquiring hearing loss?

- b) In the hearing mechanism, what frequency region is more affected with loud music exposure?
- c) Are musicians capable of identifying slight alterations in their hearing?
- d) Does music exposure cause asymmetry in hearing i.e., one ear being more affected than the other?
- e) Do female musicians have a better mean hearing threshold than male musicians?
- f) Is it possible to correlate the dips in the pure-tone audiograms with the intensity and frequency of the musical instrument?
- g) In addition to the intensity of the sound, do the spectral characteristics of the music also determine the configuration of the audiogram and the risk of damage to the hearing system?
- h) Are Distortion Product Oto-acoustic Emission (DPOAE) test results consistent with the pure-tone audiogram findings? Can DPOAE findings be used as a tool for early identification of hearing loss among musicians?
- i) Is there a significant relationship between tinnitus and hearing loss among various age groups of orchestra musicians?

#### **6.4.2 Longitudinal hearing status with increased music exposure**

- a) Do all musicians show increased risk of deterioration in hearing with increased number of years of music exposure?
- b) Does the increased number of years of music exposure increase the risk of age-induced hearing loss?
- c) Do changes in the audiogram follow a particular pattern with increased music exposure over a number of years?

#### **6.4.3 Sound environment and hearing loss**

- a) What are the typical music levels encountered in an orchestra, and by how much do they exceed the levels proposed by the Occupational Safety and Health Standard?
- b) What is a typical noise level encountered by various instrumental musicians, and how does this affect other musicians?

c) What are the typical music levels encountered by the orchestral musicians of different age groups, and how do they relate to NZ and international criteria?

d) Is hearing loss observed only in loud musical instrument players?

e) How does each instrument family vary on sound levels and the daily sound exposure?

#### **6.4.4 Factors influencing the increased risk of hearing loss among musicians**

a) Does a family history of hearing loss increase the risk of an individual musician to acquiring hearing loss from music exposure?

b) Does a history of ear infection increase the risk of an individual musician acquiring hearing loss from music exposure?

c) Does the usage of personal stereos further increase the risk of an individual musician acquiring hearing loss from music exposure?

d) Does a history of other noise exposure further increase the risk of an individual musician acquiring hearing loss from music exposure?

e) Do visits to loud music venues on a regular basis increase the risk of an individual musician acquiring hearing loss from music exposure?

f) Does a school discotheque increase the risk of music induced hearing loss among children musicians?

#### **6.4.5 General awareness and music induced hearing loss**

Does the awareness of music induced hearing loss reduce the risk of an individual musician acquiring hearing loss from music exposure?

#### **6.4.6 Usage of ear protecting devices**

- a) Does usage of ear protecting devices reduce the risk of music induced hearing loss?
- b) What are the main reasons for not using the ear protecting devices on a regular basis?

#### **6.4.7 Individual susceptibility and musicians**

- a) Is there the possibility of identifying individual musicians who are susceptible to music induced hearing loss based on hearing evaluation?
- b) Is there the possibility of identifying individual musicians who are susceptible to music induced hearing loss based on daily sound exposure?

#### **6.4.8 Damage risk criteria for music**

- a) Are damage risk criteria for music different from noise exposure?
- b) Should musicians be treated as a special group with regard to hearing, noise, and noise related hearing problems?
- c) The World Health Organization's 'WHO Guidelines for community Noise' suggests that the children could be at greater risk than the adults. Should the damage risk criteria be set at a lower level for children than for adults?

#### **6.4.9 Strategies to prevent noise levels and its effects on musicians' hearing**

- a) Is prevention of hearing loss a possibility among musicians whose by-product is music?
- b) What are the measures that can be taken in order to prevent music induced hearing loss? What workable and feasible strategies can be developed to reduce the music levels that have a risk of hearing loss?
- c) Based on the noise dosage and changes in hearing threshold, what strategies can be developed to help the orchestral musicians of various age groups, to ensure that the musicians are not placed in situations where there is a risk of hearing loss and potentially cause a barrier to continuing their music career?

## **Chapter 7 : Research Methods**

### **7.1 Introduction**

This chapter includes: subjects; exclusion criteria; study development and rationale; ethical requirement and selection of orchestra musicians/music group; physical environment; instrument preparation for sound exposure measurements; classification of musical instruments; equipment used and data collected on music survey; details of audiological evaluation performed; longitudinal analysis of hearing loss development; drawbacks of this study; and statistical analysis of collected data.

### **7.2 Subjects**

In this study, the musicians who belong to the Wellington based symphony orchestras, musicians who are part of youth orchestras, musicians belonging to the university music orchestra, and children orchestra musicians who are part of school music band or music group, participated in this study.

#### **7.2.1 Exclusion criteria**

The following exclusion criteria were used in this study. They are as follows:

- ✚ Not willing to participate in the study.
  
- ✚ To avoid the effect of temporary threshold shifts, all the musicians were tested on their day off work or before regular working time.
  
- ✚ Those with excessive cerumen (ear wax) or abnormalities of the external auditory canal or tympanic membrane were counselled to obtain medical management. Anyone with existing ear diseases was excluded.
  
- ✚ Normally excluded would be any person already working in a noisy environment unless there is some aspect of their musical exposure that could provide useful comparative data – such as could be gained from two

### **7.3 Study development and rationale**

The thorough review of literature (Chapter 4) has revealed that there is a need for a comprehensive study that involves complete hearing evaluation, measuring personal music exposure of orchestral musicians of various age groups, and also longitudinal analysis of hearing status over a number of years to enhance the understanding of music exposure and hearing loss.

The following research protocol was designed:

Fixed sound level measurement was carried out over a full session of music exposure during rehearsal and performance.

1. At the beginning of the study, a formal meeting of musicians was organised separately for each group of orchestra musicians (adult, youth and children musicians along with parents). The main purpose of the meeting was to explain the importance and objectives of this study, and the procedure that would be followed during the tests in order to help them to make an informed decision before participating in the study. There were also questions and answer sessions; the musicians were encouraged to ask questions, and these were answered. All the musicians were invited to participate in the hearing and music measurement, and it was stressed that the participation was on a voluntary basis. Although not all the musicians volunteered, there were enough participants in each age group to represent different sections/instrument group of the orchestra.
2. All the musicians/parents of the children musicians were given written information on the details of the study and were also given consent forms to sign.
3. Following an assessment of the suitability of the new light-weight doseBadges, these devices were acquired to carry out personal sound

4. To gauge information and feedback on the hearing status and possible associated factors of each musician, a case history form was developed for adults and for children (Appendices E and G).
5. A comprehensive audiological evaluation was carried out on each musician who volunteered to participate in this study.
6. The audiological test results were explained to each individual musician. A meeting was also organised to present the results to the orchestra management to help to plan preventive strategies in order to help the musicians preserve their hearing.
7. Retrospective analysis of audiological data to study hearing loss development with increased years of music exposure: This part of the research work was performed to assess the effect of long-term exposure of the orchestral music on musicians' hearing and to study hearing loss development in musicians with increased music exposure. For this purpose, we analysed the pure-tone audiometry (which was performed as part of the hearing conservation programme) of 30 adult musicians who have been undergoing regular audiometric testing for the past 10-20 years.

#### **7.4 Ethical requirements**

As the study involved children and adults as participants, full ethics committee approvals were required. Details are given in Appendix A.

#### **7.5 Selection of orchestra musicians/music group**

As most of the orchestral musicians belong to structured musician groups, governing bodies were approached first (a sample letter is included in Appendix B) and after their consent was received, the individual musicians were approached (a sample

consent form is also included in Appendix C). Similarly, the parents of children musicians were approached and provided with the information sheet (a sample information sheet is included in Appendix D) informing them of the project and consent forms for signing as well. No objections were received from any parents of children at any music groups.

For each session (rehearsal and performance) the players are chosen from different instrument groups, and though the participation was voluntary, a reasonable representation from each instrument group for the hearing test was achieved.

All consents were evaluated and were given to the Audiology Department reception for arranging appointments. Wellington Hospital Audiology Department approached the consented individual musicians and the parents of individual child musicians and arranged a suitable time to perform comprehensive audiological evaluation after the individual musician completed the case history forms (sample forms are included in Appendices E and G). Repeated fixed music measurements and personal music exposures over three different sessions were carried out for adult orchestra musicians to gain insight into the variation of repeated sound pressure levels in the same group of musicians, and repeated personal exposure levels on the same individual musicians. One session of music measurement was carried out for each youth and children orchestra musician group.

The managers of the orchestras were given the following guideline to choose musicians. The selection should:

- ✚ Have a mix of genders
- ✚ Have a representation of all types of musicians
- ✚ Exclude musicians who may not want to part take in the study
- ✚ Exclude musicians who may be more prone to cause damage to the doseBadges
- ✚ Exclude children of oversensitive parents or those likely to object.

## 7.6 Physical environment

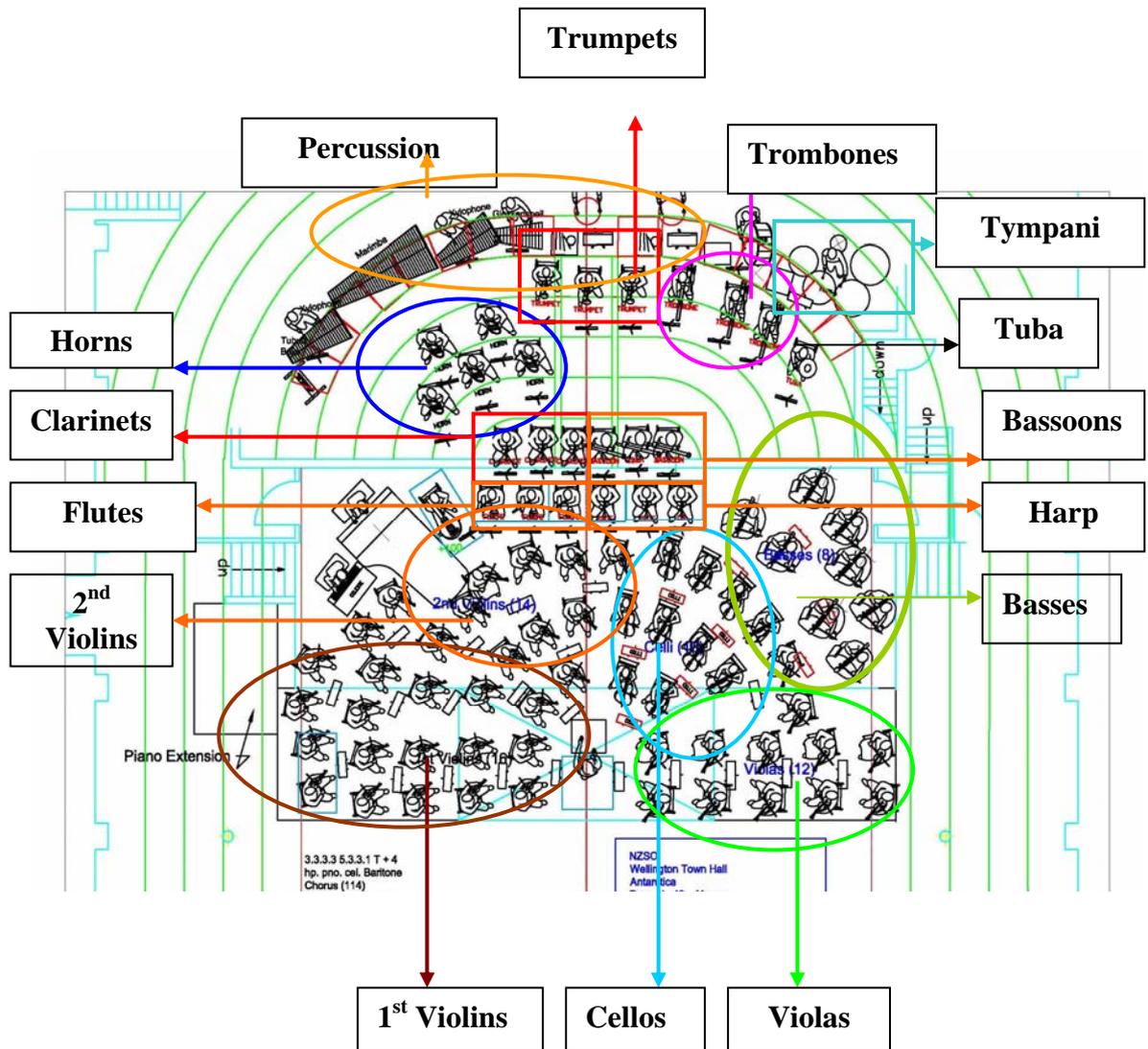


Figure 7-1 Typical orchestra seating arrangements for adult and youth orchestra musicians

## 7.7 Physical environment

All the measurements took place while the musicians were rehearsing in the orchestra, except one measurement that was made during performance.

Most of the music survey was performed during rehearsals, and one measurement was made during rehearsal and performance with adult orchestral musicians to study

the combined sound exposure (noise dosage). The music survey was performed twice while adult musicians were rehearsing, and once during rehearsal and performance; the measurement survey was done once during a youth musician's rehearsal and once during a children musicians' rehearsing. At least five musicians were encouraged to wear the doseBadge for the whole day to calculate for the whole daily sound exposure (day dosage).

## **7.8 Instrument preparation**

Each session began after all the doseBadges were charged overnight. All meters and doseBadges were calibrated with standard acoustic calibrators before each measurement, and checked at the end of the measurement session in accordance with manufacturer's instructions and the standard and code of practice promulgated in New Zealand. They were then attached with a safety pin onto the shoulder of the wearer, making sure that there was no obstruction while playing their instruments. Players were instructed to wear the doseBadges or dosimeters during the entire event and perform their job as usual. They (the children in particular) were also asked to prevent themselves from touching and speaking directly to the microphone to avoid measurement error.

At the end of the each session, the dosimeters were collected and the measurements were downloaded to a computer. The data was also copied to a separate CD for safety purposes.

The sound levels produced by the various sections were measured to identify high exposure areas. We measured the time average level of the fluctuating sound levels over a period of time, the maximum level, the peak level attained, and the percentage noise dose. The maximum permissible (100%) daily noise dose is 85dB for eight hours.

Sound levels were recorded in the rehearsal rooms and at different positions within the orchestra using integrating sound level meters over the period of playing the instruments. Different musicians had the doseBadge or dosimeter on during one

rehearsal session, and the microphone to the sound level meter was placed at a height resembling the head position.

The movement of microphone cable can generate extraneous noise; so to avoid this error, the microphone cable was secured to the stand using masking tape. The sound level meter was attached to the stand in front of each musician.

## **7.9 Classification of musical instruments**

**7.9.1 The Woodwind section:** Includes reed instruments – both single and double reeds – and those that make sound from air passing over the mouthpiece. This section of the orchestra often has only one or two players on each instrument, again depending on the orchestra size. There may be, for example, two flutes, with one performer doubling on piccolo; two oboes, with one performer perhaps doubling on cor-anglais if necessary; an Eb clarinet, two Bb clarinets, and two bassoons. Depending on the piece, other instruments may be included, such as a saxophone, a bass clarinet, or a contrabassoon.

**7.9.2 The Brass section:** In these instruments the sound is created by the vibration of the performer's lips as she or he blows into the resonating mouthpiece. The brass section generally includes four French horns; two or three trumpets; two or three trombones and a tuba. Sometimes one also finds cornets, a tenor or bass trombone, and possibly a euphonium.

**7.9.3 The Percussion section:** This section includes instruments that make sound when struck by hand or with a mallet, or when struck together. The percussion section of the orchestra often includes timpani, chimes or tubular bells, and other pitched percussion, such as xylophone, snare drum, triangle, tambourine, bass drum and cymbals.

**7.9.4 The Long Strings section:** This section includes the cellos, double bass and harp.

**7.9.5 The Short Strings section:** This section contains the first violins, the second violins, the violas, and sometimes a guitar.

**7.9.6 The Keyboard section:** This section includes a piano, and sometimes a celesta, harpsichord, organ and harmonium. The date and style of music determines which of these instruments – if any – will be employed.

## 7.10 Equipment used and data collected on music survey

The following equipment (Table 7-1) was utilised during the music survey. The data collected and noise descriptors used are given for each category of measurement.

**Table 7-1 Table of equipment used and descriptors of data obtained during music survey**

<b>Instrument</b>	<b>Purpose</b>	<b>Noise descriptors used</b>
Cirrus doseBadges	Personal sound exposure of musicians	Dose% and Pa <sup>2</sup> h L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB
Quest M28 sound level meters (where musician has not consented to have the doseBadge)	Mainly used for fixed measurements in various parts of the orchestra, but also used sometimes for personal sound exposure of musicians	L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB Sometimes also: Dose% and Pa <sup>2</sup> h
Pulsar 60 personal sound exposure meter	Personal sound exposure of musicians	Dose% and Pa <sup>2</sup> h L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB
Cirrus 831 integrating sound level meter	Fixed measurements in various positions in the orchestra	L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB
Brüel and Kjør Type 2236 Integrating Sound Level Meter	Fixed measurements in various positions in the orchestra	L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB
Quest 500 integrating sound level meter	Personal sound exposure of musicians	Dose% and Pa <sup>2</sup> h L <sub>Aeq</sub> dB L <sub>Peak</sub> dB L <sub>Amax</sub> dB

$L_{Aeq}$  dB = Time-average levels (A-frequency weighted).

✚ Dose % and  $Pa^2 h$  = the personal sound exposure expressed as either Dose % or in pascal squared hours: 1.0 pascal squared hour = 100% dose, which is equivalent to  $L_{Aeq 8hours} = 85dB$ .

✚  $L_{peak}$  dB = Peak level (unweighted or C-frequency weighted).

✚  $L_{Amax}$  dB = Maximum sound pressure level (A-frequency weighted).

### 7.10.1 Fixed sound level measurements

Typical sound pressure levels in the orchestra were recorded by the fixed sound level meters. The Quest M28 sound level meters were mainly used for the fixed measurements in various positions in the orchestra, but were sometimes used as dosimeters. For additional fixed monitoring, the CR 831 and Quest 500 meters were used. While it would have been ideal to place the microphones of the sound level meters close to the ears of the musicians, the possibility of unintentional damage interfering with the musicians' free movement and routine activity precluded this option. Microphones for all the sound level meters were connected to the meter by extension cable, and the microphone was attached to the stand in front of the musicians as close as possible with the sound level meter suspended under the stand with a small black string. Where possible, the meters were placed away from walls or other reflective surfaces. While no standard or codes of practice exist for the measurement of music, the relevant measurement requirements of the New Zealand standard for measurement of environmental sound were applied where it was possible. The practice of placing sound level meters on a tripod at a height of 1.2-1.5 meters above the ground for measurement was not possible.

The following noise descriptors were recorded:

✚ A-frequency weighted time-average levels ( $L_{Aeq}$ )

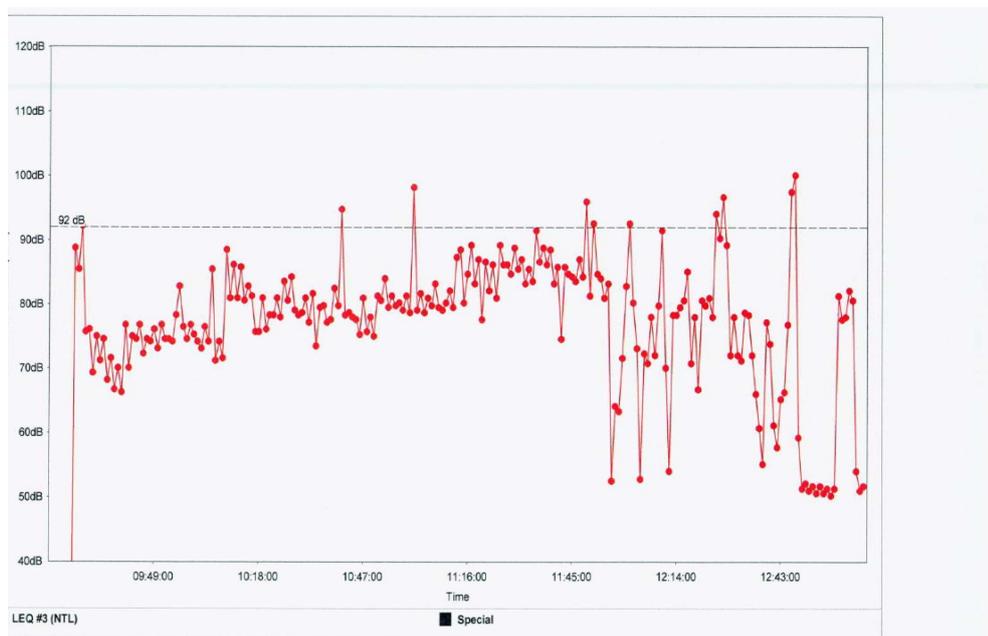
✚ Maximum sound pressure levels ( $L_{AMax}$ )

✚ Peak levels ( $L_{peak}$ )

✚ The period of time sampled

- ✚ A Log of events was kept to ascertain, as much as possible, the events occurring.
- ✚ A time history was produced for each set of fixed sound level measurements.
- ✚ An example is shown in Figure 7-2.

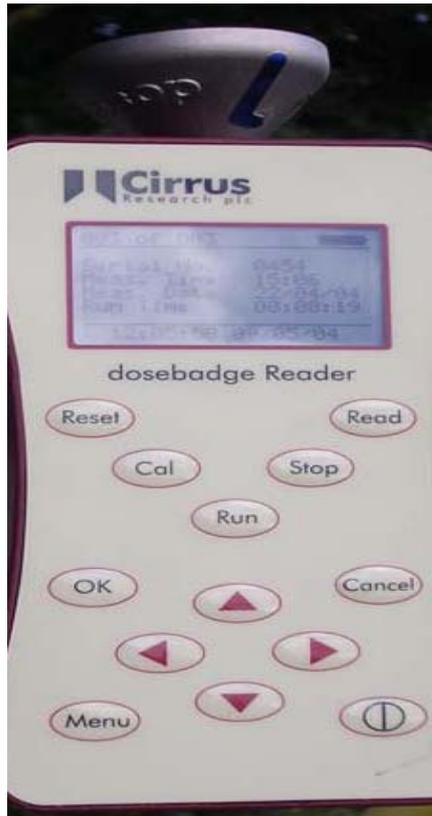
As mentioned before, all the meters were calibrated with an acoustic calibrator before each measurement and checked at the end of the measurement session in accordance with manufacturer's instructions and for the standard and code of practice promulgated in New Zealand.



**Figure 7-2 Typical time history illustrations from fixed sound level measurements**

### 7.10.2 Personal sound exposure of musicians

The difficulty of monitoring the personal sound exposure of musicians while they are playing music and having the microphone close to the ears was overcome with the acquisition of the new lightweight noise doseBadge.



**Figure 7-3 DoseBadge with the reader unit**

These instruments were developed to monitor workers in confined spaces where traditional personal sound exposure meters would not be possible to place, and they are small and lightweight enough to fit comfortably on children and adults. The doseBadges were certified as intrinsically safe and do not emit any kind of radiation such as radio waves while being worn. These units were inserted into the reader unit, and the memory was cleared, calibrated and activated (as shown in figure 7.3). The doseBadge was pinned to clothing, and for some musicians, the doseBadge had to be placed on the shoulder away from the instrument to prevent it interfering with the playing.

Prior to the musician leaving the session, the Badges were turned off, removed and data transferred into the reader unit as shown in Figure 7-3. It would have been desirable to have documented the sound exposure for both rehearsal and performance, but the management of the orchestra was reluctant to grant permission for such measurement to be made during the orchestra performance. Later, all the

data from the reader unit was downloaded in duplicate and processed with the accompanying doseBadge software and the Cirrus Acoustic Editor program.

The data collected from the doseBadges and personal sound exposure measurements was as follows:

- ✚ A-frequency weighted time-average levels ( $L_{Aeq}$ )
- ✚ Dose %
- ✚ Pascal squared hours ( $\text{Pa}^2 \text{h}$ )
- ✚ Maximum sound pressure levels ( $L_{AMax}$ )
- ✚ Peak levels ( $L_{peak}$ )
- ✚ Time sampled.

A time history was produced for each set of personal sound level measurements. An example is given with explanations in Figure 7-4. A-frequency weighted time average level lines have been added for the full sampling period ( $L_{Aeq} = 85\text{dB}$ ) and for the one-hour period between the cursors ( $L_{Aeq\ 1h} = 82\text{dB}$ ). The doseBadge software has a capacity to produce dosimetry reports where the data from each Badge use in the same sampling session can be compiled into a single report for ease of data management.

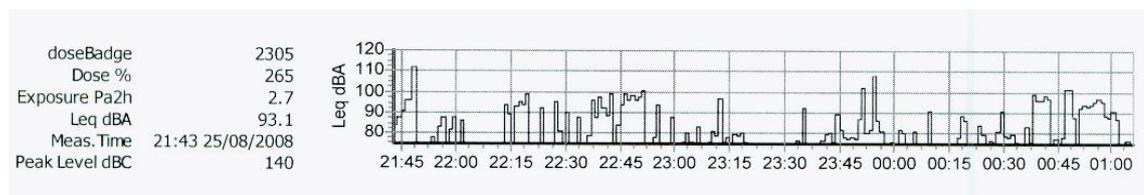
Dosimetry reports were generated for each set of measurements. An example is given in Appendix N. The doseBadges were designed for adult use in confined spaces and for compliance with the international occupational noise criteria of:

- ✚ A-frequency weighted time-average level of no more than 85dB for eight hours or equivalent ( $100\%$  dose or  $1.0 \text{ Pa}^2 \text{ h}$ ), 75dB -0.1, and 65dB -0.01.
- ✚ A peak level of no more than 140dB.

The data collected was compared to the above criteria, which are also a legal requirement of Regulation 11 of the New Zealand Health and Safety in Employment Regulations 1995. Even though the above criteria do not apply to children in

learning environments, the data collected from the doseBadges was compared to these criteria, as no other standards were available. However, it is reasonable to assume that exposure of young children to noise levels approaching the above occupational criteria is excessive.

The doseBadge being a very small unit has a memory limitations. It has a high cut-off point where noise exposure data of less than 75dB is discarded. This is not entirely suitable for children, which gives a conservative estimate of the children's exposure. Information on levels of noise, which will cause damage to young children, is problematic due to lack of information on this topic. The best guidance on this is given by the World Health Organization (1999), where they estimate that time-average levels over an 8-hour day of 75dB are unlikely to cause significant harm across the population. A lower cut-off point at 65dB would have been useful, but the meter did not have this capability.



Note: the time scale is GMT (the default setting on the meter)

**Figure 7-4 typical time-history from a doseBadge**

## 7.11 Audiological evaluation

There are three parts to this study: completion of case history, comprehensive hearing evaluation, and longitudinal study of hearing loss development with prolonged exposure to music.

### 7.11.1 Completion of case history

All participants completed a self-reporting case history form, and the form was usually completed just before hearing evaluation. The questionnaire consisted of relevant questions related to ear and hearing problems, questions about behaviour towards loud music and noise, questions about personal hearing complaints, the type

and use of hearing protection during rehearsal and performance, and subjective judgments of own hearing capacity.

There were also questions relating to musical instrument playing habits, number of years playing musical instruments, other noise and/or music exposure, practice and performance time per week, primary music genre, and instrument played and use of amplification systems.

The medical history included middle ear infection, family history of any hearing problem, tinnitus (ringing in the ear), giddiness and/or balancing difficulties, major illness, medications taken, other history of noise exposure, duration of employment in the orchestra or attending the academy of music, and also information relating to awareness about noise induced hearing loss, the duration of training time per week, leisure time activities, and in particular, for the occurrence of noise in leisure time.

The case history also included when they were last exposed to noise and/or music (Appendices E&G). When appropriate, answers were supplied in a multiple-choice format. Open-ended answers could not be avoided for specific questions, and the investigator subjectively interpreted those data.

### **7.11.2 Hearing evaluation**

#### **7.11.2.1 Ear examination**

An otoscopy examination was performed on all the participants. This is a non-invasive procedure by which the external ear is examined for presence of earwax, and to assess the eardrum status. It takes only a minute or so. Those with excessive cerumen or abnormalities of ear canal and/or ear drum were referred to an otolaryngology department for medical management.

Three different types of hearing assessment were performed on all participants. They are as follows.

### **7.11.2.2 Impedance audiometry**

The test was performed with a Grason-Stadler- GSI Middle Ear Analyzer, Version 2, (220/660Hz) for evaluation of middle ear functioning. Those with measurements indicative of tympanic membrane and/or middle ear disorder were referred to an otolaryngology department for medical management. The criteria used for referral in this study were static compliance <0.3 mmhos, ear canal volume >5.0ml or abnormal asymmetry, and tympanometric peak pressure less than -150 daPa.

### **7.11.2.3 Pure-tone audiometry**

This test was performed with an aim to assess the degree and type of hearing loss in a client. Pure-tone audiometric air conduction thresholds were obtained at 0.25, 0.5, 1, 1.5, 2, 3, 4, 6 and 8kHz, and bone conduction thresholds were obtained at 0.25, 0.5, 1, 2, 3 and 4kHz, using the Hughson-Westlake technique. Each participant's hearing ability of the right and left ears was tested.

This test was performed with a GSI 61 (Grason-Stadler- GSI) Pure-tone audiometer, which is a fully featured two channel clinical audiometer providing air, bone, masking and speech facilities through a range of transducers and stimulus variations with intensity steps of 1, 2 or 5dBHL. The standard frequency range is 125Hz–8kHz giving dose % and Pa<sup>2</sup>h with a high frequency option up to 20kHz with the maximum output of 120dB. The calibration of the audiometer and headphone was checked and found to be in compliance with ANSI S 3.6-1969 (R 1973) audiometer specifications, OSHA 1983 Exhaustive Calibration Specifications and manufacturer specification. The hearing tests were performed by the researcher in a certified purpose built sound treated booth at the Wellington Hospital Audiology department. Background sound levels were monitored in the beginning of the study with the Quest model 2900 Impulse Sound level Meter, and the sound level measurements were within allowable specifications. The biological calibration checks of audiometer function were also carried out before each day of use.

According to the National Institute for Occupational Safety and Health (NIOSH) 1998, to ensure that the worker is free from the effect of previous noise exposure, the

individual must not be exposed to noise level at or above 85dB(A) for a minimum of 12 hours before the audiometric test. Hence all the musicians' hearing was tested according to these guidelines.

#### **7.11.2.3.1 Classification of audiograms**

**Hearing within normal limits:** An individual musician is considered to have normal hearing if hearing threshold is 20dB or less in all the frequencies (250-8000Hz) in both the ears.

**Hearing loss:** In this study we have adopted a very strict criterion (a musician is considered to have a hearing loss if their hearing threshold is  $\geq 25$ dB at least in one of the frequencies and at least in one ear) to account for hearing loss in orchestra musicians.

**Normal dips in the audiograms:** A dip in the audiogram is considered normal if hearing is within normal limits  $\geq 20$ dB HL in all the frequencies and the dip observed is within those limits. (Hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.)

**Abnormal dips in the audiograms:** A dip in the audiogram is considered abnormal if the dip is outside the normal limits  $\geq 20$ dB HL. (Hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.)

#### **7.11.2.4 Diagnostic Oto-acoustic Emission testing**

Distortion Product Oto-acoustic Emission (DPOAE) testing was only performed on 31 adult musicians (50.8%), 34 youth musicians (40.0%), and 28 children musicians (75.7%) because of the time constraints and non-availability of the instrument. Oto-acoustic emissions are considered to reflect the outer hair cell activity of the cochlea, which in turn is recognised as the site most affected by noise exposure. Emissions appear to be more sensitive to cochlear changes following noise exposure and therefore more appropriate for screening and monitoring ears at risk of noise induced hearing loss (NIHL). The objectivity of the measurements and the short test time

required further enhance their usefulness as a cochlear measure. The tests were performed with the latest ILO 292 USB-11 DPEchoport – an objective, frequency specific analyser of cochlear status with binaural testing capabilities.

The instrument's probe was calibrated on a daily basis, and Distortion Product Oto-acoustic Emission was investigated in the frequency range from 1.0 to 8.0kHz ( $f1/f2 = 1.22$ ,  $I1 = I2 = 70\text{dB}$ ) in all subjects. Distortion Product Oto-acoustic Emission was evoked using pairs of tones  $f1$  and  $f2$  with particular intensity and frequency relations ( $f1:f2$  ratio). The evoked response from these stimuli occurs at a third frequency, the distortion product frequency  $f_{dp}$ , which is calculated as  $f_{dp} = 2 \times f1 - f2$ . The levels of the primary tones, of the Distortion Product Oto-acoustic Emission:  $L1$  and  $L2$ , were 75 and 70dB SPL respectively. The frequency ratio of  $f2/f1$  was 1.22. Distortion Product Oto-acoustic Emission was measured at the frequency  $2f1 - f2$  for 27  $f2$  frequencies ranging from 1000 to 8000Hz. The emission level was established on the basis of three presentations. In case of high noise floors, the measurement was repeated manually at particular frequencies, usually below 2kHz.

Following completion of testing, the test results were explained to each musician and a copy of the test results were provided on request. Those with results indicating the presence of hearing loss were advised to use ear protection on a regular basis, and on a case-by-case basis had a brief counselling on prevention of hearing loss.

## **7.12 Longitudinal analysis of hearing loss development**

To study the effects of long term music exposure on their hearing, we have analysed the audiograms of 30 individual musicians who have had periodical audiological evaluation for several years.

To date there are no studies on hearing development in classical orchestra musicians who have had continued music exposure for many years. This study also helps to analyse various audiometric patterns with increased music exposure, any possible

difference in noise and music exposure, and any difference between male and female musicians.

### **7.13 Drawbacks of this study**

Though there was enough representation from all types of musical instrumental musicians, only 61 adult musicians from the total of 90 musicians (75%) attended for audiological examination. As it is voluntary, the response was low among the adult musicians, and if a significant number of those not attending have a hearing loss then the risk of music exposure may be seriously underestimated. Unlike adult musicians, among the youth and children musicians the willingness to participate in this study was high.

Most measurements are taken during rehearsals, and this may have influenced the sound level measurements. However, the orchestral dress rehearsal is conducted in a similar setting and the programme is typically the same as that of the actual performance.

The managers of the orchestras were given guidelines to choose the participants – this might have resulted in a selection bias.

The longitudinal study was performed from the existing hearing evaluation performed as part of hearing conservation programme, and though the hearing evaluation was performed by a qualified audiologist, the data was not collected by the researcher.

### **7.14 Statistical analysis of collected data**

The method for analysing hearing loss included presenting the number of musicians suspected to have acquired hearing loss due to music exposure and comparing their hearing levels with a reference population. Both of these have shortcomings: the definition of noise induced hearing loss and identifying a well matched reference population are often difficult.

In this study the following statistical tests have been used to analyse the data obtained.

**Pearson's Chi-square test:** This tests the independence of two variables. It assesses whether paired observations of two variables, expressed in a contingency table, are independent of each other. The null hypothesis is that the occurrence of the two outcomes is statistically independent.

**P-value:** This test is used to find statistical significance – whether a result is statistically independent or dependent. The p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. The null hypothesis is rejected when the p-value is less than 0.05. When the null hypothesis is rejected, the result is said to be statistically dependent.

**Fisher exact test:** This tests the independence of two variables. It is used when Pearson's Chi-square test is found to be inadequate (when any of the cells of a contingency table are below five). The alternative is Fisher's exact test, which is used in the analysis of contingency tables where sample sizes are small.

## **Chapter 8 : Results – Audiological evaluation performed on various age groups of musicians**

### **8.1 Subjects**

Table 8.1 shows the participants in this study out of the 93 musicians invited to participate: 61 adult orchestra musician of both genders – 39 (63.9%) of male sex and 22 (36.1%) of female sex with a minimum age of 27 years and maximum age of 66 (average: 46.5 years and standard deviation: 9.4 years). Out of the 111 musicians invited to participate, 85 youth musicians 37 (43.5%) were of male sex and 48 (56.5%) of female sex with a minimum age of 18 years and maximum age of 38 (average: 23.6 years and standard deviation: 3.8 years). Out of the 51 children's parents invited, 37 children musicians 26 (70.3%) were of male sex and 11 (29.7%) of female sex with a minimum age of eight years and maximum age of 12 (average: 9.7 years and standard deviation: 1.1 years).

### **8.2 Classification of musicians**

Musicians are classified based on the music group which they belong to: they are classified as Adult musicians, Youth musicians and Children musicians. There seems to be an overlap on the age group between adult and youth orchestral musicians. (Ref: Table 8-1)

**8.2.1 Adult orchestra musicians:** (In the age range of 27-66 Yrs with the mean age of 46.5 Yrs): Orchestral musicians who belong to the well established orchestra music group.

**8.2.2 Youth orchestra musicians:** (In the age range of 18-38 Yrs with the mean age of 23.6 Yrs): Orchestral musicians who belong to the youth orchestral music group.

**8.2.3 Children musicians:** (In the age group of 8-12 Yrs with the mean age of 9.7 Yrs): Children musicians who belong to the school band.

**Table 8.1 Subjects participated in this study**

	Total number of musicians	Male	Female	Minimum age	Maximum age
<b>Adult musicians</b>	61	39 (63.9%)	22 (36.1%)	27 Yrs	66 Yrs
				Average Age-46.5 Yrs(SD-9.4 Yrs)	
<b>Youth orchestra musicians</b>	85	37 (43.5%)	48 (56.5%)	18 Yrs	38 Yrs
				Average Age-23.6 Yrs(SD-3.8 Yrs)	
<b>Children musicians</b>	37	26 (70.3%)	11 (29.7%)	8 Yrs	12 Yrs
				Average Age-9.7 Yrs(SD- 1.1 Yrs)	

### 8.3 Number of years of professional music activity

Among the adult musicians, nine (14.8%) musicians had 10-19 years of experience, 10 of the musicians (16.4%) had 20-29 years of experience, 21 (34.4%) had 30-39 years of experience, 19 (31.1%) had 40-49 years of experience, and two (3.3%) had 50 or more years of experience. The professional activity time average was 33.3 years, with a standard deviation of 10.7 years.

Among the youth musicians: 30 of the musicians (35.3%) had 10-14 years of experience, 44 (51.8%) had 15-19 years of experience, and 11 (12.9%) had 20 or more years of experience. The musical activity time average was 15.5 years, with a standard deviation of 3.4 years.

Among the children orchestra musicians: 30 musicians (81.08%) informed they began their music activity when they were five years old or less, and seven children musicians (18.9%) mentioned they had been playing for more than five years. The musical activity time average was 4.4 years, with a standard deviation of 1.2 years.

### 8.4 Daily time exposure to music

When we researched the daily time exposure to music, among the adult orchestral musicians 32 participants (52.5%) informed us that they are exposed between 4 to 5 hours, 24 participants (39.3%) stated the daily exposure is between 5 to 6 hours, and

five participants 8.2 (20%) had exposure time of around seven hours. The participants' average daily exposure is 4.4 hours and standard deviation: 2.24.

Among the youth musicians, 53 participants (62.4%) informed us that they are exposed between 2 to 3 hours, 27 participants (31.8 %) stated the daily exposure was above three hours, and five participants (5.9%) had an exposure time more than four hours. The participants' average daily exposure is 2.7 hours and standard deviation: 2.24. Among the children musicians, 26 participants (70.3%) informed us that they are exposed from 30 minutes to one hour, and 11 participants (36.6%) stated the daily exposure to be more than one hour. The participants' average daily exposure is 0.95 hours and standard deviation is 0.25 hours.

The specific interview data analysis confirmed that regarding the subjective perception, among the adult musicians, 29 (47.5%) of the musicians informed us that they work in highly noisy places and 26 (30.6%) of the youth musicians informed us that they work in an environment that may cause a hearing problem. Six (16.2%) of the children musicians informed us that their musical activity is loud at times. Eighty-two percent of adult musicians, 72% youth musicians and 20% of children musicians have been in a musical environment that caused a discomfort. When we asked about the occurrence of the auditory complaint type, the participants' most mentioned symptom was buzzing, followed by the difficulty of understanding speech in noisy environments.

As to the level of awareness about unamplified music causing hearing problems, 100% of the adult musicians, 82% of the youth musicians and 11% of the children musicians were aware of this.

The external ear examinations found all them to have normal ear canals free from ear wax, and the impedance audiometry confirmed the presence of normal tympanometry among all the musicians, confirming that the middle ear didn't interfere with the hearing test results obtained (except for two adult musicians, one youth musician and one child musician who were suspected to have abnormal middle ear function; their hearing test results were not taken into consideration for this study).

## 8.5 Orchestra musicians and various instruments played

### 8.5.1 Adult orchestra musicians and musical instruments played

Figure 8-1 shows that among the 61 adult orchestra musicians: 23 (37.7%) played the violin, one (1.6%) played the bass trombone, two (3.3%) played the bassoon, six (9.8%) the cello, one (1.6%) the clarinet, five (8.2%) the double bass, one (1.6%) played the flute doubling on the piccolo, four (6.6%) played the French horn, one (1.6%) played not only the French horn but the trumpet as well, two (3.3%) played the oboe, two (3.3%) played percussion, one (1.6%) was a timpanist, one (1.6%) played the trombone, two (3.3%) played the trumpet, three (4.9%) played second violin, and six (9.8%) played the viola.

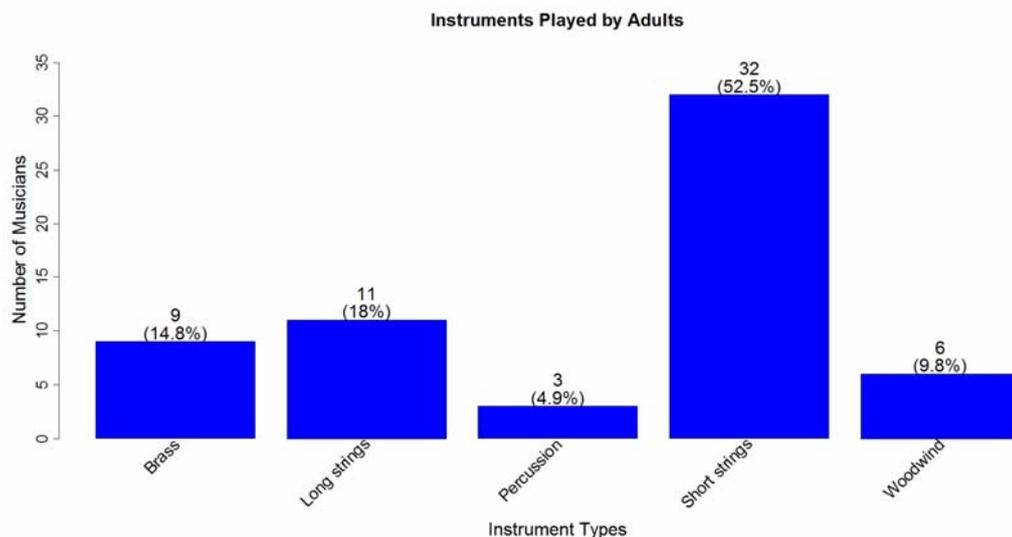


Figure 8-1 Classification of adult orchestra musicians based on musical instrument

### 8.5.2 Youth orchestra musicians and musical instruments played

Figure 8-2 shows that among the 85 youth orchestra musicians: 21 (24.7%) played the violin, two (2.4%) played the bassoon, one (1.2%) played the bassoon doubling on the saxophone, one (1.2%) played a brass instrument, nine (10.9%) played the cello, eight (9.4%) played the clarinet, five (5.9%) played the double bass, one (1.2%) played the drums, five (5.9%) played the flute doubling on the piccolo, three (3.5%) played the French horn, two (2.4%) played the harp, two (2.4%) played on keyboards, two (2.4%) played the oboe, three (3.5%) played percussion, one (1.2%) percussionist specialised on the Marimba, one (1.2%) was a singer, one (1.2%) was a

timpanist, three (3.5%) played the trombone, five (5.9%) played the trumpet, one (1.2%) played the tuba, and eight (9.4%) played the viola.

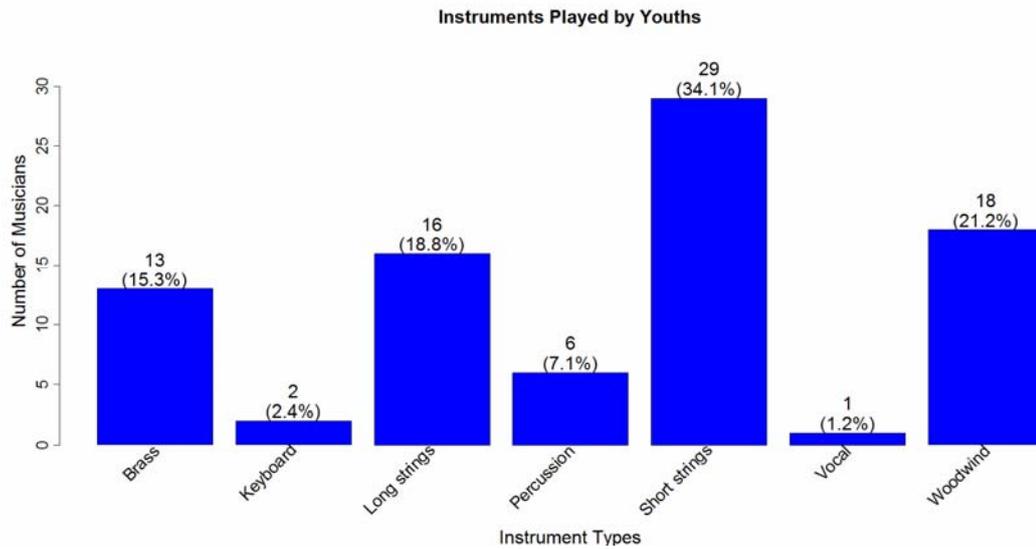


Figure 8-2 Classification of youth orchestra musicians based on musical instrument

### 8.5.3 Children orchestra musicians and musical instruments played

Figure 8-3 shows that among the 37 children musicians: three (8.1%) played the clarinet, two (5.4%) played the drums, two (5.4%) played percussion, six (16.2%) played the recorder, two (5.4%) played the saxophone, six (16.2%) played the trumpet and 16 (43.2%) played the violin.

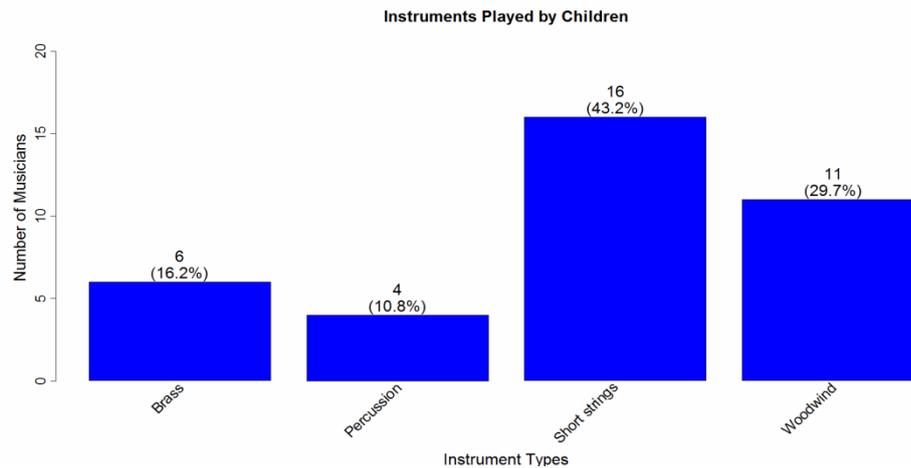


Figure 8-3 Classification of children orchestra musicians based on musical instrument

## 8.6 Mean hearing threshold of musicians of all age groups

Table 8-2 summarises the mean hearing threshold of 183 (61 adult, 85 youth and 37 children) orchestra musicians who took part in this study. The pure-tone audiometry was performed in the frequency region from 250-8000Hz, and the mean hearing thresholds are presented in various age groups.

**Table 8-2 Mean hearing threshold (dB HL) of musicians of all age groups [dB, (SD)]**

		<b>Frequency (Hz)</b>								
		<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Age Groups (Yrs)</b>	<b>Right Ear</b>									
	<b>6-9</b>	5.5 (2.4)	5.8 (2.6)	7.4 (3.1)	7.6 (3.9)	6.3 (4.4)	7.6 (4.8)	7.2 (4.3)	12.9 (5.1)	10.5 (9.3)
	<b>10-19</b>	5.5 (2.4)	6.6 (2.7)	7.1 (3.7)	7.9 (3.9)	7.1 (4.5)	8.3 (6.2)	7.8 (4.5)	12.4 (5.8)	11.0 (7.6)
	<b>20-29</b>	5.1 (2.1)	7.0 (2.7)	7.4 (3.2)	8.5 (4.1)	7.7 (4.9)	8.5 (5.0)	8.9 (5.2)	13.4 (6.5)	7.7 (5.0)
	<b>30-39</b>	6.8 (2.5)	7.4 (2.6)	7.4 (4.2)	8.7 (8.1)	8.7 (11.3)	8.4 (6.2)	8.7 (5.5)	10.8 (7.3)	7.9 (5.1)
	<b>40-49</b>	6.3 (2.8)	8.9 (2.7)	7.9 (3.8)	8.2 (4.2)	7.1 (4.2)	10.3 (6.6)	11.6 (7.3)	20.0 (12.7)	18.2 (16.7)
	<b>50-59</b>	7.3 (2.5)	8.2 (2.9)	9.5 (5.1)	9.8 (3.9)	9.5 (6.3)	13.6 (11.7)	17.7 (12.0)	21.8 (11.9)	24.8 (16.0)
	<b>60+</b>	6.0 (2.2)	6.0 (4.2)	13.0 (7.6)	11.0 (4.2)	12.0 (5.7)	16.0 (10.9)	19.0 (14.7)	32.0 (14.8)	36.0 (12.9)
	<b>Left Ear</b>									
	<b>6-9</b>	6.1 (3.9)	5.5 (2.3)	6.8 (3.4)	7.6 (5.6)	6.1 (5.2)	6.3 (5.7)	8.2 (7.5)	13.9 (8.8)	10.3 (7.2)
	<b>10-19</b>	6.0 (3.6)	5.3 (3.5)	5.5 (3.1)	5.3 (4.2)	6.7 (6.2)	6.6 (6.6)	6.4 (6.1)	13.3 (7.0)	10.9 (8.5)
	<b>20-29</b>	6.2 (3.2)	7.4 (2.9)	7.6 (3.3)	7.9 (4.9)	7.8 (4.8)	7.4 (5.2)	8.5 (5.6)	13.5 (7.3)	7.6 (6.1)
	<b>30-39</b>	7.6 (4.5)	7.4 (3.5)	6.8 (4.2)	7.4 (7.1)	7.1 (8.2)	5.5 (5.7)	6.6 (5.8)	12.1 (7.3)	8.4 (6.5)
	<b>40-49</b>	8.4 (4.1)	7.4 (5.1)	7.6 (3.9)	7.1 (6.3)	7.6 (6.9)	11.3 (10.9)	12.6 (11.8)	19.5 (12.2)	17.1 (14.3)
	<b>50-59</b>	9.8 (3.9)	9.3 (4.4)	10.5 (5.8)	9.3 (5.8)	11.1 (7.5)	17.5 (13.2)	22.7 (14.7)	24.3 (13.3)	21.8 (15.4)
<b>60+</b>	8.0 (5.7)	9.0 (5.5)	12.0 (8.4)	13.0 (6.7)	11.0 (4.2)	21.0 (22.2)	25.0 (28.1)	33.0 (22.5)	31.0 (22.5)	

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

### 8.6.1 Mean hearing threshold in the high frequency region of musicians of all age groups

Table 8-3 Mean hearing threshold (dB HL) of 183 (61 adult, 85 youth and 37 children)

Age Groups	Right Ear				Left ear			
	3kHz	4kHz	6kHz	8kHz	3kHz	4kHz	6kHz	8kHz
<b>6-9</b>	7.6 (4.8)	7.2 (4.3)	12.9 (5.1)	10.5 (9.3)	6.3 (5.7)	8.2 (7.5)	13.9 (8.8)	10.3 (7.2)
<b>10-19</b>	8.3 (6.2)	7.8 (4.5)	12.4 (5.8)	11.0 (7.6)	6.6 (6.6)	6.4 (6.1)	13.3 (7.0)	10.9 (8.5)
<b>20-29</b>	8.5 (5.0)	8.9 (5.2)	13.4 (6.5)	7.7 (5.0)	7.4 (5.2)	8.5 (5.6)	13.5 (7.3)	7.6 (6.1)
<b>30-39</b>	8.4 (6.2)	8.7 (5.5)	10.8 (7.3)	7.9 (5.1)	5.5 (5.7)	6.6 (5.8)	12.1 (7.3)	8.4 (6.5)
<b>40-49</b>	10.3 (6.6)	11.6 (7.3)	20.0 (12.7)	18.2 (16.7)	11.3 (10.9)	12.6 (11.8)	19.5 (12.2)	17.1 (14.3)
<b>50-59</b>	13.6 (11.7)	17.7 (12.0)	21.8 (11.9)	24.8 (16.0)	17.5 (13.2)	22.7 (14.7)	24.3 (13.3)	21.8 (15.4)
<b>60+</b>	16.0 (10.9)	19.0 (14.7)	32.0 (14.8)	36.0 (12.9)	21.0 (22.2)	25.0 (28.1)	33.0 (22.5)	31.0 (22.5)

#### orchestra musicians in the high frequency region

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-2 shows that musicians seem to show no significant deterioration in the low frequencies, particularly in the frequency region of 250-1000Hz. The deterioration with increased music exposure and/or aging also is very slow in the low frequency region when compared to the mid and high frequency region. One should take presbycusis into account, but unfortunately with current knowledge this cannot be done.

Though hearing deterioration is predominately in the high frequency region, on average deterioration is more at 6kHz than in the other frequencies.

The pure-tone audiometry results of various age groups of orchestra musicians show that the mean average hearing threshold increases with increasing age and increased years of professional music exposure. This trend is observed particularly in the mid and high frequency regions.

## 8.6.2 Mean hearing thresholds of all musicians in terms of frequency range

Table 8-4 shows the mean hearing thresholds in various frequency ranges to analyse the impact of sound exposure in the different frequency regions.

**Table 8-4 Mean hearing threshold (dBHL) in various frequency range**

<b>Frequency range</b>	<b>Children Musicians(dB)</b>	<b>Youth musicians(dB)</b>	<b>Adult Musicians(dB)</b>
<b>Low Freq (250-500 Hz)</b>	<b>5.7 (2.9)</b>	<b>6.5 (2.9)</b>	<b>7.9 (3.8)</b>
<b>Mid Freq (1000-2000 Hz)</b>	<b>6.5 (4.2)</b>	<b>7.9 (4.3)</b>	<b>8.6 (6.4)</b>
<b>High Freq (3000-8000 Hz)</b>	<b>9.4 (7.2)</b>	<b>9.6 (6.2)</b>	<b>16.2 (13.7)</b>

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-4 shows that musicians seem to have better hearing in the low frequency region than the mid frequencies, and this is better than in the high frequency region. It also is interesting to note that there seems to be continued deterioration in the hearing threshold with age and with more exposure to music. The cause is more likely to be the years of experience. Also note that the fact that the two variables are correlated does not mean the causal link exists. The reference chart in ISO 7029 was not used as it is not possible to separate the effects of aging and music exposure.

## 8.7 Hearing loss in various groups of adult orchestra musicians

In this study, 37 of the adult orchestra musicians (60.7%) out of 61 musicians, 19 youth musicians (22.4%) out of 85 musicians, and six children musician (16.2%) out of 37 musicians were found to have a hearing loss (hearing threshold is  $\geq 25$ dB at least in one of the frequency regions and at least in one ear).

### 8.7.1 Adults orchestra musicians

**Table 8-5 Hearing status – adult orchestra musicians in different musician groups**

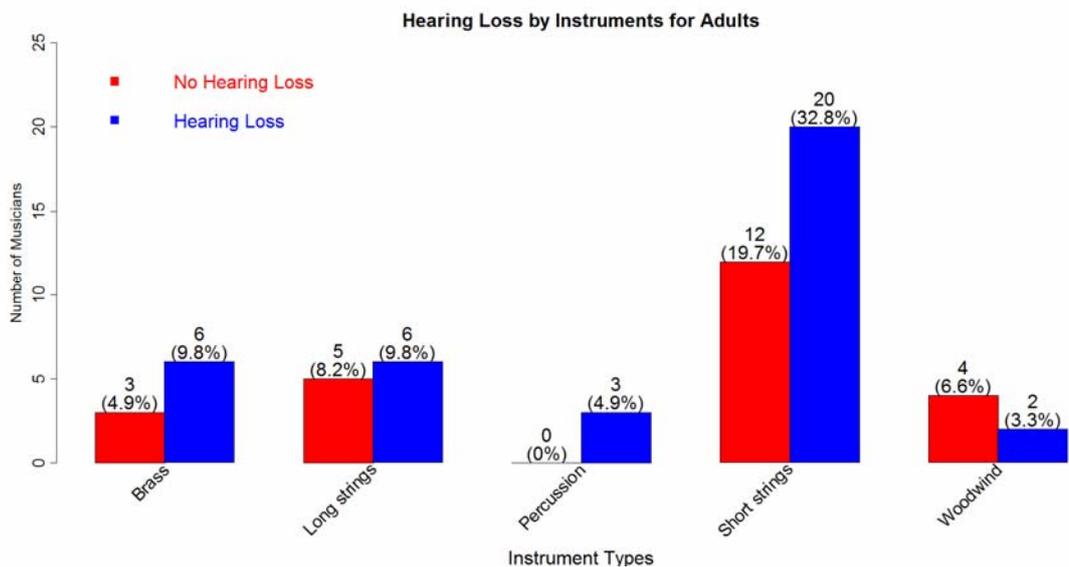
<b>Group of musicians</b>	<b>Number of musicians with normal hearing (%)</b>	<b>Number of musicians with hearing loss (%)</b>
<b>Brass</b>	3 (4.9)	6 (9.8)
<b>Long strings</b>	5 (8.2)	6 (9.8)
<b>Percussions</b>	0	3 (4.9)
<b>Short strings</b>	12 (19.7)	20 (32.8)
<b>Woodwind</b>	4 (6.6)	2 (3.3)

Note: Number of musicians with percentage in brackets. This table is constructed by treating a musician as having a hearing loss if their hearing threshold is  $\geq 25$ dB at least in one of the frequency regions and at least in one ear.

**Table 8-6 Mean age – adult orchestra musicians with and without hearing loss**

<b>Group of musicians</b>	<b>Mean age of musicians with normal hearing(SD)</b>	<b>Mean age of musicians with hearing loss (SD)</b>
<b>Brass</b>	50.0 (3.8)	46.8 (9.6)
<b>Long strings</b>	42.4 (9.8)	49.8 (12.8)
<b>Percussions</b>	NA	42.3 (10.0)
<b>Short strings</b>	40.3 (6.7)	51.5 (8.0)
<b>Woodwind</b>	37.5 (5.8)	53.0 (4.2)

**Note:** Mean age in years with SD within brackets



**Figure 8-4 Hearing status of adult orchestra musicians**

**Results:** Table 8-6 shows that the hearing loss is greater for the older musicians except in the brass section. The cause is more likely to be the years of experience. Also note that the fact that the two variables are correlated does not mean the

causal link exists. Though this data shows that with an increased number of years of music exposure there is an increase probability of acquiring hearing loss in all musicians, there also seem to be individual variations. Figure 8-4 shows hearing loss is found in all groups of musicians, and it is not specific to loud musical instruments: six out of nine brass instrument players, six out of 11 long string instrument players, three out of three percussionists, 20 out of 32 small string instrument players, and two out of six woodwind musicians were found to have hearing loss.

### 8.7.2 Youth orchestra musicians

**Table 8-7 Hearing status – Youth orchestra in different musician groups**

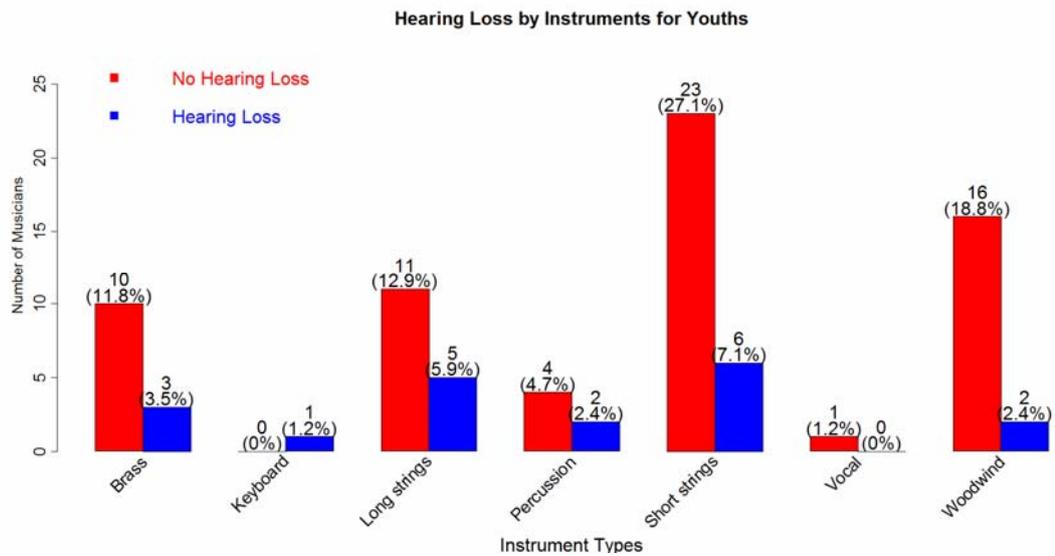
<b>Group of musicians</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>
<b>Brass</b>	<b>10 (11.8)</b>	<b>3 (3.5)</b>
<b>Keyboard</b>	<b>1 (1.2)</b>	<b>1 (1.2)</b>
<b>Long strings</b>	<b>11 (12.9)</b>	<b>5 (5.9)</b>
<b>Percussions</b>	<b>4 (4.7)</b>	<b>2 (2.4)</b>
<b>Short strings</b>	<b>23 (27.1)</b>	<b>6 (7.1)</b>
<b>Woodwind</b>	<b>16 (18.8)</b>	<b>2 (2.4)</b>
<b>Vocal</b>	<b>1 (1.2)</b>	<b>0</b>

Note: Number of musicians with percentage with in brackets. This table is constructed by treating a musician as having a hearing loss if their hearing threshold is  $\geq 25$ dB at least in one of the frequency regions and at least in one ear.

**Table 8-8 Mean age – Youth orchestra musicians with and without hearing loss**

<b>Group of musicians</b>	<b>Musicians with normal hearing (Yrs)</b>	<b>Musicians with hearing loss (Yrs)</b>
<b>Brass</b>	<b>25.8 (4.7)</b>	<b>23.0 (4.0)</b>
<b>Keyboard</b>	<b>0</b>	<b>23.0</b>
<b>Long strings</b>	<b>22.1 (2.7)</b>	<b>23.8 (3.1)</b>
<b>Percussions</b>	<b>23.0 (3.4)</b>	<b>27.5 (4.9)</b>
<b>Short strings</b>	<b>22.4 (4.1)</b>	<b>21.3 (1.8)</b>
<b>Vocal</b>	<b>22.0</b>	<b>0</b>
<b>Woodwind</b>	<b>25.8 (3.6)</b>	<b>23.5 (0.7)</b>

**Note:** Mean age in years with SD within brackets. Standard deviation was not calculable for keyboard and vocal as there was only one (n=1) musician in each category.



**Figure 8-5 Hearing status of youth orchestra musicians**

**Results:** Table 8-8 shows that the mean age of youth orchestra musicians with normal hearing is lower than the mean age of musicians with hearing loss in the long strings and percussion sections, and the mean age is lower in musicians with hearing loss in the brass, short string and woodwind sections. Also note that the fact that although the two variables are correlated in some group of musicians, it does not mean the causal link exists. Although the data shows that with increased music exposure there is an increase in the probability of acquiring a hearing loss in all musicians, there seem to be individual variations. Figure 8-5 shows that hearing loss is found in all groups of musicians; it is not specific to loud musical instruments.

### 8.7.3 Children orchestra musicians

**Table 8-9 Hearing status – Children orchestra in different musician groups**

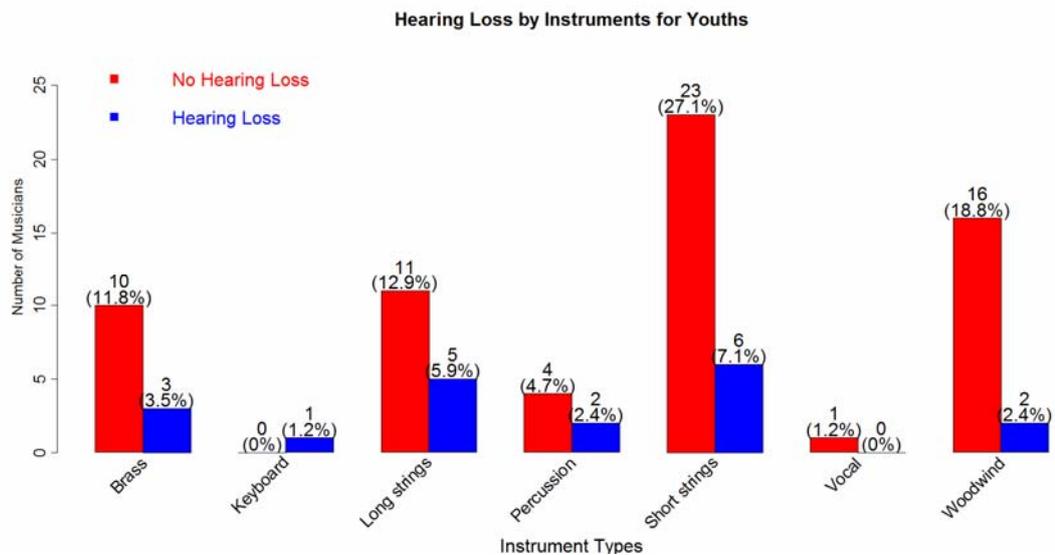
<b>Group of musicians</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>
<b>Brass</b>	<b>5 (13.5)</b>	<b>1 (2.7)</b>
<b>Percussions</b>	<b>3 (8.1)</b>	<b>1 (2.7)</b>
<b>Short strings</b>	<b>14 (37.8)</b>	<b>2 (5.4)</b>
<b>Woodwind</b>	<b>9 (24.3)</b>	<b>2 (5.4)</b>

Note: Number of musicians with percentage with in brackets. This table is constructed by treating a musician as having a hearing loss if their hearing threshold is  $\geq 25$ dB at least in one of the frequency regions and at least in one ear.

**Table 8-10 Mean age – child orchestra musicians with and without hearing loss**

<b>Group of musicians</b>	<b>Number of musicians with normal hearing(Yrs)</b>	<b>Number of musicians with hearing loss (Yrs)</b>
<b>Brass</b>	<b>10.8 (1.5)</b>	<b>10.0</b>
<b>Percussions</b>	<b>9.0</b>	<b>10.5 (0.7)</b>
<b>Short strings</b>	<b>9.4 (0.9)</b>	<b>9.3 (1.5)</b>
<b>Woodwind</b>	<b>9.9 (0.9)</b>	<b>9.7 (2.1)</b>

**Note:** Mean age in years with SD within brackets. Standard deviation is not calculated for musicians with normal hearing for percussion section and musician with hearing loss in brass section as there was only one (n=1) musician in each category.



**Figure 8-6 Hearing status of children orchestra musicians**

**Results:** Table 8-10 shows that the mean age of children orchestra musicians with normal hearing is higher than the mean age of musicians with hearing loss in the brass, short string and woodwind sections. Also note that the fact that the two variables are correlated does not mean the causal link exists. Although the data shows that with increased music exposure there is an increase in the probability of acquiring a hearing loss in all musicians, there seem to be individual variations. Figure 8-6 shows hearing loss is found in all groups of musicians; it is not specific to loud musical instruments.

## 8.8 Asymmetry in hearing – orchestra musicians of various age groups

### 8.8.1 Asymmetry in hearing adult orchestra musicians

Table 8-11 Difference in mean hearing threshold (dB HL) between the ears

Frequency (Hz)									
Frequency (Hz)	250	500	1kHz	1.5kHz	2kHz	3kHz	4kHz	6kHz	8kHz
<b>Right ear (SD)</b>	6.7 (2.7)	8.0 (2.9)	8.7 (5.0)	8.8 (5.5)	8.5 (7.9)	11.2 (9.3)	13.4 (10.5)	19.3 (12.8)	19.4 (16)
<b>Left ear (SD)</b>	8.7 (4.4)	8.1 (4.5)	8.5 (5.3)	8.3 (6.7)	9.0 (7.6)	12.7 (13.0)	15.6 (15.2)	20.1 (14.0)	17.6 (15.2)
<b>Difference (SD)</b>	2 0.66	0.1 0.69	-0.2 0.93	-0.5 1.11	1.5 1.40	1.5 2.05	2.2 2.37	0.8 2.43	-1.8 2.83

$\text{Sqrt}((s_1^2+s_2^2)/N)$  N = 61

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-11 shows that in adult musicians, the mean hearing threshold is elevated in the left ear in more frequencies than in the right ear in the following frequencies: 250, 500, 2000, 3000, 4000 and 6000Hz. The mean hearing threshold is better in the left ear than the right ear in 1000, 1500 and 8000Hz. These observed differences between the ears are not significant.

#### 8.8.1.1 Ear specific data

##### Hearing losses in right ear

Table 8-12 Hearing status in right ear in adult musicians

Frequency (Hz)	250	500	1kHz	1.5kHz	2kHz	3kHz	4kHz	6kHz	8kHz
<b>Hearing loss</b>	0 (0%)	0 (0%)	1 (1.6%)	1 (1.6%)	1 (1.6%)	6 (9.8%)	10 (16.4%)	22 (36.1%)	20 (32.8%)
<b>Normal hearing</b>	61 (100%)	61 (100%)	60 (98.4%)	60 (98.4%)	60 (98.4%)	55 (90.2%)	51 (83.6%)	39 (63.9%)	41 (67.2%)

**Note:** Number of musicians in each frequency with percentage in parentheses

## Hearing losses in left ear

**Table 8-13 Hearing status in left ear in adult musicians**

<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Hearing loss</b>	0 (0%)	0 (0%)	1 (1.6%)	1 (1.6%)	2 (3.3%)	11 (18.0%)	15 (24.6%)	17 (27.9%)	16 (26.2%)
<b>Normal hearing</b>	61 (100%)	61 (100%)	60 (98.4%)	60 (98.4%)	59 (96.7%)	50 (82.0%)	46 (75.4%)	44 (72.3%)	45 (73.8%)

**Note:** Number of musicians in each frequency with percentage in parentheses

## Relationship between right and left ears

**Table 8-14 Hearing status in right and left ear in adult musicians**

<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5 kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Hearing loss in only right ear</b>	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1.6%)	3 (4.9%)	11 (18.0%)	6 (9.8%)
<b>Hearing loss in only left ear</b>	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1.6%)	6 (9.8%)	8 (13.1%)	6 (9.8%)	2 (3.3%)
<b>Hearing loss in both ears</b>	0 (0%)	0 (0%)	1 (1.6%)	1 (1.6%)	1 (1.6%)	5 (8.2%)	7 (11.5%)	11 (18.0%)	14 (23.0%)

**Note:** Number of musicians in each frequency with percentage in parentheses

**Results:** Tables 8-12, 8-13, 8-14 show that (p-value from Fisher's exact test is 0.10) in adult musicians there is no statistically significant variation in the hearing thresholds in the right and left ears.

### 8.8.1.2 Asymmetry in hearing: Mean hearing thresholds (dB HL) in adult violinists

**Table 8-15 Mean hearing threshold of adult violinist in right and left ear**

<b>Frequency (Hz)</b>									
<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1000</b>	<b>1500</b>	<b>2000</b>	<b>3000</b>	<b>4000</b>	<b>6000</b>	<b>8000</b>
<b>Right ear (SD)</b>	6.1 (3.0)	7.0 (2.9)	6.5 (3.2)	7.4 (4.0)	6.5 (4.6)	8.3 (4.9)	12.2 (9.1)	19.1 (12.8)	21.7 (16.8)
<b>Left ear (SD)</b>	8.7 (3.8)	7.1 (3.9)	5.9 (4.2)	5.4 (4.5)	6.1 (5.2)	7.6 (9.3)	12.6 (15.0)	18.7 (14.5)	18.9 (13.6)
<b>Difference (SD)</b>	2.7 1.43	0 1.01	-0.6 1.10	-2 1.26	-0.4 1.45	-0.7 2.19	0.4 3.66	-0.4 4.03	-2.8 4.51

N = 23

**Note:** Audiometric thresholds (dB HL) are expressed as mean scores, with SD in parentheses

**Results:** Table 8-15 shows that the mean hearing thresholds of 32 violin players shows that the hearing is better in the left ear at 1000, 1500, 2000, 3000, 6000, and 8000Hz and poorer at 250, 500 and 4000Hz.

### 8.8.1.3 Mean hearing thresholds for adult string players with hearing loss

**Table 8-16 Mean hearing threshold of adult violinists with hearing loss**

<b>Frequency (Hz)</b>									
<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Right ear (SD)</b>	7.0 (3.0)	8.3 (3.4)	9.3 (5.4)	9.5 (3.9)	10.0 (4.6)	12.5 (7.2)	17.0 (8.6)	27.8 (9.5)	30.3 (16.5)
<b>Left ear (SD)</b>	9.8 (3.4)	8.3 (4.4)	10.0 (6.7)	9.3 (5.7)	9.5 (5.8)	14.3 (10.2)	20.5 (13.9)	25.5 (12.9)	22.8 (16.0)
<b>Difference (SD)</b>	2.8 0.95	0 1.16	0.7 1.79	-0.2 1.44	-0.5 1.54	1.8 2.60	3.5 3.41	-2.3 3.34	-7.5 4.79

N=23 **Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-16 shows that the mean hearing thresholds of 20 violin players with hearing loss show that the hearing is poorer in the right ear at 1500, 2000, 6000, and 8000Hz and better at 250, 1000, 3000, 4000Hz and equal at 500Hz.

### 8.8.2 Asymmetry in hearing youth orchestra musicians

#### 8.8.2.1 Hearing threshold in both the ears

**Table 8-17 Mean hearing thresholds of youth musicians in both ears**

<b>Frequency (Hz)</b>									
<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Right ear (SD)</b>	5.4 (2.0)	7.2 (2.7)	7.7 (3.1)	8.9 (4.2)	8.0 (4.8)	8.9 (5.4)	8.9 (4.9)	13.4 (6.2)	8.1 (5.2)
<b>Left ear (SD)</b>	5.4 (3.3)	7.1 (3.2)	7.6 (3.3)	7.8 (4.8)	8.5 (4.9)	9.2 (5.3)	9.3 (5.5)	15.1 (6.9)	8.4 (6.8)
<b>Difference (SD)</b>	0 0.42	-0.1 0.45	-0.1 0.49	-1.1 0.69	0.5 0.74	0.3 0.82	0.4 0.80	1.7 1.01	0.3 0.93

N=85

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-17 shows that in youth musicians the mean hearing threshold is elevated in the left ear compared to the right ear in the higher frequencies from 2000 to 8000Hz, but the hearing threshold is the same in both ears in the lower frequency region from 250 to 1000Hz, and at 1500Hz the left ear hearing threshold seems to be better than the right ear.

### 8.8.2.2 Ear specific data

#### Hearing losses in right ear

**Table 8-18 Hearing status in right ear in youth musicians**

<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Hearing loss-n (%)</b>	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>1</b> (1.2)	<b>2</b> (2.4)	<b>2</b> (2.4)	<b>9</b> (10.6)	<b>1</b> (1.2)
<b>Normal hearing loss-n (%)</b>	<b>85</b> (100)	<b>85</b> (100)	<b>85</b> (100)	<b>85</b> (100)	<b>84</b> (98.8)	<b>83</b> (97.6)	<b>83</b> (97.6)	<b>75</b> (88.2)	<b>84</b> (98.8)

**Note:** Number of musicians in each frequency with percentage in parentheses

#### Hearing losses in left ear

**Table 8-19 Hearing status in left ear in youth musicians**

<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Hearing loss-n (%)</b>	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>8</b> (9.4)	<b>3</b> (3.5)
<b>Normal hearing loss-n (%)</b>	<b>85</b> (100)	<b>85</b> (100)	<b>85</b> (100)	<b>84</b> (98.8)	<b>84</b> (98.8)	<b>84</b> (98.8)	<b>84</b> (98.8)	<b>77</b> (90.6)	<b>82</b> (96.5)

**Note:** Number of musicians in each frequency with percentage in parentheses

#### Relationship of hearing loss in right and left ears

**Table 8-20 Hearing status in right and left ear in youth musicians (Number of musicians)**

<b>Frequency (Hz)</b>	<b>250</b>	<b>500</b>	<b>1kHz</b>	<b>1.5kHz</b>	<b>2kHz</b>	<b>3kHz</b>	<b>4kHz</b>	<b>6kHz</b>	<b>8kHz</b>
<b>Hearing loss in only right ear</b>	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>5</b> (5.9)	<b>0</b> (0)
<b>Hearing loss in only left ear</b>	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>1</b> (1.2)	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>4</b> (4.7)	<b>2</b> (2.4)
<b>Hearing loss in both ears</b>	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>0</b> (0)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>1</b> (1.2)	<b>4</b> (4.7)	<b>1</b> (1.2)

**Note:** Number of musicians in each frequency with percentage in parentheses

**Results:** Tables 8-18, 8-19 and 8-20 show that there is no link between the number of people with asymmetric hearing loss (favouring the left or the right) and the frequency. This data shows that in youth musicians, there is statistically no significant variation in hearing threshold in right and left ear.

### 8.8.3 Asymmetry in hearing children orchestra musicians

#### 8.8.3.1 Hearing threshold in both the ears

**Table 8-21 Mean hearing thresholds of children musicians in both ears**

		Frequency (Hz)							
Frequency (Hz)	250	500	1000	1500	2000	3000	4000	6000	8000
<b>Right ear (dB)</b>	5.4 (2.5)	5.8 (2.5)	6.6 (3.3)	7.2 (3.6)	6.4 (4.0)	7.3 (4.7)	7.5 (4.6)	12.3 (5.7)	11.1 (8.9)
<b>Left ear (dB)</b>	6.1 (3.8)	5.7 (2.9)	5.9 (3.3)	6.4 (4.8)	6.6 (5.9)	6.2 (6.1)	7.3 (7.0)	13.6 (8.5)	10.1 (7.6)
<b>Difference (dB)</b>	0.7 0.75	-0.1 0.63	-0.7 0.77	-0.8 0.99	0.2 1.17	-1.1 1.27	-0.2 1.38	1.3 1.68	-1 1.92

N=37

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-21 shows that in children musicians, mean hearing threshold is elevated in the right ear in more frequencies than in the left ear. In the frequencies 500, 1000, 1500, 3000, 4000 and 8000Hz the mean hearing threshold is better in the left ear than the right ear, but in the frequencies 250, 2000 and 6000Hz the hearing threshold is better in the right ear.

#### 8.8.3.2 Ear specific data

#### Relationship of hearing loss in right and left ears

**Table 8-22 Hearing status in children musicians (Number of musicians)**

Frequency (Hz)	250	500	1000	1500	2000	3000	4000	6000	8000
<b>Hearing loss in only right ear (%)</b>	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2.7)	1 (2.7)
<b>Hearing loss in only left ear n (%)</b>	0 (0)	0 (0)	0 (0)	0 (0)	0 (2.7)	0 (0)	1 (2.7)	3 (8.1)	0 (0)
<b>Hearing loss in both ears n (%)</b>	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (5.4)	1 (2.7)

**Note:** Number of musicians in each frequency with percentage in parentheses

**Results:** Table 8-22 shows that the null hypothesis is that there is no significant relationship of hearing loss in right and left ears. As the p-value from Fisher’s exact test is 0.36, the null hypothesis is not rejected and there is no evidence of a significant relationship. In other words, the two variables are independent. This data show that in children musicians, there is no statistically significant variation in hearing threshold in right and left ear.

## 8.9 Gender difference in hearing loss in orchestra musicians

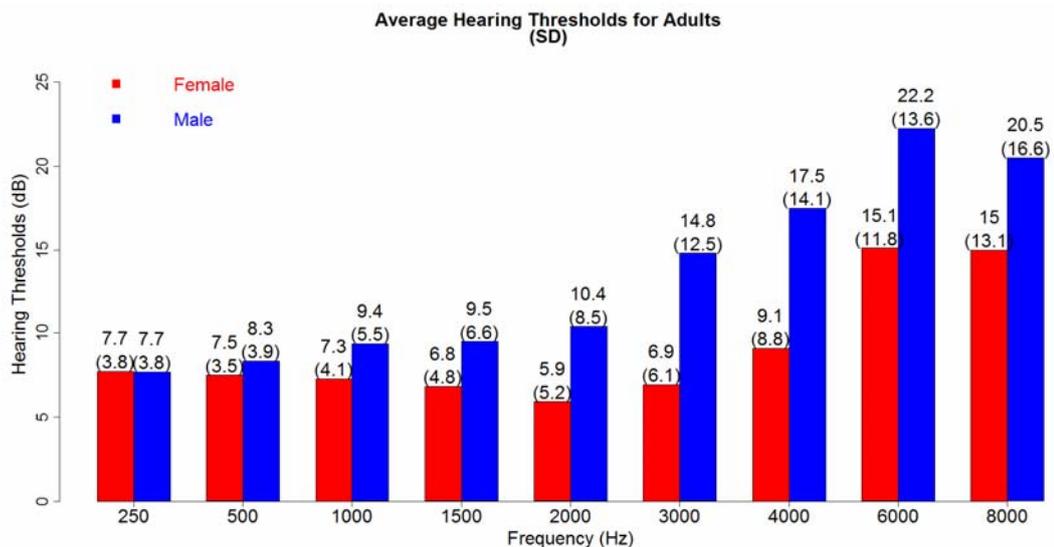
### 8.9.1 Gender difference (mean hearing thresholds) in adult orchestra musicians

**Table 8-23 Adult musicians – gender difference in mean hearing thresholds (dB HL)**

Frequency (Hz)									
Frequency (Hz)	250	500	1000	1500	2000	3000	4000	6000	8000
<b>Female (dB)</b>	7.7 (3.8)	7.5 (3.5)	7.3 (4.1)	6.8 (4.8)	5.9 (5.2)	6.9 (6.1)	9.1 (8.8)	15.1 (11.8)	15.0 (13.1)
<b>Male (dB)</b>	7.8 (3.9)	8.3 (3.9)	9.4 (5.5)	9.5 (6.6)	10.4 (8.5)	14.8 (12.5)	17.5 (14.1)	22.2 (13.6)	20.5 (16.6)
<b>Difference (dB)</b>	0.1 1.03	0.8 1.00	2.1 1.35	2.7 1.61	4.5 2.00	7.9 2.85	8.4 3.33	7.1 3.46	5.5 4.12

$\text{Sqrt}(((n1-1)*s1^2+(n2-1)*s2^2)/(n1+n2-2)*(1/n1+1/n2))$  Nfemale = 22 Nmale = 39

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses



**Figure 8-7 Adult musicians – Comparison of males and females mean hearing threshold**

**Results:** Table 8-23 and Fig 8-7 show that female musicians have a better mean hearing threshold in all the frequencies (250 to 8000Hz) than male musicians. In the low frequencies (250 to 500Hz) 0.4dB, in the mid frequencies (1000 to 2000Hz) 3.1dB and better hearing thresholds (7.2dB) in the frequency region of 3000 to 8000Hz (7.9dB at 3000Hz, 8.4dB at 4000Hz, 7.1dB at 6000Hz and 5.5dB at 8000Hz). At 4000Hz female musicians have a better hearing threshold (8.4dB) than at all other frequencies.

### 8.9.2 Gender difference (mean hearing threshold) in youth orchestra musicians

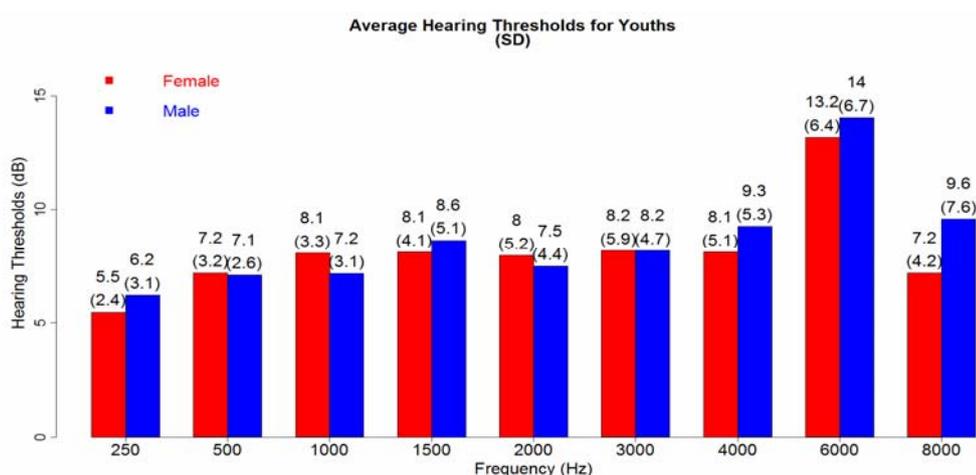
**Table 7-24 Youth musicians – gender difference in mean hearing thresholds**

		Frequency (Hz)							
Frequency (Hz)	250	500	1000	1500	2000	3000	4000	6000	8000
<b>Female (dB)</b>	5.5 (2.4)	7.2 (3.2)	8.1 (3.3)	8.1 (4.1)	8.0 (5.2)	8.2 (5.9)	8.1 (5.1)	13.2 (6.4)	7.2 (4.2)
<b>Male (dB)</b>	6.2 (3.1)	7.1 (2.6)	7.2 (3.1)	8.6 (5.1)	7.5 (4.4)	8.2 (4.7)	9.3 (5.3)	14.0 (6.7)	9.6 (7.6)
<b>Difference (dB)</b>	0.7 0.60	-0.1 0.65	-0.9 0.70	0.5 1.00	-0.5 1.07	0 1.18	1.2 1.13	0.8 1.43	2.4 1.30

Nfemale = 48 Nmale = 37

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

#### 8.9.2.1 Mean hearing thresholds (dBHL) in males and females of youth musicians



**Figure 8-8 Youth musicians - Comparison of males and females mean hearing threshold**

**Results:** Table 8-24 and Fig 8-8 show that among the youth musicians, the female musicians have better mean hearing threshold in the frequency region of 250, 1500,

4000, 6000 and 8000Hz than males. At 500, 1000 and 2000Hz, female musicians have a poorer hearing threshold.

### 8.9.3 Gender difference (mean hearing threshold) in children orchestra musicians

Table 8-25 Children musicians – gender difference in mean hearing thresholds (dB HL)

		Frequency (Hz)							
Frequency (Hz)	250	500	1000	1500	2000	3000	4000	6000	8000
Female (dB)	6.1 (3.1)	5.8 (2.9)	5.9 (3.3)	6.3 (4.6)	6.2 (4.3)	7.0 (5.7)	9.1 (6.3)	14.5 (7.7)	9.8 (3.9)
Male (dB)	5.6 (3.2)	6.2 (2.6)	6.4 (3.3)	6.5 (4.1)	6.1 (5.3)	7.5 (5.2)	10.7 (5.6)	15.3 (7.0)	11.0 (9.5)
Difference (dB)	0.5 1.14	0.4 0.97	0.5 1.19	0.2 1.53	-0.1 1.81	0.5 1.92	1.6 2.09	0.8 2.59	1.2 2.98

Nfemale = 11, Nmale= 26

**Note:** Audiometric thresholds are expressed as mean scores, with SD in parentheses

**Results:** Table 8-25 shows that among the children musicians, the female musicians have a poorer mean hearing threshold in the frequency region of 250, 500, 1500, 2000, 3000, 4000 and 6000Hz than males. At 1000 and 8000Hz, male musicians have a poorer hearing threshold.

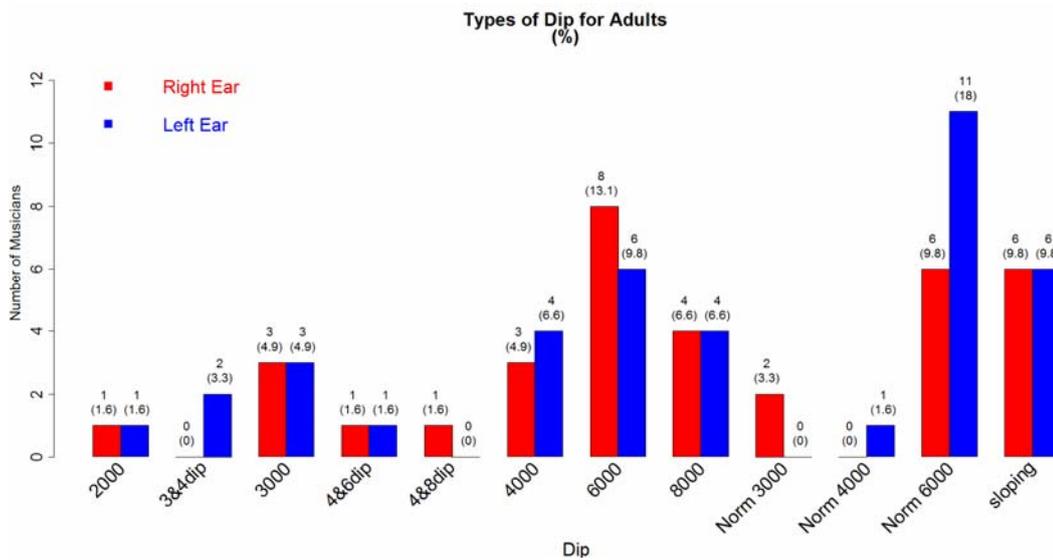
### 8.10 Configuration of audiograms

**Normal dips in the audiograms:** An individual musician is considered to have a normal dip, if hearing is within normal limits  $\geq 20$ dB in all the frequencies, but there is a dip in the audiogram, that is hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.

**Abnormal dips in the audiograms:** An individual musician is considered to have an abnormal dip, if he or she has a hearing loss and there is a dip in the audiogram that is hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.

### 8.10.1 Dips in pure-tone audiograms in adult orchestra musicians

#### Comparison of right and left ear dips in the audiograms

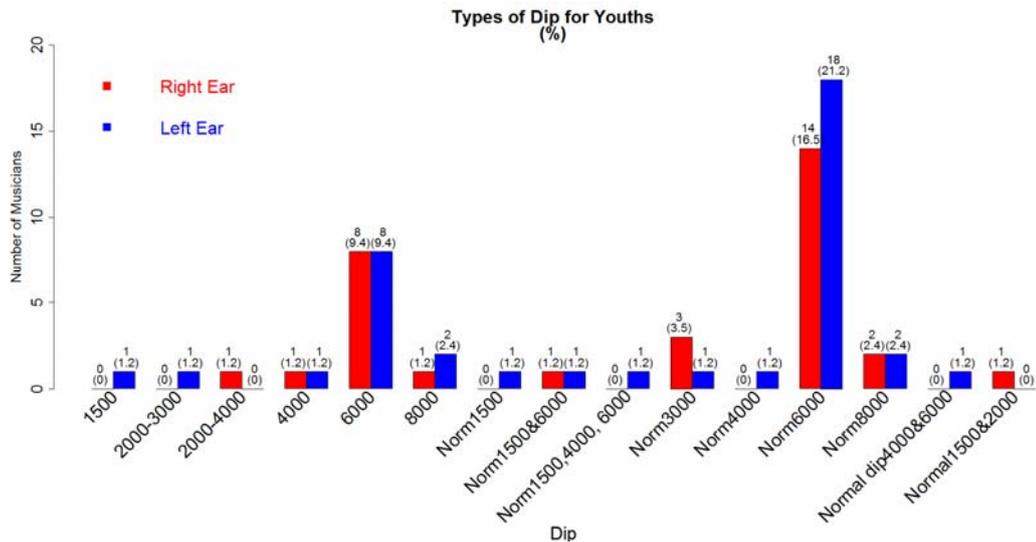


**Figure 8-9 Adult musicians – Comparisons of dips in right and left ear**

**Results:** Figure 8-9 shows that among the adult musicians, dips are observed in various frequencies from 1500 to 8000Hz. In the right ear more numbers of musicians – eight (13.1%) – were found to have dips at 6000Hz with a hearing loss. Six musicians (9.8%) had normal dips at 6000Hz with hearing within normal limits. In the left ear, however, six musicians (8.2%) were found to have dips at 6000Hz with a hearing loss, and 11 musicians (18.0%) had a normal dip with hearing within normal limits.

## 8.10.2 Youth orchestra musicians – Dip in pure-tone audiograms

### Comparison of right and left ear dips in the audiograms



**Figure 8-10 Youth musicians – Comparison of dips in right and left ear**

**Results:** Figure 8-10 shows that among the youth musicians, dips are observed in various frequencies from 1500 to 8000Hz. In the right ear, eight (9.4%) musicians had a dip at 6kHz with hearing loss, and 14 (16.5%) musicians had normal dips with hearing within normal limits. In the left ear, however, eight musicians (9.4%) had a dip at 6kHz with a hearing loss, and 18 (21.2%) had normal dips at 6kHz with hearing within normal limits.

## 8.10.3 Dips in pure-tone audiograms in children orchestra musicians

### 8.10.3.1 Dips in right ear

**Table 8-26 Children musicians – Dips in the pure-tone audiogram of right ear**

Dip categories	6000	8000	Sloping	Norm 6000	Norm slop at 6000 & 8000
<b>Numbers</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>3</b>	<b>1</b>
<b>(%)</b>	<b>(2.7)</b>	<b>(2.7)</b>	<b>(2.7)</b>	<b>(8.1)</b>	<b>(2.7)</b>

**Note:** Number of children musicians with percentage within bracket

### 8.10.3.2 Dip in the left ear

**Table 8-27 Children musicians – Dips in the pure-tone audiogram of left ear**

<b>Dip categories</b>	<b>4000</b>	<b>6000</b>	<b>Sloping</b>	<b>Norm 6000</b>	<b>Norm 8000</b>
<b>Numbers (%)</b>	<b>1 (2.7)</b>	<b>3 (8.1)</b>	<b>1 (2.7)</b>	<b>3 (8.1)</b>	<b>1 (2.7)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Tables 8-26 and 8-27 show that among the children musicians, in the right ear one musician had a dip at 6kHz with a hearing loss and three musicians had a normal dip with hearing within normal limits. In the left ear, three musicians had a dip at 6kHz with a hearing loss and three had a normal dip with hearing within normal limits.

## 8.11 Tinnitus and hearing loss in orchestra musicians

### 8.11.1 Tinnitus and hearing loss in adult musicians

#### 8.11.1.1 Tinnitus and hearing loss in right ear

In the right ear, 25 musicians (41.0%) had noticed tinnitus (continuous), 25 (41.0%) noticed tinnitus sometimes, and 11 (18.0%) have not noticed tinnitus at all. Twenty-seven musicians (44.3%) had some degree of hearing loss, 10 (16.4%) had normal dips, and 10 (39.0%) had no hearing loss.

**Table 8-28 Adult musicians – Tinnitus and hearing loss in right ear**

<b>Tinnitus (Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dips</b>
<b>No tinnitus</b>	<b>8 (13.1)</b>	<b>1 (1.6)</b>	<b>2 (3.3)</b>
<b>Tinnitus (some times) (%)</b>	<b>12 (20.0)</b>	<b>7 (11.5)</b>	<b>6 (9.8)</b>
<b>Tinnitus (Continuous) (%)</b>	<b>4 (6.5)</b>	<b>19 (31.1)</b>	<b>2 (3.3)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-28 shows that among the adult musicians there is a statistically significant relationship between tinnitus and hearing loss in the right ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing

loss in the right ear. As the p-value from Fisher’s exact test is 9.58e-5, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are dependent. Also note that the fact that although the two variables co-exist in some musicians, it does not mean the causal link exists.

### 8.11.1.2 Relationship between tinnitus and hearing loss in left ear

In the left ear, 22 musicians (36.1%) noticed tinnitus most of the time, 31 (50.8%) experienced tinnitus sometimes, and eight (13.1%) have not noticed tinnitus at all. Twenty-five musicians (41.0%) had some degree of hearing loss, 14 (23.0%) had normal dips in the audiograms, and 22 (36.0%) had no hearing loss.

**Table 8-29 Tinnitus and hearing status of musicians in left ear**

<b>Tinnitus(Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dips</b>
<b>No tinnitus</b>	<b>6 (9.8)</b>	<b>2 (3.3)</b>	<b>0 (0)</b>
<b>Tinnitus (some times) (%)</b>	<b>9 (14.8)</b>	<b>11 (18.0)</b>	<b>11 (18.0)</b>
<b>Tinnitus all the time (%)</b>	<b>7 (11.5)</b>	<b>12 (19.7)</b>	<b>3 (4.9)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-29 shows that among the adult musicians there is a statistically significant relationship between tinnitus and hearing loss in the left ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing loss in the left ear. As the p-value from Fisher’s exact test is 0.05, the null hypothesis is rejected and there is moderate evidence of a significant relationship. In other words, the two variables are most likely dependent. Among the adult musicians there is a statistically significant relationship between tinnitus and hearing loss in the left ear. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.11.2 Tinnitus and hearing loss in youth orchestra musicians

#### 8.11.2.1 Tinnitus and hearing loss in right ear

Among the youth musicians 17 (20.0%) experienced tinnitus most of the time, 19 (23.4%) experienced tinnitus some of the time, and 49 (57.6%) experienced no

tinnitus at all. Fourteen musicians (16.5%) had some degree of hearing loss, 49 (57.6%) had normal hearing, and 22 (25.9%) had normal dips in the audiogram.

**Table 8-30 Youth musicians – Tinnitus and hearing status of musicians in right ear**

<b>Tinnitus (Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dip</b>
<b>No tinnitus</b>	<b>43 (50.6)</b>	<b>4 (4.7)</b>	<b>2 (2.4)</b>
<b>Tinnitus (some times) n (%)</b>	<b>6 (7.1)</b>	<b>2 (2.4)</b>	<b>11 (12.9)</b>
<b>Tinnitus (Continuous) n (%)</b>	<b>0 (0)</b>	<b>8 (9.4)</b>	<b>9 (10.6)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-30 shows that among the youth musicians, there is a statistically significant relationship between tinnitus and hearing loss in the right ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing loss in the right ear. As the p-value from Fisher’s exact test is 6.0e-13, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are dependent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### **8.11.2.2 Tinnitus and hearing loss in left ear**

Among the youth musicians 28 (32.9%) experienced tinnitus most of the time, 25 (29.4%) experienced tinnitus some of the time, and 32 (37.7%) experienced no tinnitus at all. Thirteen musicians (15.3%) had some degree of hearing loss, 26 (30.6%) had a normal dip, and 46 (54.1%) had normal hearing.

**Table 8-31 Youth musicians – Tinnitus and hearing status of musicians in left ear**

<b>Tinnitus(Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dip</b>
<b>No tinnitus</b>	<b>27 (31.8)</b>	<b>2 (2.4)</b>	<b>3 (3.5)</b>
<b>Tinnitus (some times) n (%)</b>	<b>10 (11.8)</b>	<b>2 (2.4)</b>	<b>13 (15.3)</b>
<b>Tinnitus (Continuous n (%))</b>	<b>9 (10.6)</b>	<b>9 (10.6)</b>	<b>10 (11.8)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-31 shows that among the youth musicians there is a statistically significant relationship between tinnitus and hearing loss in the left ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing loss in the left ear. As the p-value from Fisher’s exact test is 3.7e-05, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are dependent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### **8.11.3 Tinnitus and hearing loss in children orchestra musicians**

#### **8.11.3.1 Relationship between tinnitus and hearing loss in right ear**

Among the children musicians, in the right ear three (8.1%) children musicians were found to have hearing loss, four (10.8%) had normal dips, and 30 (81.1%) had no hearing loss. One child (2.7%) reported tinnitus, two (5.4%) had noticed tinnitus sometimes, and 34 (91.9%) had not experienced tinnitus at all.

**Table 8-32 Children musicians – Tinnitus in right ear**

<b>Tinnitus(Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dip</b>
<b>No tinnitus</b>	<b>28 (75.7)</b>	<b>2 (5.4)</b>	<b>4 (10.8)</b>
<b>Tinnitus (some times) n (%)</b>	<b>2 (5.4)</b>	<b>0 (0)</b>	<b>0 (0)</b>
<b>Tinnitus (Continuous n (%))</b>	<b>0 (0)</b>	<b>1 (2.7)</b>	<b>0 (0)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-32 shows that among the children musicians, there is no statistically significant relationship between tinnitus and hearing loss in the right ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing loss in the right ear. As the p-value from Fisher’s exact is 0.25, the null hypothesis is not rejected and there is no evidence of a significant relationship. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.11.3.2 Relationship between tinnitus and hearing loss in left ear

In the left ear, three children (8.1%) had noticed tinnitus sometimes and 33 (89.1%) musicians had not noticed tinnitus at all. Four children (10.8%) had hearing loss, four (10.8%) a normal dip, and 28 (75.8%) had hearing within normal limits.

**Table 8-33 Children musicians – Tinnitus and hearing status of musicians in left ear**

<b>Tinnitus(Category)</b>	<b>Number of musicians with normal hearing</b>	<b>Number of musicians with hearing loss</b>	<b>Number of musicians with normal dip</b>
<b>No tinnitus</b>	<b>28 (75.7)</b>	<b>3 (8.1)</b>	<b>2 (5.4)</b>
<b>Tinnitus (some times) n (%)</b>	<b>0 (0)</b>	<b>1 (2.7)</b>	<b>2 (5.4)</b>
<b>Tinnitus (Continuous n (%))</b>	<b>0 (0)</b>	<b>0 (0)</b>	<b>0 (0)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-33 shows that among the children musicians, there is statistically no significant relationship between tinnitus and hearing loss in the left ear. The null hypothesis is that there is no significant relationship between tinnitus and hearing

loss in the left ear. As the p-value from Fisher's exact test is 0.0005, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

## 8.12 Family history of hearing loss

### 8.12.1 Family history of hearing loss in adult orchestra musicians

Among the adult musicians, 29 (47.5%) had a positive family history of hearing loss and 32 (52.5%) did not have any family history of hearing loss. Among the 37 musicians with hearing loss, 21 (34.4%) had a positive family history of hearing loss and 16 (26.4%) had no family history of hearing loss. Among the 24 musicians with normal hearing, 16 (26.2%) had no family history of hearing loss and eight (13.1%) had a positive family history of hearing loss. There was no statistically significant between these family histories of hearing loss and the prevalence of hearing loss in adult musicians (the p-value from Pearson's Chi-square test is 0.13).

**Table 8-34 Adult musicians – Family history of hearing loss and hearing status**

<b>Family History of hearing loss</b>	<b>Hearing loss in both ears</b>	<b>Hearing loss in left ear</b>	<b>Hearing loss in right ear</b>	<b>Normal hearing</b>
<b>No family history</b>	<b>4 (6.6)</b>	<b>3 (4.9)</b>	<b>9 (14.8)</b>	<b>16 (26.2)</b>
<b>Positive family history</b>	<b>11 (18.0)</b>	<b>7 (11.5)</b>	<b>3 (4.9)</b>	<b>8 (13.1)</b>

**Note:** This table is constructed by treating normal dip as no hearing loss. Number of musicians with percentage within brackets.

**Results:** Table 8-34 shows that among the adult musicians there is no statistically significant (p-value from Pearson's Chi-square test is 0.13) relationship between family history of hearing loss and music induced hearing loss in the right ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.12.2 Family history of hearing loss in youth orchestra musicians

Among the youth musicians, 21 (24.7%) had a positive family history of hearing loss and 64 (75.3%) had no family history of hearing loss.

**Table 8-35 Youth musicians – Family history of hearing loss and hearing status**

<b>Family History of hearing loss</b>	<b>Hearing loss in both ears</b>	<b>Hearing loss in left ear</b>	<b>Hearing loss in right ear</b>	<b>Normal hearing</b>
<b>No family history</b>	<b>4 (4.7)</b>	<b>4 (4.7)</b>	<b>6 (7.1)</b>	<b>50 (58.8)</b>
<b>Positive family history</b>	<b>2 (2.4)</b>	<b>3 (3.5)</b>	<b>2 (2.4)</b>	<b>14 (16.5)</b>

**Note:** This table is constructed by treating normal dip as no hearing loss. Number of musicians with percentage within brackets

**Results:** Table 8-35 shows that among the youth musicians there is no statistically significant (the p-value from Pearson’s Chi-square test is 0.44) relationship between family history of hearing loss and music induced hearing loss. The two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.12.3 Family history of hearing loss in children orchestra musicians

Among the children musicians, 14 (37.8%) had a positive family history of hearing loss and 23 (62.2%) had no family history of hearing loss.

**Table 8-36 Children musicians – Family history of hearing loss and hearing status**

<b>Family History of hearing loss</b>	<b>Hearing loss in both ears</b>	<b>Hearing loss in left ear</b>	<b>Hearing loss in right ear</b>	<b>Normal hearing</b>
<b>No family history</b>	<b>0 (0)</b>	<b>3 (8.1)</b>	<b>2 (5.4)</b>	<b>18 (48.6)</b>
<b>Positive family history</b>	<b>2 (5.4)</b>	<b>4 (10.8)</b>	<b>0 (0)</b>	<b>8 (21.6)</b>

**Note:** This table is constructed by treating a normal dip as no hearing loss. Number of musicians with percentage within brackets

**Results:** Table 8-36 shows that among the children musicians there is no statistically significant (the p-value from Fisher’s exact test is 0.32) relationship between family history of hearing loss and music induced hearing loss in children. In other words,

the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

## 8.13 History of ear infection and hearing loss in orchestra musicians

### 8.13.1 History of ear infection in adult orchestra musicians

Among the adult musicians, 16 (26.2%) had a history of ear infection and 45 (73.8%) did not have any history of ear infection.

#### 8.13.1.1 Relationship between ear infection and hearing loss in right ear

**Table 8-37 Adult musicians – ear infection and hearing in right ear**

<b>Ear Infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>
<b>History of no ear infection-n (%)</b>	<b>27 (44.3%)</b>	<b>18 (29.5%)</b>
<b>History of ear infection-n (%)</b>	<b>7 (11.5%)</b>	<b>9 (14.8%)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-37 shows that among the adult musicians there is no statistically significant (p-value from Pearson’s Chi-square test is 0.41) relationship between previous history of ear infection and music induced hearing loss in the right ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

#### 8.13.1.2 Relationship between ear infection and hearing loss in left ear

**Table 8-38 Adult musicians – ear infection and hearing in left ear**

<b>Ear infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>	<b>No. of normal dip</b>
<b>History of No ear infection</b>	<b>14 (23.0)</b>	<b>21 (34.4)</b>	<b>10 (16.4)</b>
<b>History of ear infection</b>	<b>8 (13.1)</b>	<b>4 (6.6)</b>	<b>4 (6.6)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-38 shows that among the adult musicians there is no statistically significant (p-value from Fisher’s exact test is 0.28) relationship between previous history of ear infection and music induced hearing loss in the left ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.13.2 History of ear infection in youth orchestra musicians

Among the youth musicians, 21 (24.7%) had a history of ear infection and 64 (75.3%) did not have any history of ear infection in the past.

#### 8.13.2.1 Relationship between ear infection and hearing loss in right ear

**Table 8-39 Youth musicians – ear infection and hearing in right ear**

<b>Ear Infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>	<b>Normal dips</b>
<b>History of ear infection-n (%)</b>	<b>9 (10.6)</b>	<b>5 (5.9)</b>	<b>7 (8.2)</b>
<b>No history of ear infection-n (%)</b>	<b>40 (47.1)</b>	<b>9 (10.6)</b>	<b>15 (17.6)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-39 shows that among the youth musicians there is no statistically significant (Fisher’s exact test is 0.27) relationship between previous history of ear infection and hearing loss in the right ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

#### 8.13.2.2 Relationship between ear infection and hearing loss in left ear

**Table 8-40 Youth musicians – ear infection and hearing in left ear**

<b>Ear Infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>	<b>Normal dips</b>
<b>History of ear infection-n (%)</b>	<b>11 (12.9)</b>	<b>5 (5.9)</b>	<b>5 (5.9)</b>
<b>No history of ear infection-n (%)</b>	<b>35 (41.2)</b>	<b>8 (9.4)</b>	<b>21 (24.7)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-40 shows that among the youth musicians there is no statistically significant (the p-value from Fisher’s exact test is 0.45) relationship between ear infection in the left ear and music induced hearing loss in the left ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.13 History of ear infection in children orchestra musicians

Among the children musicians, 10 (27.0%) were reported to have had a history of ear infection and 27 (73.0%) had no history of ear infection.

#### 8.13.1 Relationship between ear infection and hearing loss in right ear

**Table 8-41 Children musicians – ear infection and hearing in right ear**

<b>Ear infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>	<b>No. of normal dip</b>
<b>History of ear infection</b>	23 (62.2)	1 (2.7)	3 (8.1)
<b>No history of ear infection</b>	6 (16.2)	3 (8.1)	1 (2.7)

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-41 shows that among the children musicians there is no statistically significant (the p-value from Fisher’s exact test is 0.10) relationship between previous history of ear infection and music induced hearing loss in the right ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

#### 8.13.2 Relationship between ear infection and hearing loss in left ear

**Table 8-42 Children musicians – ear infection and hearing in left ear**

<b>Ear infection</b>	<b>Normal hearing</b>	<b>Hearing loss</b>	<b>No. of normal dip</b>
<b>History of ear infection</b>	20 (54.1)	5 (13.5)	2 (5.4)
<b>No history of ear infection</b>	5 (13.5)	4 (10.8)	1 (2.7)

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-42 shows that among the children musicians there is no statistically significant (the p-value from Fisher’s exact test is 0.35) relationship between previous history of ear infection and music induced hearing loss in the left ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### **8.14 Youth orchestra musicians – Usage of personal stereo and hearing loss**

Among the youth orchestra musicians, the usage of personal stereo is very common; 40 (47.1%) musicians use a personal stereo on a regular basis and 45 (52.9%) musicians do not use a personal stereo on a regular basis.

#### **8.14.1 Relationship between personal stereos and hearing loss in right ear**

**Table 8-43 Youth musicians – personal stereo usage and hearing status in right ear**

<b>Personal stereo usage</b>	<b>Normal Hearing</b>	<b>Hearing loss</b>	<b>Normal dips</b>
<b>No personal Stereos usage -n (%)</b>	<b>31 (36.5)</b>	<b>6 (7.1)</b>	<b>8 (9.4)</b>
<b>Uses Personal stereo-n (%)</b>	<b>18 (21.2)</b>	<b>8 (9.4)</b>	<b>14 (16.5)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-43 shows that among the youth musicians there is no statistically significant relationship (the p-value from Pearson’s Chi-square test is 0.08) between usage of personal stereo and music induced hearing loss in the right ear. In other words, the two variables are independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.14.2 Relationship between personal stereos and hearing loss in left ear

**Table 8-44 Youth musicians – personal stereo usage and hearing status in left ear**

<b>Personal stereo usage</b>	<b>Normal Hearing</b>	<b>Hearing loss</b>	<b>Normal dips</b>
<b>No personal Stereos usage-n (%)</b>	<b>38 (44.7)</b>	<b>3 (3.5)</b>	<b>4 (4.7)</b>
<b>Uses Personal stereo (%)</b>	<b>8 (9.4)</b>	<b>10 (11.8)</b>	<b>22 (25.9)</b>

**Note:** Number of musicians with percentage within brackets. Normal dip: hearing is within normal limits  $\geq 20$ dB in all the frequencies, but there is a dip in the audiogram that is hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.

**Results:** Table 8-44 shows that among the youth musicians there is a statistically significant relationship (p-value from Pearson’s Chi-square test is  $1.84e-8$ ) between personal stereo usage and music induced hearing loss. In other words, the two variables are dependent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

### 8.15 Youth orchestra musicians and other noise exposure

Among the youth orchestra musicians, 17 (20%) are exposed to other types of noise and 68 (80%) are not.

**Table 8-45 Youth musicians – other noise exposure and hearing status**

<b>History of other noise exposure</b>	<b>Musician with hearing loss</b>	<b>Musicians with normal hearing</b>	<b>Musicians with normal dips</b>
<b>No other Noise exposure (%)</b>	<b>10 (11.8)</b>	<b>40 (47.1)</b>	<b>18 (21.2)</b>
<b>With other noise exposure (%)</b>	<b>4 (4.7)</b>	<b>9 (10.6)</b>	<b>4 (4.7)</b>

**Note:** Number of musicians with percentage within brackets. Normal dip: hearing is within normal limits  $\geq 20$ dB in all the frequencies, but there is a dip in the audiogram that is hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.

**Results:** Table 8-45 shows that among the youth musicians there is no statistically significant relationship (the p-value from Fisher’s exact test is 0.41) between other noise exposure and music induced hearing loss. In other words, the two variables are

independent. Also note that the fact that the two variables are co-existing in some musicians, but it does not mean the causal link exists.

## 8.16 Musicians’ awareness of music induced hearing loss

### 8.16.1 Youth musicians’ awareness

Among the youth orchestra musicians 70 (82.4%) were aware of unamplified music and hearing loss and 15 (17.6%) were not aware.

**Table 8-46 Youth musicians – Awareness on Music Induced Hearing Loss**

<b>Awareness</b>	<b>Musicians with hearing loss</b>	<b>Musicians with normal hearing</b>
<b>Not Aware of MIHL (%)</b>	<b>6 (7.1)</b>	<b>9 (10.6)</b>
<b>Aware of MIHL (%)</b>	<b>15 (17.6)</b>	<b>55 (64.7)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-46 shows that among the youth musicians there is no statistically significant positive relationship between increased awareness of MIHL and hearing loss. The null hypothesis is that there is no significant relationship between increased awareness and hearing loss. As the p-value from Pearson’s Chi-square test is 0.24, the null hypothesis is not rejected and there is no evidence of a significant relationship. In other words, the two variables are independent.

### 8.16.2 Children musician’s awareness

Table 8-47 shows that among the children musicians, four (10.8%) were aware of music induced hearing loss and 33 (89.2%) reported that they are not aware.

**Table 8-47 Youth musicians – Awareness on Music Induced Hearing loss**

<b>Awareness of Musicians</b>	<b>Musicians with hearing loss</b>	<b>Normal hearing</b>
<b>Not Awareness of MIHL (%)</b>	<b>9 (24.3)</b>	<b>24 (64.9)</b>
<b>Awareness of MIHL (%)</b>	<b>2 (5.4)</b>	<b>2 (5.4)</b>

**Note:** MIHL-Music Induced hearing loss. Number of musicians with percentage within brackets

## 8.17 Subjective hearing loss and actual hearing loss

### 8.17.1 Relationship between subjective and actual hearing loss in right ear

**Table 8-48 Youth musicians - subjective and actual hearing loss in right ear**

<b>Subjective Perception</b>	<b>Musicians with normal hearing</b>	<b>Musicians with hearing loss</b>	<b>Musicians with normal dip</b>
<b>No subjective hearing loss (%)</b>	<b>47 (55.3)</b>	<b>10 (11.8)</b>	<b>16 (18.8)</b>
<b>Subjective hearing loss (%)</b>	<b>2 (2.4)</b>	<b>4 (4.7)</b>	<b>6 (7.1)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-48 shows that among the youth musicians there is a statistically significant relationship between subjective perception and hearing status in the right ear. The null hypothesis is that there is no significant relationship between actual and subjective hearing loss in the right ear. As the p-value from Fisher's exact test is 0.005, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are dependent.

### 8.17.2 Relationship between actual and subjective hearing loss in left ear

**Table 8-49 Youth musicians – subjective and actual hearing loss in left ear**

<b>Subjective Perception</b>	<b>Musicians with normal hearing</b>	<b>Musicians with hearing loss</b>	<b>Musicians with normal dip</b>
<b>No subjective hearing loss (%)</b>	<b>44 (51.8)</b>	<b>6 (7.1)</b>	<b>23 (27.1)</b>
<b>Subjective hearing loss (%)</b>	<b>2 (2.4)</b>	<b>7 (8.2)</b>	<b>3 (3.5)</b>

**Note:** Number of musicians with percentage within brackets

**Results:** Table 8-49 shows that among the youth musicians there is a statistically significant relationship between subjective perceptions and hearing status in the left ear. The null hypothesis is that there is no significant relationship between actual and subjective hearing loss in the left ear. As the p-value from Fisher's exact test is 0.0001, the null hypothesis is rejected and there is strong evidence of a significant relationship. In other words, the two variables are dependent.

## **8.18 Visits to loud concerts**

Among the youth musicians, 78 (91.8%) had been to loud concerts (estimated in excess of 100dB) and seven (8.2%) had not been to, or tried to avoid, loud concerts. None of the musicians used any form of ear protection in spite of being aware that loud music can cause hearing loss. Seventy-three (85.9%) indicated that they will use ear plugs if made available, and 12 (14.1%) musicians indicated that they will not use them, even if they are made available free of cost.

## **8.19 Usage of musician plugs**

This information was collected from 61 adult musicians (mean age of 46.5 years) 85 youth musicians (mean age of 23.6 years) and 37 children musicians (mean age of 9.7 years). The musicians were asked to fill out a questionnaire to collect information on ear symptoms, music practice and playing habits, knowledge on hearing conservation practice and use of hearing protecting device (HPD) during practice and performance.

### **8.19.1 Adult musicians with hearing loss**

#### **8.19.1.1 Usage of ear protecting devices during rehearsal**

Table 8-50 shows that among 37 (Average age = 48.7) established musicians with some degree of hearing loss, only three of the musicians used ear protection devices on a regular basis, four musicians used them 50% of the time, and one musician used them 45% of the time. Seventeen musicians never used ear protection devices, and the majority of the musicians who used the protector did so only during loud passages based on subjective perception.

**Table 8-50 Adult musicians with hearing loss – usage of ear protection devices during rehearsal**

<b>Percentage of Use</b>	<b>Number of people</b>
<b>100%</b>	<b>3</b>
<b>50%</b>	<b>4</b>
<b>45%</b>	<b>1</b>
<b>20%</b>	<b>3</b>
<b>10%</b>	<b>6</b>
<b>5%</b>	<b>2</b>
<b>3%</b>	<b>1</b>
<b>0%</b>	<b>17</b>

### **8.19.1.2 Usage of Ear Protecting Devices (EPD) during performance**

Table 8-51 shows that among 37 established musicians with some degree of hearing loss (mean age 48.7 years), only one of the musicians used an ear protection device on a regular basis. One musician used ear protection devices 80% of the time, one musician used them 50% of the time, and one musician used them 40% of the time, but most of these musicians used them only during a loud passage based on subjective perception. Twenty-three of the musicians never used ear protection devices. During a performance, most musicians do not use ear protecting devices because of stress and fear of making a mistake.

**Table 8-51 Adult musicians with hearing loss – usage of ear protection devices during performance**

<b>Percentage of Use</b>	<b>Number of People</b>
<b>100%</b>	<b>1</b>
<b>80%</b>	<b>1</b>
<b>50%</b>	<b>3</b>
<b>40%</b>	<b>1</b>
<b>10%</b>	<b>6</b>
<b>5%</b>	<b>1</b>
<b>3%</b>	<b>1</b>
<b>0%</b>	<b>23</b>

## **8.19.2 Adult musicians with normal hearing**

### **8.19.2.1 Usage of ear protection devices during rehearsal**

Table 8-52 shows that among the 24 musicians with normal hearing (average age: 42.6 years) only one of them used ear protection devices 100% of the time. Eleven musicians used them only during loud passages, based on subjective perception. Twelve of the musicians did not use ear protection devices at all.

**Table 8-52 Adult musicians with normal hearing – usage of ear protection devices during rehearsal**

<b>Percentage of Use</b>	<b>Number of People</b>
<b>100%</b>	<b>1</b>
<b>50%</b>	<b>1</b>
<b>40%</b>	<b>1</b>
<b>20%</b>	<b>1</b>
<b>10%</b>	<b>4</b>
<b>5%</b>	<b>2</b>
<b>5%</b>	<b>2</b>
<b>0%</b>	<b>12</b>

### **8.19.2.2 Usage of ear protection devices during performance**

Table 8-53 shows that out of the 24 musicians with normal hearing (average age: 42.6 years), only one of them used ear protection devices 100% of the time. Three musicians used them only during loud passage based on subjective perception, and 15 of the musicians did not use ear protection devices at all.

**Table 8-53 Adult musicians with normal hearing – usage of ear protection devices during performance**

<b>Percentage of usage</b>	<b>Number of musicians</b>
<b>100</b>	<b>1</b>
<b>80</b>	<b>1</b>
<b>50</b>	<b>1</b>
<b>40</b>	<b>1</b>
<b>10</b>	<b>3</b>
<b>5</b>	<b>2</b>
<b>0</b>	<b>15</b>

### **8.19.3 Youth orchestra musicians**

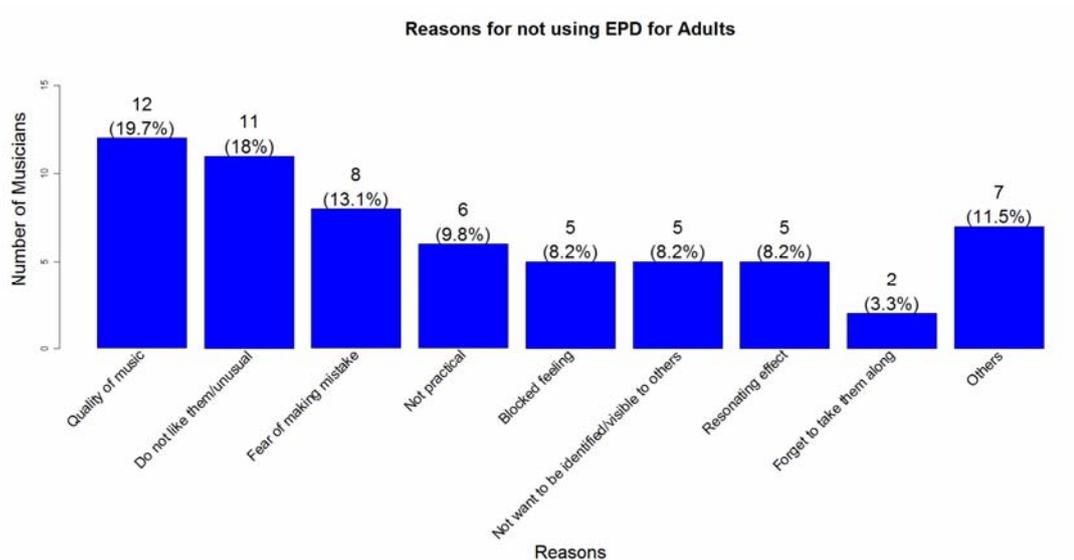
Among the 85 youth musicians (mean age: 23.6 years), although many are aware of loud music and the danger of hearing loss, musicians' ear plugs are only accessible to a few – 12 out of the 85 musicians. Two musicians used musicians' plugs on a regular basis, two used them 50% of the time, five used them only during loud passages, and three musicians seldom used them. Using hearing protection as well maintaining the quality of the music is reported to be the major issue.

### 8.19.4 Children orchestra musicians

Among the 37 child musicians (mean age: 9.7 years) who are part of the two school orchestras surveyed, only four were partly aware of the risk of hearing loss due to loud music, and none of them used any form of ear protecting device. Only three of them took up the offer of custom-made musicians' plugs. Following up after two years, they were found to be using the musicians' plugs on a regular basis and reported that the music perception is not distorted.

### 8.19.5 Reasons for not Using Ear Protecting Devices (EPD)

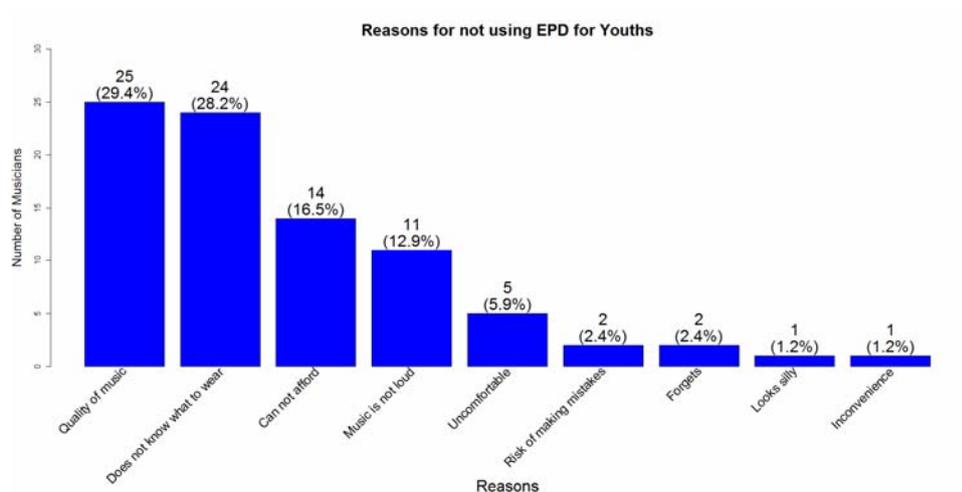
#### 8.19.5.1 Adult musicians – Reasons for not using musician plugs



**Figure 8-11 Adult musicians – the reasons for not using musicians' plugs**

**Results:** Figure 8-11 shows that in adult musicians, the reasons given for not using ear protection devices as follows: 12 of the musicians (19.7%) felt that the quality of music is affected; 11 musicians (18%) did not like them (they feel unusual); eight musicians (13.1%) did not use them for fear of making a mistake and stress; six musicians (9.8%) felt it is not practical to use them; five musicians (8.2%) felt plugs blocked feeling; five musicians (8.2%) did not want to be seen wearing them; five musicians (8.5%) felt they had a resonating effect on the music heard, two musicians (3.3%) said they forgot to take them along; and seven musicians (11.5%) had other minor issues with wearing ear protection devices such as poor fit, not used to wearing them, they gave unusual feelings etc.

### 8.19.5.2 Youth musicians – Reasons for not using musicians’ plugs



**Figure 8-12 Youth musicians – the reasons for not using musicians’ plugs**

**Results:** Figure 8-12 shows that among the youth orchestra musicians, 14 (16.5%) said they cannot afford musician’s ear plugs; 24 (28.2%) did not know what to wear; two musicians (2.4%) said they forgot; one (1.2%) thought they were inconvenient; one (1.2%) thought they look silly; 11 musicians (12.9%) thought the music was not loud enough to warrant using them; 25 (29.4%) thought the quality of music would suffer; two musicians (2.4%) would not wear them for fear of making mistakes; and five (5.9%) felt them uncomfortable.

### 8.20 Distortion Product Otoacoustic Emission (DPOAE) Test Results

Distortion Product Oto-acoustic Emission (DPOAE) testing was only performed on 31 adult musicians (50.8%), 34 youth musicians (40.0%) and 28 children musicians (75.7%) because of the time constraints and non-availability of the instrument. This test was performed as part of other audiological tests to evaluate its effectiveness in assessing musicians’ hearing. It has been shown that the outer hair cells of the cochlea are responsible for generating oto-acoustic emissions, and this test has been identified to be sensitive to noise damage. Although Oto-acoustic emission testing has been used routinely in many audiology practices, there are still practical and theoretical issues relating to usage in adult population.

The aim of this analysis was to evaluate whether distortion oto-acoustic emission testing is a feasible method to evaluate musician’s hearing, and possibly to use it as a measure for early detection of music induced hearing loss.

### 8.20.1 DPOAE results in adult orchestra musicians

The emission amplitude (the signal to noise ratio) (SNR) is presented in Table 8-54 as a mean score in each frequency band (1000-6000Hz) for the 31 adult musicians. The emission results at 8000Hz are not included for analysis because emission was absent (Figure 8-14) in this frequency for a significant number of individuals and potentially may affect the reliability of the data.

#### Adult musicians – DPOAE results

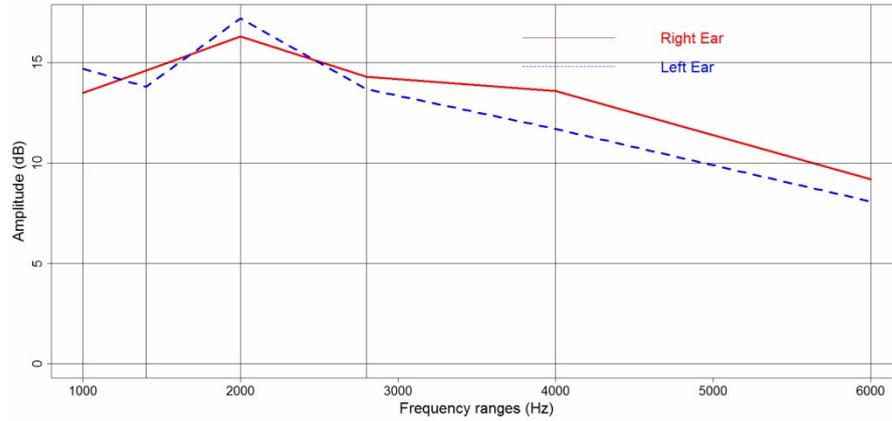
The emission amplitude – the signal to noise ratio (SNR) is presented in Table 8-54 as a mean score in each frequency band (1000-6000Hz) for the 31 adult orchestra musicians. The emission results at 8000Hz are not included for analysis because emission was absent in this frequency for a significant number of individuals and potentially may affect the reliability of the data.

Table 8-54 summarises the Distortion Product Oto-acoustic Emission (DPOAE) test results of the 31 adult musicians.

**Table 8-54 Adult musicians (31 musicians) – Ear difference in DPOAE**

	<b>Ear difference in DPOAE</b>					
<b>Frequency (Hz)</b>	<b>1000</b>	<b>1400</b>	<b>2000</b>	<b>2800</b>	<b>4000</b>	<b>6000</b>
<b>Right ear (dB)</b>	<b>13.5</b>	<b>14.6</b>	<b>16.3</b>	<b>14.3</b>	<b>13.6</b>	<b>9.2</b>
<b>Left ear (dB)</b>	<b>14.7</b>	<b>13.8</b>	<b>17.2</b>	<b>13.7</b>	<b>11.7</b>	<b>8.1</b>
<b>Difference (dB)</b>	<b>-1.2</b>	<b>0.8</b>	<b>-0.9</b>	<b>0.6</b>	<b>1.9</b>	<b>1.1</b>

**Note:** Signal to Noise ratio (SNR) are expressed as mean scores



**Figure 8-13 Adult musicians – Ear difference in DPOAE**

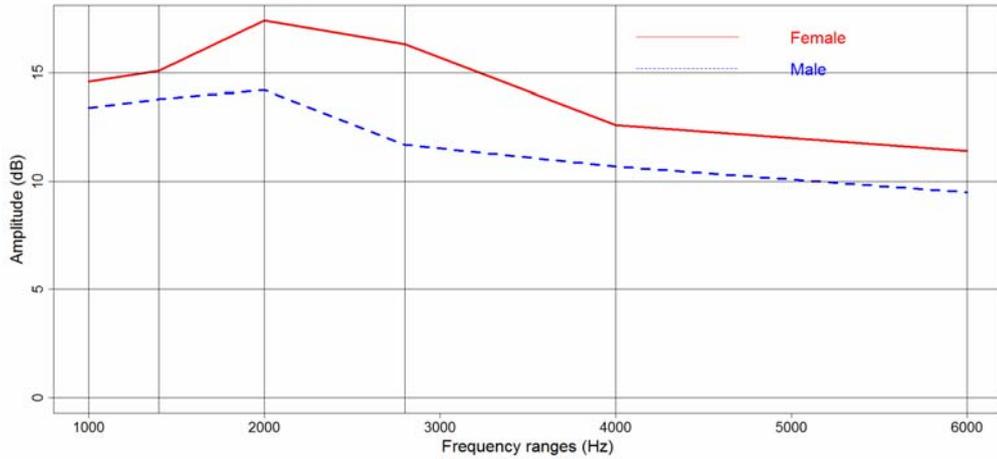
**Results:** Figure 8-13 shows that the adult musicians have better otoacoustic emissions results in the right ear than the left ear in the frequency range 3000 to 6000Hz.

**Table 8-55 Adult musicians (31 musicians) – Gender difference in DPOAE**

<b>Gender difference in DPOAE</b>						
<b>Frequency (Hz)</b>	<b>1000</b>	<b>1400</b>	<b>2000</b>	<b>2800</b>	<b>4000</b>	<b>6000</b>
<b>Females</b>	<b>14.6</b>	<b>15.1</b>	<b>17.4</b>	<b>16.3</b>	<b>12.6</b>	<b>11.4</b>
<b>Males</b>	<b>13.4</b>	<b>13.8</b>	<b>14.2</b>	<b>11.7</b>	<b>10.7</b>	<b>9.5</b>
<b>Difference (dB)</b>	<b>1.2</b>	<b>1.3</b>	<b>3.2</b>	<b>4.6</b>	<b>1.9</b>	<b>4.9</b>

**N-31**

**Note:** Signal to Noise ratio (SNR) are expressed as mean scores



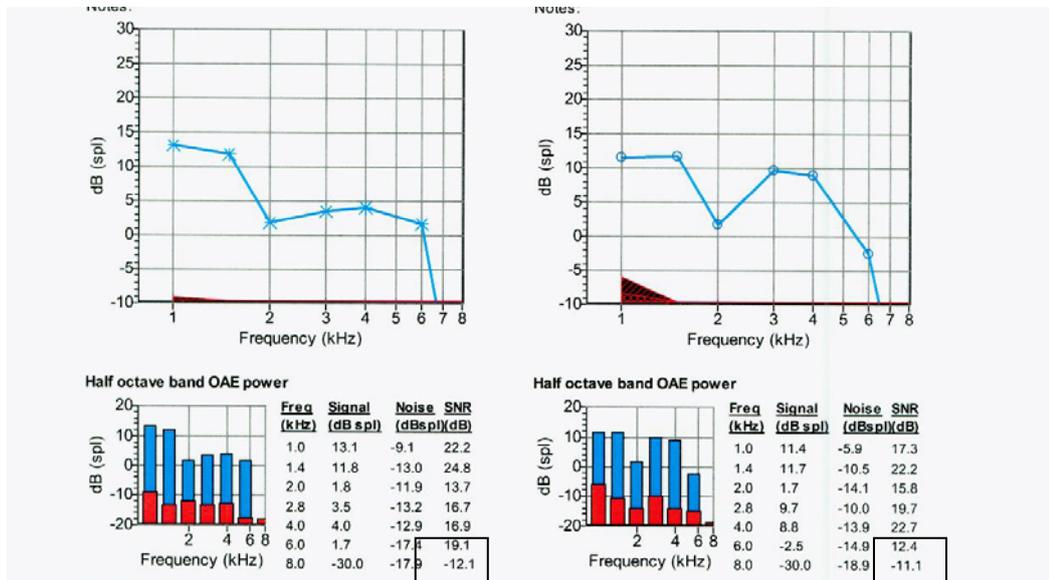
**Figure 8-14 Adult musicians (31 musicians) – mean gender difference in DPOAE**

Results: Table 8-55 and Figure 8-14 show in comparison that women have better otoacoustic emission results than men in all frequencies from 1000-6000Hz.

**8.20.1.1 DPOAE Measurement at 8KHz**

**Left ear**

**Right ear**



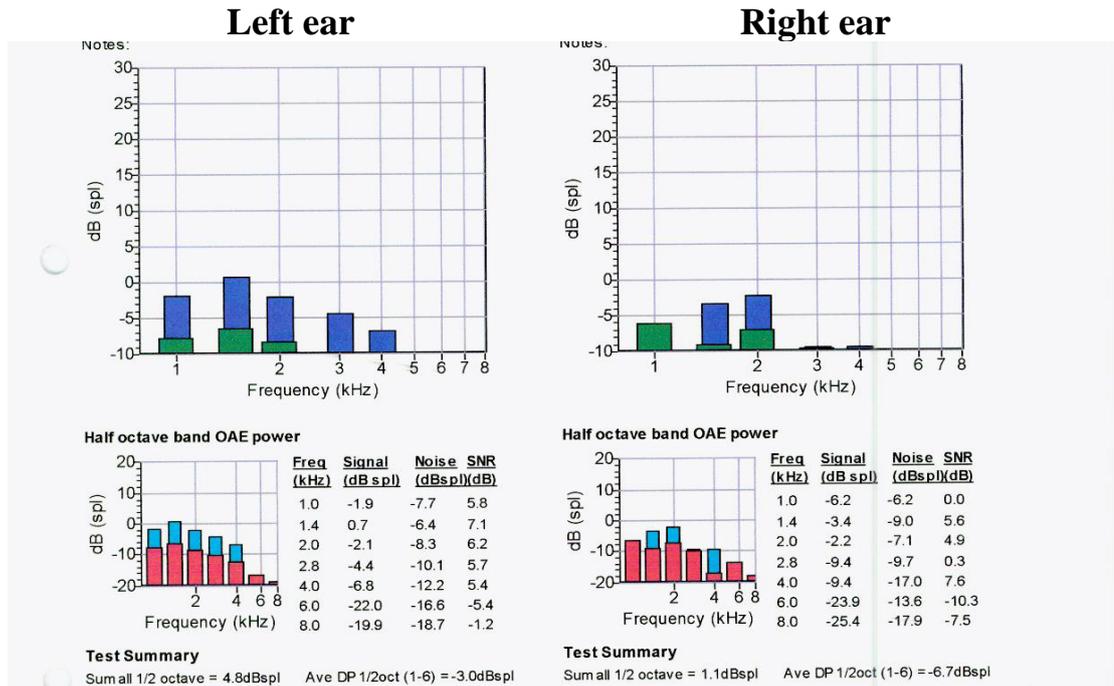
**Emissions are absent at 8 kHz**

**Figure 8-15 DPOAE Measure-Example of Emission being absent at 8 kHz**

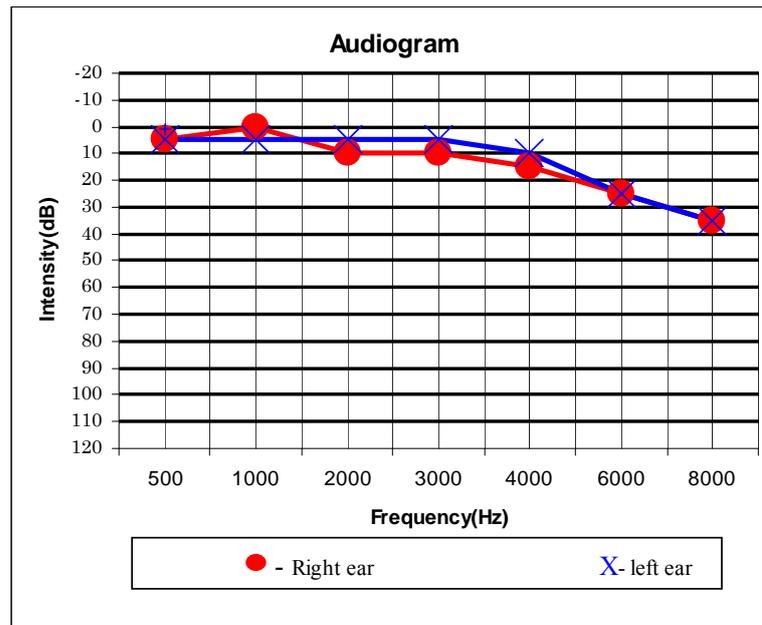
The emission results at 8000Hz are not included for analysis because emission was absent (Example given in Figure 8-15) in this frequency for a significant number of individuals and potentially may affect the reliability of the data.

### 8.20.1.2 DPOAE with prolonged music exposure and age

Figure 8-16 shows that the DPOAE recorded from a sixty year old violinist with 60 years of music exposure.



**Figure 8-16 – DPOAE measure: 66 year old violinist (60 years of music exposure)**



**Figure 8-17 pure-tone audiometry results 66 year old violinist (60 years of music exposure)**

**Results:** Figure 8-16 shows that aging and an increased number of years of music exposure have an effect on DPOAE responses by lowering the DPOAE amplitude, and the musician’s responses at higher frequencies are gradually diminishing though his hearing is within normal limits except at 6 and 8kHz (Fig 8-17).

### 8.20.2 DPOAE results in youth orchestra musicians

The emission amplitude – the signal to noise ratio (SNR) is presented in Table 8-56 as a mean score in each frequency band (1000-6000Hz) for the 34 youth orchestra musicians. The emission results at 8000Hz are not included for analysis because emission was absent in this frequency for a significant number of individuals and potentially may affect the reliability of the data.

## Youth Musicians – DPOAE Results

Table 8-56 Youth musicians (34 musicians) – Ear difference in DPOAE

Ear difference in DPOAE						
Frequency (Hz)	1000	1400	2000	2800	4000	6000
Right ear (dB)	16.5	18.2	20.3	17.4	15.7	11.2
Left ear (dB)	14.7	19.1	21.4	16.7	15.6	10.6
Difference (dB)	1.8	-0.9	-1.1	0.7	0.1	0.6

N-34 Note: Signal to Noise ratio (SNR) are expressed as mean scores

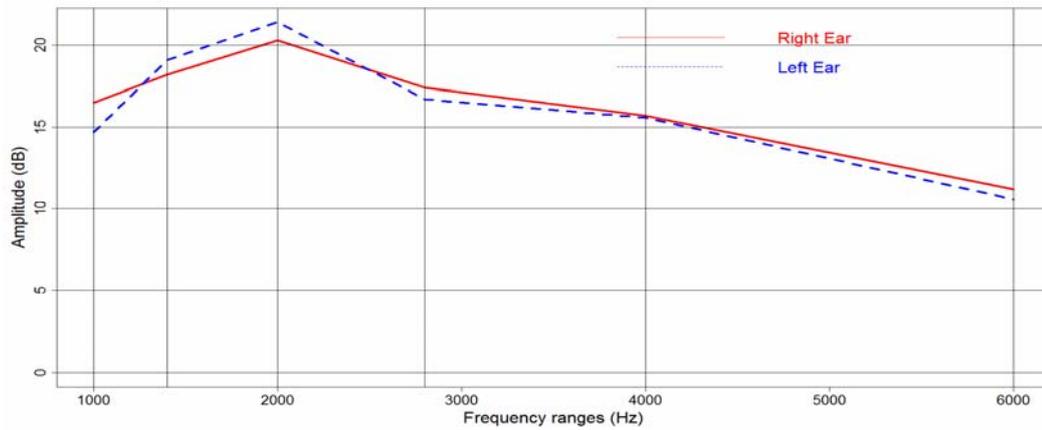
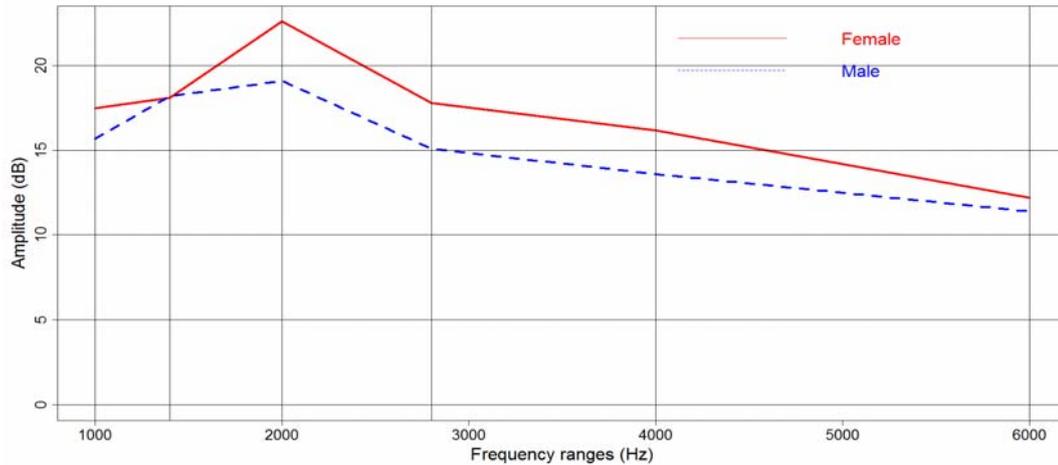


Figure 8-18 Youth musicians – Ear difference in DPOAE

Table 8-57 Youth musicians (34 musicians) – Gender difference

Gender difference in DPOAE						
Frequency (Hz)	1000	1400	2000	2800	4000	6000
Females (dB)	17.5	18.1	22.6	17.8	16.2	12.2
Males (dB)	15.7	18.2	19.1	15.1	13.6	11.4
Difference (dB)	1.8	-0.1	3.5	2.7	2.6	0.8



**Figure 8-19 Youth musicians – Gender difference in DPOAE**

**Results:** Table 8-56 and Fig 8-18 show that in youth musicians, the average DPOAE (mean value) amplitude was found to be only slightly better in the right ear than the left ear – unlike adults where the asymmetry was very evident. Table 8-57 and Fig 8-19 shows that the average DPOAE amplitude was better in female musicians than in male musicians.

### 8.20.3 DPOAE results in children orchestra musicians

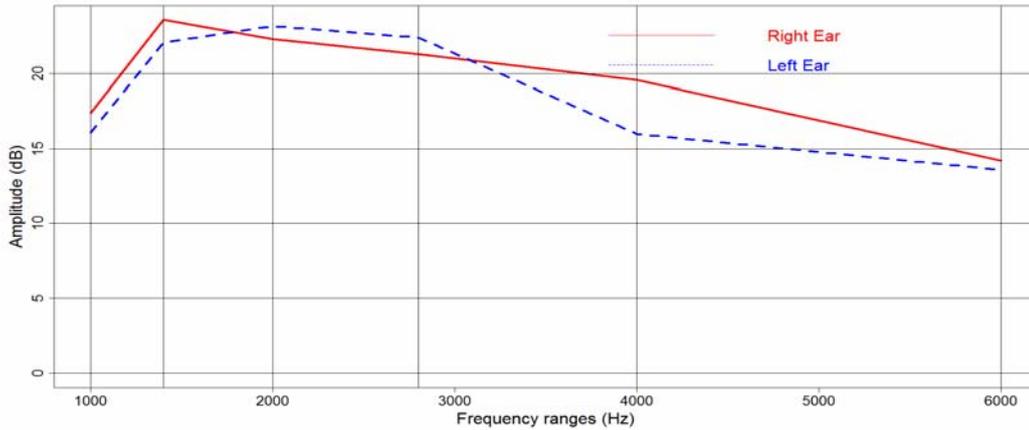
The emission amplitude (the signal to noise ratio) (SNR) is presented in Table 7-58 as a mean score in each frequency band (1000-6000Hz) for the 37 children musicians. The emission results at 8000Hz are not included for analysis because emission was absent in this frequency for a significant number of individuals and potentially may affect the reliability of the data.

#### Children Musicians-DPOAE Results

**Table 8-58 Children musicians (28 musicians) - Oto-acoustic emission test results**

Frequency (Hz)	1000Hz	1400Hz	2000Hz	2800Hz	4000Hz	6000Hz
Right ear (dB)	17.4	23.6	22.3	21.3	19.6	14.2
Left ear (dB)	16.1	22.1	23.2	22.4	16.0	13.6
Difference (dB)	1.3	1.5	-0.9	-1.1	3.6	0.6

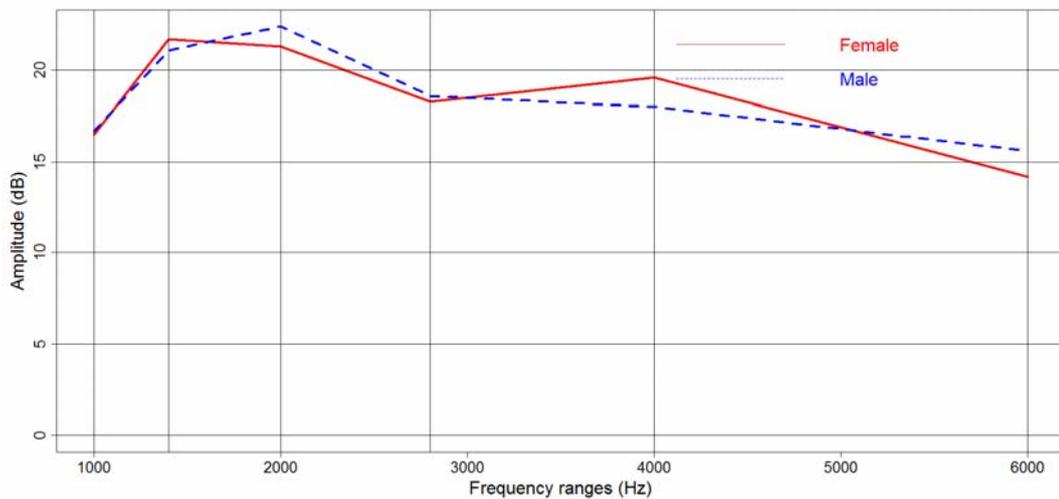
**N-28** Note: Signal to Noise ratio (SNR) is expressed as mean scores



**Figure 8-20 Children Musicians Ear difference in DPOAE**

**Table 8-59 Children musicians (28 musicians) - Mean gender difference in DPOAE**

Gender difference in DPOAE						
Frequency (Hz)	1000Hz	1400Hz	2000Hz	2800Hz	4000Hz	6000Hz
<b>Females(dB)</b>	<b>16.5</b>	<b>21.7</b>	<b>21.3</b>	<b>18.3</b>	<b>19.6</b>	<b>14.2</b>
<b>Males (dB)</b>	<b>16.7</b>	<b>21.1</b>	<b>22.4</b>	<b>18.6</b>	<b>18.0</b>	<b>15.6</b>
<b>Difference (dB)</b>	<b>-0.2</b>	<b>0.6</b>	<b>-1.1</b>	<b>-0.3</b>	<b>1.6</b>	<b>-1.4</b>



**Figure 8-21 Children Musicians – Gender difference in DPOAE**

**Results:** Table 8-58 and Fig 8-20 shows that in children musicians, the average DPOAE (mean value) amplitude was found to be better in the right ear than the left

ear in the frequency region of 3200Hz – 6000Hz. Table 8-59 and Fig 8-21 show that the average DPOAE amplitude was better in female musicians than male musicians at 1400Hz and 4000Hz, and was better in males in 1000Hz, 2000Hz, 2800Hz and 6000Hz.

### 8.20.4 DPOAE as a tool to identify susceptibility to music/noise induced hearing loss

#### 8.20.4.1 A young drummer

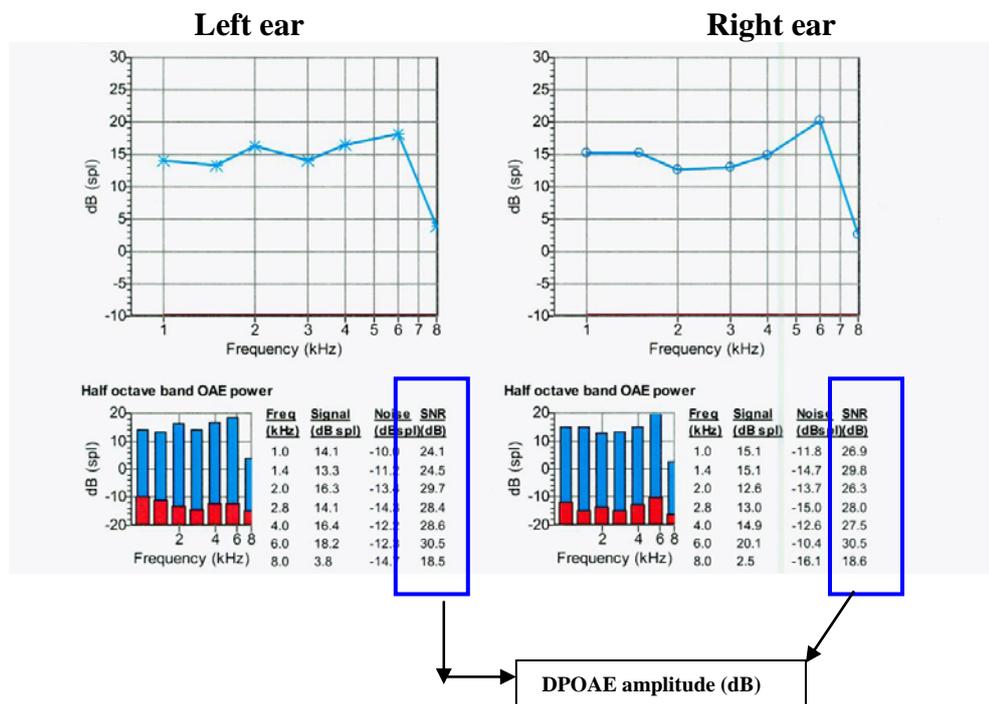


Figure 8-22 DPOAE measure – 16 year old (male) drummer

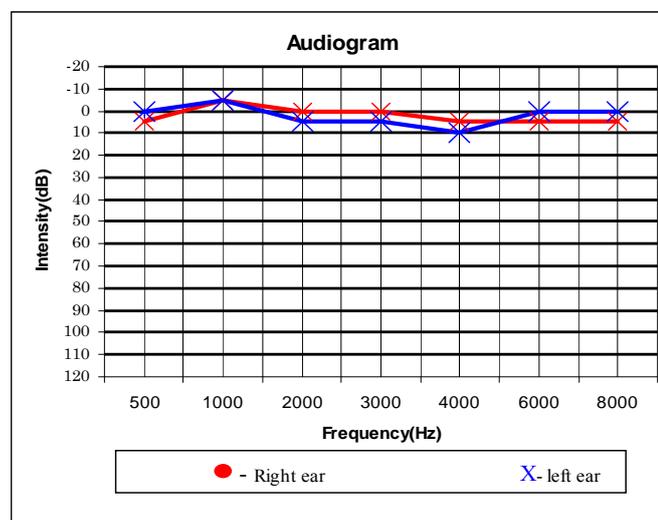


Figure 8-23 Pure-tone audiogram – 16 year old (Male) drummers

**Results:** The DPOAE (Fig 8-22) measurement was obtained from a boy (16 years old), a drummer for the past 10 years – he started playing at the age of six years. The DPOAE amplitude is very large in all frequencies and the hearing threshold (Figure 8-22) shows that the pure-tone audiometry measurements of his hearing thresholds are well within normal limits (Fig 8-23).

### 8.20.4.2 A young violinist

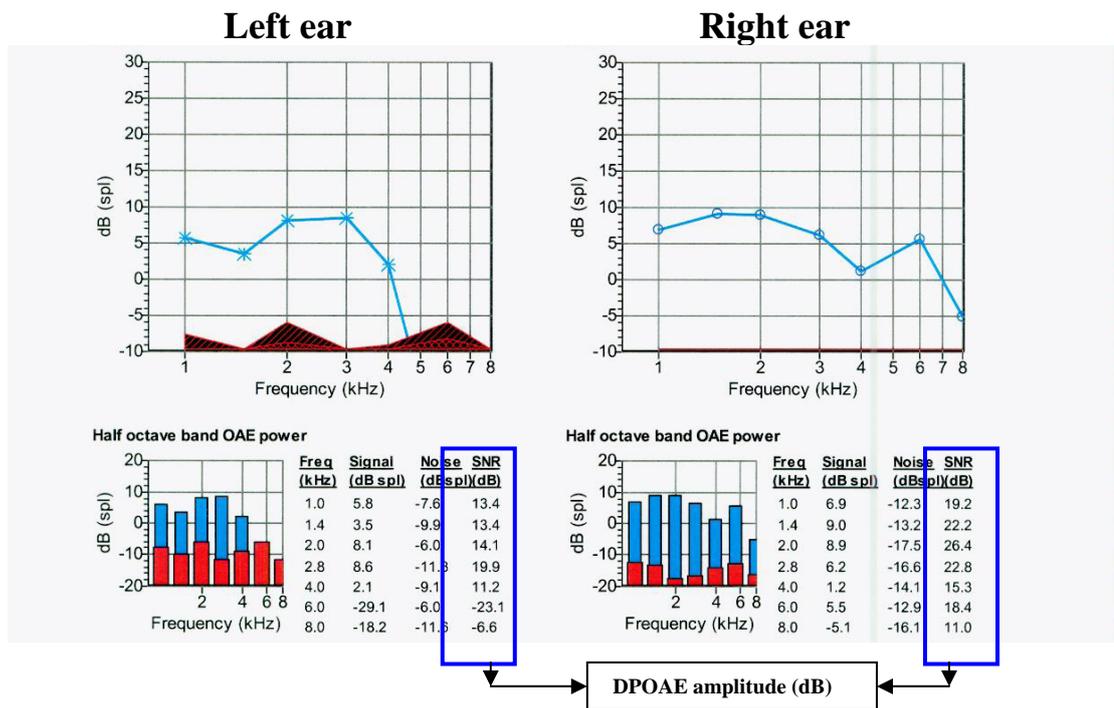


Figure 8-24 DPOAE measure – 12 year old (male) violin player

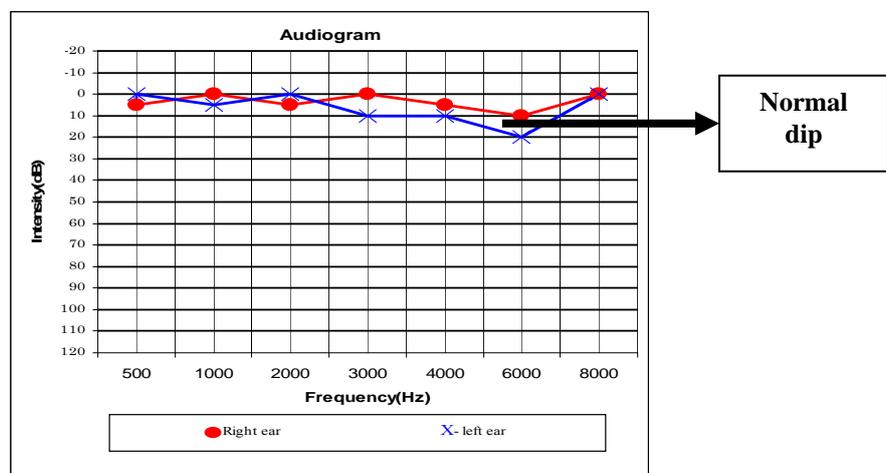


Figure 8-25 Pure-tone audiogram – 12 year old male violin player

**Normal dips in the audiograms:** An individual musician is considered to have a normal dip, if hearing is within normal limits  $\geq 20$ dB in all the frequencies, but there is a dip in the audiogram that is hearing is reduced in one frequency and the threshold is  $\geq 10$ dB in two of the adjacent frequencies.

**Results:** Figure 8-24 shows that the DPOAE is absent at 6 and 8kHz in the left ear, and also the DPOAE amplitude is reduced in all the frequencies (1-4kHz) in the left ear, showing that the outer haircells in the left cochlea are showing early damage. His pure-tone audiometry (Figure 8-25) shows a normal dip at 6kHz and hearing is within normal limits in both the ears. The average pure-tone threshold (500-8000Hz) is 8.2dB in the right ear and 9.1dB in the left ear.

### **8.20.5 Summary of OAE Finding**

The Distortion Product Oto-acoustic Emission (DPOAE) testing performed on 31 adult musicians (50.8%), 34 youth musicians (40.0%) and 28 children musicians (75.7%) shows that oto-acoustic emission (OAE) data corresponded well to the pure-tone audiometric findings data in all age groups. The reduction in hearing acuity in any frequency was accompanied by a decline in OAE amplitudes. The OAE graph resembles the configuration of the audiogram in most of the musicians.

More intense (increased amplitude) OAEs were found for musicians with better average pure-tone thresholds. The reduction in OAE response amplitude in a particular frequency associated with or without a normal dip in the audiogram, in spite of having normal hearing, suggests that DPOAE is a good tool for early detection of music induced hearing loss.

Although OAE measurements added value in the detection of noise and/or music induced hearing loss, there are instances, particularly in older adults, where the amplitude of the OAE response is reduced even though hearing is within normal limits. Hence OAEs cannot be used as a tool for hearing assessment on an individual level, and the pure-tone audiometry still remains the standard test for the assessment of Music Induced Hearing Loss (MIHL) or Noise Induced Hearing Loss (NIHL).

## **Chapter 9 : Results – longitudinal analysis of hearing loss development**

### **9.1 Introduction**

This part of the research work was performed with the main objective to assess the effect of long-term exposure of the orchestral music on musicians' hearing and to study hearing loss development in musicians with increased music exposure. For this purpose, we analysed the pure-tone audiometry (which was performed as part of the hearing conservation programme) of 30 adult musicians who have been undergoing regular audiometric testing for the past 10-20 years.

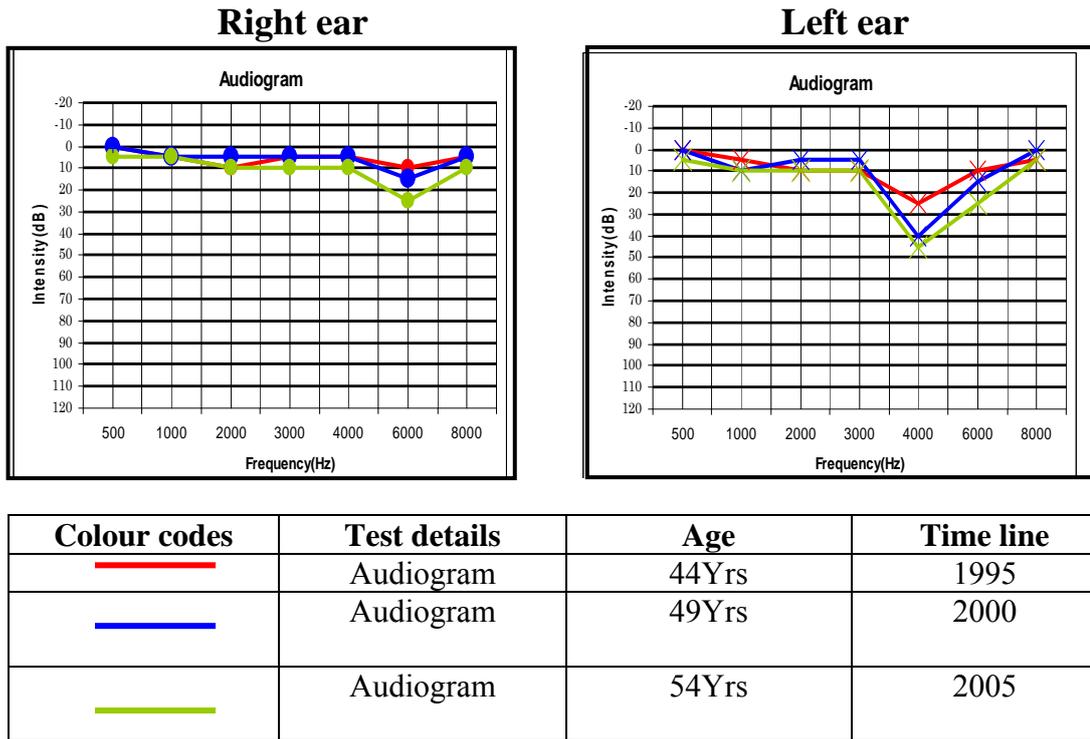
### **9.2 Progression of hearing loss in a violinist with increased years of music exposure**

#### **9.2.1 Case 1: Series of audiograms of a violin player**

Figure 9-1 is a series of audiograms of a violin player that shows the progression of hearing loss with increased music exposure. This person has been playing the violin since the age of seven and has been a professional violin player for 30 years.

**Music exposure:** 4-5 hours/day, 25-30 hours/week since the age of seven years.

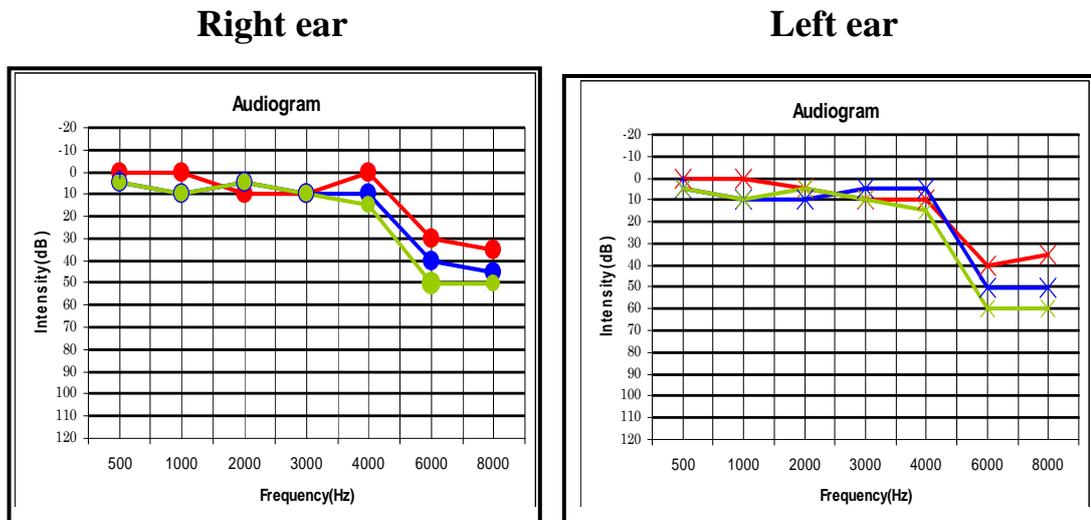
**Medical History:** No history of ear infection, no hearing loss in the family, no other noise exposure, and no giddiness and/or balancing difficulty, but has tinnitus (on and off-more in the left ear than right ear). Does not use musician plugs – feels that the quality of music is affected. He reports to have hearing difficulty in noisy background situations.



**Figure 9-1 (Case 1) Development of hearing loss in a violinist  
(54 years old, male)**

**Results:** In the right ear, hearing is within normal limits except for a mild dip at 6kHz (10dB of reduction only at 6kHz) with 10 years of orchestral music exposure. In the left ear, however, there is gradual deterioration in hearing at 4kHz by 20dB in the five year age bracket, 43-48, and 5dB in the next five year age bracket, 48-53. At 6kHz, hearing has deteriorated by about 15dB with 10 years of music exposure from the age 43-53. There is no significant change in hearing in the low and mid frequency region (500 to 4000Hz in the right ear and 500-3000 in the left ear) and at 8kHz. This audiogram shows that there is a significant asymmetry because of the left ear being much closer to the sound source than the right ear in a violin player. It is interesting to note that hearing loss development with increased music exposure follows a particular pattern – progression has begun at a particular frequency (6kHz in the right and 4kHz in the left ear), and continues to deteriorate in that frequency and with the lesser rate at an adjacent higher frequency.

### 9.2.2 Case 2: Series of audiograms of a violin player



Colour codes	Test details	Age	Time line
	Audiogram	43 Yrs	1995
	Audiogram	48 Yrs	2000
	Audiogram	53 Yrs	2005

**Figure 9-2 (Case-2) Development of hearing loss in a violinist (53 years old, male)**

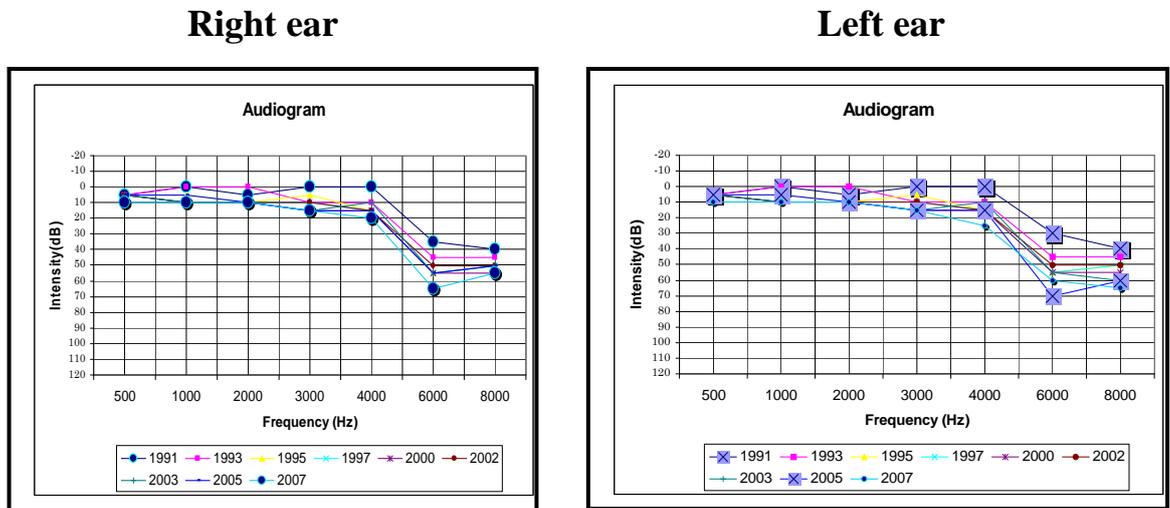
**Results:** Figure 9-2 shows the progression of hearing loss in another violin player. There is a slight asymmetry in hearing (left ear is slightly more affected than the right ear). There is no significant reduction in hearing in the frequency region of 0.5kHz-3kHz in both the ears and at 4kHz hearing is within normal limits, but there is a serious deterioration of hearing in the frequency region of 6-8kHz. In the right ear there is a deterioration of 20dB at 6kHz and 15dB at 8kHz. In the left ear there is a deterioration of 20dB at 6kHz and 2 dB at 8kHz.

### 9.2.3 Case 3: Series of audiogram of a violin player

**Music exposure:** 5-6 hours/day, 25-30 hours/week since the age of five years.

**Medical History:** No history of ear infection, no hearing loss in the family, no other noise exposure and no giddiness and/or balancing difficulty, but has tinnitus (continuous) which is reported to be very annoying. Uses musician plugs only

during loud passages; feels that the quality of music is affected otherwise. He reports to have hearing difficulty in a group and noisy background situations.



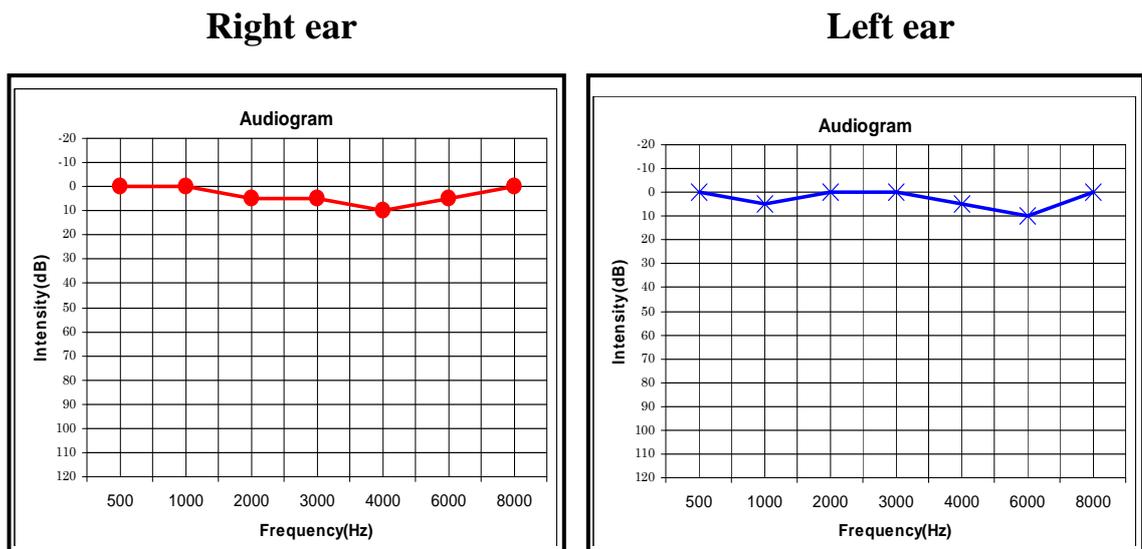
**Figure 9-3 (Case 3) Development of hearing loss in a violinist (44 years old, male)**

**Results:** These audiograms show a gradual and continuous deterioration with increased music exposure over a number of years from 28-44 years of age. There are no significant changes in hearing in the frequency region of 0.5-2kHz, but there is a deterioration of 15dB at 3kHz and 20dB at 4kHz. There is a significant deterioration of hearing of about 30dB at 6kHz and 20dB at 8kHz. The left ear seems to be slightly more affected than the right ear.

#### 9.2.4 Case 4: Audiogram of a violin player with well preserved hearing in both the ears

**Music exposure:** 5 hours/day and 25-30 hours/week. Started playing violin at the age of four years and dislikes usage of musician ear plugs, but was not a part of the hearing programme. Has been a part of orchestra for the past 24 years.

**Medical History:** No history of ear infection, no family history of hearing loss, no other noise exposure, no giddiness and/or balancing difficulty, but has tinnitus (at times in the left ear).



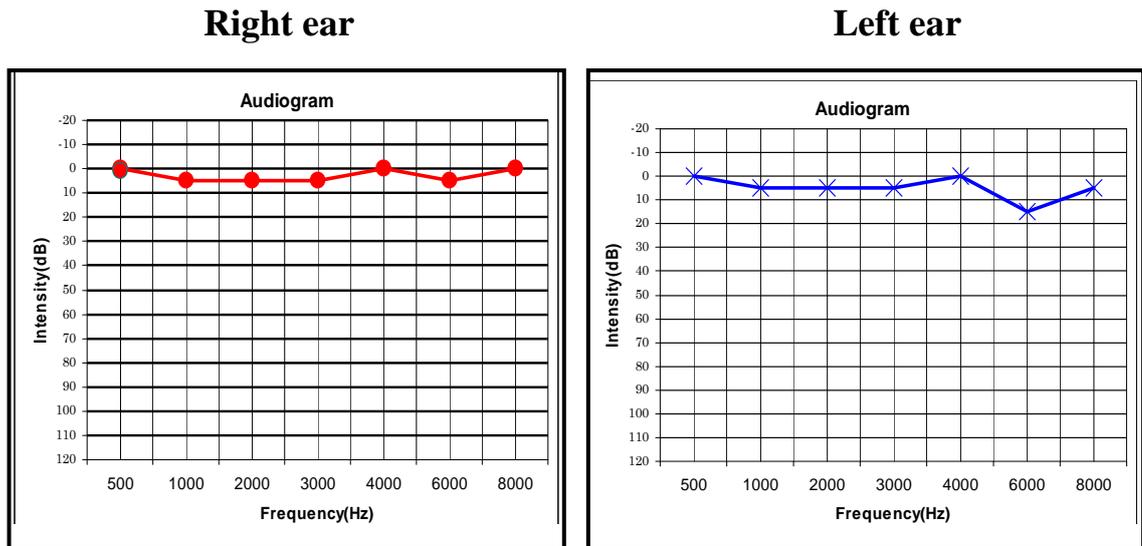
**Figure 9-4 (Case 4) Pure-tone audiogram of a violinist (46 years old, female)**

**Results:** In spite of playing violin (since the age of four) and being a part of an orchestra for many years (24 years), hearing is well within normal limits in both ears. There may be a mild tendency of hearing loss at 4kHz in the right ear and at 6kHz in the left ear.

**9.2.5 Case 5: Audiogram of a violin player with well preserved hearing in both the ears**

**Music exposure:** 4-5 hours/day, 25-30 hours/week. Has been playing violin since seven years of age and has been part of the orchestra for 30 years. Joined the hearing conservation programme last year.

**Medical History:** No history of ear infection, no family history of hearing loss, no other noise exposure, no giddiness and/or balancing difficulty, but has tinnitus (at times in the left ear) and does not like to use musician plugs as the quality of the music is affected.



**Figure 9-5 (Case 5) Pure-tone audiogram of a violinist (51 years old, female)**

**Results:** In spite of playing the violin and being a part of an orchestra for many years, hearing is well within normal limits in both the ears except for a normal (mild) dip at 6kHz in the left ear. This could be attributable to music exposure.

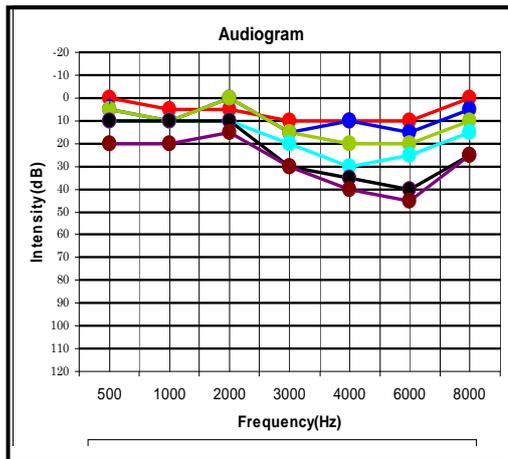
### **9.3 Progression of hearing loss in a double bass player with increased years of music exposure**

#### **9.3.1 Case 1: Series of audiograms of a double bass player**

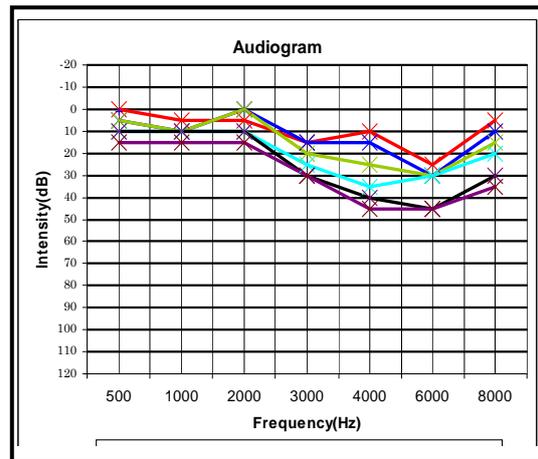
**Music exposure:** 5 hours/day and up to 26 hours/week. Started playing double bass at the age of 10 years, also dislikes musician ear plugs (cannot hear the conductor's voice, misses out some parts of the music), hence uses them only during loud passage rehearsal and concert performances, part of the hearing conservation programme. He has been a professional musician for the past 35 years.

**Medical History:** No history of ear infection, no family history of hearing loss, no other noise exposure, no giddiness and/or balancing difficulty, but has tinnitus (continuous and high pitched, which has been noticed for many years).

### Right ear



### Left ear



Colour codes	Test details	Age	Time line
<span style="color: red;">—</span>	Audiogram	34Yrs	1985
<span style="color: blue;">—</span>	Audiogram	42Yrs	1993
<span style="color: green;">—</span>	Audiogram	44Yrs	1995
<span style="color: cyan;">—</span>	Audiogram	49Yrs	2000
<span style="color: black;">—</span>	Audiogram	54Yrs	2005
<span style="color: purple;">—</span>	Audiogram	56Yrs	2007

**Figure 9-6 Development of hearing loss in a double bass player  
(56 years old, male)**

**Table 9-1 Double bass player - Development of hearing loss in the right ear  
(56 years old, male)**

Age	Frequency				
	Low freq (500-2kHz)	3kHz	4kHz	6kHz	8kHz
34Yrs	5dB	10dB	10dB	10dB	0dB
42Yrs	5dB	10dB	10dB	15dB	0dB
44Yrs	5dB	15dB	20dB	20dB	10dB
49Yrs	10dB	20dB	30dB	25dB	15dB
54Yrs	10dB	30dB	35dB	40dB	25dB
56Yrs	18dB	30dB	40dB	45dB	25dB

**Table 9-2 Double bass player - Development of hearing loss in the left ear  
(56 years old, male)**

Age	Frequency				
	Low freq (500-2kHz)	3kHz	4kHz	6kHz	8kHz
34Yrs	3dB	15dB	10dB	25dB	5dB
42Yrs	3dB	15dB	15dB	25dB	10dB
44Yrs	5dB	20dB	25dB	30dB	15dB
49Yrs	10dB	25dB	35dB	30dB	20dB
54Yrs	10dB	30dB	40dB	45dB	30dB
56Yrs	15dB	30dB	45dB	45dB	35dB

**Results:** With 22 years of music exposure, in the right ear (Table 9-1), there is a threshold shift of 13dB in the low frequency region (500-2000Hz). This increases to 20dB at 3kHz, 30dB at 4kHz, 35dB at 6kHz, and 25dB at 8kHz. In the left ear (Table 9-2), there is a frequency shift of 12dB in the frequency region of 0.5-2kHz; this increases to 25dB at 3kHz, 35dB at 4kHz, 20dB at 6kHz, and 30dB at 8kHz. The series of audiograms shows that in general the deterioration in hearing follows the same pattern as the gradual increase of music exposure. There is a very slight asymmetry in hearing (the left ear is more affected than the right ear). The deterioration in hearing is gradual, unlike a rapid deterioration observed with the combined effect of music and other noise exposure.

### **9.3.2 Case 2: Series of audiograms of a double bass player**

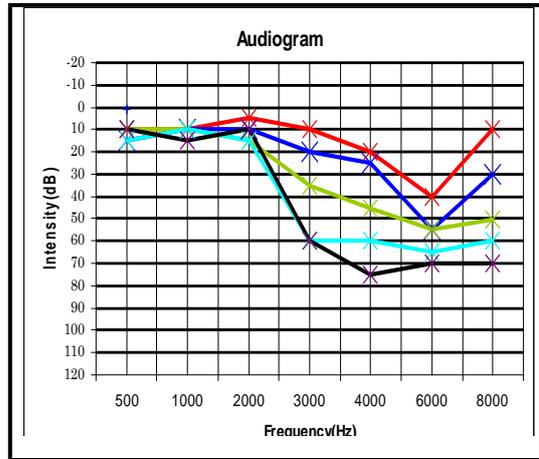
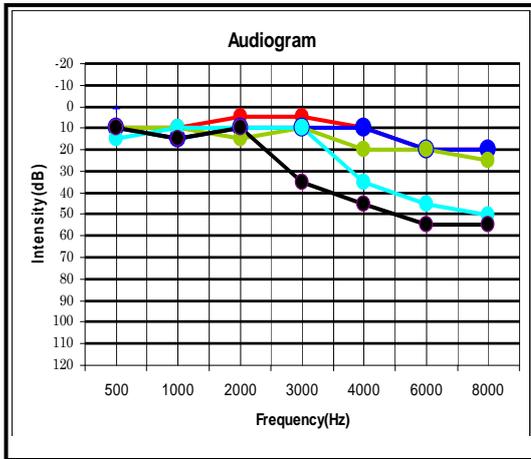
**Music exposure:** 5 hours/day and up to 25-30 hours/week. Started playing double bass at the age of 11 years, does not use musician ear plugs on a regular basis – uses them 20% of the time and only during rehearsal – does not use them during a concert performance as he is fearful of making mistakes. Is part of the hearing screening programme. Has been a professional musician for the past 42 years.

**Medical History:** No history of ear infection, no family history of hearing loss and no giddiness and/or balancing difficulty. There is a history of other noise exposure (gun shooting) on a few days – once in six months. Reported to have tinnitus in both the ears – described to be continuous and high pitched (more noticeable in the left ear).

Figure 9-7 is series of audiograms showing the progression of hearing loss with a combined effect of music, noise exposure and age in a double bass player.

**Right ear**

**Left ear**



Colour codes	Test details	Age	Time line
	Audiogram	37Yrs	1985
	Audiogram	47Yrs	1995
	Audiogram	52Yrs	2000
	Audiogram	57Yrs	2005
	Audiogram	62Yrs	2007

**Figure 9-7 Development of hearing loss in a double bass player (62 years old, male)**

**Table 9-3 Double bass player – Development of hearing loss in the right ear (62 years old, male)**

Age	Frequency				
	Low freq (0.5-2kHz)	3kHz	4kHz	6kHz	8kHz
42 Yrs	No Change	0dB	10dB	20dB	20dB
47Yrs	No Change	10dB	10dB	20dB	20dB
52Yrs	No Change	10dB	20dB	20dB	25dB
57Yrs	No Change	15dB	35dB	45dB	50dB
62Yrs	No Change	35dB	45dB	55dB	55dB

**Table 9-4 Double bass player – Development of hearing loss in the left ear (62 years old, male)**

Age	Frequency				
	Low freq (0.5-2kHz)	3kHz	4kHz	6kHz	8kHz
42 Yrs	No Change	10dB	20dB	40dB	10dB
47Yrs	No Change	20dB	25dB	55dB	30dB
52Yrs	No Change	35dB	45dB	55dB	50dB
57Yrs	No Change	60dB	60dB	65dB	60dB
62Yrs	No Change	60dB	75dB	70dB	70dB

**Results:** In the right ear, there was no significant change in hearing in the frequency region of 0.5-2kHz, but there is a deterioration of 35dB at 3kHz, and there has been a significant shift of about 20dB in the last five years (from 57 to 62 years of age); possibly a combined effect of music, age and noise. The deterioration in hearing is 35dB at 4kHz, 35dB at 6kHz, and 35dB at 8kHz. In the left ear, there was no significant change in hearing in the frequency region of 0.5-2kHz.

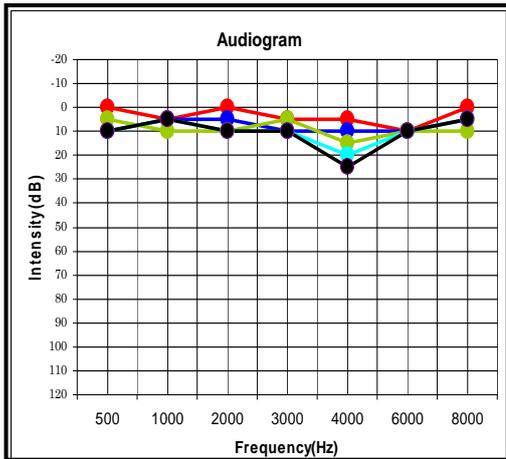
There was a deterioration of 50dB at 3kHz, 55dB at 4kHz, 30dB-6kHz and 60dB at 8kHz. The series of audiograms shows that in general, hearing deterioration has followed the same pattern as the gradual increase of music exposure. There is a significant asymmetry in hearing; the left ear is more affected than the right ear. There seems to be significant deterioration in hearing with combined effect of music and noise exposure, and in the last 15 years (47-62 years) there has been a rapid deterioration in hearing, possibly due to the additional effect of aging as well as noise and music exposure.

### **9.3.3 Case 3: Series of audiograms of a double bass player**

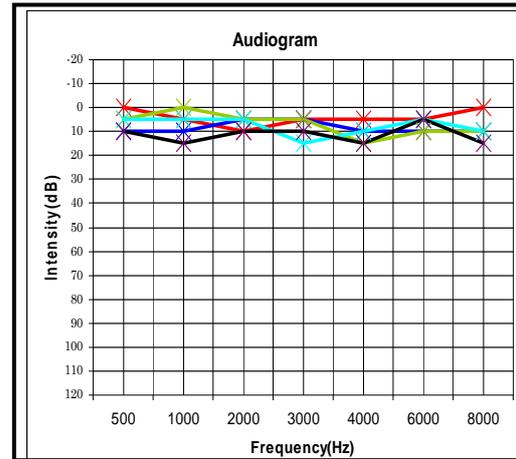
**Music exposure:** 5 hours/day, 26 hours/week, part of orchestra, and has played music since the age of nine.

**Medical history:** No history ear infection, no family history of hearing loss, no other noise exposure, and no giddiness and/or balancing difficulty, but has tinnitus (at times noticeable when she is in quiet situations). Does not use musician plugs as often she forgets to take them along, but she is aware of a slight loss in the right ear.

### Right ear



### Left ear



Colour codes	Test details	Age	Time line
	Audiogram	43Yrs	1985
	Audiogram	48Yrs	1990
	Audiogram	53Yrs	1995
	Audiogram	58Yrs	2000
	Audiogram	63Yrs	2005

**Figure 9-8 Development of hearing loss in a double bass player  
(63 years old, female)**

**Results:** In spite of being exposed to music for many years (since the age of nine) and being a part of an orchestra for 33 years, hearing is well within normal limits in both ears, except for a mild dip at 4kHz in the right ear.

## 9.4 Development and progression of hearing loss in a cello player with increased years of music exposure

### 9.4.1 Case 1: Development of hearing loss in a cello player

**Music exposure:** On an average, 4-5 hours/day – 25-30 hours/week since the age of 11 years.

**Medical History:** No history ear infection, no other noise exposure, and no giddiness and/or balancing difficulty, but has tinnitus (on and off). Noticeable more in the left ear than right ear). Does not use musician plugs during individual and group practice as feels that the instrument is not too loud, and the musician plugs are not as good as they are suppose to be. No family history of hearing loss, but reports to have slight hearing difficulty in group situations and meetings.

#### Right ear

#### Left ear

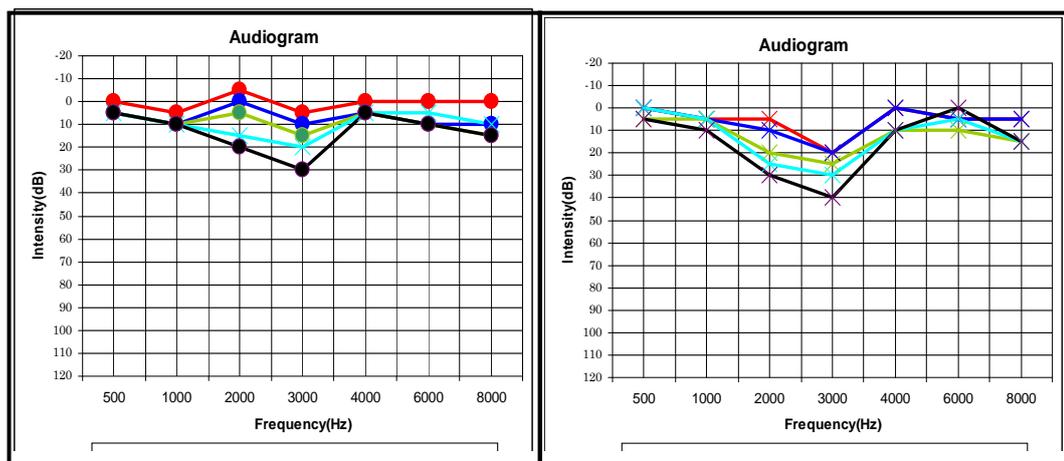


Figure 9-9 Development of hearing loss in a cello player (54 years old, male)

Colour codes	Test details	Age	Time line
<span style="color: red;">—</span>	Audiogram	45Yrs	1999
<span style="color: blue;">—</span>	Audiogram	47Yrs	2001
<span style="color: green;">—</span>	Audiogram	48Yrs	2003
<span style="color: cyan;">—</span>	Audiogram	50Yrs	2005
<span style="color: black;">—</span>	Audiogram	52Yrs	2007

**Results:** Figure 9-8 shows that hearing is within normal limits in the right ear, but there was a mild dip in the left ear when tested at the age of 45 years. With the eight years of music exposure there seems to be a significant deterioration in hearing in the

frequency region of 2kHz-3kHz in both the ears; the audiograms show that the left ear is more affected than the right. There also seems to be a mild deterioration in the high frequency region as well.

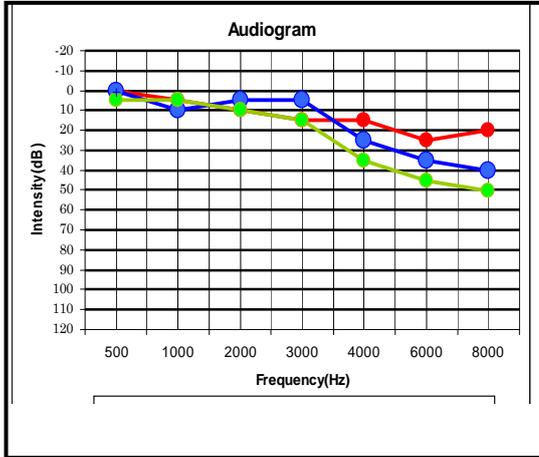
### **9.5 Development and progression of hearing loss in a flautist with increased years of music exposure**

**Music exposure:** On an average, 4-5 hours/day – 25 hours/week since the age of five and has been part of an orchestra for the past 33 years.

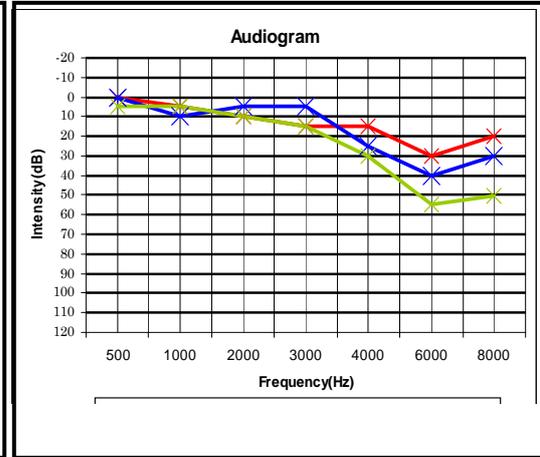
**Medical History:** No history ear infection, no other noise exposure, and no giddiness and/or balancing difficulty, but has tinnitus (continuous and noticeable in both the ears). Uses musician plugs 100% of the time during rehearsal but does not use them during individual practice as feels the instrumental alone is not too loud; nor are they used on a regular basis during performance because of the fear of making mistakes. There is a family history of hearing loss and reports to have slight hearing difficulty in group situations and meetings.

### 9.5.1 Case 1: Development of hearing loss in a flutist

#### Right ear



#### Left ear



Colour codes	Test details	Age	Time line
<span style="color: red;">—</span>	Audiogram	43 Yrs	1995
<span style="color: blue;">—</span>	Audiogram	48Yrs	2000
<span style="color: green;">—</span>	Audiogram	53Yrs	2005

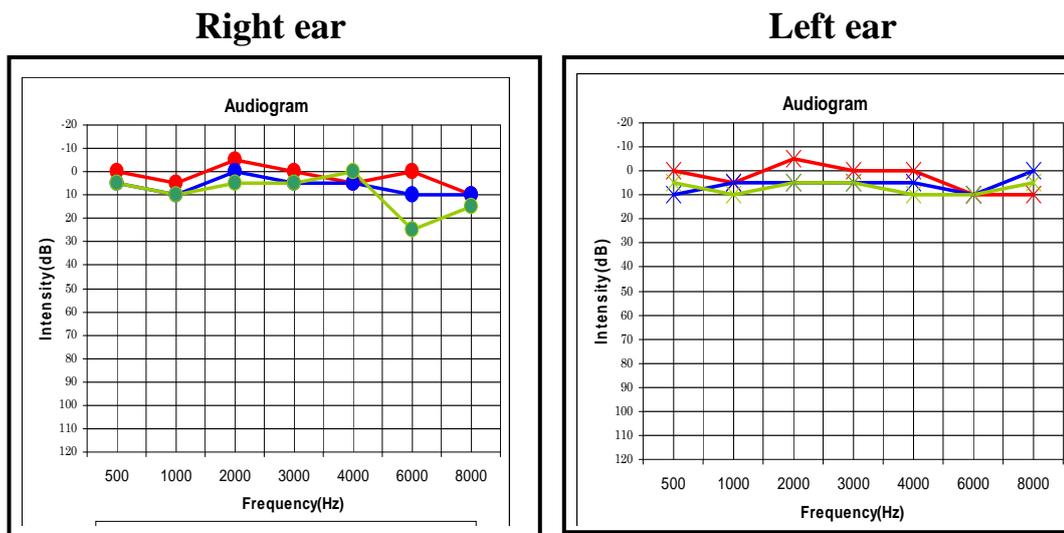
**Figure 9-10 Development of hearing loss in a flutist (53 years old, female)**

**Results:** Figure 9-9 shows the progression of hearing loss in a flutist. Hearing is within normal limits in the frequency region of 0.5-3kHz in both the ears with no significant changes. In 10 years of music exposure, at 3kHz there is 10dB of deterioration in both ears. Hearing deterioration is observed in the frequency region of 4 to 8kHz in both ears with the deterioration slightly more in the left ear than the right. In the right ear the deterioration is 20dB at 4kHz and 6kHz, and 30dB at 8kHz, whereas in the left ear it is 15dB at 4kHz, 25dB at 6kHz, and 30dB at 8kHz.

### 9.5.2 Case 2: Development of hearing loss in a flutist (beginning effect of noise)

**Music exposure:** On an average, 5-6 hours/day-26-30 hours/week since the age of six years.

**Medical History:** No history of ear infection, no other noise exposure, no giddiness and/or balancing difficulty and no tinnitus. Does not use musician plugs because of the difficulty in appreciating the quality of music. No family history of hearing loss. No hearing difficulty.



Colour codes	Test details	Age	Time line
	Audiogram	25 Yrs	2005
	Audiogram	26Yrs	2006
	Audiogram	27 Yrs	2007

**Figure 9-11 Development of hearing loss in a flutist (27 years old, female)**

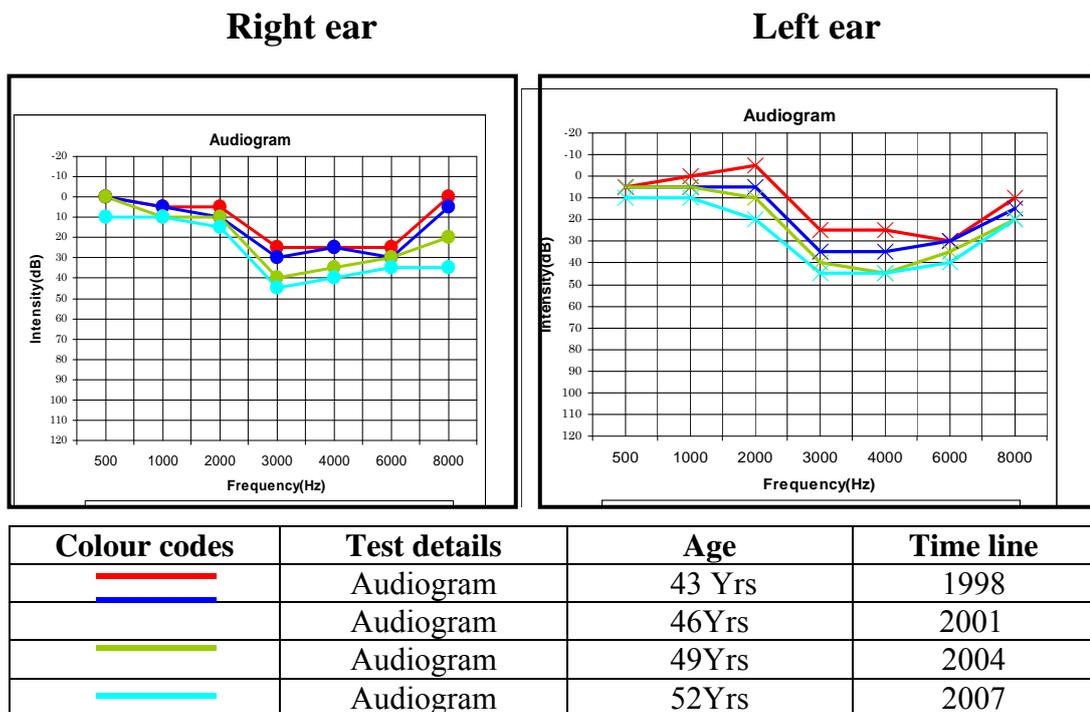
**Results:** Figure 9-11 shows that hearing was within normal limits in both the ears when tested at the ages of 25 and 26 years. At the age of 27 there is a mild dip at 6kHz in the right ear as the right ear is more exposed to the sound than the left ear.

## 9.6 Development and progression of hearing loss in a percussionist with increased years of music exposure

### 9.6.1 Case 1: Development of hearing loss in a percussionist

**Music exposure:** On an average of 4-5 hours/day – 20 hours/week, has been a part of the orchestra for 17 years, and reported to have started playing musical instruments at the age of 10 years.

**Medical History:** No history of ear infection, no other noise exposure and no giddiness and/or balancing difficulty, but has tinnitus (noticeable only at times). Uses musician plugs 10% time during a concert performance. The reason for not using them all the time is for fear of making mistakes, and also has noticed that the musicians who use musician plugs play their instruments loudly. During dress rehearsal uses musician plugs for 50% of the time as it is not practical to use them all the time. There is no family history of hearing loss. He is reported to have hearing difficulty in group situations, in meetings, and when there is lots of background noise.



**Figure 9-12 Development of hearing loss in a percussionist  
(52 years old, male)**

**Results:** The series of audiograms shows a gradual and progressive deterioration of hearing in both ears, particularly in the frequency region of 3-8kHz in the right ear and 2-6kHz in the left ear. With 10 years of increased music exposure from age 42 to 52, the deterioration in hearing in the right ear is 10dB at 3kHz, 20dB at 4kHz, 10dB at 6kHz, and 35dB at 8kHz. In the left ear the deterioration is 25dB at 2kHz, 20dB at 3kHz and 4kHz, and 10dB at 6kHz and 8kHz. There seems to be

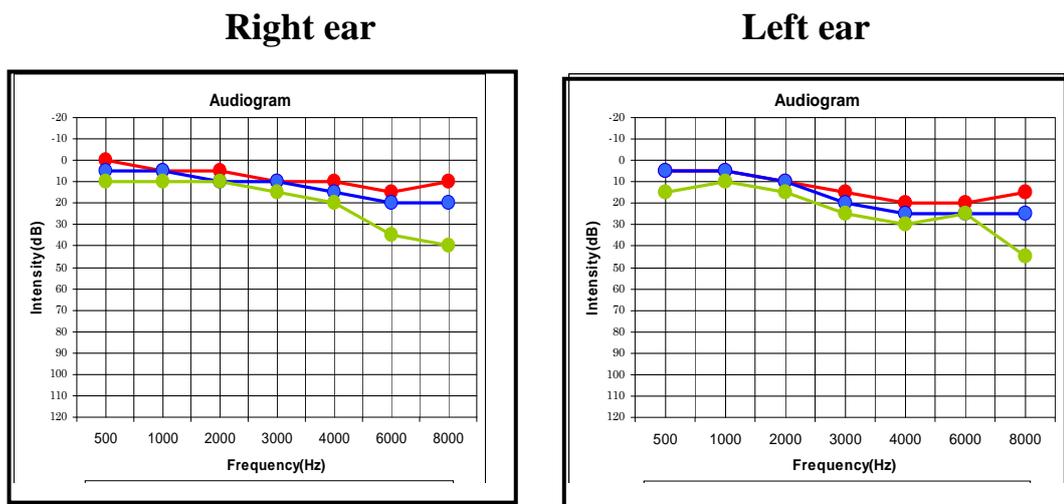
some deterioration in hearing also in the frequency region of 1500 to 8000Hz. The left ear seems to be slightly more affected than the right ear.

## 9.7 Development and progression of hearing loss in a trumpet player with increased years of music exposure

### 9.7.1 Case 1: Development of hearing loss in a trumpet player

**Music exposure:** 3-5 hours/day, 26-30 hours/week since the age of six years.

**Medical History:** No history of ear infection, no other noise exposure, and no giddiness and/or balancing difficulty, but has tinnitus (occasionally) and does not use musician plugs because of a resonance effect. Has a strong family history of hearing loss (father and grandfather). Has noticed hearing difficulty in noisy background situations.



**Figure 9-13 Development of hearing loss in a trumpet player (44 years old, male)**

Colour codes	Test details	Age	Time line
<span style="color: red;">—</span>	Audiogram	34Yrs	1995
<span style="color: blue;">—</span>	Audiogram	39Yrs	2000
<span style="color: green;">—</span>	Audiogram	44Yrs	2005

**Results:** At 34 years of age, hearing was within normal limits in both ears. In 10 years of music exposure, hearing deterioration in the right ear was 10dB at 4kHz, 20dB at 6kHz and 30dB at 8kHz. In the left ear, the deterioration was 10dB at 3kHz, 20dB at 6kHz and 30dB at 8kHz.

10dB at 4kHz, 5dB at 6kHz and 30dB at 8kHz. There were no peaks in the audiogram.

### 9.7.2 Case 2: Development of hearing loss in a French horn player

**Music exposure:** 4-5 hours/day, 25-30 hours/week. Has played French horn for the past 50 years, does not use any form of ear protection; says does not like them in the ears. Not part of hearing conservation programme.

**Medical history:** No history of ear infection, no family history of hearing loss, no other noise exposure, no giddiness and/or balancing difficulty, but has tinnitus (very rarely).

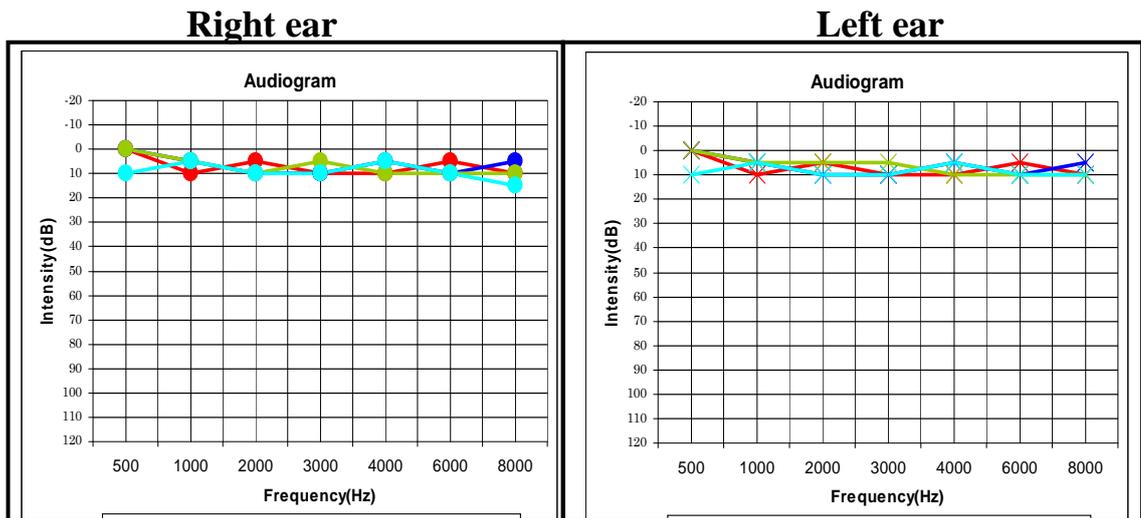


Figure 9-14 Series of audiogram of a French horn player (60 years old, male)

Colour codes	Test details	Age	Time line
<span style="color: red;">—</span>	Audiogram	45 Yrs	1990
<span style="color: blue;">—</span>	Audiogram	50Yrs	1995
<span style="color: green;">—</span>	Audiogram	55Yrs	2000
<span style="color: cyan;">—</span>	Audiogram	60Yrs	2005

**Results:** In spite of being a professional musician for many years, the hearing is well within normal limits in both ears in the entire frequency range from 500-8000Hz.

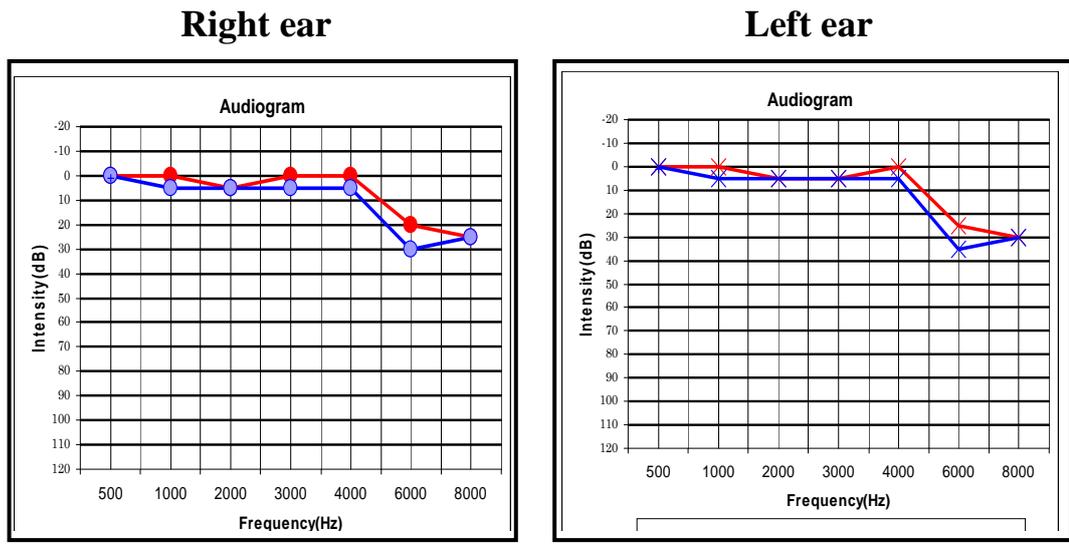
## **9.8 Progressive hearing loss with music exposure in children**

### **9.8.1 Case 1: Combined effect of music exposure with previous history of ear infection and a family history of hearing loss**

Figure 9-15 shows the audiograms performed on a teenage musician at 12 and 16 years of age showing the development of hearing loss with increased music exposure. Figures 9-16, 9-17 and 9-18 show the DPOAE results. Medical history includes a history of significant ear infection, had two sets of grommets at the age of two and then another set at three years of age, and there is a positive family history of hearing problems with aging (father and grandfather). Reported to have tinnitus most of the time, and has noticed slight hearing difficulty in the classroom when it is noisy.

**Music exposure at 12 years of age:** started playing recorder from the age of six and learned piano from the age of nine, part of a music academy (10 hours of music exposure/week).

**Music exposure at 16 years of age:** Jazz band: 4 hours/week + saxophone: 1 hour a week + concert band 1.5 hours/week. One hour of practice every day (16.5 hours/week of music since three years old).



Colour codes	Test details	Age	Time line
	Audiogram	12 Yrs	2006
	Audiogram	16Yrs	2011

Figure 9-15 Development of hearing loss in a teenage musician (16 year old, male)

DPOAE Testing results at 12 years of age

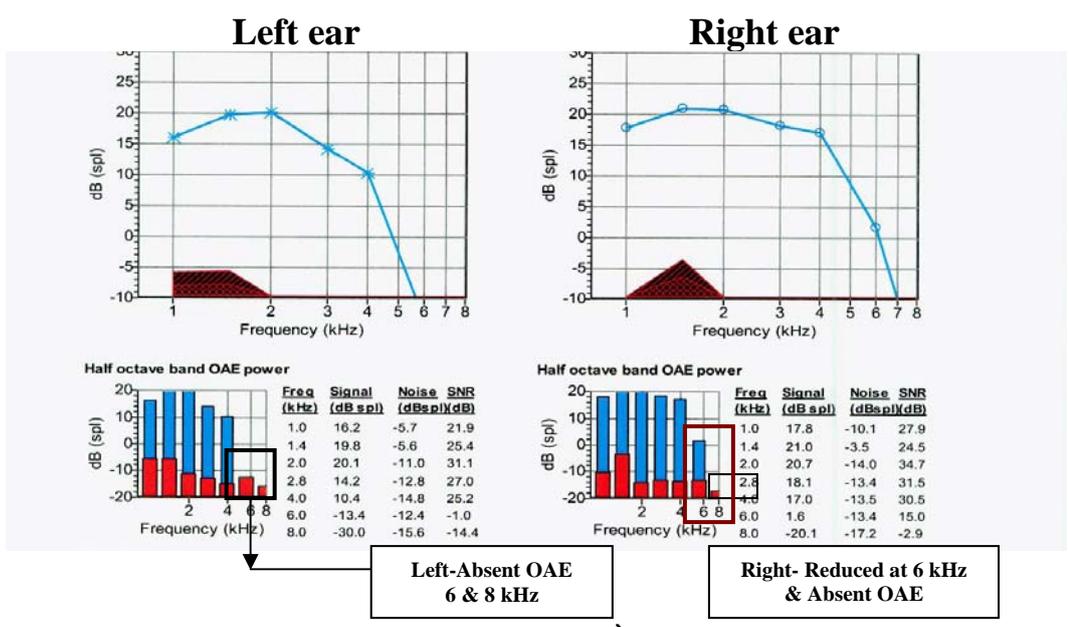
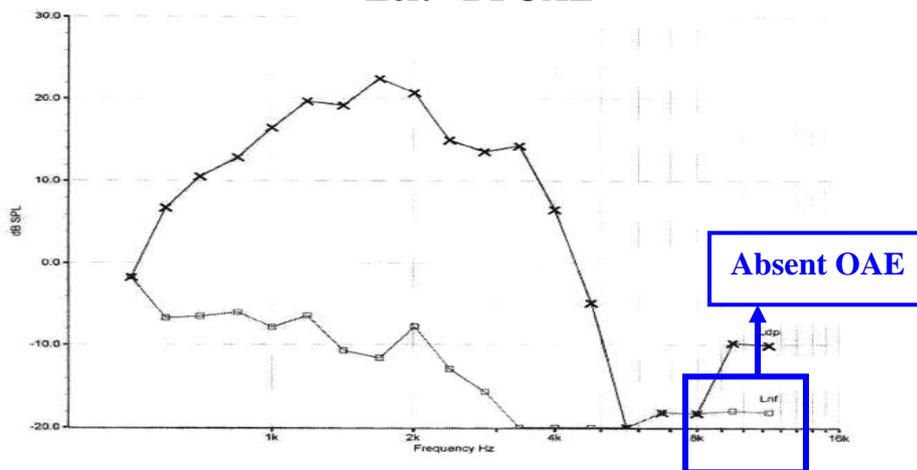


Figure 9-16 DPOAE Test results at 12 years of age

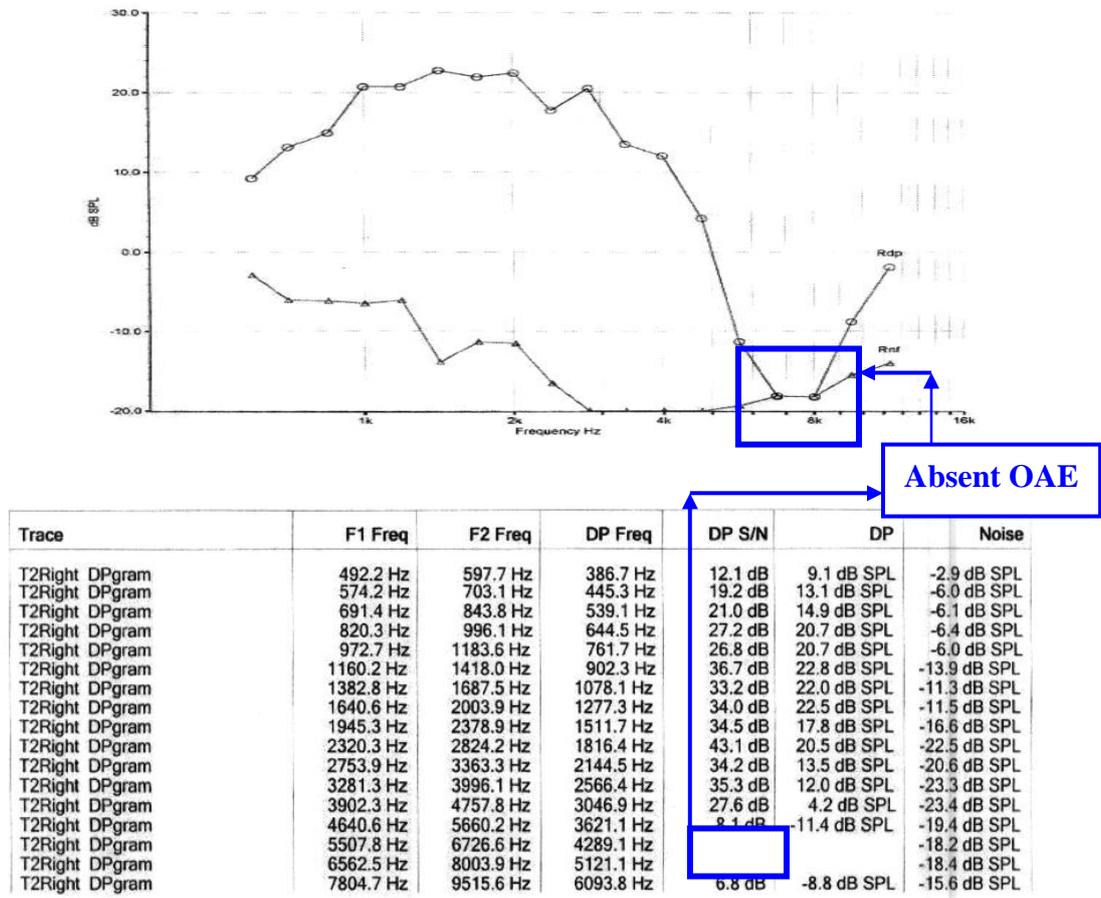
## Left - DPOAE



Trace	F1 Freq	F2 Freq	DP Freq	DP S/N	DP	Noise
T1Left DPgram	410.2 Hz	503.9 Hz	316.4 Hz			-1.8 dB SPL
T1Left DPgram	492.2 Hz	597.7 Hz	386.7 Hz	13.5 dB	6.7 dB SPL	-6.8 dB SPL
T1Left DPgram	574.2 Hz	703.1 Hz	445.3 Hz	17.0 dB	10.5 dB SPL	-6.5 dB SPL
T1Left DPgram	691.4 Hz	843.8 Hz	539.1 Hz	18.9 dB	12.9 dB SPL	-6.1 dB SPL
T1Left DPgram	820.3 Hz	996.1 Hz	644.5 Hz	24.4 dB	16.5 dB SPL	-7.9 dB SPL
T1Left DPgram	972.7 Hz	1183.6 Hz	761.7 Hz	26.2 dB	19.7 dB SPL	-6.5 dB SPL
T1Left DPgram	1160.2 Hz	1418.0 Hz	902.3 Hz	29.9 dB	19.2 dB SPL	-10.7 dB SPL
T1Left DPgram	1382.8 Hz	1687.5 Hz	1078.1 Hz	34.1 dB	22.4 dB SPL	-11.6 dB SPL
T1Left DPgram	1640.6 Hz	2003.9 Hz	1277.3 Hz	28.5 dB	20.7 dB SPL	-7.7 dB SPL
T1Left DPgram	1945.3 Hz	2378.9 Hz	1511.7 Hz	27.9 dB	15.0 dB SPL	
T1Left DPgram	2320.3 Hz	2824.2 Hz	1816.4 Hz	29.2 dB	13.5 dB SPL	
T1Left DPgram	2753.9 Hz	3363.3 Hz	2144.5 Hz	35.0 dB	14.3 dB SPL	
T1Left DPgram	3281.3 Hz	3996.1 Hz	2566.4 Hz	30.5 dB	6.6 dB SPL	-23.9 dB SPL
T1Left DPgram	3902.3 Hz	4757.8 Hz	3046.9 Hz	20.3 dB	-4.9 dB SPL	-25.2 dB SPL
T1Left DPgram	4640.6 Hz	5660.2 Hz	3621.1 Hz			-22.3 dB SPL
T1Left DPgram	5507.8 Hz	6726.6 Hz	4289.1 Hz			-18.2 dB SPL
T1Left DPgram	6562.5 Hz	8003.9 Hz	5121.1 Hz			-18.3 dB SPL
T1Left DPgram	7804.7 Hz	9515.6 Hz	6093.8 Hz	8.2 dB	-9.8 dB SPL	-18.0 dB SPL
T1Left DPgram	9269.5 Hz	11308.6 Hz	7230.5 Hz	8.1 dB	-10.1 dB SPL	-18.2 dB SPL

**Figure 9-17 DPOAE (left ear) results of teenage musician  
(16 years of age, male)**

## Right ear - DPOAE



**Figure 9-18 DPOAE (right ear) results of a teenage musician  
(16 years old, male)**

**Results:** The comparison of the audiograms (Figure 9-15) shows there is 10dB of deterioration in hearing in both the ears, and DPOAE results are consistent with the audiogram. These results shows the progression of hearing loss in an individual with a previous history of glue ear with surgical intervention, a family history of hearing loss and increased music exposure.

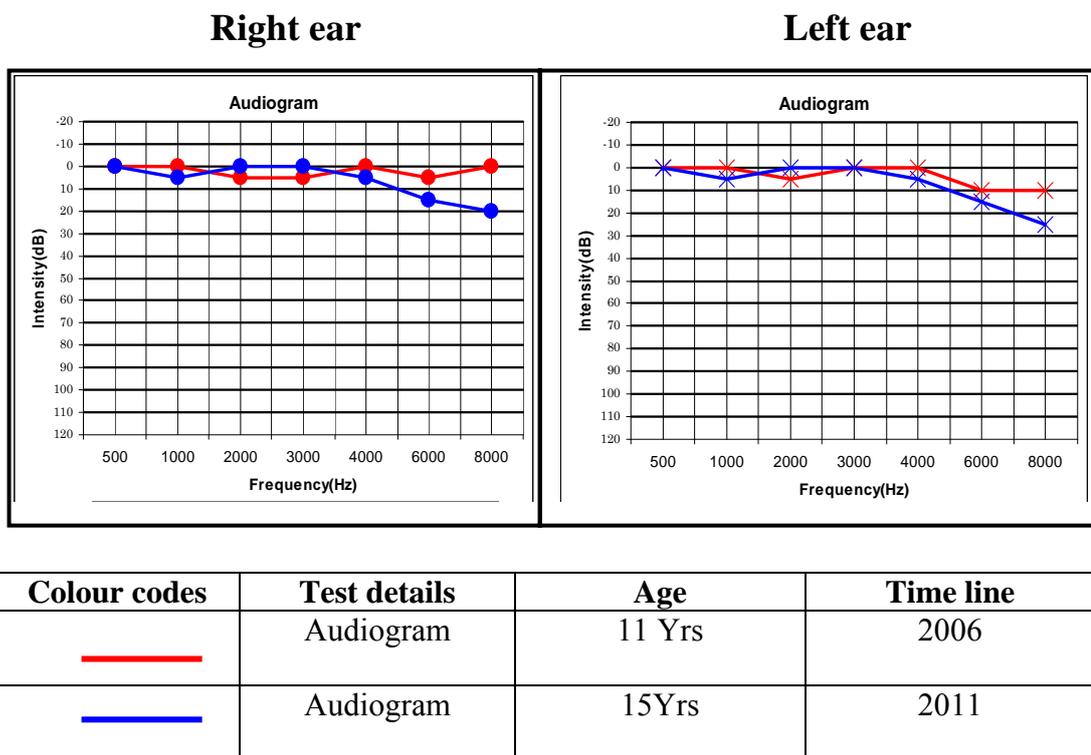
### 9.8.2 Case 2: Effect of music exposure with a family history of hearing loss

Figure 9-19 shows the audiograms performed on a teenager at 10 and 15 years of age showing the development of hearing loss with increased music exposure. Figures 9-20, 9-21 and 9-22 show the DPOAE results. The medical history includes a positive

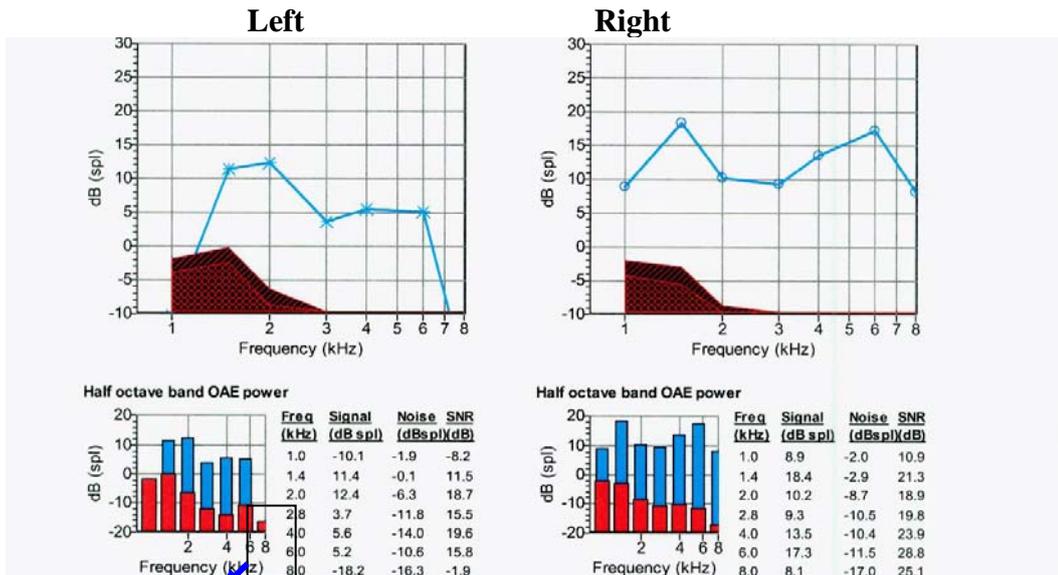
family history of hearing problems with aging on male side, no history of ear infection, and no hearing difficulty, but noticed tinnitus at times.

**Music exposure at 11 years of age:** Started playing recorder from the age of three and learned saxophone from the age of nine, part of a music academy (12 hours of music exposure/week).

**Music exposure at 15 years of age:** Jazz band: 3 hours/week + saxophone: 45 min / week + concert band 1.5 hours/week + one hour of music practice every day (12 hours/week of music since three years of age).



**Figure 9-19 Development of hearing loss in a teenage musician (15 years of age, male)**



Left-Absent OAE  
At 8 kHz

Figure 9-20 DPOAE Test results at 11 years of age

Left ear - DPOAE

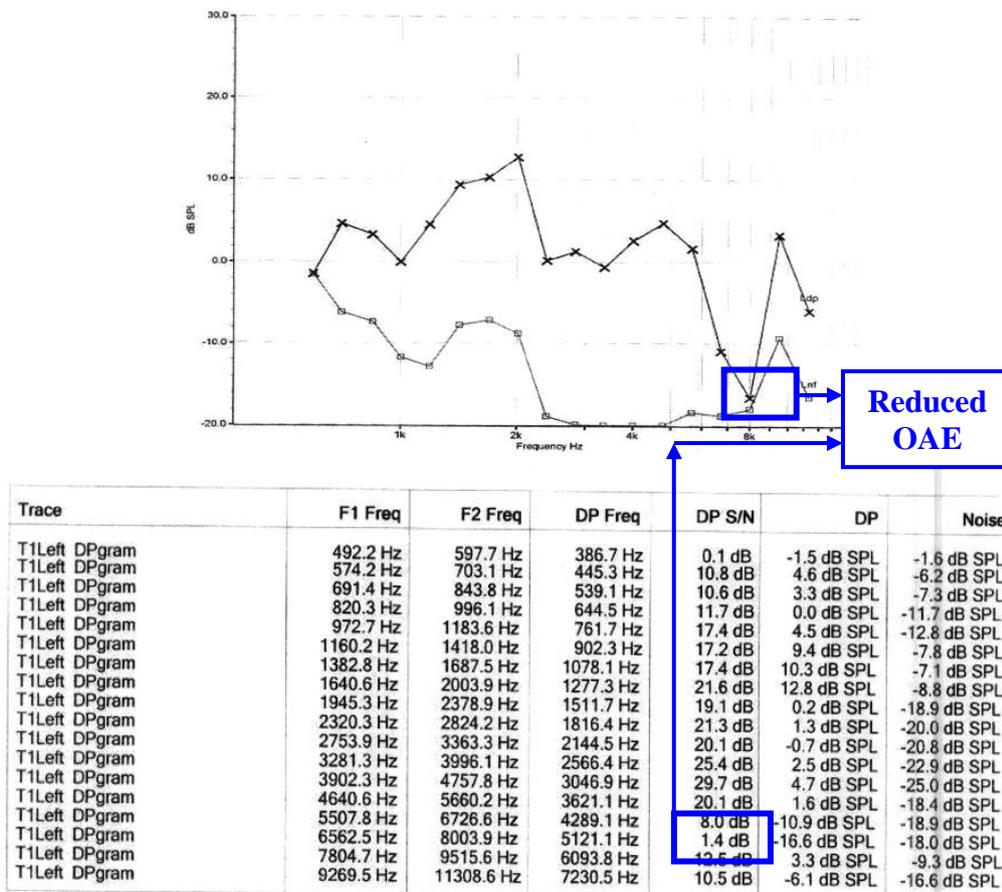
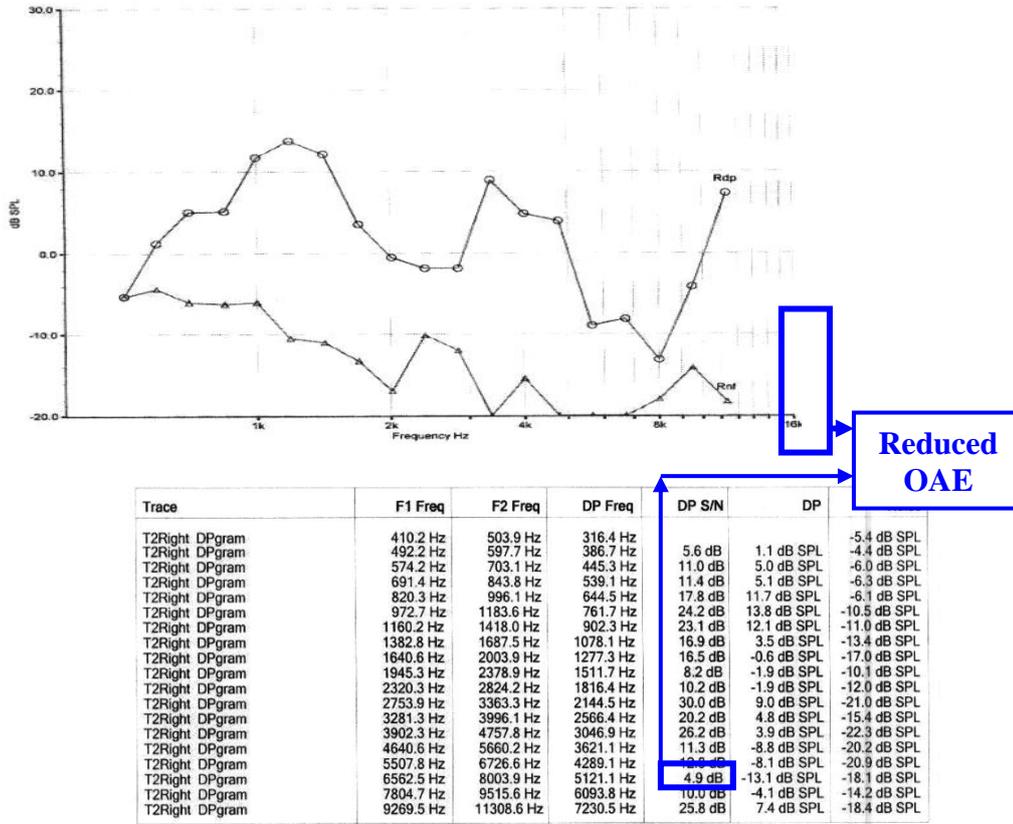


Figure 9-21 DPOAE (left ear) results at 15 year

## Right ear - DPOAE



**Figure 9-22 (Right ear) DPOAE results at 15 years of age**

**Results:** The comparison of the audiograms (Figure 9-19) shows there is deterioration in hearing in both the ears at 6 and 8kHz, and DPOAE results are consistent with the audiogram (absent OAE at 6 and 8kHz and recovery at higher frequencies). This result shows the progression of hearing loss in a teenager. Increased music exposure and family history may be a contributing factor.

### 9.9 Summary

Some individual musician's hearing loss starts at a very early age, when they start playing music, and gradual deterioration is observed with increased music exposure. In some individuals, however, the hearing is well preserved in spite of several years of music exposure. There seem to be large individual variations in susceptibility to music exposure. It is interesting to note that hearing loss development with increased music exposure follows a particular pattern; for example, in Figure 9-1

deterioration has begun at a particular frequency (6kHz in the right and 4kHz in the left ear), and hearing continues to deteriorate in that frequency and with the lesser rate in an adjacent higher frequency. There is also large individual variation in the rate of progression of hearing loss. In general, women have a better hearing threshold than men, and the rate of progression of hearing loss is also significantly different between males and females. It is a known fact that the duration of noise and/or music exposure increases the impact on hearing, assuming that the orchestra music causes hearing loss. It is likely that those musicians with more years of experience would be at a greater risk of developing more hearing loss, but this trend is not observed in all the musicians.

## **Chapter 10 : Results of personal sound exposures of musicians and fixed time-average levels taken**

### **10.1 Introduction**

Determining the music exposure of musicians in an orchestra, for the purpose of estimating the risk of hearing loss, is not an easy task. Many variables are involved and their influence is difficult to assess. For example, there are variations between the music levels from the different pieces being played and changes in the exposure from surrounding instruments due to the seating arrangement. Also, there is the assessment of the effective exposure duration, which includes playing at home and at other venues – something that is an almost impossible task.

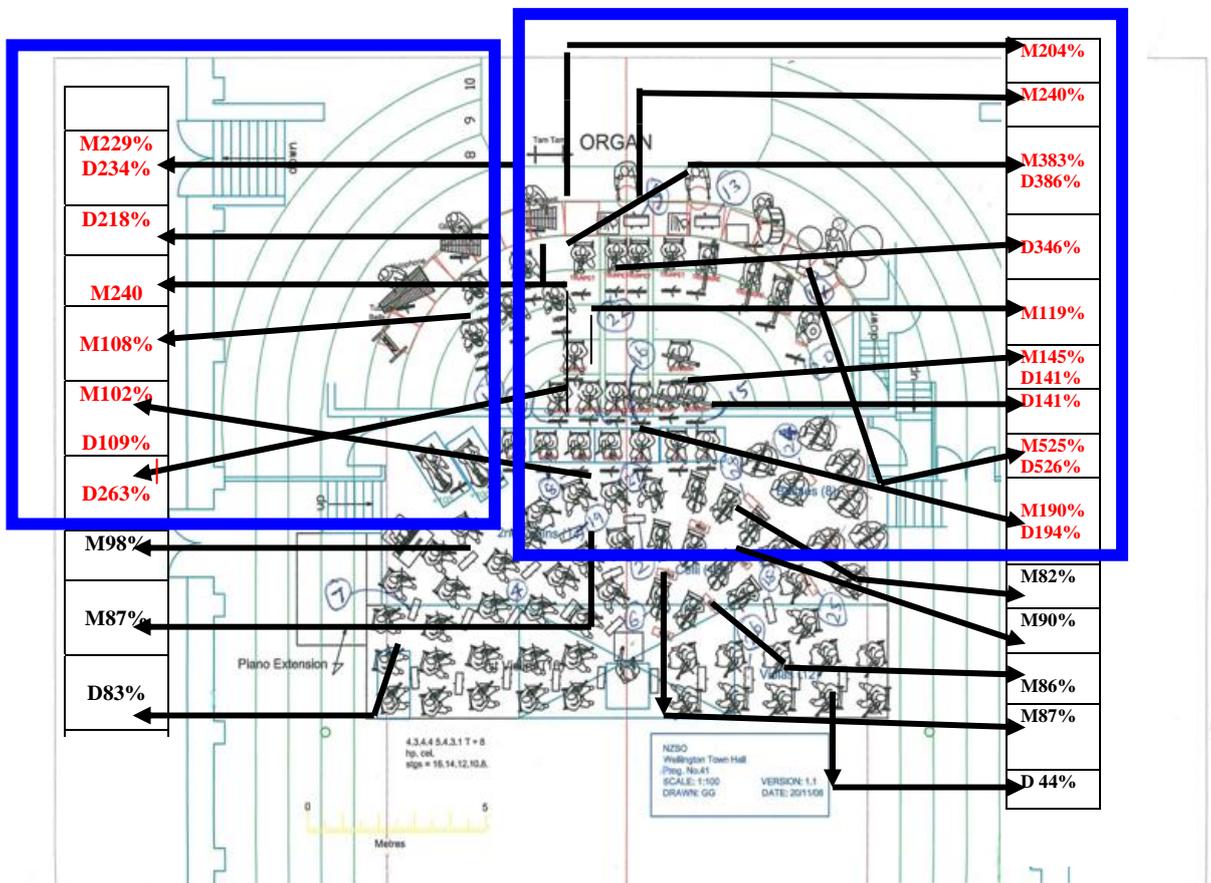
In this study we performed a complete audiology evaluation and also a music survey in order to further assess the risk of hearing loss among musicians. The music survey was performed twice during adult musicians' rehearsals and once during a rehearsal and a concert performance, once during a youth musicians' rehearsal and once during a children musicians' rehearsal. At least six adult musicians wore a doseBadge for the entire day to assess the daily sound exposure. The music exposure for musicians in various categories is summarised and listed in their categories, and the results are presented for each measurement.

### **10.2 Adult orchestra musicians – Music Survey**

#### **10.2.1 Adult orchestra musicians – Measurement (1) during Rehearsal**

A total of 23 simultaneous sound exposure measurements were made using six doseBadges and 17 M28 sound level meters. As shown in Figure 10-1, the sound level measurements were made from various locations in the orchestra, making sure that the sound measurements were made from all the instrument groups. The percentage maximum permitted daily sound exposures measured are shown in Figure 9-2 (100% is the maximum permitted daily sound exposure for an adult industrial worker). The Percussion section received a dosage of 114.5% (standard deviation:

34.7), the Woodwind section received a dosage of 75.6% (standard deviation: 15.3), the Brass section received a dosage of 75% (standard deviation: 14.5), the Long Strings section received a dosage of 47% (with the standard deviation: 0), and the Short Strings section received a dosage of 39.4% (standard deviation: 10.7). Table 10-1 shows the total time average level ( $L_{Aeq}$ ) for the entire orchestra (over a time period of 2 hours 49 minutes and 36 seconds) was 87.5dB. The highest time average level within the orchestra was 92.6dB in the horn section, and the lowest was 83.3dB in the first violin section. The average dosage was 65.7% (the highest dosage of 146% was received by the timpanist and the lowest dosage of 30% by a first violinist). The Peak level ( $L_{peak}$ ) averaged across the entire orchestra was 143dB.



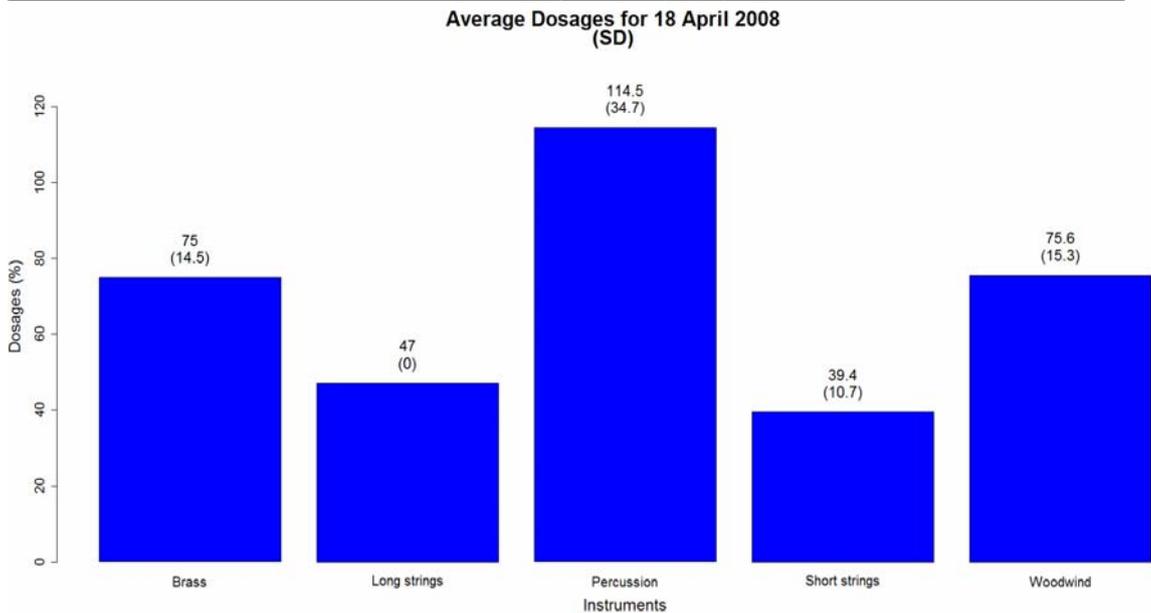
**Figure 10-1 Instrument setup for music survey  
(D-DoseBadge and M-Sound level meter)**

Figure 10-1 shows the orchestra arrangement. The major noise sources (the percussion and brass sections) are at the back of the stage, and the risk of exposure to

sound levels that exceed NIOSH and OSHA recommended standards is reduced when the musician is seated further away.

**Table 10-1 Adult orchestra musicians – Time average level measurements (1)**

Measurement details	Mean (sd)
<b>L<sub>Aeq</sub> dB</b>	87.5 (2.8)
<b>Dose (%)</b>	65.7 (32.4)
<b>Peak level (L<sub>peak</sub>) dB</b>	143.0 (1.6)
<b>Time (h.m.s)</b>	2.49.36 (0.7.9)
<b>Double dose (%)</b>	130.3 (64.8)



**Figure 10-2 Adult orchestra musicians – Average dosage for various groups of musicians (during rehearsal) – measurement (1)**

**Results:** The musicians belonging to the percussion section received a daily sound exposure greater than that recommended by law for an adult industrial worker, and this is for rehearsal alone. This measurement does not include the sound exposure during individual and group practice and concert performance, music lessons as a teacher, and other noise exposures that are likely to increase the risk of hearing loss.

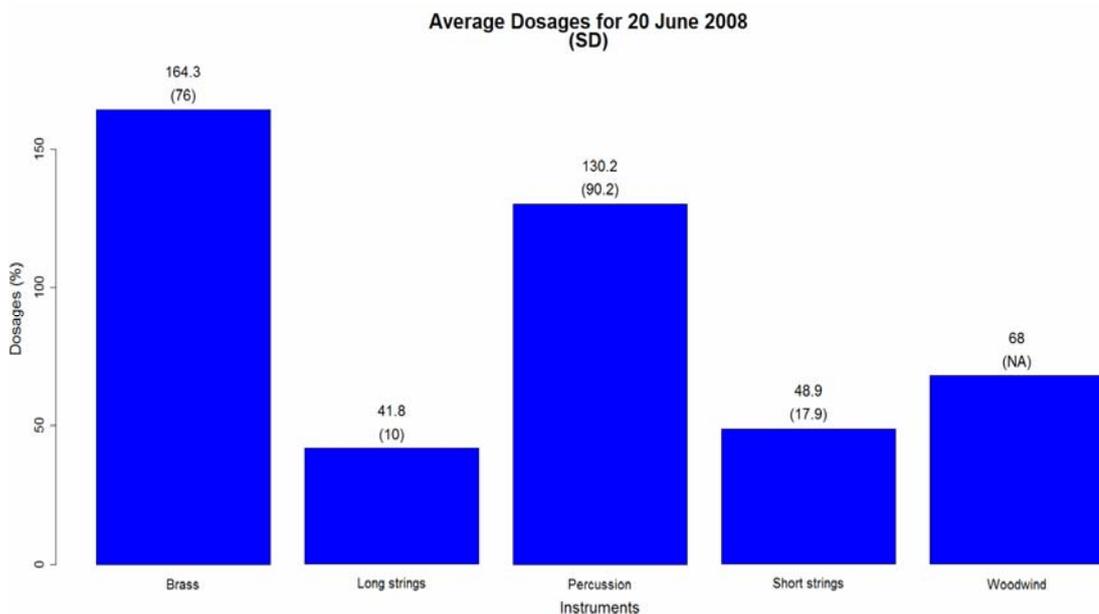
### 10.2.2 Adult orchestra musicians - Measurement (2) during Rehearsal

A total of 19 simultaneous measurements were made using M28 sound level meters. As shown in Figure 10-3, the sound level measurements were made from various locations in the orchestra, making sure that the sound measurements were made from

all the instrument groups. The average maximum percentage daily sound exposure (dosage) measured over a total time period of 3 hours 43 minutes and 18 seconds is given in Figure 10-3. The percussion section received a dosage of 130.3% (standard deviation: 90.2), the Brass section received a dosage of 164.3% (standard deviation: 76), the Long Strings section received a dosage of 41.8% (standard deviation: 10), the Woodwind section received a dosage of 68% (standard deviation: N/A), and the Short Strings section received a dosage of 48.9% (standard deviation: 17.9). Table 10-4 shows the time average level ( $L_{Aeq}$ ) overall was 85.0dB (the highest was 92.6dB, received by the timpanist and the lowest, 82.7dB, was received by the Bass player). The average dosage was 83.7% (the highest dosage of 264% was received by the timpanist and the lowest dosage of 30% by a first violinist). The average Peak level across the orchestra was 141.7dB (Ref to Table 10-2).

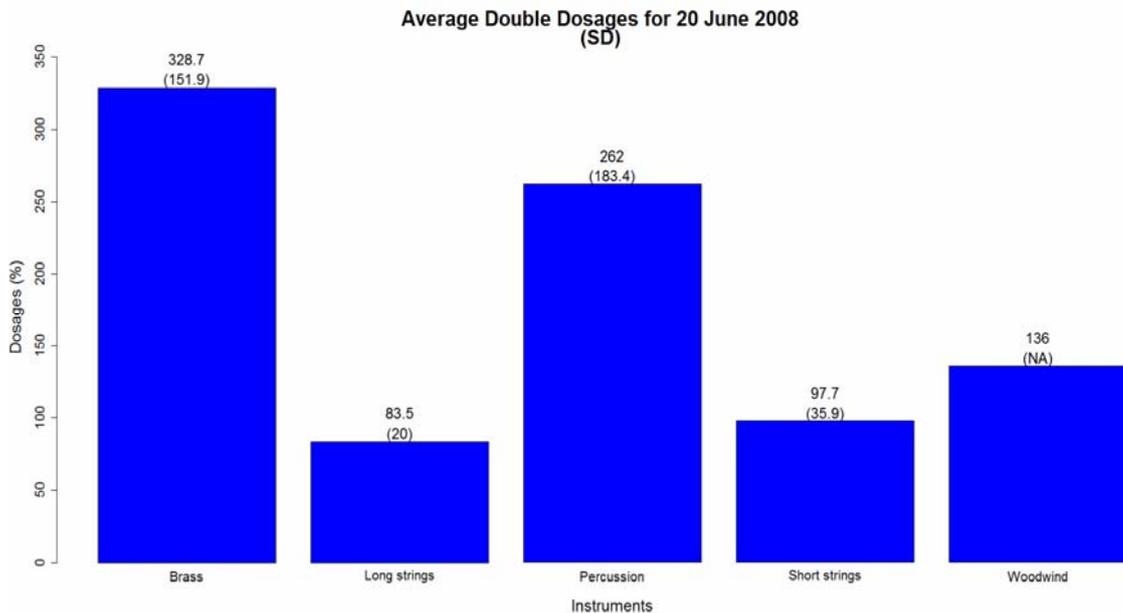
**Table 10-2 Adult orchestra musicians – Time average level measurement (2) details**

Measurement details	Mean (sd)
$L_{Aeq}$ dB	85.0 (6.9)
Dose (%)	83.7 (67.6)
Peak level ( $L_{peak}$ ) dB	141.7 (3.1)
Time (h.m.s)	3.43.18 (0.13.40)
Double dose (%)	167.8 (136.0)



**Figure 10-3 Adult Orchestra musicians – Average dosage for various groups of musicians (during rehearsal) - measurement (2)**

**Double dosage:** As most of the orchestra musicians have their rehearsal and performance on the same day, we calculated the double dosage for adult musicians (Ref - Figure 10-4).



**Figure 10-4 Adult Orchestra musicians – Average double dosage for various groups of musicians (during rehearsal) – measurement (2)**

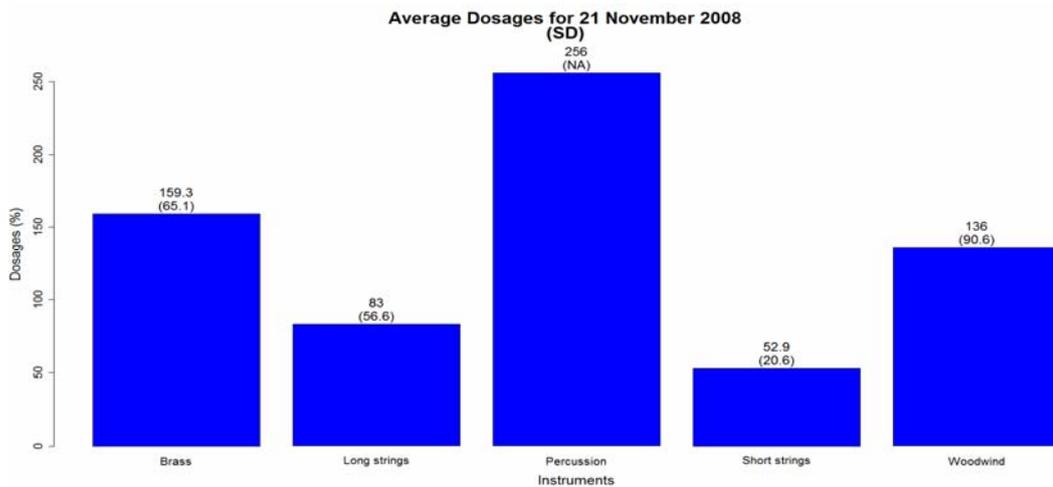
**Results:** The musicians belonging to the Brass and Percussion sections received daily sound exposure in excess of the maximum permitted for an adult industrial worker, and this is for rehearsal alone. The measurement result does not include the individual and group practice or exposure during a concert performance. As most of the orchestra musicians have their rehearsal and performance on the same day, we calculated the double dosage for adult musicians. Figure 10-4 shows that the double dosage increases the risk further with more sections of the orchestra (Brass, Percussion and Woodwind) receiving music levels in excess of the permissible dosage levels. This measurement does not include the individual and group practices, music lessons as a teacher, and other noise exposures, which likely increase the risk of hearing loss.

### 10.2.3 Adult orchestra musicians – Measurement (3) during Rehearsal and Performance

This measurement was made to assess the risk of combined effect of both rehearsal and performance (as most of the orchestra musicians have their rehearsal and performance on the same day). A total of 42 measurements were made using 26 Quest M28 sound level meters attached to the music stand in front of the musician and 16 Cirrus doseBadges pinned to the clothing of the consenting musicians. Figure 10-5 gives the daily sound exposure as a percentage of the maximum permitted for an adult industrial worker (the dosage). The percussion section received a dosage of 256% (standard deviation: NA), the Brass section received a dosage of 159.3% (standard deviation: 65.1), the Long Strings section received a dosage of 83% (standard deviation: 56.6), the Woodwind received a dosage of 136% (standard deviation: 90.6), and the Short Strings received a dosage of 52.9% (standard deviation: 20.6). Table 10-3 shows the time average level over the entire orchestra ( $L_{Aeq}$ ) was 87.4dB (the highest time average level was 95.2dB, received by the Clarinet player, and the lowest, 83dB, was received by the violinist). The average dosage was 110.2% (the highest dosage of 264% was received by the Clarinet player, who sat just in front of the trombones and the lowest dosage, at 70%, was received by a first violinist), the average Peak level was 142.0dB, and the total time measured was 11h.10m.42s.

**Table 10-3 Adult orchestra musicians – Average measurement (3) details  
(during Rehearsal and Concert Performance)**

<b>Measurement details</b>	<b>Mean (sd)</b>
<b><math>L_{Aeq}</math> dB</b>	87.4 (4.2)
<b>Dose (%)</b>	110.2 (77.9)
<b>Peak level (<math>L_{peak}</math>) dB</b>	142.0 (3.6)
<b>Time (h.m.s)</b>	11.10.42



**Figure 10-5 Adult orchestra musicians – Average dosage for various groups of musicians (during rehearsal and concert performance) – measurement (3)**

**Results:** The time average levels taken during an adult orchestra rehearsal and a concert performance show that the majority of the musicians seated towards the back of the stage received sound exposures in excess of the permissible exposure levels. This data shows that when rehearsal and performance is on the same day, the daily sound exposure is exceeded in three of the sections: the Percussion section received a dosage of 256%, the Brass section received a dosage of 159.3% and the Woodwind, which sits just in front of the Brass section, received a dosage of 136%. On the other hand, the musicians in the Short Strings and Long Strings sections received a dosage that is within the permissible range. This measurement does not include the individual and group practices, music lessons as a teacher, and other noise exposures likely to increase the risk of hearing loss.

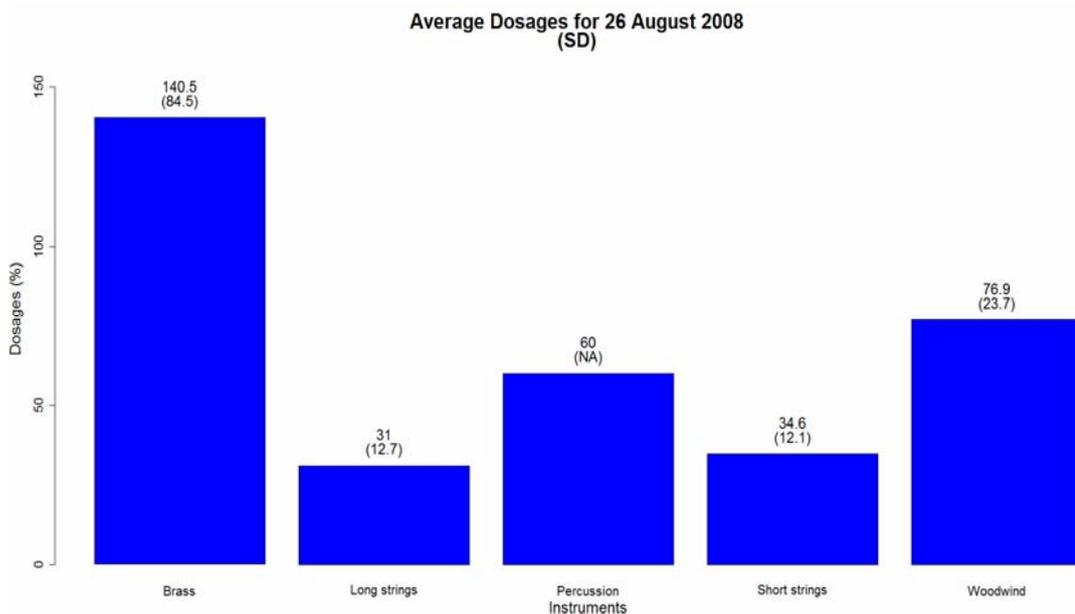
### **10.3 Youth orchestra musicians -Measurement during Rehearsal (1)**

A total of 20 measurements (14 sound level meters and six doseBadges) were made. Figure 10-6 shows the daily sound exposure measured. The Percussion section received a dosage of 60% (standard deviation: NA), Brass section received a dosage of 140.5% (standard deviation: 84.5), the Long Strings section received a dosage of 31% (standard deviation: 12.7), the Woodwind received a dosage of 78.9% (standard deviation: 23.7), and the Short Strings received a dosage of 34.6% (standard deviation: 12.1). Table 10-4 shows the average level ( $L_{Aeq}$ ) across the entire orchestra was 85.5dB (the highest time average level was 93.1 dB received by the

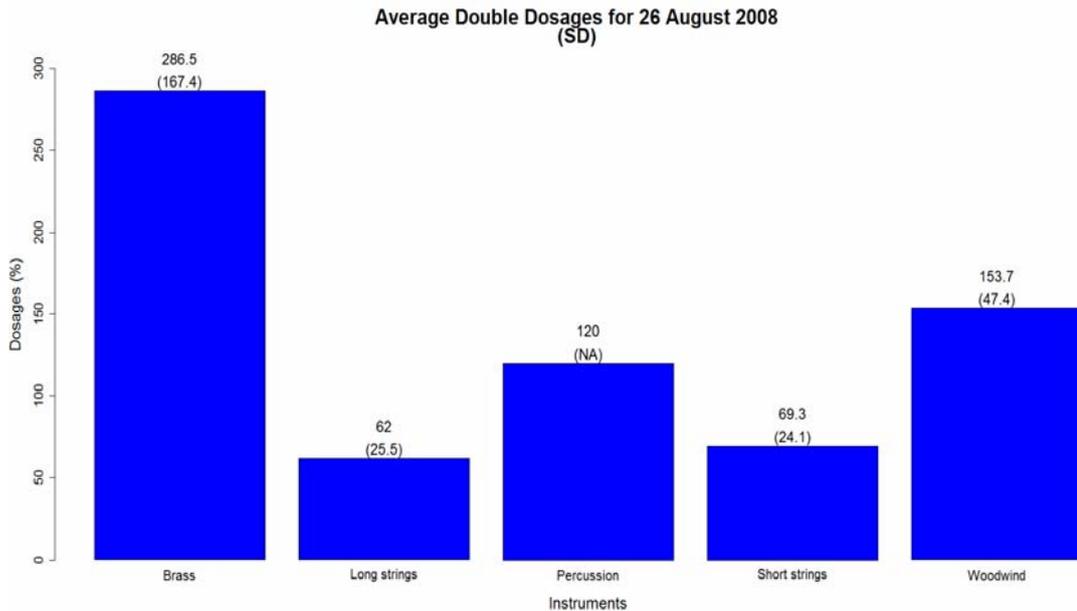
Trumpet player and the lowest, at 82.7dB, was received by the violinist). The average dosage was 67.3% (the highest dosage of 265% was received by the Trumpet player and the lowest dosage of 22% by a first violinist). The average Peak level was 143.0dB and the total time measured was 3h.56m.9s.

**Table 10-4 Youth orchestra musicians – Average measurement details (During rehearsal)**

Measurement details	Mean (sd)
<b>L<sub>Aeq</sub> dB</b>	85.5 (3.0)
<b>Dose (%)</b>	67.3 (55.2)
<b>Peak level(L<sub>peak</sub>) dB</b>	143.0 (2.2)
<b>Time (h.m.s)</b>	3.56.9 (0.19.54)
<b>Double dose (%)</b>	135.7 (111.6)



**Figure 10-6 Youth Orchestra musicians – Average dosage for various groups of musicians – measurement during rehearsal**



**Figure 10-7 Youth orchestra musicians-double dosage – Average dosage for various groups of musicians – measurement during rehearsal**

**Results:** The fixed time average levels, taken during a youth orchestra rehearsal, show that only the musicians in the percussion section have received sound exposures in excess of the permissible dosage. As most of the orchestra musicians have their rehearsal and performance on the same day, we calculated the double dosage for youth musicians. Figure 10-7 shows that the double dosage increases the risk further with more sections of the orchestra (the Brass, the Percussion and the Woodwind) receiving music sound exposure in excess of the permissible dosage. This measurement does not include the individual and group practices, music lessons as a student, personal stereo usage, and other noise exposures that are likely to add to the daily dosage and potentially further increase the risk of hearing loss.

#### **10.4 Children musicians-Measurement during Rehearsal (1)**

A total of 15 measurements were made (six sound level meters and nine doseBadges). Table 10-6 shows the daily sound exposure as a percentage of the maximum recommended level for an adult industrial worker. The Percussion section received a dosage of 109.3% (standard deviation: 1.5), the Brass section received a dosage of 111.2% (standard deviation: 2.1), the Woodwind received a dosage of 54.7% (standard deviation: 2.6), and the Short Strings received a dosage of 44.2%

(standard deviation: 11.2). In Table 10.5 the average level ( $L_{Aeq}$ ) was 83.5dB (the highest, at 90.1dB, was received by the Percussionist and lowest, at 81.1dB, was received by the violinist). The average dosage was 68.4% (the highest dosage of 155% was received by the percussionist and the lowest dosage of 32% by a violinist). The average Peak level was 144.0dB, and the total time measured was 1h.54m.10s.

**Table 10-5 Children orchestra musicians – Average measurement details (during rehearsal)**

Measurement details	Mean (sd)
<b><math>L_{Aeq}</math> dB</b>	83.5 (3.0) Highest average received-90.1dB % by a percussionist and lowest-81.1.dB by a violinist
<b>Dose (%)</b>	68.4 (55.2) Highest dosage received-155% by a percussionist and lowest-32 % by a violinist
<b>Peak level(<math>L_{peak}</math>) dB</b>	144.0 (2.2)
<b>Time (h.m.s)</b>	1h.54m.10s (0.18.44)

**Table 10-6 Children Orchestra musicians – Average dosage for various groups of musicians during rehearsal**

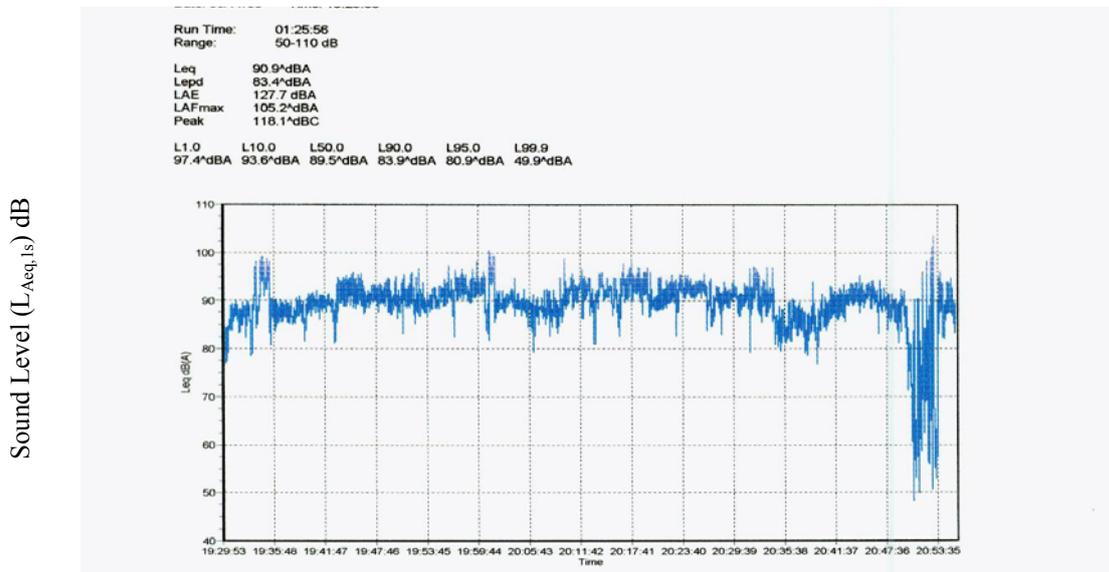
Group of musicians	Average Dosage(SD)
<b>Brass</b>	111.2% (2.1)
<b>Percussions</b>	109.3% (1.5)
<b>Short Strings</b>	44.2% (11.2)
<b>Woodwind</b>	54.7% (2.6)

**Results:** The fixed time average level and personal dosage measurements taken during a children orchestra rehearsal show at the musicians in the Percussion and Brass sections have received sound exposures in excess of the maximum permissible dosage for adults in industry. This measurement does not include the individual and group practices, music lessons as a student, personal stereo usage, and other noise exposures such as noisy toys, which are likely to increase the dosage and further increase the risk of hearing loss.

## 10.5 Sound exposure during school discotheques

As we wanted to analyse the risk of other noise exposure in children, sound measurements were performed during a school disco. The two sound level meters were mounted on a tripod and were placed in the disco hall where most children were dancing during the session. Among the 37 children musicians, 23 (62.1%) children

musicians felt that it was loud and 14 (37.8%) felt that it was normal and not very loud. Figure 10.8 shows the measured time average level ( $L_{Aeq}$ ) was 90.9dBA and  $L_{epd}$  is 83.4dBA. The peak level was 118dBC and the running time: 01hr: 25min: 56sec.



**Figure 10-8 Sound Level measurements taken during a School disco**

**Results:** This finding emphasises the importance of educating children on hearing health and the risks associated with increased music and noise exposure.

### 10.6 Assessment of whole day exposure for selected musicians

In order to assess the overall risk of music exposure and to measure the whole day exposure, six adult musicians wore doseBadges for the whole day (10am-9pm).

**Table 10-7 Measurement details (whole day sound exposure) for selected musicians)**

Musical Instrument	Equipment	$L_{Aeq}$	Dose (%)	Peak level ( $L_{peak}$ )
Tympani	doseBadge	91.0dB	526%	Exceeded 140
Clarinet	doseBadge	89.1dB	349%	Exceeded 140
Trumpet	doseBadge	88.0dB	263%	Exceeded 140
Trombone	doseBadge	84.0dB	110%	Exceeded 140
2 <sup>nd</sup> Violin	doseBadge	83.8dB	109%	Exceeded 140
1 <sup>st</sup> Violin	doseBadge	80.0dB	44%	Exceeded 140

**Results:** Table 10-7 shows that when rehearsal and performance is on the same day, the maximum permitted daily sound exposure (dosage) is exceeded by five out of the six musicians (Tympani, Clarinet, Trumpet, Trombone, and 2<sup>nd</sup> violin). Only the 1<sup>st</sup> Violinist did not exceed the permissible daily dosage limit of 100%. On the other hand, all exceeded the maximum permitted peak level. The musicians were asked to inform of any other noise exposure apart from the music exposure. The timpanist is reported to have driven a motor cycle for 42 minutes and also had an individual practice for 30 minutes during the break. The rest of the five musicians had 45 minutes of individual practice during the break before the performance.

## **10.7 Summary**

Data was grouped according to instrument family and specialty (Brass, Percussion, Woodwind, Long Strings and Short Strings). As a group, the Brass instruments experienced the highest average sound levels and exposures. The musicians on stringed instruments experienced the lowest average sound levels and exposures during musical activities.

The highest noise exposure was found among the Percussion and Brass instruments, followed by the Woodwind, and then the Strings, but understandably this will vary, depending on the type of music played. In general, the measured noise exposure decreases with the distance from the Brass and Percussion sections. For example, the music exposure of the viola and cello players was higher than that of the first violins, which are further away from the Percussion and Brass. The woodwind section sits directly in front of the Brass section and so receives much sound that is not of its own making. The implications from this study confirm that the woodwind, brass and percussion musicians are exposed to sound levels that exceed international and national standards for daily sound exposure, and that also having the rehearsal and performance on the same day increases the risk of a hearing loss to other musicians. The main music source that increases the potential risk of noise induced hearing loss (NIHL) comes from the back of the orchestra. The other noise exposure apart from daily musical activity may further increase the risk of acquired hearing loss in musicians.

Among the adult musicians, while they were playing, the average sound levels ranged from 61dB for a violin player to 92.6dB for a timpanist on the first measurement and from 82.7dB for a violin player to 92.6dB for a timpanist on the second measurement. The average sound levels ranged from 83dB for a violin player to 95.2dB for a clarinet player on the third measurement. Among the youth musicians, daily average sound levels ranged from 81.1dB for a violin player, to 93.1dB for a trumpet player, and among the children musicians from 81.3dB for a violin player to 91.6dB for a percussionist.

## **Chapter 11 : Discussion**

### **11.1 Introduction**

Orchestral music forms a valuable and integral part of human cultural life. The review of available literature regarding hearing loss among orchestral tends to show that the risk can be quantified as minimal or nonexistent. The huge variation in drawn conclusions is possibly due to the fact that the impact of orchestral music on the hearing of an individual musician, music group or organisation is dependent on many factors, some of which are known and some unknown. Some are not quantifiable, measurable and comparable, some are intrinsic, and some are extrinsic factors. It is impossible to calculate the complete dosage of music exposure for each musician that accounts for each factor that might have directly or indirectly influenced the resulting hearing loss, and also almost all of the musicians have other music exposure such as individual and group practice, and other music assignments in various locations which are acoustically very different. The exposure durations, loudness and music characteristics are randomly distributed throughout the entire life of a musician.

The results of this research project show that there are several factors that determine the status of individual musician's hearing. Each orchestra is different, and with a varied composition with various backgrounds of professional musical experience, hence it is not possible to compare one group with another and draw conclusions, or to expect similar findings. For example, Fleischer and Muller (2005) found that the hearing of 83.4% was better than that predicted by the ISO 1999 standard. The authors supported the theory that a high noise level may indeed build resistance to hearing loss. Some of the studies found that the hearing of classical musicians is similar or only slightly affected when compared to a non-exposed population (Bremmelgaard & Obeling, 1996; Obeling & Poulsen, 1999; Kahari et al., 2001; Beale, 2002). However, according to Emmerich et al., (2006), professional musicians often suffer from occupational hearing loss.

Sound levels generated by musical instrument are different from industrial noise. They are different in sound characteristics – the industrial noise is often low, flat frequency noise with few discrete frequencies whereas music differs in intensity, frequency distribution and duration of exposure (Chasin, 1996). The maximum frequency energy from music varies between different musical instruments in the orchestra and musical pieces played. It is also complex as the music played by the orchestra contains reflections from the surfaces of the often specially designed space in which the music is played. The very nature of music is intermittent and has both quiet and intense passages. This variability in sound pressure levels has been thought to reduce the risk of hearing loss when compared to an industrial noise exposure, where it is constant (Chasin, 1996).

The musical sound level can be intense over limited periods with the presence of high peak levels, but in general the intensity continues to fluctuate and includes periods of quiet passages and some small gaps during performance, and between rehearsal and performance; hence it is believed that the hearing mechanism gets an opportunity to rest between intense passages in the music and to possibly recover from possible temporary threshold shift. According to Clark and Bohne (1987); Sine, Clark & Bohne, (1987); and Clark & Bohne, (1992), an interrupted exposure to noise (e.g., six hours a day for 36 days) initially produces the same magnitude of temporary threshold shift as a continuous exposure; however, as the interrupted exposure paradigm continues, thresholds begin to improve and may eventually return to within 10-15dB of the pre-exposure baseline. It is thought that this phenomenon helps to preserve the hearing. It is also thought that there is a toughening effect from auditory training during rehearsal and individual practice (Canlon, 1992; Miyakita, Hellstrom, Frimanson and Axelsson, (1992), and according to Micheyl, Morlet, Giraud, Collet and Morgon, (1995), the musicians have a stronger medial efferent feedback on the auditory periphery.

In this study we found that 60.7% of the adult, 22.4% of youth, and 16.2% of the children have hearing loss (a musician is considered to have a hearing loss if their hearing threshold is  $\geq 25$ dB at least in one of the frequencies and at least in one ear). This goes against the proposed theory that the hearing mechanism gets an opportunity to rest and recover from temporary threshold shift and this helps to

preserve their hearing. Also, if the auditory toughing effect or building resistance with auditory training during practice and rehearsal is a true phenomenon, then adult musicians should have better hearing than youth musicians, youth musicians would be expected to have better hearing than the children musicians, and musicians in general should have better hearing than the general population. During the hearing evaluation, the researcher found that the musicians were good with detecting pure-tones and were capable of identifying subtle variations in intensity and frequency. This may be the reason for some of the research studies finding better hearing thresholds than in the general population. This observation is in agreement with Dowling and Harwood (1986) who found that musicians perform better in pure-tone audiometry.

Some of the studies on the hearing of orchestral musicians have found that their pure-tone hearing thresholds do not really deviate from that of a non-exposed population (e.g. Kähäri et al., 2001a, b; Eaton & Gillis, 2002; Obeling & Poulsen, 1999). It has been hypothesised that specific ‘music and/or musicians characteristics’ are responsible for this result: Wanted or good sounds such as music could be less harmful than unwanted sounds such as industrial noise (Karlsson et al., 1983), or musicians perform relatively well on pure-tone audiometry testing because of a strong motivation and familiarity with detecting pure-tones (Dowling & Harwood, 1986). Another study (Seither-Peisler et al., 2007) found that for musicians with their well-trained ears and developed sensitivity to sound and music in general, a hearing evaluation using pure-tone audiometry seems to produce very different results to those from, for instance, workers in a noisy industry or the general population.

The participation of orchestral musicians was on a voluntary basis. We are aware that this could have produced a selection bias, probably towards the better hearing musicians and those who were more cautious regarding their hearing, as musicians with existing hearing loss may have been reluctant to having their hearing tested or participate in this study.

## **11.2 As a special group**

In this study, one of the research questions was whether symphony orchestras should be treated as a special group with regard to hearing, music, and music-related hearing problems. Unlike industrial workers, a combination of some important factors has a significant effect on the hearing of many professional orchestra musicians at risk: they are often subjected to intense music levels for long periods of time, beginning from childhood years, while studying music, during individual practice, and when rehearsing and performing music. Boasson (2002) reported that they often play or practise in an acoustically poorly equipped space, and also because music is their product of their job, many are not regular in using the musician plugs and feel very uncomfortable in using them in spite of their being made available.

Given that the musicians' hearing requirements are much different from the general population, in this study we have not applied any age or gender correction, including the longitudinal data, to the normal-hearing reference group of ISO 7029 (2000) standard.

## **11.3 Impact of hearing loss in musicians**

Although small and possibly mild, a hearing loss caused by loud music exposure may have significant effects on an orchestra musician's career. The success of the musician is dependent on their musical ability to accurately match frequencies over a very broad range (Kahari et al., 2001a). For a musician, any degree of hearing loss is not desirable, as it can make it difficult to hear the higher musical tones, because music induced hearing loss is greater in the high frequency region. The quieter musical sounds may become inaudible and have an effect on the timbre and balance of one's music. It has been known that the perception of timbre or the spectrum of music is affected by even a mild form of hearing loss caused by loud music exposure. In the perception of music, the overtones, or cluster of individual musical tones, define the quality or timbre of a musical instrument. A musician with the difficulty to perceive certain musical tones may play excessively loud and produce music that is artistically undesirable Teie, (1998).

In some of the orchestral musicians, music induced hearing damage can have a significant negative effect on their entire lifestyle. In the audiology clinical environment, it is a common observation that some individuals who have normal hearing with slight high frequency hearing loss as little as 5-10dB perceive it as a hearing handicap and seek help. The individual's hearing difficulties become more obvious when they try to understand speech in the presence of background noise or in group situations. Moreover, our world has become a noisy place, and an individual even with a mild hearing difficulty will find it challenging in certain difficult-to-hear environments. The hearing difficulties imposed by this mild subclinical hearing loss can become frustrating and have significant effects on the individual's quality of life. Tinnitus is also known to have a significant negative effect on an individual's quality of life as it is a threat to the individual's silence and may have a significant impact on other activities of daily living.

Good hearing is critical for a musician who must correctly perceive and produce the accurate pitch, loudness, timbre, tempo, and style of a musical piece. While for non-musicians the critical frequency range for speech perception is 250 to 4000Hz, musicians must be able to discriminate specific frequencies over a much broader frequency range. The range for a piano is 16 to 8000Hz, and for a pipe organ up to 16,744Hz. Psychological issues related to hearing difficulties also may be present (McBride et al., 1992; Chasin, 1999; Zembower, 2000; Kahari et al, 2001).

#### **11.4 Hearing Handicap**

The high frequency loss associated with difficulty in perceiving high pitched sounds and inability to discriminate speech sounds in difficult-to-hear environments, such as group situations or background noise, results in major communication problems for an individual (Hetu & Getty, 2001).

The musicians who participated in this study were interested in the evaluation of their hearing. They emphasised that hearing plays an important role for practising their profession. However, even those with a significant loss of hearing turned down the diagnosis of 'hearing deficit'. The fear of a loss in personal reputation or being stigmatised as a handicapped person seems to be a major hindrance.

## **11.5 Hearing loss in various age groups of orchestra musicians**

Orchestra musicians are a very special group of professionals, and hearing plays a very important role in their career. Even a slight alteration in their hearing may have an impact on their ability as musicians. Given this fact, in this study to account for hearing loss in orchestra musicians, we have adopted a very strict criterion – a musician is considered to have a hearing loss if an individual musician's hearing threshold is  $\geq 25$ dB at least in one of the frequencies tested and at least in one ear. Some of the earlier studies had concluded that musicians had poorer hearing levels than age-matched control groups (Kaharit, Zachau, Eklof, Sandsjo & Moller, 2003; Emmerich et al., 2006). Other studies contradicted these findings; Kahari et al., 2001b, in studies of Swedish orchestras, did not find such a correlation. It should be noted, however, that different study designs (use of questionnaires, audiometry, dosimetry and differences in measurement methods used), and also the small numbers of participants in a study performed in one orchestra, might be reasons for the conflicting results (Palin, 1994). In another study (Sataloff, 1991), audiological evaluation and music surveys while rehearsing were performed to analyse the risk of hearing loss in orchestra musicians. Analysis of the audiometric results reveal that some orchestra musicians have reduced hearing thresholds when compared to an otologically normal ISO 7029 population, and some of them even have better hearing. Sataloff concluded that difference between the orchestra musicians with hearing loss and a control population were relatively small, ranging from 3-6dB across the frequency region from 1.5-8kHz.

In this study we have found that out of 61 adult musicians, 37 (60.7%) had a hearing loss. Out of the 85 youth musicians, 19 (22.4%) were found to have hearing loss, and six out of the 37 children musicians (16.2%) had hearing loss. This finding is similar to or slightly higher than the 52% of the orchestra students reported by Phillips et al., (2008); 58% by Ostri et al., (1989); and 53% of the orchestra musicians found to have a hearing loss by Royster et al., (1991). This finding is also similar to the findings by Fearn (1993), who found that 33% of orchestra musicians and 50% of those playing amplified music had an absolute threshold of 15-20dB at 6000Hz. Each composition of the music group is different, and they are not matched in terms of various contributing variables (such as age, sex, instruments played,

individual susceptibility of each of the musicians, years of professional activity etc). Although our findings are similar to other findings, it is not feasible to compare various orchestras, and the drawn conclusions from one to another should not be applied.

In this study we observed from the pure-tone audiometry results of various age groups of orchestra musicians (Tables 8-2 to 8-3) that the mean average hearing thresholds increases with increasing age and increased years of professional music exposure. This trend is observed particularly in mid and high frequency regions. Music induced hearing loss does not show significant deterioration in hearing in the low frequency region, particularly in the frequency region of 250-1000Hz. Also, the deterioration in hearing with increased music exposure is very slow in the low frequency region when compared to the mid and high frequency regions. Though hearing deterioration is predominately in the high frequency region, for a significant number of musicians deterioration is more at 6kHz than in the other frequencies.

Karlsson et al., (1983) found that the average threshold levels for symphony musicians were within the range expected for their age and therefore concluded that performing with a symphony orchestra was not a risk to hearing. Obeling and Poulsen (1999) arrived at a conclusion that musicians are not expected to suffer significant hearing loss compared to the median audiogram from ISO 7029 for the same age and gender from industrial noise exposure.

In this study we have not compared the hearing threshold of musicians with the average population because musicians are a special group of people who possess a unique ability to identify the subtle differences in intensity and frequency of sounds. Even a small change or alteration in their hearing will have a significant effect on their musical ability while even a large alteration may not be an issue for someone who is not a musician.

### 11.5.1 Hearing loss distribution among adult musicians-Sample size (n) = 61

**Table 11-1 Distribution of hearing loss among adult orchestra musicians**

Group of musicians	Number of musicians With normal hearing (%)	Musicians with normal hearing-Mean age in Years(SD)	Musicians with normal hearing-Age range in years	Number of musicians with hearing loss (%)	Musicians with hearing loss-Mean age in Years(SD)	Musicians with hearing loss-Age range in years
Brass	3 (4.9)	50.0 (3.8)	47-54	6 (9.8)	46.8 (9.6)	31-60
Long strings	5 (8.2)	42.4 (9.8)	30-55	6 (9.8)	49.8(12.8)	27-63
Percussions	0 (0)	NA	NA	3 (4.9)	42.3(10.0)	32-52
Short strings	12 (19.7)	40.3 (6.7)	29-51	20 (32.8)	51.5 (8.0)	34-66
Woodwind	4 (6.6)	37.5 (5.8)	32-45	2 (3.3)	53.0 (4.2)	50-56

Comparison of age distribution among the adult orchestra musicians (Table 11-1) with normal hearing and those with a hearing loss shows that the mean age of musicians with hearing loss is higher than the musicians with normal hearing except in the Brass section. It is also clear that hearing loss is found in all musicians groups, the minimum age in the Brass section is 31 years, in the Long Strings 27 years and in the Percussion 32 years. This finding clearly demonstrates that there is a large individual variation. Some musicians acquire hearing loss during their early 30s, some during their 40s, and some even maintain normal hearing throughout their professional music career.

### 11.5.2 Hearing loss distribution among youth musicians-Sample size (n) = 85

**Table 11-2 Distribution of hearing loss among youth orchestra musicians**

Group of musicians	Number of musicians With normal hearing (%)	Musicians with normal hearing-Mean age in Years(SD)	Musicians with normal hearing-Age range in years	Number of musicians with hearing loss (%)	Musicians with hearing loss-Mean age in Years(SD)	Musicians with hearing loss-Age range in years
Brass	10 (11.8)	21-36	25.8 (4.7)	3 (3.5)	19-27	23.0 (4.0)
Long strings	11 (12.9)	18-27	22.1 (2.7)	5 (5.9)	21-28	23.8 (3.1)
Percussions	4 (4.7)	19-27	23.0 (3.4)	2 (2.4)	24-31	27.5 (4.9)
Short strings	23 (27.1)	18-38	22.4 (4.1)	6 (7.1)	18-23	21.3 (1.8)
Woodwind	16 (18.8)	22-34	25.8 (3.6)	2 (2.4)	23-24	23.5 (0.7)
Vocal	1 (1.2)	22	22.0 (NA)	0 (0)	NA	NA
Key Board	0 (0)	NA	NA	1 (1.2)	23	23.0 (NA)

### 11.5.3 Hearing loss distribution among children musicians-Sample size (n) = 37

**Table 11-3 Distribution of hearing loss among children orchestra musicians**

Group of musicians	Number of musicians With normal hearing (%)	Musicians with normal hearing-Mean age in Years(SD)	Musicians with normal hearing-Age range in years	Number of musicians with hearing loss (%)	Musicians with hearing loss-Mean age in Years(SD)	Musicians with hearing loss-Age range in years
Brass	5 (13.5)	10.8 (1.5)	9-12	1 (2.7)	10.0 (NA)	10
Percussions	3 (8.1)	9.0 (0)	9	1 (2.7)	10.5 (0.7)	10-11
Short strings	14(37.8)	9.4 (0.9)	8-11	2 (5.4)	9.3 (1.5)	8-11
Woodwind	9 (24.3)	9.9 (0.9)	9-11	2 (5.4)	9.7 (2.1)	8-12

This study has found that some of the musicians start acquiring hearing loss at a very early age (Table 11-3) while some may continue to maintain normal or near normal hearing throughout their professional music career. In Table 11-1, three of the musicians in the Brass section with an age range of 47 to 54 years and a mean age of 50 years were found to have normal hearing in all the frequencies whereas among the children (Table 11-3) six of the children musicians with an age range of eight to 12 years of age and mean age of 10 years were found to have hearing loss. One of the unanswered questions is, “Is every professional musician (music instrument player) at risk for acquiring hearing loss?” Maybe every musician is at risk of acquiring hearing loss, but there seems to be a large individual variation in susceptibility.

### 11.6 Longitudinal analysis of hearing loss

According to Strasser et al., (2003) music has less harmful effect to hearing than the comparable amount of industrial noise; hence the progression of hearing loss may not follow a similar course. The only longitudinal follow-up study in the literature is by Kahari et al., (2001) using pure-tone audiometry. They undertook hearing reassessment of 56 classical musicians who participated in Axelsson & Lindgren's study 16 years earlier, in 1995. The main conclusions drawn from Kahari's study

were that the male musicians, compared to the female, showed a tendency toward a more pronounced, although not significant, hearing reduction in the high frequency region and higher threshold distribution within the 90th percentile than the female musicians. In this New Zealand study, however, we found that the increased years of music exposure causes progressive hearing loss in a significant number of individual musicians, and this trend is observed in all age groups of musicians. It was also observed in this study that female musicians have a better hearing threshold than males, and the progression of hearing loss is observed to be slower in females than males.

Kahari et al., (2001) also found that the hearing loss is mostly found in the left ear. The median audiogram for all females showed a notch configuration at 6kHz, compared to the males who had a high-tone sloping configuration. While we found that this observation may be true in some individual musicians, the notch is also observed in other frequencies (Figure 8-9). There are several studies on noise induced hearing loss that report a notch centred about 4kHz with some recovery above this frequency and the notch of noise induced hearing loss may range between 3 and 6kHz. After a period of time the high frequency recovery disappears, leaving a nondescript high frequency loss (similar to age-induced hearing loss), but in this study we found that in some individual musicians, even from a young age they start to have a sloping type of configuration (Figure 9-19) that is found in older adults.

Kahari et al., (2001) also found that when comparing high frequency pure-tone average values with ISO 7029, the females are distributed around the ISO 7029 median and well within the 90th percentile. The average hearing threshold of the males was equal with the median. This follow-up study showed no progressive hearing loss in pure-tone hearing threshold values in spite of an additional 16 years of musical noise exposure, whereas in this New Zealand study we find that in some musicians, who are known to be susceptible, pure-tone hearing threshold values are continuing to change. A gradual deterioration and progressive loss is observed with increasing number of years of music exposure.

In the group of 37 orchestra musicians with hearing loss, the few who have other music assignments also have poorer hearing thresholds than the musicians with no

other assignments apart from regular orchestra music exposure – but this trend is not observed in all musicians who have normal or near normal hearing in spite of several years of music exposure. Similarly, in the group of orchestra musicians with hearing loss, more years of experience exhibited worse hearing thresholds, and again this did not correlate well with the hearing thresholds of those orchestra musicians who have been identified to have normal hearing. Kahari (2001) reported that those who have had a longer career are also at increased risk of hearing loss, but in this study we found that this trend is not observable in all cases.

Our observation shows that in an individual who is susceptible or vulnerable to music or noise exposure, the initial notch based at 3, 4 or 6kHz (or the sloping loss in some cases) may begin early but the loss continues to grow for several years. The rate of progression also depends on susceptibility, and the duration and intensity of music exposure at these frequencies. After several years the hearing loss may spread into other adjacent frequencies (low and high). High frequency recovery disappears and the loss at the initial frequencies may also continue to grow, but a lesser rate. In some individuals, the ear seems to age faster because of music and noise exposure, and it is difficult to disentangle presbycusis from MIHL.

In other words, in an individual who is susceptible or vulnerable to music or noise exposure, normal progression of hearing loss associated with aging will occur from an early age.

### **11.7 Tinnitus and orchestra musicians**

One of the commonest symptoms associated with noise or music exposure is tinnitus. According to Hart, Geltman, Schupback and Stanucci (1987) hearing loss is often accompanied by tinnitus, reduced frequency resolution and reduced temporal resolution, which exacerbate the difficulties perceived by the orchestra.

In this study, among the adults with normal hearing, 13 ears (21.3%) had tinnitus most of the time, 29 ears (47.6%) had experienced tinnitus sometimes, and 14 ears (22.9%) had no tinnitus at all. Among those with hearing loss, 31 ears (50.8%) showed hearing loss associated with tinnitus most of the time, 18 ears (29.5%) had

hearing loss associated with tinnitus sometimes, and 3(4.9%) did not notice tinnitus at all. There was a statistically significant relationship between hearing loss and tinnitus in adults (Fisher's exact test showed right ear p value =  $9.58e-5$  and in left ear p-value =  $3.7e-05$ ).

Among the youth musicians with hearing loss, 18 ears (20%) experienced tinnitus, four ears (4.8%) experienced tinnitus sometimes, six ears (7.1%) experienced no tinnitus and among those with normal hearing, 70 ears (82.4%) did not experience tinnitus at all. There was a statistically significant relationship between hearing loss and tinnitus in youth musicians as well (Fisher's exact test showed right ear p value =  $6.0e-13$  and in left ear p-value =  $3.7e-05$ ). Among children musicians, tinnitus is reported only in three ears (8.1%); one (2.7%) reported tinnitus most of the time and two (5.4%) reported it sometimes, and there is no statistically significant relationship between tinnitus and hearing loss, so it is not a major problem among children.

Our study has found that with increased music exposure the prevalence of tinnitus increases, which is similar to the findings of Lockwood, Salvi and Burkhard (2002), who reported that it is a common problem and about half of those tested mentioned tinnitus as a complaint. In other studies tinnitus has been reported in 2–20% of people (Axelsson & Ringdahl, 1989; Coles, 1984; Skarzyjski, Rogowski, Bartnik and Fabijajska, 2000).

Tinnitus is estimated to affect 14% to 17% of the general population, with 1% to 2.4% of the population experiencing significantly disabling effects on their quality of life (Coles, 1994; Axelsson & Ringdahl, 1989). The increased prevalence of tinnitus is of concern for young musicians, as the prevalence of tinnitus typically increases with an increased number of years of music exposure. Tinnitus is often a known sign that either temporary or permanent damage has occurred, most often to the outer hair cells of the cochlea. The ringing in the ear can be very bothersome and can have a negative effect when trying to hear tones that may be similar in pitch to that of tinnitus.

## **11.8 Music Induced hearing loss (MIHL) and Asymmetry in hearing loss**

In this study, though there is no statistically significant asymmetry between right and left ears in adult, youth and children musicians, in adult and youth musicians mean hearing threshold is elevated in the left ear in more frequencies than in the right ear (Table 8-11, Table 8-17). In children musicians this is not observed (Table 8-21).

In Table 8-15 the mean hearing thresholds of 20 violin players with hearing loss shows that the hearing is poorer in the right ear at 1500, 2000, 6000, and 8000Hz and better at 250, 1000, 3000, 4000 and equal at 500Hz. According to Ostri et al., (1989) the reason for the unexpected symmetrical or asymmetrical hearing deficits in most of the string instrumental musicians is that it is assumed that the noise produced by the instruments in the vicinity of an individual musician would be more harmful than the sound emission by their own instrument. Therefore they recommended a 12 hour noise-free interval between rehearsals and performances.

Music induced hearing loss in a musician is often asymmetric – probably relating to the position of their instruments (or others' instruments) to their ears and the way they position their head in particular, and their body, while playing the musical instrument. In the rock drummer, for instance, it tends to be worse in the left ear owing to its closer proximity to the high-hat cymbals. It also tends to be worse in the left ear of violinists and worse in the right ear of flute and piccolo players. Because of this imbalance, it is not unusual for these musicians to complain of distortion even in their better ear. The majority of the violin players have shown left ear notches at 6kHz, which would seem to be related to the musical instrument played or the musician's position in ensemble playing. Instruments such as flute and piccolo are played to the right and may produce more hearing loss in that ear while playing alone during their practice, but this may cause overexposure to the left ear of a fellow musician during rehearsal and performance.

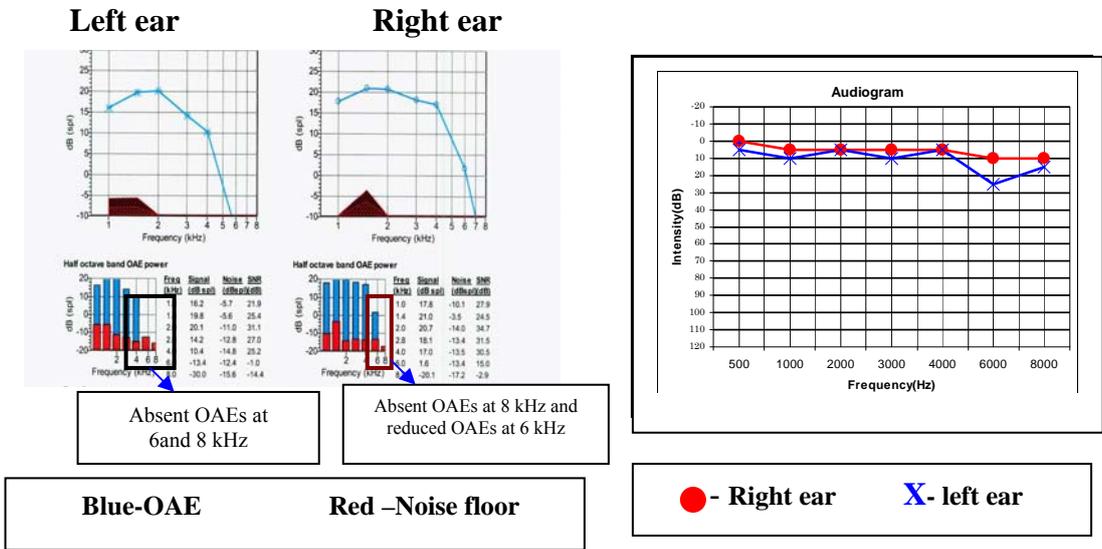
There are some studies that have reasoned out the left ear is more affected than the right. The literature review suggests that there may be differences in the physiological susceptibility of left and right ears to NIHL (Watson, 1967). It is also

interesting to note that many reports indicate that Transient Evoked Oto-acoustic Emissions appear to be stronger in the right than in the left ear in infants (Keefe, Gorga, Jesteadt and Smith, 2008). It should be noted that in many of these studies the right ear is tested first, which could account for the asymmetry by producing an efferent response prior to the subsequent left ear test.

Exactly what type of differences could account for the asymmetry is still a source of speculation. There are studies that propose that olivocochlear efferents are stronger on the left side or that there is a difference in the middle ear reflex between the two ears. Nageris et al., (2007) reported that noise induced hearing loss is more severe in the left ear than the right ear. After studying the files of 4,277 army personnel with NIHL, they found that NIHL is more pronounced in the left ear, regardless of demographic characteristics, noise exposure parameters, acoustic reflex measures or handedness, and concluded that the asymmetry in hearing loss severity may be attributable to the cortical pathways, specifically to the more pronounced efferent auditory system on the right side, which reduces the susceptibility of the right ear to cochlear insult. In Figure 11-1 the DPOAE is of a six year old violin player and shows that in the left ear the emissions are absent at 6 and 8kHz. The pure-tone audiogram shows only a mild hearing loss at 6kHz. This demonstrates that in this violin player there is an asymmetry in hearing (the left ear is more affected than the right ear) because the left ear receives more sound than the right ear owing to its closer proximity to the sound source.

DPOAE Results

Pure-tone Audiogram



**Figure 11-1 DPOAE and pure-tone audiometry test results - Violin player (Female, 9yrs old)**

So it can be concluded that though some of the studies have tried to explain why the left ear is more affected than the right ear, in reality, the reason for the asymmetry is still a source of speculation. At least in some musicians, the sound of their instrument is directed more to one ear than the other, or where they get sound from a neighbouring player because of the seating arrangements in the orchestra and their head and body position, so the reason for asymmetry in hearing (more loss in one ear than the other ear) is obvious. In a significant number of musicians the asymmetry is observed at least in the beginning of their music career because of the proximity of their own musical instrument to one ear more than the other, but as they increase their involvement in group musical activity while being a part of an orchestra, this asymmetry tends to disappear with increased music exposure in group musical activities.

**11.9 Gender difference in music induced hearing loss**

The gender of an individual musician has been often considered as a possible influencing factor with men appearing somewhat more affected than women. The difference, however, seems minimal if present (Müller & Richartz (1989). These

gender differences are thought to be due to greater exposure of males to noise rather than to their inherent susceptibility to its effects. Firth et al., (2001) and McBride et al., (2003), who conducted an occupational health survey of 381 farmers in Southland, reported that 11.6% had noise induced hearing loss – 17.1% of the men and 1.5% of the women – and according to Pearson et al., (1995), “hearing sensitivity declines more than twice, as fast in men as in women at most ages and frequencies. Longitudinal declines in hearing sensitivity are detectable at all frequencies among men by age 30, but the age of onset of decline is later in women at most frequencies, and varies by frequency in women. Women have more sensitive hearing than men at frequencies above 1000Hz but men have more sensitive hearing than women at lower frequencies” into advanced age.

Many other studies have mentioned that male musicians tend to have more pronounced hearing losses than females, but whether this has a biological cause or is a function of men playing louder instruments is not clear (Axelsson and Lindgren 1981; Strasser et al., 2003; Kahari et al., 2001; Kahari et al., 2003). In this study, we came to the same conclusion for adult and youth musicians but not for children, and that males had more pronounced hearing losses than females. Among the children musicians 26 (70.3%) were male and 11 (29.7%) were female. The same gender difference that males having more pronounced hearing loss could not be observed; in fact female musicians were found to have a poorer mean hearing threshold in more frequencies than male musicians. This may possibly be due to the fact that it is a small sample and also, the duration of music exposure is limited.

So it can be concluded that among youth and adult musicians, the gender of an individual can be considered an influencing factor with men appearing to be more affected than women, who have more sensitivity than men at frequencies above 1000Hz but less than men at lower frequencies. In children this trend was not observed.

### **11.10 Music exposure and configuration of the audiogram**

Noise induced hearing loss in humans commonly begins in the high frequencies around 4kHz, regardless of the frequency content of the noise. With continued exposure, the threshold at 4kHz worsens and the hearing loss spreads to involve

higher and lower frequencies (Taylor et al., 1965). There were some concerns raised previously about a notch in the audiogram at 4kHz as not being sufficient evidence to diagnose noise induced hearing loss because numerous other medical conditions also produce notches (Sataloff, 1998).

Mostafapour, Lahargoue and Gates (1998) found that presence of a notch among students did not correlate with any source of noise exposure, including personal listening devices, home stereos or firearms.

Some studies have come up with the suggestion that deviations at 6kHz, and possibly also at 4 and 8kHz, are caused by shortcomings in the ISO 389 (1991) standard regarding its representation of hearing threshold levels to be expected in otologically normal adults (Lutman & Davis, 1994). In this study we found that the dips in the pure-tone audiogram are also observed in other frequencies (3, 4 and 6kHz), and longitudinal analysis of development of hearing loss shows that the increased hearing loss happens around that frequency of dip (for example: Figure 9-9 for a cello player initially had a dip at 3kHz and Figure 9-1 for a violinist with a dip at 4kHz in the left ear and 6kHz in the right ear). Though music exposure causes high frequency hearing loss, a significant number demonstrate a dip at 6kHz, at least in the initial stage. It is possible that the configuration of the pure-tone audiogram is influenced by the spectral characteristics of the sound exposure apart from other possible contributing factors.

There are more detailed studies that have shown that the initial dip in hearing can be at 3, 4 or 6kHz. Ward (1995) explained the effect of noise with most energy in a limited frequency band. The characteristics of the noise are important in determining the type of hearing loss. Burns (1968) described a study conducted on jute mill workers and found a dip at 4kHz with a good recovery at 8kHz with noise exposure. There are other studies that have reported that impact noise affects 6kHz more than other frequencies. The effect of single frequency noise is reported to have maximum effect on a frequency half an octave above that frequency (Engdahl & Kemp, 1996). Thus a 2000Hz noise will affect hearing at 3000Hz. The duration of noise exposure will also have been identified to have an effect on the configuration/shape of the audiogram. This is largely because the rate of deterioration of hearing loss varies at

any given frequency: For example, in the first 10-15 years hearing at 4kHz deteriorates rapidly and then remains relatively unchanged, but then in the next 10-15 years of noise exposure deterioration in hearing at 2kHz is reported with a more rapid change occurring after 20-49 years of noise exposure.

Johnsson and Hawkins (1976) studied the degenerative patterns related to noise exposure on 33 male patients with noise exposure, and concluded that for the entire group the commonest form of lesion, associated with a 4kHz dip in the audiogram, was a relatively diffuse degeneration in the second quadrant of the basal turn, in the 9-13 mm area. An advanced form of this lesion had a wide gap of more or less complete sensorineural degeneration affecting the entire second quadrant and displaying various degrees of extension toward the apex and base. In most of the material, the degeneration pattern differed markedly from the diffuse degeneration seen with presbycusis. The pattern associated with an 'abrupt high-tone loss,' with more or less complete hair cell and nerve degeneration in both the second and first quadrants and extending to the basal end of the cochlea, was rare. There are other types of hearing loss such as ototoxic drug induced, age related changes and some of the familial hearing losses that are known to cause dips in the high frequency region. In the industrial population, the significant threshold shift is generally observed at 4000Hz (Bauer, Korpert, Neuberger, Raber & Schwetz, 1991; Rachiotis et al., 2006). In this study we found that the configuration of the audiogram is influenced by the spectral characteristics of the noise to which they were exposed. In this study we observed that the dip in the pure-tone audiogram varies widely in various frequencies from 1500 to 8000Hz. Though the numbers of audiograms with dips in the mid frequencies (1500-3000) are less common than high frequency (4-8kHz) dips, the dips are observed in the entire frequency region of 1500 to 8000Hz. Among adults, however, a dip at 6kHz is more common than other frequency dips. Fourteen (21%) of the audiograms for adult musicians with a hearing loss had a dip at 6kHz, as did seven (28%) of the audiograms for those with normal hearing. Among the youth musicians with a hearing loss, 16 (19%) audiograms had dips at 6kHz as did 32 (38%) audiograms for those with normal hearing. Among the children musicians with hearing loss six (16%), audiograms had dips at 6kHz as did six (16%) for those with normal hearing.

There has been some expressed concern regarding the standards for audiometric threshold testing at 6000Hz as not being accurate (Davis, Cheever, Krieg & Erway, 1999; and Davis et al., 2001), but given that in this study not all the musicians show a dip at 6kHz, this makes it clear that the problem is not related to the audiometric standards.

One of the research questions in this study was: In addition to the intensity of the sound, do the spectral characteristics of the music also determine the configuration of the audiogram and the risk of damage to the hearing system? The answer is yes, and the variety of dips observed in the pure-tone audiograms and the configuration of the audiograms show the influence of the spectral characteristics of music exposure. It is not possible, however, to correlate the dips in the pure-tone audiograms with the intensity and frequency of the musical instrument as they are a part of an orchestra and are exposed to a variety of musician instrumental noise.

### **11.11 Personal stereo usage among young musicians**

Moustafapour et al., (1998) found that 18% of the 50 students (aged 18-30 yrs) tested had a notch >10dB at 6000Hz. The students are reported to have used the personal listening system at least one hour/day. A greatest shift in hearing threshold was found around 6kHz in those who listen to loud music (Mori, 1985). Many young people were found to have a drop in hearing threshold (Bauer et al., 1991), which is in agreement with the thought that this loss is induced by the societal noise. It is important to notice that the young musician is also exposed to many other sources of loud noise or music apart from the regular orchestra music. Listening to loud music with personal listening device is reportedly the largest contributor in this study among young musicians. LePage and Murray (1998) reported that the decline in oto-acoustic emission strength forewarns premature hearing loss in personal stereo users.

Among the 85 youth orchestra musicians, the usage of personal stereo is very common. Forty (47%) musicians use personal stereo on a regular basis and 45 (53%) do not use personal stereo on a regular basis. Among the 45 musicians who possess a personal stereo, 18 (21%) were found to have hearing loss, whereas among the 40 musicians who do not use a personal stereo, nine (11%) were found to have hearing

loss. However, no statistically significant ( $p$  value = 0.08) relationship was observed in the right ear (Table 7-46, but a statistically significant ( $p$  value =  $1.84e-8$ ) relationship is observed in the left ear (Table 7-47). So it can be concluded that personal stereo usage contributes to increased risk of hearing loss among musicians and they need to be educated on this risk (an educational handout created for this purpose is given in Appendix K).

### **11.12 Individual susceptibility and music induced hearing loss**

Apart from loud orchestra music exposure, no single music or non-musical variable could be identified as a major contributory factor that makes the individual musician more susceptible than others. Does it mean that the genetic susceptibility/factors that could not be identified make the individual musician more susceptible? The new European Union directive (10/2003/EU) sets new limits for allowable noise levels, and sets new requirements to accommodate the individual susceptibility factors, but does not define these factors.

First of all, it is impossible to match the musicians in terms of the intensity and duration of the sound and the effects of all the predisposing factors that may have a significant influence on resulting hearing loss. And it also a well known fact that not all the musicians demonstrate a similar shift in hearing threshold in spite of being exposed to similar music; hence individual vulnerability or susceptibility is an important factor. There are several animal studies that have demonstrated a genetic susceptibility to noise induced hearing loss (Robinowitz et al., 2002; Van Laer et al, 2006). It may be that the other known environmental factors may further contribute to an increased amount of hearing loss due to noise and/or music exposure in an individual, who is already vulnerable or susceptible.

Several studies have documented the interaction of biological and environmental factors with noise exposure (Humes & Jesteadt, 1991; Boettcher, Henderson, Gratton & Byrne, 1989). There are studies that focus on finding a genetic base or origin for noise induced damage. There are several studies on animals and humans that have documented the individual variability in resulting hearing loss attributable to individual susceptibility (Burns & Robinson, 1970; Passchier-Vermeer, 1973), a

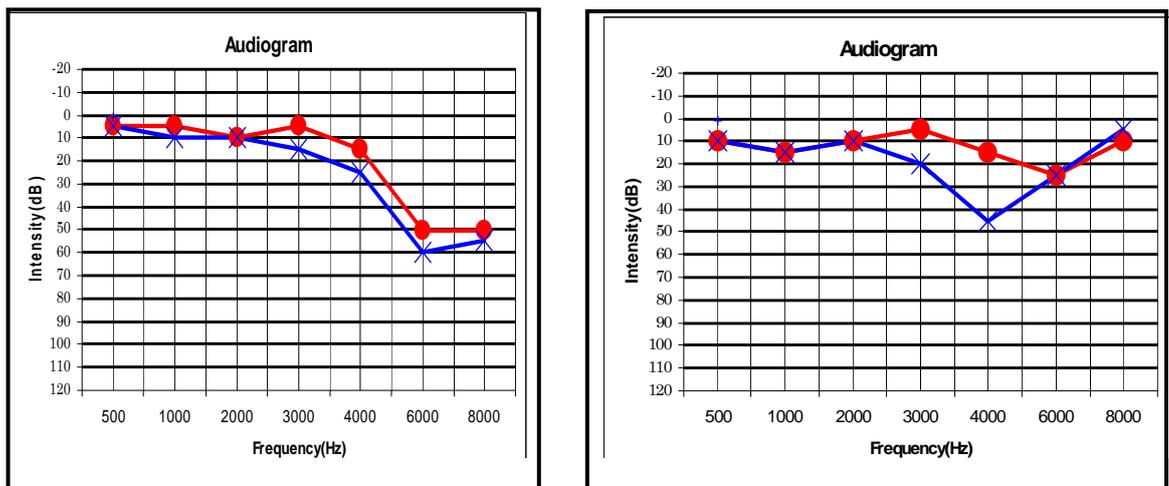
controlled laboratory study on temporary threshold shift (Davis, 1950) and permanent threshold shift on animals (Henderson & Hamemik, 1986). A large demographic study was done by Taylor et al., (1965) on weavers; each weaver had a well documented noise exposure history, noise conditions were stable throughout their work history, and they all had a medical and otological examination. This study concluded that in spite of the homogeneity of the group there was a large individual variability in the resulting hearing loss. Henderson et al., (1993) concluded after examining several studies on individual variability on noise induced hearing loss, it is likely that the variability stems from multiple causes. Thus an effective screening procedure for susceptibility to NIHL is likely to require the assessment of several factors. They also concluded that earlier attempts to predict susceptibility to NIHL using non-auditory factors can only account for a minor amount of variability across the subjects.

In this study, when we look at all the musicians of all ages, the proportion of musicians with hearing loss is found in all age groups and in all instrument players, and there is also an increased number of musicians with hearing loss with increased number of years of music exposure. If individual susceptibility is a true statement, it may well be that the initiation and progression of noise induced hearing loss should also vary, depending on the individual susceptibility. Though it is clear that those who play loud musical instruments show tendencies to an increased shift in hearing thresholds, there seem to be large individual variations in hearing thresholds among all types of instrumental musicians. There are individual musicians whose hearing thresholds continue to deteriorate with increased music exposure from one year to the next (Figure 9-3 shows a violin player whose hearing thresholds continue to deteriorate with increased number of years of music exposure) while other musicians have maintained fairly normal hearing in spite of being exposed to music for many years (Figure 9-5 shows a violin player (51yrs old) with normal hearing except a mild dip at 6kHz in the left ear). This finding supports the hypothesis that some individuals are more susceptible to noise and/or music exposure than others. A significant individual variation in the progression of hearing loss occurs for known and unknown reasons as well. Some people have 'stronger/harder ears' while others have 'weaker/tender' ears with marked hearing loss after minimal music exposure. This stresses the importance of personalised hearing loss prevention programmes that

will help to identify early signs of noise and/or music induced cochlear damage to help start a personal plan to avoid any further deterioration in hearing for that particular individual.

### **11.12.1 Ear susceptibility in an individual musician**

The hearing loss is often asymmetric, usually with more loss in the left ear than the right ear (McBride & Williams, 2001; Nageris et al., 2007; Phillips and Mace., 2008). Violinists have an increased risk for developing worse hearing losses in their left ear and flautists in their right ear due to the placement of their instruments (Ostri et al., 1989). Apart from the individual susceptibility, there is also a possibility of ear susceptibility in a given individual musician. In Figure 10-2, the audiograms of an individual 44 year old musician show slight asymmetry in hearing (the left ear is slightly more affected than the right ear – with a moderate degree of loss at 6-8kHz), whereas the audiogram of the 52 year old violin player shows a very significant asymmetry in hearing (the right ear shows a minimal loss only at 6kHz whereas in the left ear there is a significant loss of hearing at 4kHz and a minimal loss at 6kHz). Though the left ear is more affected than the right ear, despite being in an orchestra for several years with the exposure to other musical instruments, the musician has near normal hearing in the right ear. So this leads us to think that apart from the individual susceptibility, a particular ear may be more susceptible than the other ear in a given individual.



**Figure 11-2 – Pure-tone audiograms of Violin players**

**(44yr old, male violin player)  
37 years of violin playing**

**(52 yr old, male violin player)  
44 years of violin playing**

### 11.13 Music induced hearing loss in children

To date there are no studies on music induced hearing loss in children, but there are several reports suggesting that there is an increase in incidence and prevalence of hearing loss among children and young adults. This increase of risk is consistent with a study by Niskar et al., (2001), who estimated the prevalence of noise induced hearing threshold shift among children aged 6-19 years in the third national health and nutrition examination survey of 1988-1994 in the USA. They found that 12.5% had noise induced threshold shift (NITS) in one or both ears, with higher prevalence in boys (14.2%) compared to girls (10.1%), and in older children aged 12-19 (15.5%) compared to 6-11 year olds (8.5%). The most affected frequency was 6kHz (77.1%) compared to 4kHz (23.8%) and 3 kHz (14.1%). A single frequency was involved in 88.4% of children. Among children meeting NITS criteria 14.6% had a noise notch for both ears. In the earlier studies (Davis, 1989; Smith, Davis, Ferguson & Lutman, 2000) there was no evidence of such notches in 18-25 year old individuals in the UK. According to Phillips et al., (2010) 44% of students were found to have a dip at 6kHz in a university school of music.

In our study we found that six children musicians (16.2%) out of 37 were found to have hearing loss, only four (10.8%) were aware of music induced hearing loss, and

33 (89.2%) reported that they were not aware; hence it is important to organise an educational programme for all the music teachers in the country, and to also inform the Ministry of Health about the importance of hearing health education and urge the ministry to introduce hearing health as part of the educational curriculum at least to music students, for they need to be made aware of the importance of protecting their hearing as some of them may choose music as a career for life.

Table 10-6 shows that Percussion section in a children's orchestra received a dosage of 109.3% (standard deviation: 1.5), the Brass section received a dosage of 111.2% (standard deviation: 2.1), the Woodwind received a dosage of 54.7% (standard deviation: 2.6), and the Short Strings received a dosage of 44.2% (standard deviation: 11.2). Given this finding, it is important that the teachers are also trained in the ways and means of minimising the music exposure. Music lessons should be conducted with the view to teach musicality, but not to a volume that would cause distress or harm to the children. Children should be taught and encouraged to play instruments musically and not bash them for the purpose of making noise. Very young children may be encouraged by giving them claves instead of drums, and other percussion instruments should be made of plastic or flax so as to give the musical benefit without generating sharp, piercing and impact-type sound.

The World Health Organization (WHO, April 1999) suggests, from evidence collected from animal experiments, that children may be more vulnerable to acquiring noise induced hearing loss than the adult population. This is difficult to quantify due to individual susceptibilities and ethnic factors throughout the populations of the world. From the limited data available, WHO suggests that an A-frequency weighted time-average level of 75dB or less over an 8-hour day ( $L_{Aeq\ 8h} < 75dB$ ) is unlikely to cause any hearing impairment even over prolonged exposure. In the absence of other data this is particularly important for children. For the total noise exposure (including environmental and leisure time) over 24 hours/day, the WHO considers that A-frequency weighted time-average levels of less than 70dB ( $L_{Aeq\ 24h} < 70dB$ ) would not cause hearing impairment in a large majority of people (over 95%). WHO also suggests that the calculation method from ISO 1999 for specifying hearing impairment should be accepted for environmental and leisure time noise.

## **11.14 Tests for susceptibility to noise induced hearing loss**

For the past many years, there have been several attempts to identify factors (auditory and non-auditory) that are contributing to individual variability: non auditory factors such as gender, eye colour, age smoking, drugs etc; and auditory factors such as temporary threshold shift as a predictor, acoustic reflex, auditory toughing effect induced by prior exposure to moderate levels of noise, and difference in the efferent auditory system. But until today we have not identified any particular test that would help us to identify an individual's susceptibility to noise exposure. According to Henderson et al., (1993) an effective screening procedure for susceptibility to NIHL is likely to require assessment of several factors, but they have not been identified and some still are being experimented and subject to great debate even today. In our study, we found that there is a large individual susceptibility to music induced hearing loss in all age groups. If individual susceptibility is a true factor, the damage risk criteria could not be generalised and has to be individualised. It is likely that there may be a number of individuals with individual susceptibility who acquire or continue to notice deterioration in hearing with increased music exposure though they are exposed to noise that is within international standard recommendations.

With current limited knowledge about individual susceptibility to noise induced hearing loss, the best means of identifying individual susceptibility is to rely on available comprehensive and thorough audiological evaluation and follow-ups starting from an early stage of music exposure, and also sound measurements for assessment of risk. And the tests must be performed by a hearing professional with formal training and capable of identifying early damage caused by noise and/or music exposure (for example, from a variation in the pure-tone audiogram configuration such as dips even though hearing may be within normal limits). The audiological evaluation should include a thorough case history (auditory and non auditory factors) together with pure-tone audiometry with inter-octave frequency testing, and distortion product oto-acoustic emission testing (DPOAE) to identify early damage to the cochlea.

At a national level, there are many individuals exposed to occupation and non occupation noise and music on a regular basis who are not part of any hearing conservation programme. In order for a hearing loss preventive programme to be effective, we must make sure that a facility for hearing evaluation is accessible to everyone to prevent hearing loss in the general public, and hearing loss prevention should become a national priority – otherwise a significant amount of money will be required for rehabilitation.

### **11.15 Usage of Ear Protecting Device among musicians**

Though musicians and non-musicians are subject to work related hearing loss from exposure to noise, unlike other noise exposures, the sound created is not a by-product of their work – it is their product, and good hearing is so important to produce music well. This particular distinction makes musicians a special case, and it is difficult to determine what regulation should apply to them. For many professional orchestras, the acoustical environment during practising or performing is far from ideal with respect to avoiding or at least minimising the risks for hearing damage – which is important. Several studies stress the importance of using hearing protection and the increased risk of hearing loss with increased duration of exposure. (McBride et al., 1992) acknowledged the issues that arise in the provision of hearing protection, but felt that harmful levels of sound exposure may not occur often enough in an orchestra.

It is a necessity for musicians to be able to hear correctly. Usually all are exposed to high sound levels that may adversely affect their auditory system. The music exposure varies, depending on the specific location and instrumental group within the orchestra. Noise induced hearing loss strongly relates to the average daily dose influenced by different circumstances. Besides hearing loss, annoyance and functional limitations due to high sound exposure for certain orchestra members, caused by the instruments of colleagues, is an important practical issue.

Eaton and Gillis (2002) reported, after evaluating the hearing test results for 53 members of the Vancouver Symphony Orchestra, that less than half of the musicians regularly used hearing protection: 47% of the musicians reported regular use of

hearing protection. In this New Zealand study we found that of 61 adult musicians who are provided with standard musician plugs, only a very few use them on a regular basis; this is far from ideal. During rehearsal (Table 8-50), among 37 established musicians (average age 48.7 years) with some degree of hearing loss, only three of the musicians used hearing protection on a regular basis during rehearsal, four used plugs 50% of the time, and 17 never use them. But during performance (Table 8-51), only one of the musicians uses musician plugs on a regular basis, one of them used them 80% of the time, one musician used them 50% of the time, and most of the musicians used them only during a loud piece of music based on subjective perception; 23 of the ear protecting devices were never used. During performance more numbers of musicians do not use ear protecting devices because of stress and fear of making a mistake.

During rehearsal (Table 8-52) among the 24 musicians (average: 42.6 years) with normal hearing, only one of them used ear protecting devices 100% of the time, 11 of them used the ear protecting device only during loud passages based on subjective perception, and 12 of the musicians did not use ear protecting devices at all. During performance (Table 7-53) only one musician used them 100% of the time. Our findings are similar to Laitinen (2005) who found that classical musicians are often exposed to sound levels that exceed the Finnish national action limit value of 85dB(A). Still, the use of hearing protectors is uncommon among musicians and according to Zander et al., (2008), hearing protectors were found to be seldom used by orchestral musicians.

According to Callahan et al., (2011), music students played their primary instrument from five to 17 hours a week, and 79 percent said they never wear hearing protection (like foam or wax plugs, or sound-blocking headsets) during practice or rehearsal. In our study among the youth musicians, though many are aware of loud music and hearing loss, musician plugs are only accessible to a few (12 out of 85). Two use the musician plugs on a regular basis, two persons use them 50% of the time, five of them use them only during loud passages, and three seldom use the musician plugs. The quality of the music is reported to be the major issue Callahan et al., (2011). The majority of the musicians showed a casual attitude about hearing protection despite elevated risks of hearing loss, and this finding supports the need for

continuing efforts to raise awareness in students about the risks of excessive noise and/or music exposure.

Among the 37 children who are part of the two school orchestras studied, only four of them are partly aware of the risk of hearing loss due to loud music and none of them use any form of ear protecting device. Only three of them took up the offer of custom made musician plugs and in a follow-up after two years, they have been found to be using the musician plugs on a regular basis, and find that the music perception is not distorted.

Historically, the usage of hearing protection by musicians has been seen as undesirable or even somewhat of a taboo (Chasin & Chong, 1992). The main reasons are:

- 1) The occlusion effect, which causes the user to feel echoey, blocked-up, and stuffed-up.
- 2) The stronger attenuation in the high frequency region relative to low frequency (Killion et al., 1988; Chasin & Chong, 1991).
- 3) It has been considered taboo because a musician doesn't want their peers or their audience to perceive them as having less-than-perfect hearing (Ostri et al., 1989).

The developments in the hearing protection devices (earplugs) have come a long way, and now there are several commercially available models specially designed for use by musicians. It is also interesting to know that the percentage of usage is more common among musicians who have already acquired a significant amount of loss and also, hearing protectors were used more often among musicians having tinnitus than those reporting no symptoms. This finding is similar to Laitinen (2005) who found that ear symptoms increased usage rate, but the usage levels are still far from ideal.

Additionally, the orchestra musicians are older, and as a result may be more conscious of the effect of hearing loss. It is also likely that these individual orchestra musicians have already experienced some effects of hearing loss and wanted to protect their residual hearing. This hypothesis likely explains the contradiction of professional orchestra musicians using ear protection more often but demonstrating

poorer hearing thresholds. The support and determination to get accustomed to hearing protector use are important factors in hearing conservation. For better hearing conservation, it is important to identify and eliminate the causes for having low motivation to use hearing protection. All the musicians are aware of the dangers of loud music, yet they rarely use hearing protection. However, musicians with hearing disorders use hearing protectors more frequently.

Laitinen (2005) stressed the importance of motivation, and training is needed to improve hearing protector use among musicians. It becomes an individual musician's responsibility to protect their hearing after learning that music induced hearing loss starts during the early stages of one's career. Great beneficial effects were observed for musicians using musician plugs. Some of the musicians, particularly the youth orchestra musicians, are using foam ear protecting devices as these were the type used most often. Foam plugs are cheap, readily available, and are known to provide music attenuation if they are inserted in the ear properly. However, it is a common problem noticed by the musicians that this type of ear plug muffles the quality of music and does not allow for effective monitoring of one's own music. This 'distortion' effect is due to the greater attenuation in the high frequencies. Ear protecting devices that provide attenuation similar to that of the foam plugs but with the flatter frequency response would be expected to have great positive effects in protecting musicians' hearing and allow for more effective monitoring. The musician plugs with the various attenuation filters (ER25, ER15, and ER 10) produced by Etymotic Research come with specific attenuation characteristics and are widely recommended for all orchestras.

A collective effort in using the ear plugs may work better than an individual effort. Being a part of a hearing loss prevention programme has to be made collective, and if possible, compulsory, given the fact that the effect is interlinked between individual musicians. There is a necessity for further research on musician plugs and their usage.

Miller et al., (2007) conducted a study on college music students. Although many (74%) reported receiving information about noise and hearing health, none of the surveyed students reported wearing hearing protection devices all of the time and

only 22% reported any use of hearing protection when exposed to potentially harmful sound levels. Similar results were found in freshman college music majors, with 95% reporting never using ear protecting devices when performing in concerts, 85% never using ear protecting devices during rehearsals, and 64% never using ear protecting devices in other environments, such as when attending rock concerts and using lawn mowers (Zeigler & Taylor, 2001). Though only a few children and young adults use musicians' plugs, the adaptability to using ear protectors is much better among the children and young adults. Possibly they adapt better if they start during the early years, whereas established musicians can sense the change in the loudness of music to which they are not accustomed. Hence it is important to encourage the young musicians to start using the musicians' plugs in the early years of professional activity. It also important that different strategies are used for different musicians taking into account their individual susceptibility (early signs of hearing loss identified with available audiological test results) and the personalised hearing loss prevention programme.

### **11.16 Factors that may influence the prevalence of hearing loss among musicians**

One thoroughly established characteristic of NIHL is that, on an average, more intense and longer-duration noise exposures cause more severe hearing loss. A second characteristic is that there is a remarkably broad range of individual differences in sensitivity to any given noise exposure. Several factors have been proposed to explain differences in NIHL among individuals; others may be associated with differences over time within the same individual. It is important to distinguish those factors that have a role in determining susceptibility.

As there seem to be large individual variations in the onset and progression of hearing loss we did research a few of the associated factors that may have influence on the prevalence and incidence of hearing loss among orchestra musicians.

### **11.16. 1 Family history of hearing loss and music induced hearing loss**

This part of the study was an attempt to identify individual musicians whose auditory system may be genetically susceptible to music exposure and environmental factors. It is a well established fact that the prevalence and severity of hearing loss increase with aging, and the contribution of familial factors to age-related hearing loss has been identified but it is difficult to quantify. This is because hearing loss in older people has both genetic and environmental influence. Exposure to outside noise appears to be a determining factor in who develops these declines (Phillips and Mace, 2008). It has also been concluded that a genetic predisposition factor is a likely risk factor. As environmental factors play an increasing role with aging it is difficult to separate the contribution of genetic factors to age-induced hearing loss.

In this study there was a positive correlation between high frequency hearing loss in the left ear and positive hearing loss and concluded that familial hearing loss could manifest itself or may contribute to noise induced hearing loss. McMahon, Kifley, Rochtchina, Newall and Mitchell (2008) found a strong relationship between positive maternal family history of hearing loss and moderate to severe hearing loss in women. They also found that a positive paternal family history of hearing loss was also significantly, though less strongly, associated with moderate to severe hearing loss in men.

Among the 37 adult musicians with hearing loss, 21 (34.4%) had a positive family history of hearing loss and 16 (26.4%) had no family history of hearing loss. Among the 24 musicians with normal hearing, 16 (26.2%) had no family history of hearing loss and eight (13.1%) had a positive family history. There was no statistically significant relationship between family history of hearing loss and prevalence of hearing loss in adult musicians (the p-value from Pearson's Chi-square test is 0.13). Among the 21 youth musicians with hearing loss, seven (8.4%) had a positive family history and 14 (16.5%) had no family history, and there was no statistically significant relationship between family history of hearing loss and prevalence of hearing loss in youth musicians (p-value from Pearson's Chi-square test is 0.44). Even among children musicians there was no statistically significant relationship (P-value from Fisher's exact test is 0.32). Although there is no statistically significant

relationship between family history of hearing loss and noise induced hearing loss, we must be aware that a positive family history could either manifest itself or reveal itself as an increased vulnerability to noise.

### **11.16.2 History of ear infection and music induced hearing loss**

Job et al., (1999) investigated the effects of personal stereo use in young adults and found that hearing threshold elevations could be demonstrated only in subjects with a history of recurrent otitis media in childhood. De Beer, Graamans, Snik, Ingels & Zielhuis (2003) found that young adults with a history of recurrent otitis media in childhood did not show a greater susceptibility to hearing loss from personal stereo use than their peers without a history of otitis media. However, a history of recurrent otitis media was associated with significant mean air-conduction hearing loss of 4dB and a mean bone-conduction hearing loss of 2dB compared with the participants without a history of otitis media, and it was concluded that recurrent ear infection in childhood may have an irreversible effect on the middle ear and the cochlea, and may lead to hearing deficits in later life. No interaction with personal stereo exposure is seen. Among the 37 adult musicians with some degree of hearing loss, 39 ears (63.9%) had no history of ear infection, and 13 (21.4%) had a history of ear infection in the past. There was no statistically significant relationship between previous history of ear infection and hearing loss among musicians (the p-value in right ear = 0.41 and p-value in left ear = 0.28 from Pearson's Chi-square test). Among the 27 youth musicians with some degree of hearing loss, 17 ears (20.0%) had no history of ear infection and 10 ears (11.8%) had a history of ear infection in the past. There was no statistically significant relationship between previous history of ear infection and hearing loss among youth musicians (the p-value in right ear = 0.27 and p-value in left ear = 0.45 from Fisher's exact test). Even among children musicians, there was no statistically significant relationship (the p-value in right ear = 0.10 and p-value in left ear = 0.35 from Fisher's exact test). Although in this study we have not found a statistically significant relationship between a history of ear infection and increased susceptibility, it is important that this information is collected as part of the case history to further assess individual musician's susceptibility.

### **11.16.3 Musician's awareness of music induced hearing loss**

In a study by Callahan et al (2011), 53% of the student musicians said they did not think hearing protection was needed as the music is not loud enough, and the majority of them showed a casual attitude about hearing protection despite musicians' elevated risks of hearing loss. The general awareness about music induced hearing loss should help an individual to take necessary preventive measures to protect their hearing. In this New Zealand study, among the adult orchestra musicians everyone is aware of the risk of acquired hearing loss with unamplified music exposure. Among the youth orchestra musicians, 70 (82.4%) are aware of unamplified music and hearing loss and 15 (17.6%) were not aware. Among the 24 with hearing loss, six (7.1) were not aware and 15 (17.6) were aware. There was no statistically significant relationship between increased awareness and hearing loss (the p-value from Pearson's Chi-square test is 0.24). Among the children musicians, four (10.8%) were aware of music induced hearing loss and 33 (89.2%) reported that they were not aware. These results emphasise the importance of hearing conservation programmes for all the music groups and schools. Our findings are consistent with the Phillips et al (2010) study on music students. This study found that music major students display a healthy attitude toward music, but they exhibit greater declines in hearing than the general population of college students.

### **11.16.4 Youth orchestra musicians and other noise exposure**

According to Hart et al., (1987) poor acoustic design of venues is especially important for rock musicians; this may pose a greater risk for musicians' hearing as well. As the resulting hearing loss in an individual musician depends on the daily noise dosage, we wanted to study the effect of other noise exposure and hearing loss among the youth orchestra musicians. Among the youth orchestra musicians, 17 (20%) were exposed to other types of noise and 68 (80%) were not. Six (7.0%) of them were involved regular gun shooting activities and 11 (12.9%) of the musicians were exposed to loud amplified music. All of the musicians who were involved in shooting used ear protecting devices on a regular basis and the reason specified was everyone felt that the gun shooting noise is too loud, whereas of the musicians who are exposed to loud amplified music, only two (18%) out of 11 used a foam type of ear protecting but not on a regular basis. Analysis of the effect of other noise

exposure on musicians' hearing ability shows that there is no statistically significant relationship between other noise exposure and hearing loss (p-value from Fisher's exact test is 0.41). Qian, Behar & Wong (2011) concluded that the noise exposure levels from only the orchestra's activities do not present risk of hearing loss. This finding stresses the importance of educating musicians, particularly the children and the youth musicians, about the importance of preserving their hearing from other noise exposure.

#### **11.16.5 Visits to loud concerts**

A study by Barlow (2010) found 94% of subjects reported attending concerts or nightclubs at least once per week, and the measured exposure in two of these venues ranged from 98 to 112dB ( $L_{Aeq}$ ) with a mean of 98.9dB over a 4.5 hour period. According to Callahan et al., (2011), participation in other musical activity further increases the risk of hearing loss in musicians. Unnoticeable effects can also occur over years as indicated by small instabilities in cochlea functioning that were observed in students exposed to noise in their leisure times (Rosanowski et al., 2006). Among the youth musicians, 78 (91.8%) have been to loud concerts and seven (8.2%) have not and try avoiding them. None use any form of ear protection in spite of being aware that the loud music can cause hearing loss. Seventy-three (85.9%) indicated that they will use the ear plugs if they are made available, and 12 (14.1%) musicians indicated that they will not them even if made available free of cost. Smith et al., (2000) found that the numbers of young people with social noise exposure had tripled (to around 19%) since the early 1980s, whilst occupational noise had decreased. This finding stresses the importance of hearing health being a part of music educational curriculum and also instituting hearing conservation programmes for all.

## **11.17 Distortion Product Oto-Acoustic Emission (DPOAE) test Results**

In this study we found that DPOAE testing could provide valuable additional information about the musician's early cochlear damage; hence it could be used as an additional tool to test susceptibility or vulnerability to noise/music exposure.

In all of the adult test subjects, the features of music induced emissions loss closely resembled the behavioural NIHL parameters, and the configuration of the audiogram resembles the DPOAE amplitude graph. The noise induced emission loss was found in musicians with normal pure-tone audiograms with normal dips in the audiogram but with a history of music exposure. A clear association between the OAEs and the severity of the NIHL was noted. As the severity of NIHL increased, the emissions range became narrower and the amplitude smaller.

In all, except for a few elderly test subjects, the features of music induced emissions loss closely resembled the behavioural music induced hearing loss parameters and the configuration of the pure-tone audiogram resembles the DPOAE amplitude graph. LePage and Murray (1998) obtained otoacoustic emission records from 1724 people (1066 males and 658 females) and found that otoacoustic emission strength declined with age, was significantly lower in males than females, lower in people exposed to industrial noise than those not exposed, and significantly lower in users of personal stereo systems than non-users. People with both kinds of noise exposure had values that were significantly lower again, indicating an additive effect. According to Lucertini, Moleti and Sisto, (2002) theoretical considerations and experimental evidence suggest that otoacoustic emission parameters may be used to reveal early cochlear damage, even before it can be diagnosed by standard audiometric techniques. Otoacoustic emissions have been shown to identify outer hair cell damage, the site of damage in music induced hearing loss, before it is even apparent to the musician (Engdahl, 2002).

Kähäri, Axelsson, Hellstrom and Zachau (2001b) compared the audiometric results of musicians to that of the ISO 7029:2000 population. Musicians showed better

hearing thresholds at all tested frequencies, except at 6kHz. This supports the observation that professionals perform relatively well on pure-tone audiometry despite intense exposure. It is possible that this effect is able to mask early signs of NIHL, and in that case screening techniques other than the pure-tone hearing thresholds could be better for the detection of early stages of NIHL in professional musicians. As Distortion Oto-Acoustic Emission (DPOAE) testing is not a hearing test and cannot be used to quantify hearing loss, it will not be able to replace pure-tone audiometry but it can certainly provide very useful objective information about outer hair cell functions of the cochlea.

In this study there seems to be a clear pattern suggesting that the orchestral have more absent DPOAEs in the frequency regions of 3000-8000Hz, and also the dips in the pure-tone audiograms are evident in the DPOAE amplitude graph (including the normal dips). The DPOAE seems to be absent in a particular frequency where there is a loss of more than 30dB, but also on such occasions even the adjacent frequencies may be affected.

The earliest damage of occupational hearing loss occurs in the 3000-6000Hz frequency range, with the worst hearing loss occurring at 4000Hz. Music induced hearing loss appears to follow the same pattern as a general occupational-induced hearing loss (Attias et al., 1998), except that the worst early cochlear damage occurs at 6000Hz rather than 4000Hz in a significant number of musicians, and the early damage is also observed as dips in other high frequencies (2000-8000Hz).

There is no clinical standard for determining at what level emission is considered present, reduced or absent. Therefore caution must be used in comparing absent emissions from one study to another.

Previous studies have found that 25% of the noise exposed ears have absent OAEs in the frequency region of 1000-6000Hz range (Sataloff & Sataloff, 1998). In conclusion, the high incidence of absent or reduced oto-acoustic emission in specific frequencies in orchestral musicians with normal hearing indicates the effectiveness of this as an early identification of potential cochlear damage due to music exposure or increased susceptibility in the individual musician. Hence this instrument should

be a part of audiological evaluation of musicians. Otoacoustic emissions are more sensitive to outer hair cell damage than the pure-tone threshold assessment. This study clearly demonstrates that DPOAE can indicate early cochlear damage before a hearing loss is indicated by pure-tone threshold audiometry. Along with pure-tone audiometry, DPOAE can also serve as an important tool in classifying an individual as being susceptible to music induced hearing loss before even an individual musician can perceive the damage.

### **11.18 Music Survey**

Williams (1995) concluded that orchestra musicians do not have a major noise exposure, and that if an orchestral pit is being used, the noise levels in the orchestra pit are not a major issue although they will always be louder than in the open area. The highest noise exposure was found among the Percussion and Brass instruments, followed by the Woodwind and then the Strings, but understandably this will vary, depending on the type of music played. In general, the measured noise exposure decreases with the distance from the Brass and Percussion sections. For example, the music exposure of the Woodwind players is higher than that of the Viola and Cello players, which is higher than the First Violins because they are further away from the Percussion and Brass. The implications from this study supports that the Woodwind, Brass and Percussion are exposed to sound levels that exceed recommended international standards for daily sound exposure in industry, and that also having the rehearsal and performance on the same day increases the risk to other musicians. The main music source that increases the potential risk of noise induced hearing loss comes from the back of the stage. As many of the musicians participate in group activities, the resulting hearing loss can be influenced by the musician's position in the group or the orchestra, with those positioned in front of the Brass or Percussion sections reporting worse hearing (Westmore & Eversden, 1981). The other noise exposure apart from daily musical activity may further increase the risk of acquired hearing loss in musicians.

Eaton and Gillis (2002) reported on three studies of musicians' noise exposures. On analysis the mean equivalent sound level ( $L_{Aeq}$ ) of 146 symphonies was 90dB. Brass and woodwind players have higher equivalent sound level values than stringed

instrumentalists. This study concluded that most musicians are overexposed. Determining the music exposure of musicians in an orchestra, for the purpose of estimating the risk of hearing loss, is not an easy task. Many variables are involved and their influence is difficult to assess. For example, there are variations between the sound levels from the different pieces being played, there are changes in the exposure from surrounding instruments due to seating arrangements, and finally, there is the assessment of the effective exposure duration, which includes playing at home and at other venues, something that is an almost impossible task. In our study, Table 10-7 demonstrates that when rehearsal and performance are on the same day, the maximum permitted daily sound exposure is exceeded in all sections of the orchestra except the Strings. The Timpanist recorded 526%, the Clarinet 346%, the Trumpet 263% and the Trombone 196%, whereas the 1st Violin recorded 83% and the 2nd Violin 80%, and they did not exceed the permissible daily limit of 100%. Any other noise exposure increases the risk of hearing loss even further. These findings stress the importance of educating the musicians about the importance of limiting their daily sound exposure. It also shows the importance of repertoire or programme.

#### **11.18.1 Individual susceptibility based on music survey**

In this study we found that the musicians in the back of the orchestra (woodwind and brass) are exposed to sound levels above the occupational standards and are at a higher risk for acquiring hearing loss than the low risk group (strings) in the front of the stage, but there are several musicians in the low risk group who have a significant loss of hearing compared to the high risk group, suggesting that there is a large individual variation or individual susceptibility. Hence, based on the music survey, calculating the risk of hearing loss could be misleading. For example, sometimes the researcher has only performed sound measurements and not linked them to audiological test findings (Williams, 1995; Karlsson et al., 1983). Rather, this information is to be used to plan preventive measures such as modifying the stage and seating arrangements, work scheduling, type of ear protecting device etc. Given that some of the individual musicians who play louder musical instruments (Brass, Percussion and Woodwind) were found to have normal or near normal hearing and some of the musicians who play relatively softer instruments were found to have

significant progressive hearing loss with increased music exposure, it is clear that there are large individual variations, and the variation could be attributable to individual susceptibility. This variation also stresses the importance of an individualised plan for prevention of hearing loss. If individual susceptibility is true, then the damage risk criteria and daily dosage limit is likely to be different for different individuals. Hence a music survey should be undertaken to prevent that particular individual musicians. Apart from using personal ear protecting devices, and it is also important that the sound measurement is linked to the hearing test results of that particular musician to plan person specific hearing loss preventive measures for each musician.

### **11.18.2 Difficulty in calculating overall dosage and its effects on hearing**

It is impossible to know and very difficult to estimate with any degree of certainty the total music exposure for each individual musician as, besides their individual practising alone and orchestral work, most of the musicians have other music exposure such as teaching music or being a part of other music activities, and to quantify the effects of all the factors that may have a significant influence on the resulting hearing loss. The duration of music exposure varies from day to day. For example, rehearsal often involves several practices with stops and repetitions before the actual performance.

Researchers and clinicians working in the industrial domain, however, compare measures of exposure with well-defined models of hearing loss. This is possibly because many sources of noise have similar physical properties, such as spectrum shape, spectrum level, and even peak-to-average intensity (or crest factor) features. Music, by contrast, has highly variable spectral shapes, differing spectral levels, varying 'on-off' times (between intense and quiet passages), and is played in every environment from garages to concert halls. Making definitive predictions concerning the damage-risk criteria of music may be a far more difficult task than for industrial noise exposure.

Given these factors, it is a very difficult task to determine the total noise exposure of a musician. Unlike industrial noise exposure, musicians work in highly variable

venues and have ‘exposure schedules’ that are almost impossible to predict (Chasin, 1996).

### **11.18.3 Sound levels based on instrument played**

According to Kahari et al., (2004) the duration of music exposure increases the risk. Kahari et al., (2001), Axelsson and Lindgren (1981), Karlsson et al., (1983) and Eaton and Gillis (2002) all reported that playing louder musical instruments, such as bassoon, French horn, trumpet, double bass, flute and trombone, increases the risk of hearing loss in a musician. According to Hensch and Chesky (2000), playing music that is consistently loud increases the risk of hearing loss among musicians. In the United States, the National Institute for Occupational Safety and Health (NIOSH) established a criteria document outlining recommendations for a noise standard to prevent occupational hearing loss in the industrial worker population. Because no guidelines yet exist to prevent hearing loss in the musician population, the OSHA guidelines are often extended to determine the risk of music induced hearing loss.

According to Boasson (2002), ‘short string’ players are usually the least exposed group and found that the audiograms corrected for age and gender resulted in better threshold levels for ‘short-string’ players, as compared to ‘long-string’ and woodwind players. The average sound exposure for string instruments during rehearsal is well below the daily exposure limit even when we account for the exposure during performance. But there are a number of string instrument players who have hearing loss in the high frequencies, and we have not accounted for practice and other music exposure. In this study (Table 10-1) we found that out of the 32 short string players 20 (32.8%) of them were found to have hearing loss. If we were to follow the damage risk criteria based on the music survey results, it would be expected that the more heavily exposed group (i.e. Brass and Woodwind players) would show a larger increase in the thresholds than the other groups, but in this study we found that out of the nine Brass instrument players with mean age of 50 years, three (4.9%) of them had normal hearing in all the frequencies. Boasson (2002) also found that all the instrument categories show an evenly profound notch in the hearing-thresholds at 6kHz, a frequency that is known to be very sensitive for noise induced hearing loss, but in this study, we found that though a significant

number of individual musicians were found to have dip at 6kHz, the dips in the audiogram are also observed in other frequencies.

After measuring sound levels during five rehearsals and two concert performances of the Symphony Orchestra of the City of Birmingham, McBride et al., (1992) found that some are exposed to sound levels in excess of the recommended limit and are therefore at risk. In our study, given the longitudinal and progressive hearing loss in individual musicians, at least the hearing loss in some can be associated with the duration and intensity of the music that they are exposed to, but there seems to be a large individual susceptibility. Mikl (1995) concluded that the highest overall noise power comes from the Brass and Percussion sections.

O'Brien et al., (2008) found that the principal trumpet, first and third horn, and principal trombone are at greatest risk of exposure to excessive sustained noise levels, and that the percussion and timpani are at greatest risk of excessive peak noise levels. However, the findings also strongly support the notion that the true nature of orchestral noise is a great deal more complex than this simple statement would imply.

#### **11.18.4 Noise standards and music survey results**

The music survey performed on various age groups of musicians shows that Brass, Percussion and Woodwind are exposed to sound levels that exceed recommended international standards for daily sound exposure in industry. This research finding is in agreement with research by Eaton and Gillis (2001) and Owens (2003), who concluded that some orchestra musicians were exposed to average sound levels that exceed the maximum permissible daily dosage of 100%, placing them at risk for music induced hearing loss. Moreover, the findings of this New Zealand study, relative to musical activities of the orchestra musicians including rehearsal and performance, concurred with previous studies that measured sound levels and sound exposure of musicians. Royster et al., (1991), Camp and Hortsman (1992), and Early and Hortsman, (1996) all determined that some orchestra musicians were exposed to average sound levels that resulted in doses above 100% using American standards. Other studies done by Sablesky and Korczynski (1995) and Mikl (1995) measured

orchestra members using Canadian (i.e., 80dBA with 3dB exchange) and American standards, respectively, and also determined that some were exposed to average sound levels that resulted in dose percentages over 100.

It is also interesting to note that there are musicians who are exposed to music levels (rehearsal and performance) that are within the permissible level, yet were found to have significant loss of hearing, particularly in the players of string instruments. They are exposed to percentages less than 100% using international standards. Hence it leads us to believe that the damage risk criteria we all use is not adequate enough to protect everyone's hearing, and the risk assessment based on just noise and/or music exposure could be very misleading. Among several factors, smoking and cholesterol are independently but causally related to NIHL and may cause the subject to be more susceptible for noise damage (Pyykko, Toppila, Zou & Kentala, 2007). Ageing further confounds some of these factors. The current ISO 1999:1990 noise standard has methodological deficiencies in not encompassing these susceptibility factors.

According to Pyykko et al., (2007) the new EU directive (10/2003/EU) sets new limits for allowable noise levels and also sets new requirements to accommodate the individual susceptibility factors but does not define these factors.

### **11.19 Acoustic Trauma with high impulse noise**

The Equal Energy Hypothesis is based on the assumption that hearing loss from a given exposure is proportional to the total energy of the exposure. A corollary of this assumption is the power of the exposure and the duration of the exposure are interchangeable and musicians are often exposed to high impulses; however, studies of impulse and impact noise show that hearing loss does not follow the prediction of the equal energy hypothesis (Ward, 1986). In our study we found that the majority of the musicians in all age groups are exposed to Peak levels ( $L_{\text{peak}}$ ) more than 140 dB, particularly the Brass, Percussion and Woodwind sections of the orchestra.

Impulse noise causes evidently more severe hearing loss than steady state noise. The additional effect of occupational impulse noise has been shown to be from 5-12dB at

4kHz (Starck, Toppila & Pyykko, 2003). The exposure to impulse noise is often composed of very rapid sound bursts that have short duration and low energy content. As a consequence the audibility is lower than the actual level of the impulses. There is substantial evidence that high peak noise levels produce more damage than would be expected, based on the equal energy hypothesis (Henderson et al., 1994; Levine et al., 1998). So far there is no valid method to combine the steady state and impulse noise (Starck et al., 2003). A statistical method for the measurement of impulse noise is needed to get a preferably single number for risk assessment. Children may be even more vulnerable in acquiring noise induced hearing loss than adults. The peak level exposure to which children are subjected should never exceed 120dB, but noise from activities such as fireworks and playing with noisy toys can potentially reach such levels (ISVR consultancy report 1997).

Most of the models of noise induced hearing loss are adequate for levels up to 115 dB ( $L_{Aeq}$ ); however, they tend to break down for more intense impulse stimuli. Price and Kalb (1991) and Price (1994) investigated the effects of intense impulse sounds and found that the motion of the basilar membrane during the impulse sound was also important for the prediction of hearing loss (other than intensity and duration). Price (1994) notes that, “at lower SPLs losses are in all likelihood largely a function of the metabolic demand on the inner ear (it gets ‘tired out’) and that above some spectrally dependent critical level, the loss mechanism changes to one of mechanical disruption (the ear gets ‘torn up’).”

He argues that if the basilar membrane is allowed to oscillate past the zero (atmospheric pressure) point, then more damage will be sustained by the hair cells in the Organ of Corti. If impulses possess either completely positive or completely negative pressure waves, the displacement of the middle ear ossicles cannot impart sufficient energy to create a ‘tearing’ action to the inner ear structures.

## **11.20 Existing noise standards and inadequacies**

New Zealand Health and Safety Regulation 11 of the Health and Safety in Employment Regulations 1995 requires an employer to take all practicable steps to ensure no worker is exposed to sound pressure levels greater than:

- A time-average level over an 8-hour working day of 85dB A ( $L_{Aeq} 8h = 85dB$ ) or equivalent.
- A peak level ( $L_{peak}$ ) of not more than 140dB

A code of practice, promulgated under the New Zealand Health and Safety in Employment Act 1992 for the management of noise in workplace, gives a statement of preferred work practices and guidance in meeting the requirements of the legislation.

Dr. Van Atta (1973), who is generally considered the author of the initial US Occupational Safety and Health Administration noise regulation (1971), stated, “It is not scientifically possible to set a realistic standard for exposure to materials or to energy that will protect the whole of any population that is exposed.” Pell (1973) has shown, in one of the very few longitudinal noise exposure studies, as a basis for regulation, that the protection of almost all employees can indeed be accomplished through an effective hearing conservation programme. He also emphasises that effective programme must continue to grow in regulations and spread throughout industry to cover all the employees to achieve maximum prevention of hearing impairment.

Sulkowsky (1980) stressed that despite millions of audiometric records gathered from exposed workers, the relations between noise exposure and the resultant noise induced permanent threshold shift are still imprecise, and the data from field and laboratory studies, on which the present damage risk criteria and standards are based, are imperfect and controversial. Sulkowsky’s final conclusion is, “there is no general agreement about trading relation between level and exposure time, but it seems that the 5dB doubling rate is more appropriate than 3dB time/intensity trade off value.” The US Occupational Safety and Health Administration amendment regulation of March 3, 1983 was the first step towards reliance on a hearing-conservation-programme-based regulation for occupational noise exposure and stresses the importance of a shift from sole reliance on damage risk criteria.

The damage risk criteria in the United States is based on noise measurements made from hand held type 2 sound level meters. Typically the microphone was 3ft from

the noise source, preferably without the employee present. Selection of the damage risk criteria implies that there will be some percentage of the exposed population remaining at risk at that level. Given that the damage risk criteria is not enough to protect all the employees, every hearing conservation programme should be aware of the drawbacks and realise that once a specified exposure limit is reached in the workplace, it is still necessary to protect employees whose hearing remains at risk or below the regulated levels. The several studies of workers exposure to noise have historically relied on voluntary subjects and questionnaires.

As explained above, in this New Zealand study we found that music induced hearing loss doesn't necessarily depend on the loudness of the instrument played and there are large individual variations in susceptibility. The calculation of damage risk criteria is likely to be different for different individuals. The hearing loss prevention programme will only be effective when we shift our reliance from damage risk criteria based to one that is person specific. Each musician should have their own individual hearing loss prevention programme, and it is important that we adopt different strategies for different individuals as there is a large individual variation in susceptibility or vulnerability to noise and/or music; otherwise prevention of hearing loss will remain an elusive goal.

### **11.21 Prevention and Early identification of hearing loss in musicians**

Westmore and Eversden (1981), after performing audiometry and recording sound pressure levels within orchestras during performances, concluded that preventing hearing loss in musicians is not entirely possible.

According to Backus & Williamon (2009), the earliest audiometric indicator of impending NIHL for musicians may be a developing hearing threshold notch at 6kHz in the left ear. Hence it is important that any decrease in hearing from the baseline measurements, as indicated by both pure-tone audiometry including any variation within normal range (normal dip at 3, 4 and 6kHz) and reduced oto-acoustic emissions at a particular frequency, is carefully noted, for it will indicate the need to initiate an individualised hearing conservation programme. This programme must

include identifying appropriate musician plugs and a requirement for periodical audiological evaluation, including appropriate case history, to identify signs of early damage to inner ear. Pure-tone audiometry (with stricter hearing threshold and inter-octave frequency threshold measurement) and DPOAE measurements should be included in the audiological test battery of every hearing loss prevention programme for musicians.

The most important component of the orchestra musician hearing loss prevention programme is education. Most of the adult orchestra musicians are aware of the harmful effect of music induced hearing loss. Callahan et al., (2011) concluded that as young musicians they don't really think about hearing loss being a factor for them right now. Palmer (2009) stressed the importance of targeting the life-long habits of school-age music instrumental students and their teachers through an education and hearing protection programme and encouraging life-long healthy hearing habits in them. The majority of the children and some of the youth orchestra musicians are not aware of the harmful effects of unamplified music and preventive strategies to prevent any harmful effects. According to Miller, Stewart, & Lehman, (2007) there is a need for on-going hearing conservation programmes to educate student musicians and student directors about the dangers of excessive exposure to loud music. According to Eaton and Gillis (2002), an educational programme to inform musicians about the effects of sound exposure, risk of hearing loss, and exposure control options is warranted. Hence hearing and hearing loss prevention should become a part of their music educational curriculum in every school of music and all the schools where music is being taught. Music educators have a special obligation to teach their music students the basic information of hearing loss prevention (Eaton & Gillis 2002). All the musicians also must be educated to modify the acoustic environment in which they practice music on a regular basis, and also seriously evaluate their playing habits.

In industrial practice, the first step in noise control is to reduce sound emission at source – obviously not an option for a symphony orchestra. It is difficult since classical music has to be played at a certain loudness to produce the typical sound. Therefore a demand to play more quietly and to reduce the sound emissions down to 85dB(A), as allowed in industry, cannot be a solution to the problem. Regardless of

the means, the goal is to convince an orchestra musician that protecting his/her hearing is medically and professionally necessary, thus enabling a long and audiologically healthy career in music. However, doing so will be futile if that musician is not equipped with ear protectors and other devices that make protection acceptable to the individual musician.

One of the big hurdles in convincing a musician to wear protection is that past experiences wearing earplugs, particularly among youth musicians, have not allowed them to hear the music in a natural manner. This is because conventional earplugs cut as much as 50dB in the high frequencies and 35dB in the low frequencies. This is more attenuation than necessary to bring concert level music into a safe listening range, and the difference between the high and low frequencies makes the music sound muffled, and affects the quality of music. Moreover, these earplugs create an uncomfortable side effect of voice distortion called the occlusion effect, which is the sensation of feeling like one's own voice is much louder than outside sounds.

Different filters can be used by the same musician in various venues according to the loudness level of that venue. These musician plugs are gaining in popularity among musicians because of their many advantages over conventional earplugs. Hearing loss is a real threat to an individual musician's career. All should be concerned about the potential loss of their hearing and should be motivated to preserve it throughout their careers. Individual attention to the sound environment and awareness of hazards is a large part of the solution. Keeping in mind the three most potentially dangerous sound environments in a school of music setting (ensemble rehearsals, private lessons, and practice rooms), let us recall the possible solutions. If again bombarded by such levels of noise within that very sensitive recovery time, the hair cells are at risk of permanent damage or total destruction. This knowledge enables the musician to realise that the risk of permanent damage can be reduced by 'giving the ears a break' during long musical sessions and nightly concert schedules.

According to the recommendations by Ostri et al., (1989) musicians should have noise-free intervals between rehearsals or performances. They should practise in sound shielded rehearsal rooms that have noise-limiting walls or wainscots. The use of hearing protectors should be recommended from the beginning of formal training

at the academies of music. The instruments in the surroundings of an individual musician can be more harmful than the sound emission by their own instrument, and therefore Ostri et al., (1989) recommended a 12 hour noise-free interval between rehearsals or performances.

Prevention of hearing loss among musicians continues to be an elusive goal. Dampening of sound levels while still allowing for the fine appreciation and monitoring of musical tones seems to be a fundamentally contradictory concept. It is therefore not surprising that, in general, musicians have been reluctant to use ear protectors. However, at least the loud instrument players and individuals who are susceptible need some form of ear protection if they are to continue with their music careers. Simple strategies such as break periods during practice and playing on alternate days might substantially reduce the risks. Another possibility is the programming of various performances daily and seasonally to make sure that densely orchestrated and 'loud' music is offset by some softer orchestra work, and not having a full rehearsal and performance on the same day may also help. There must be an effective solution attained that would allow the musicians to play the music and express their talent while protecting their hearing sense that is fundamental to their achievements.

### **11.21.1 Playing time**

Mikl (1995) found that the placement of the performers in the orchestra, coupled with a tight schedule, contributes to a significant risk of noise induced hearing loss. It is a known fact that the duration of noise and/or music exposure increases the impact on hearing, assuming that the orchestra music causes hearing loss. According to Kahari et al., (2004) the duration of music exposure increases the risk. It is likely that those with more years of experience would be at greater risk of developing more hearing loss. It must be noted that the amount of playing time can vary significantly among individuals with the same amount of experience. Assessing hearing loss associated with playing time may be more indicative of the effects of long-term music exposure rather than years of experience.

### **11.22.2 Seating arrangement**

As emphasised above: The highest noise exposure was found among the Brass instruments, followed by the Woodwind, and then the Strings. In general, the measured noise exposure decreases with the distance from the Brass and Woodwind. The exposure level strongly depended on the instrument being played and where the musician was seated in the orchestra. It is clear that the musicians at the back of the stage are at high risk (Woodwind and Brass) whereas the musicians in the front (the Strings) are at low risk. Hence the orchestra management should be made aware of the impact of seating arrangements on musicians' hearing.

### **11.22.3 Importance of Music Survey**

A music survey should be a part of the hearing loss prevention programme, to gain greater insight to the orchestral noise environment, guide future work into orchestral noise management and hearing conservation strategies, and provide a basis for the future education of musicians and their management. Given the effect of individual susceptibility to noise or music exposure, apart from a collective effort to reduce the group impact of such exposure, the most important or effective requirement is a personalised prevention programme utilising the available standard audiological test results. It is a necessity; otherwise the goal of hearing loss prevention will remain elusive and preventing hearing loss in musicians not entirely possible.

### **11.23 Original contribution to knowledge**

1) This study identifies that the reason for the huge variation in drawn conclusions regarding hearing loss in musicians is possibly due to the fact that the impact of orchestral music on the hearing of an individual musician, music group or organisation is dependent on many factors, some of which are known and some unknown. Some are not quantifiable, measurable and comparable, some are intrinsic, and some are extrinsic factors.

2) It is impossible to calculate the complete dosage of music exposure for each musician and also accounting for each factor that might have directly or indirectly influenced the resulting hearing loss.

2) Each composition of the music group is different, and they are not matched in terms of various contributing variables (such as age, sex, instruments played, individual susceptibility of each of the musicians, years of professional activity etc). Although our findings are similar to other findings, it is not feasible to compare various orchestras, and the drawn conclusions from one to another should not be applied.

3) There are several factors that determine the status of individual musician's hearing. Each orchestra is different, and with a varied composition with various backgrounds of professional musical experience; hence it is not possible to compare one group with another and draw conclusions, or to expect similar findings.

4) During hearing evaluation, the researcher found that the musicians were good with detecting pure-tones and were capable of identifying subtle variations in intensity and frequency. This may be the reason for some of the research studies finding better hearing thresholds than in the general population.

5) Given the musician's requirement of hearing is much different from the general population, in this study we have not applied any age or gender correction. And there lies a risk of underestimating the prevalence of hearing loss in musicians.

6) In this study we have not compared the hearing threshold of musicians with the average population because musicians are a special group of people who possess a unique ability to identify the subtle differences in intensity and frequency of sounds. Even a small change or alteration in their hearing will have a significant effect on their musical ability, while even a large alteration may not be an issue for someone who is not a musician.

7) In a significant number of musicians the asymmetry is observed at least in the beginning of their music career because of the proximity of their own musical

instrument to one ear more than the other, but as they increase their involvement in group musical activity while being a part of an orchestra, this asymmetry tends to disappear or change in degree with increased music exposure in group musical activities.

8) Among youth and adult musicians, the gender of an individual can be considered as an influencing factor with men appearing to be more affected than women, who have more sensitivity than men at frequencies above 1000Hz but less than men at lower frequencies. In children this trend was not observed.

9) In this study we observed that the dip in the pure-tone audiogram varies widely in frequencies from 1500 to 8000Hz. The numbers of audiograms with dips in the mid frequencies (1500-3000) are less common than high frequency (4-8kHz) dips. The configuration of the audiograms is possibly influenced by the spectral characteristics of music exposure.

10) In this study, when we look at all the musicians of all ages, the proportion of musicians with hearing loss is found in all age groups and in all instrument players, and also there is an increased number of musicians with hearing loss with increased number of years of music exposure. If individual susceptibility is a true statement, it may well be that the initiation and progression of noise induced hearing loss should also vary, depending on the individual susceptibility.

11) A significant individual variation in the progression of hearing loss occurs for known and unknown reasons as well. Some people have 'stronger/harder ears' while others have 'weaker/tender' ears with marked hearing loss after minimal music exposure. This stresses the importance of personalised hearing loss prevention programmes that will help to identify early signs of noise and/or music induced cochlear damage to help start a personal plan to avoid any further deterioration in hearing for that particular individual.

12) It is possible that apart from the individual susceptibility, a particular ear may be more susceptible than the other ear in a given individual.

13) To date there are no studies on music induced hearing loss in children, but there are several reports suggesting that there is an increase in incidence and prevalence of hearing loss among children and young adults. In our study we found that six children (16.2%) out of 37 musicians, who are susceptible, were found to have hearing loss. They need to be made aware of the importance of protecting their hearing as some of them may choose music as a career for life.

14) In our study, we found that there is a large individual susceptibility to music induced hearing loss in all age groups. If individual susceptibility is a true factor, the damage risk criteria could not be generalised and has to be individualised. It is possible that there may be a number of individuals with individual susceptibility who acquire or continue to notice deterioration in hearing with increased music exposure though they are exposed to noise that is within international standard recommendations.

15) Though only a few children and young adults use musicians' plugs, the adaptability to using ear protectors is much better among the children and young adults. Possibly they adapt better when they start during the early years, whereas established musicians can sense the change in the loudness of music to which they are not accustomed. Hence it is important to encourage the young musicians to start using the musicians' plugs in the early years of professional activity.

16) There was no statistically significant relationship between family history of hearing loss, history of ear infection and music induced hearing loss.

17) This study clearly demonstrates that DPOAE can indicate early cochlear damage before a hearing loss is indicated by pure-tone threshold audiometry. Along with pure-tone audiometry, DPOAE can also serve as an important tool in classifying an individual as being susceptible to music induced hearing loss, even before an individual musician can perceive the damage.

18) Given the large individual susceptibility, the calculation of damage risk criteria is likely to be different for different individuals. The hearing loss prevention

programme will only be effective when we shift our reliance from damage risk criteria based to one that is person specific.

19) Each musician should have an individualised hearing loss prevention programme. It is important that we adopt different strategies for different individuals as there is a large individual variation in susceptibility or vulnerability to noise and/or music; otherwise prevention of hearing loss will remain an elusive goal.

20) In some cases an individual musician's hearing loss starts at a very early age, when they start playing music, and gradual deterioration is observed with increased music exposure. In some individuals, however, the hearing is well preserved in spite of several years of music exposure.

21) Hearing loss development with increased music exposure follows a particular pattern deterioration that has begun at a particular frequency, and hearing continues to deteriorate in that frequency and with the lesser rate in an adjacent higher frequency. There is also a large individual variation in the rate of progression of hearing loss.

22) It is a known fact that the duration of noise and/or music exposure increases the impact on hearing, assuming that the orchestra music causes hearing loss. It is likely that those musicians with more years of experience would be at a greater risk of developing more hearing loss, but this trend is not observed in all the musicians.

## **11.24 Limitations to this Study**

There were several limitations to the research methods. They are as follows:

### **11.23.1 Fixed sound level measurements**

Unlike the New Zealand standards for the measurements and assessment of environmental noise or the approved code of practice for noise in the workplace, the lack of standard methods for the measurement of sound levels in musical settings remains a significant limitation. This means that it remains the choice of individuals

taking the measurements, which can vary greatly and significantly affect the results obtained.

### **11.23.2 Personal sound exposure of musicians**

The doseBadges were designed for measuring compliance with the international workplace exposure criteria for noise. Due to memory limitations and their being very small units, the doseBadges have a high cut-off point where sound that is less than 75dB is discarded. Because of this, it is not entirely suitable for children, giving a conservative estimate of the children's exposure. A lower cut-off point at 65dB (i.e. data of less than 65dB is discarded) would have given a better representation of the personal exposure for children.

### **11.23.3 Self Selection bias**

In the context in which data was collected, self-selection bias is the first and foremost among the possible limitations in this data set. It is possible that only orchestra musicians who suspected a hearing loss chose to have their hearing tested. They were also informed about the predictive value of oto-acoustic emission testing. It is assumed that those who are suspected to have normal hearing would be more inclined to have their hearing tested once they were aware that there was an objective measure that predicts cochlear outer hair cell dysfunction prior to the onset of noticeable or measurable hearing loss. Additionally, those who did not want to be identified as having a hearing problem might have not volunteered to have their hearing tested. It was assumed that most musicians understand the necessity of good hearing and most of the musicians among the youth and children who had never had a hearing test came forward to have their hearing tested.

### **11.23.4 Musician's well trained ears**

Orchestral musicians are found to be better in detecting pure-tones than other people with their well-trained ears and developed sensitivity to sound and music in general Seither-Peisler et al., (2007). The evaluation of hearing with pure-tone audiometry

seems to give very different results than that of, for instance, workers in a noisy industry or the general population.

#### **11.23.5 Responses to Questionnaire**

Though we have collected all the related information from individual musicians, it is impossible to account for all the contribution of previous sound exposure as we do not have accurate information of the time, duration and intensity of the sounds. Reliance had to be placed on the test subjects themselves to estimate contributions of other factors and previous music exposure.

#### **11.23.6 Sound measurements and risk assessment**

Firstly, this study does not account for all of the individual practice musicians have to undertake. Secondly, though we have some measurements on whole day music exposure, it is impossible to determine other sound exposure outside the orchestral activities, and the musicians can be overexposed with the addition of these activities such as ‘do-it-yourself’ activities, night clubs, playing for another music band or orchestra, and of course the hours of individual practice. In order to calculate the total risk for each musician, all these activities have to be taken into account, but this is often not always achievable for reasons of practicality.

#### **11.23.7 Sound measurements errors and uncertainties in measurements**

The data was collected primarily during rehearsals which are indicative exposures, and performance data presented is limited. The measurement errors in this study include accidental touching and movement of the microphone and cables. The slow response time used should render them negligible if they are occasional and instantaneous. We also examined the time history traces of the measurements to ensure data integrity.

### **11.23.8 Doubling exposure to assess risk assessment**

There are some that show no risk of hearing loss when judged solely from their rehearsal activity, but doubling the exposure levels to account for rehearsal and performance after only five hours of interval will add to the noise exposure and reach a level that now presents a risk. In this, apart from the rehearsal we could not account for other non-musical and musical activities.

### **11.23.9 Longitudinal analysis of existing audiometric data**

The retrospective pure-tone audiometric data used for longitudinal analysis to study progression of hearing loss with increased years of music exposure was not collected during this study, and the existing audiometric data was used, which was collected as part of hearing loss prevention programme.

### **11.23.10 Age and Gender correction were not undertaken**

Given that the musician's requirement of hearing is much different from the general population, we have not applied any age or gender correction to this study, including the longitudinal data from the normal-hearing reference group of ISO 7029 (2000) standard.

## **Chapter 12 : Conclusions**

### **12.1 Introduction**

The primary aim of this research work was to contribute to increasing our understanding of the effects of music on musicians' hearing, to help in planning preventive measures, and also to provide different strategies to minimise hearing damage. After a complete review of literature, given the very nature of music, there is a controversy about the presence of hearing loss in musicians and a long lasting disagreement and confusion on music induced hearing loss and the other factors involved. This research set out to answer a number of questions regarding musicians' hearing and the long term effects of exposure to long periods of loud music during the course of their careers. Unlike workers in industry whose environment may contain unwanted high levels of sound, that by law must be reduced to acceptable levels, for musicians their product is sound that may be of a high level at times, but necessarily so as they need to preserve the culture of classical music. So musicians are a special case, needing special attention to preserve their hearing, which is so necessary to their careers.

### **12.2 Hearing status of various groups of musicians**

#### **a) Is every professional musician (music instrument player) at risk for acquiring hearing loss?**

Though this study confirms that with increased duration, loudness and number of years of music exposure there is an increased probability of acquiring hearing loss in all musicians, there seem to be large individual variations in susceptibility to music exposure. Hearing loss is found in all groups of musicians; it is not specific to loud musical instruments or musicians with many years of music exposure.

#### **b) In the hearing mechanism, what frequency region is more affected with loud music exposure?**

Though hearing deterioration is predominately in the high frequency region, on average deterioration is more at 6kHz than in the other frequencies – at least in the

initial stage. So it can be concluded that a greater number of musicians show more deterioration in hearing at 6kHz when compared to other frequencies.

Music induced hearing loss does not show deterioration in hearing in the low frequency region, particularly in the frequency region of 250-1000Hz. Musicians have better hearing in the low frequency region than the mid frequencies, and in the mid frequencies this is better than in the high frequency region.

The deterioration in hearing with increased music exposure is very slow in the mid frequency region (1500-3000Hz) when compared to the high frequency region (4000-6000Hz).

**c) Are musicians capable of identifying slight alteration in their hearing?**

The musicians are good at detecting pure-tones and are capable of identifying subtle variations in intensity and frequency. This may be one of the reasons for some of the research studies finding better hearing thresholds than the general population. Unfortunately, significant numbers of musicians are not aware of slight alterations in their hearing, but this may be influenced by subjective bias.

**d) Does music exposure causes asymmetry in hearing, one ear being more affected than the other?**

On average, in all age groups of musicians oto-acoustic emissions results are better in the right ear than the left ear in the frequency range 3000 to 6000Hz. Depending on the position of the body or head in relation to their musical instrument, and to other musical instruments if they play in an orchestra or band, some of the sound may be shielded from one ear, causing the other ear to be more affected. So it is reasonable to conclude that the music exposure, depending on the musical instrument played, causes asymmetry in hearing at least at the beginning of their music exposure. As they start becoming involved in group activities or change the musical instrument, and depending on the position of the musician in the orchestra or band, the asymmetry may disappear or change in degree.

**e) Do female musicians have better mean hearing threshold than male musicians?**

Among youth and adult musicians, the gender of an individual has been often considered as a possible influencing factor, with men appearing to be more affected than women. This study found that female musicians have better hearing thresholds than males, and that the progression of hearing loss is slower in females than males. On average, female musicians have a higher amplitude distortion product oto-acoustic emission (DPOAE) than male musicians.

**f) Is it possible to correlate the dips in the pure-tone audiograms with the intensity and frequency of the musical instrument?**

This study found that it is not possible to correlate the dips in the pure-tone audiograms with the intensity and frequency of the musical instrument given the complex sound exposure of each musician, and also given their increased amount of group activities. The earliest pure-tone audiometric indicator of impending NIHL for musicians may be a developing notch at 6kHz.

**g) In addition to the intensity of the sound, do the spectral characteristics of the music also determine the configuration of the audiogram and the risk of damage to the hearing system?**

Though a greater number of musicians are observed to have dip at 6kHz in their pure-tone audiograms, dips are also observed in various other frequencies from 1500 to 8000Hz. This could be because, in addition to the intensity of the sound, the spectral characteristics of the music also determine the configuration of the hearing loss and the risk of damage to the hearing system.

**h) Are Distortion Product Oto-acoustic Emission (DPOAE) test results consistent with the pure-tone audiogram findings? Can DPOAE findings be used as a tool for early identification of hearing loss among musicians?**

The OAE data corresponded well to the audiometric findings in all age groups. The alteration in pure-tone audiometry was accompanied by a decline in oto-acoustic emission amplitudes and in general, configuration of the emission graph resembles the configuration of the pure-tone audiogram.

The otoacoustic emissions of the musicians with normal hearing is clearly distinguishable from the oto-acoustic emissions of the musicians with alterations in the pure-tone audiometry, suggesting a signalling function for early detection of noise and/or music induced hearing loss.

Reduced DPOAEs in any frequency without hearing loss or a normal dip in any frequency provides the first objective sign of early damage to cochlea to say that the musician is susceptible and/or vulnerable to music induced damage.

This study shows that oto-acoustic emission measure provides objectivity and greater accurate information, complementing the pure-tone audiometric findings in the diagnosis and monitoring of the cochlear status following music exposure.

Given its sensitivity and specificity in detecting early damage to outer hair cells in the cochlea, DPOAE can be used as a tool to identify susceptibility to music or noise induced hearing loss along with other measurements in the audiological test battery.

More intense oto-acoustic emissions (OAEs) were found for groups with better average pure-tone thresholds.

The otoacoustic emissions of the musicians with normal hearing is clearly distinguishable from the otoacoustic emissions of the musicians with alterations in the pure-tone audiometry, suggesting a signalling function for early detection of music induced hearing loss.

Otoacoustic measure can't be used to assess the severity of hearing loss, but there is a clear association. As the severity of music induced hearing loss increased, the emissions range became narrower and the amplitude smaller. Oto-acoustic Emission testing (OAE) is not a test of hearing. OAE findings cannot be used in isolation to diagnose auditory dysfunction or to predict the degree of hearing loss.

OAEs were found to be more sensitive to music induced damage than behavioural pure-tone threshold measures.

Music induced reduced emission levels were found in musicians with normal audiograms. Given its objectivity and sensitivity, an oto-acoustic measure is a useful tool in planning an individual hearing loss prevention programme.

DPOAEs can also be very effective in verify the effectiveness of both musicians' earplugs and in the ear monitors.

**i) Is there a significant relationship between tinnitus and hearing loss among various age groups of orchestra musicians?**

One of the commonest symptoms associated with music exposure is tinnitus. Among the youth and adult musicians there is a statistically significant relationship between tinnitus and hearing loss, but this trend has not been observed in children.

### **12.3 Longitudinal hearing status with increased music exposure**

**a) Do all musicians show increased risk of deterioration in hearing with increased number of years of music exposure?**

We found that the increased years of music exposure causes progressive hearing loss in significant numbers of individual musicians, and this trend is observed in all age groups of musicians but not in all musicians. In some musicians who are known to be susceptible to music exposure, pure-tone hearing threshold values continue to change gradually and progressive hearing loss is observed with increased number of years of music exposure. We also observed that in some cases individual musician's hearing loss starts at a very early age of music exposure and gradual deterioration is observed with increased music exposure, whereas in some individuals hearing is well preserved in spite of several years of music exposure. There is also a large individual variation in the rate of development and progression of hearing loss.

**a) Does the increased number of years of music exposure increase the risk of age induced hearing loss?**

It is often difficult to separate the effect of music and age. In some musicians, there is no notch, but the pure-tone audiogram is of sloping configuration (similar to age induced hearing loss) from the beginning of music exposure and continues to follow

the same pattern with increased music exposure. So it can be concluded that some musicians' ears seem to age faster with increased music exposure.

**c) Do changes in the audiogram follow a particular pattern with increased music exposure over a number of years?**

It is interesting to note that in general hearing loss development with increased music exposure follows a particular pattern from the beginning. In most of the musicians, it starts with a dip at a particular frequency and the dips become deeper and continue to deteriorate in that frequency, with the lesser rate in an adjacent higher frequency. In some musicians, the audiometric configuration is sloping from the early stage of music exposure.

## **12.4 Sound environment and hearing loss**

a) What are the typical music levels encountered in an orchestra, and by how much do they exceed the levels proposed by the Occupational Safety and Health Standard?

In New Zealand, a noise dose of hundred percent is the maximum permitted daily sound exposure for an adult industrial worker (85dB over an 8-hour working day). A measurement made during orchestra rehearsal and performance obtained shows that the percussion section received a dosage of 256% (standard deviation: NA), the Brass section received a dosage of 159.3% (standard deviation: 65.1), the Long Strings section received a dosage of 83% (standard deviation: 56.6), the Woodwind received a dosage of 136% (standard deviation: 90.6), and the Short Strings received a dosage of 52.9% (standard deviation: 20.6).

In general the Brass, Percussion and Woodwind receive music level in excess of the permissible dosage levels. The small and long string instrumental musicians experienced the lowest average sound level exposures during musical activities.

**b) What is a typical noise level encountered by various instrumental musicians and how does this have an effect on other musicians?**

This study could not find an answer to this question, but in an orchestra, as it is a complex group activity, it is difficult to accurately account the effect of sound produced by one's own instrument and the effect of others around.

The main music source that increases the potential risk of music induced hearing loss (MIHL) comes from the back of the orchestra. The fixed time average levels taken during an adult orchestra rehearsal and concert performance shows most of the musician at the back of the stage received sound level in excess of the permissible dosage levels.

Most of the musicians in all age groups are exposed to Peak level ( $L_{peak}$ ) of more than 140dB, particularly the Brass, Percussion and Woodwind sections of the orchestra.

In general, the measured noise exposure decreases with the distance from the Brass and Percussion sections. For example, the music exposure of Viola and Cello players were higher than the first violins, which are further away from the Percussion, Brass and Woodwind.

**c) Is hearing loss observed only in loud musical instrument players?**

It is a known fact that the duration and loudness of noise or music exposure increases the impact on hearing. It is likely that those musicians with more years of experience and the musicians who play louder instrument would be at a greater risk of developing more hearing loss, but this trend is not observed in all the musicians.

**d) How does each instrument family vary on sound levels and the daily sound exposure received?**

The highest noise exposure was found among the Percussion and Brass instruments, followed by the Woodwind and then the Strings, but understandably this will vary, depending on the type of music played.

## **12.5 Factors influencing the increased risk of hearing loss among musician**

### **a) Does a family history of hearing loss increase the risk of individual musician risk of acquiring hearing loss with music exposure?**

Among all age groups of orchestra musicians, there was no statistically significant relationship between family history and hearing loss, but it is important to collect this information to analyse possible familial or genetic influences on that musician.

### **b) Does a history of ear infection increase the risk of individual musician acquiring hearing loss with music exposure?**

Among all age groups of orchestra musicians, there was no statistically significant relationship between music induced hearing loss and a previous history of ear infection, but it is important to collect this information to analyse the possible influence of a history of ear infection in that individual musician.

### **c) Does the usage of personal stereos further increase the risk of individual musician acquiring hearing loss with music exposure?**

Among the youth musicians, there was a statistically significant relationship between the usage of personal stereos and hearing loss only in the left ears – not in the right ears. The usage of personal stereo is very common among youth musicians. Young musicians are also exposed to other sources of loud noise and music apart from the regular orchestra music. Listening to loud music with personal stereo was found to be the largest contributor to music induced hearing loss in this study among young musicians.

### **d) Does a history of other noise exposure further increase the risk of individual musician acquiring hearing loss with music exposure?**

Though no statistically significant relationship was found between other noise exposure and incidence of hearing loss among youths, it is important to collect this information as part of case history to plan individualised programmes for prevention of hearing loss for that particular musician.

**e) Do visits to loud music venues on a regular basis increase the risk of individual musician acquiring hearing loss with music exposure?**

Among the youth musicians a significant number of musicians attend loud concerts and night clubs. None of the musicians used any form of ear protection in spite of being aware that the loud music can cause hearing loss. The majority of the musicians indicated that they will use ear plugs if made available. Others indicated that they will not use them, even if they are made available free of cost.

**f) Does a school discotheque increase the risk of music induced hearing loss among children musicians?**

It may not cause a hearing problem on its own but adds to the daily din of noise exposure and increases the risk of hearing loss if children have had other noise and/or music exposure on the same day. The children who take part in a school discotheque are exposed to high levels of noise above the maximum permissible levels allowed for adults in industry.

## **12.6 General awareness and music induced hearing loss**

**Does the awareness of music induced hearing loss reduce the risk of individual musician acquiring hearing loss with music exposure?**

From our research it would appear that awareness about music induced hearing loss does not reduced the risk of an individual musician acquiring hearing loss with music exposure. Among the children and youth musicians there was no statistically significant relationship between increased awareness of music induced hearing loss and actual hearing loss. In other words, the two variables are independent. A significant number of youth and children musicians, however, were not aware of the relationship between music exposure and hearing loss.

## **12.7 Usage of Ear Protecting Devices**

**a) Does the usage of ear protecting devices reduce the risk of music induced hearing loss?**

From this research it seems logical that the usage of ear protecting devices will reduce the risk of music induced hearing loss in the majority of musicians, but the

data collected was not enough to give a definitive answer. Although the adult and youth orchestra musicians are aware of the dangers of repeated exposure to loud music and the benefits of musician plugs, their compliance in using these devices is far from ideal. Musician plugs were available to only a few of the youth musicians, but the adults had ready access if wanted. Many of the children musicians were not aware of the relation between loud music and hearing loss, and none of them use any form of ear protection. Having had ear disease increased the usage of musician plugs, but the usage levels are still far from ideal. It is interesting to see that the usage of musician plugs is common among musicians with hearing loss and tinnitus.

Though only few children and young adults use musician ear plugs, the adaptability to using ear protectors is much better among the children and youth musicians. The reason may be due to the fact that established musicians cannot tolerate even a slight alteration in quality and loudness of music to which they are not accustomed. Hence it is important to encourage the musicians to start using the musician plugs early/at the beginning of their music learning.

Motivation and further training is needed to further encourage the musicians to use musician plugs.

It is unrealistic to expect all the musicians to use musician plugs on a regular basis. However, at least the individual who is known to be susceptible (shows early signs of music induced hearing loss) or musicians showing continued deterioration in hearing with increased music exposure should be encouraged to use musician plugs.

**b) What are the main reasons for not using the ear protecting devices on a regular basis?**

Adult musicians gave several reasons for not using the musician plugs. The main reason may be due to the fact that established musicians cannot tolerate even a slight alteration in quality and loudness of music to which they are not accustomed. The plugs felt unusual, giving them also a blocked feeling and a resonating effect in the ears. This gave them a fear of making a mistake giving stress. Some felt wearing them was not practical and they did not want to be identified as wearing them. Some

said they just forgot to take them along. Some of the youth musicians thought they looked silly, and the music was not loud enough to warrant wearing them.

## 12.8 Individual susceptibility in musicians

### **a) Is there the possibility of identifying individual musicians who are susceptible to music induced hearing loss based on hearing evaluation?**

The research found that some musicians may not acquire any hearing loss in spite of spending several years playing significantly loud music, whilst other musicians may get a significant hearing loss within a few years of exposure to loud music. It may be concluded that some other biological or environmental factors may further contribute to increasing the amount of hearing loss due to noise or music exposure in an individual who is perhaps already vulnerable or susceptible.

As mentioned above, reduced distortion product oto-acoustic emissions in any mid or high frequency region may provide the first objective sign of early damage to cochlea to say that the musician is susceptible or vulnerable to noise or music induced damage.

### **b) Is there the possibility of identifying individual musicians who are susceptible to music induced hearing loss based on daily sound exposure?**

It is impossible to calculate the entire dosage of music exposure for each musician as almost all of the musicians have other music exposure such as individual practice and group sessions, together with other music assignments. The exposure durations, loudness and music characteristics are randomly distributed throughout the entire life of a musician. If individual susceptibility is a true statement, the daily dosage limit will also be different for different individuals. It may well be that the initiation and progression of noise or music induced hearing loss should also vary, depending on the individual susceptibility. Apart from loudness and duration of orchestra music exposure, there was no single music or non musical variable that could be identified to be a major contributory factor which makes one musician more susceptible than another.

## **12.9 Damage Risk Criteria for music**

There are a number of individuals, including children and youth musicians, perhaps with individual susceptibility, who acquire or continue to notice deterioration in hearing with increased music exposure although they are exposed to sound that is below international standard criteria for workers in industry. The variation in individual susceptibility also stresses the importance of individualised plans for prevention of hearing loss. If individual susceptibility is true, then the damage risk criteria and daily dosage limit is likely to be different for different individuals. It can be concluded that the damage risk criteria given in international standards is not adequate enough to protect everyone's hearing, and any risk assessment based on sound exposure against the available standards could be very misleading.

### **a) Are damage risk criteria for music different from noise exposure?**

Given the large individual variation in individual susceptibility, it is not realistic and scientifically possible to set a one standard for exposure to music or noise with the expectation to protect the entire community.

Given that the individual musicians who play louder musical instruments (Brass, Percussion and Woodwind) are found to have normal or near normal hearing and musicians who play relatively softer instruments were found to have significant progressive hearing loss with increased music exposure, it is clear that there are large individual variations, and the variation could be attributable to individual susceptibility.

Because of individual susceptibility, damage risk criteria cannot be generalised and has to be individualised.

We will not be able to protect every individual with one standard criterion for damage risk.

**b) Should musicians be treated as a special group with regard to hearing, noise, and noise related hearing problem?**

Musicians are a special group of people who possess a unique ability to identify the subtle difference in intensity and frequency of sounds; even a small change in their hearing acuity will have a significant effect on their musical ability while even a large alteration in hearing may not be an issue for someone who is not a musician. Unlike those who work in industry, musicians are often subjected to intense music levels for long periods of time, beginning from childhood years, then while studying music, during individual practice, and when rehearsing and performing music. The production of sound for others to enjoy is their work; the sound is not an unwanted by-product as it is in industry. The sound cannot be reduced at source, so other measures are needed to protect the musicians' hearing.

**c) The World Health Organization's 'WHO Guidelines for community Noise' suggests that the children could be at greater risk than the adults. Should the damage risk criteria be set at a lower level for children than for adults?**

Personal sound exposure levels varied greatly, but it was never expected that personal dose levels recorded by children could well exceed the occupational noise criteria of the health and safety in employment legislation. In our study we found that six children musicians (16.2%) out of 37 were found to have a hearing loss. It may be reasonable to conclude that some children may acquire a hearing loss even though the sound exposure does not exceed the adult occupational noise criteria. Our study did not get sufficient data to show the sound exposure level at which the children have developed their hearing loss, but it is fairly clear that the damage occurs at a lower sound level than for an adult in industry.

### **12.10 Some other important findings**

During the course of this research work, the following findings were made:

- ✚ There is no cure for noise and/or music induced hearing loss. In fact, prevention is the only treatment. There is a great need for a protocol for the prevention of hearing loss in musicians.

- ✚ The significant complexity of music exposure and its effects on individual musicians clearly support the statement that the orchestral music exposure is significantly more complex than the simple statement would imply.
- ✚ Each orchestra is different, with varied compositions of musicians with various backgrounds of professional musical experience. Hence it is not possible to compare one group with another, draw conclusions and expect similar findings.
- ✚ The musicians are good at detecting pure-tones and are capable of identifying subtle variations in intensity and frequency. This may be one of the reasons for some of the research studies finding better hearing thresholds in musicians than the general population.
- ✚ Given that the requirement of hearing in musicians is different from the general population, it is inappropriate to compare the musicians' hearing with general population, and the drawn comparative results can be very misleading.
- ✚ As each of the music group composition is different and they are not matched in terms of various variables (such as age, sex, instruments played, individual susceptibility of each of the musicians, years of professional activity etc), it is not feasible to compare various orchestra musicians, and the drawn conclusions cannot be generalised or applied to one another.
- ✚ There are several factors that are known and unknown, and determine the status of individual musician's hearing
- ✚ In the review of literature there is a huge variation in drawn conclusions, due to the fact that the impact of orchestral music on the hearing of an individual musician or music group is dependent on many factors. Some are not quantifiable, measurable and comparable, some are intrinsic, and some are extrinsic factors.
- ✚ The orchestra musicians are to be treated as a special group of professionals with special and unique hearing sensitivity.
- ✚ The success of musicians is very much dependent on the ability to accurately match frequencies over a very broad range. Any amount of hearing loss can have a direct effect on performance and is undesirable.
- ✚ Given that the incidence and prevalence of hearing loss in musicians of all ages can be attributable to music exposure, and also, at least in some individual musicians, the increased music exposure increases the prevalence of hearing loss, the results of this study could not support the proposed theory that in musicians

- ✚ We could not find any basis for the auditory toughing effect or building resistance with auditory training during practice and/or rehearsal as a true phenomenon.
- ✚ All musicians need to treat their hearing with care, and any harmful influences, such as damaging sound pressure levels, should be carefully avoided to protect their hearing to maintain good music perception ability.

## **Chapter 13 : Recommendations**

### **13.1 Strategies to prevent excessive noise exposure and its effects on musicians' hearing**

#### **Introduction**

There is no cure for noise and/or music induced hearing loss. In fact, prevention is the only treatment. There is a great need for a protocol for the prevention of hearing loss in musicians. The significant complexity of music exposure and its effects on individual musicians clearly supports the statement that the orchestral music exposure is significantly more complex than the simple statement would imply.

#### **a) Is prevention of hearing loss a possibility among musicians whose by-product is music?**

It is a huge challenge, but it is a possibility only when we have a strategic plan for each individual musician, and the hearing loss prevention programme will only be effective when we shift our reliance from damage risk criteria based to one that is person specific. Each musician should have their own individual hearing loss prevention programme, and it is important that we adopt different strategies for different individuals as there is a large individual variation in susceptibility or vulnerability to noise or music; otherwise prevention of hearing loss in musicians will remain an elusive goal.

#### **b) What are the measures that can be taken in order to prevent music induced hearing loss? And what workable and feasible strategies can be developed to reduce the noise and/or music level where there is a risk of hearing loss?**

The orchestra management should conduct a periodical music survey on a regular basis that must include overall noise exposure, including individual practice, rehearsals, performances, and all other musical assignments and noise exposure. A hearing loss prevention programme is absolutely essential, and everyone should be aware that the usual international standards damage risk criteria used for workers in industry has its drawbacks and may not apply to orchestra musicians. It is likely that musicians may suffer damage at lower levels of sound exposure. The programmes

need to be person specific due to the large susceptibility of some musicians to sound, as explained above. Hearing loss prevention must be a team approach, and the team must include an acoustician, who possesses knowledge about music exposure and hearing loss.

**c) Based on the noise dosage and changes in hearing threshold, what strategies can be developed to help the orchestral musicians of various age groups, to ensure that the musicians are not placed in situations where there is a risk of hearing loss that potentially causes a barrier to continuing their music career?**

### **13.1.1 Hearing loss prevention programmes must include:**

Organisational Measures (scheduling of programmes, seating arrangements, facility for individual practice and rehearsal sessions, and education).

Engineering Measures (seating arrangements, acoustical properties of venues and modification of stage set-up to reduce the impact of music etc).

Individual Measures (encouragement and motivation to protect musicians' hearing, periodic hearing evaluation, provision of high quality musician plugs, and training).

#### **13.1.1.1 Organisational measures**

Serious consideration should be given to limit the music exposure before organising music practice and rehearsals or while organising and scheduling the programmes for the orchestra. This may be done by shortening rehearsals, incorporating a break in the midst of a session, and avoid having the rehearsal and actual performance on the same day.

#### **13.1.1.2 Engineering measures**

All the musicians should have available special acoustically designed rooms for practice and for rehearsals. For rehearsals there should also be individual acoustic screens to limit the sound received from nearby loud instruments. This is

particularly important to protect the Woodwind from the Brass, and the Strings from the Woodwind.

#### **13.1.1.3 Individual measures**

Musicians must be encouraged to protect their hearing, emphasising that their careers totally depend on their having good hearing. They should be encouraged to wear hearing protection whenever they are practising, rehearsing or performing. Periodic hearing evaluation by a trained audiologist is essential, and each musician should have feedback on the status of their hearing and education regarding the need and measures for preserving their hearing. The education programmes must include complete information on the range of musician plugs available and advantages and disadvantages of each of them, together with information on the care and maintenance of them. Each musician should have their own individual hearing loss prevention programme – different preventive strategies may be required for different musicians, depending on the music exposure and hearing status of each musician.

#### **13.1.1.4 Audiological evaluation**

In order to have an effective hearing loss prevention programme, it is important that the hearing assessment of musicians is performed by a trained hearing professional who possesses knowledge of music induced hearing loss and is constantly willing to up skill with the current advancement as it is still a developing area. The evaluation must include complete case history that includes all the risk factors and signs and symptoms associated with hearing loss, and a comprehensive audiological evaluation that includes an otoscopy examination, impedance testing, pure-tone audiometry and distortion product oto-acoustic emission testing. Given that the oto-acoustic test is a useful tool in evaluating early cochlear damage, it should be used as a tool for monitoring the effects of music exposure. It should be an integral part of hearing loss prevention programme along with other audiological instruments in evaluating, monitoring, educating and counselling musicians who are at high risk for music induced hearing loss. The audiologist should help in developing the hearing loss prevention programme for each individual musician.

### **13.1.2 Youth Musicians**

A musician's hearing is vital to his or her career. Education regarding music induced hearing loss should begin in the early stage of a musician's training. There must be established guidelines and standards for noise and music exposure in the music school environment. Hearing health should become an integral part of the educational curriculum of music education; the young musicians need to be taught that their ears are their most important musical instrument.

The education curriculum must include:

1. Basic anatomy and physiology of the ear
2. Noise and music induced hearing loss
3. Methods and strategies for prevention of hearing loss
4. Types of ear protecting devices
5. Various types of musician plugs
6. Information on availability of musician plugs and the cost involved.

Every music school should have a hearing conservation programme in place, with regular hearing tests on all its members (including oto-acoustic emission tests), and each school should make sure that all the rooms used for practice and rehearsals are specially designed acoustically. The music school management should periodically seek the advice of an acoustical consultant to assess the rehearsal and performance sessions.

All the music students must be made aware of the importance and the means of limiting the daily dosage limit by minimising other noise exposure such as personal stereos, noisy hobbies (gun shooting, race cars, and mechanical tools), and visits to loud concerts and night clubs.

### **13.1.3 Children Musicians**

There must be established guidelines and standards for noise and music exposure in the school environment. Hearing health should become a part of the educational curriculum from primary education. Children should be taught that their ears are their most important musical instrument. It is the responsibility of the music teacher

that each student receive age-appropriate hearing-health information at all stages of their development.

Children musicians should be encouraged and made aware that protecting their hearing is medically and professionally necessary, thus enabling a long and audiological healthy future in music.

#### **13.1.3.1 Suggestions to the music teachers**

Music lessons should be conducted with the view to teaching musicality, but not at a volume to cause distress or harm to the children. The children should be taught and encouraged to play instruments musically, and not to bash them for the purpose of making noise. Very young children may be encouraged to use claves and other percussion instruments made of plastic or flax so as to give the musical benefit without generating sharp, piercing and impact-type sound, and serious consideration should be given to limit the music exposure before organising music practices, rehearsals and the position of the seating of the children to minimise the risk.

Music rooms should have a good acoustic environment, such as away from noisy classrooms, and have sound-absorbing materials in the walls, ceilings and floors. Noisy repertoires should be avoided and sectional rehearsals held whenever possible.

The children should be introduced to all types of musician plugs available and taught about the care and maintenance of musician plugs and their correct use. It is a good idea to periodically seek the advice of an acoustical consultant to assess the rehearsal and performance sessions.

### **13.2 Prevention of hearing loss in general public**

Prevention of hearing loss should become a health priority at a national level. There are many individuals exposed to occupation and non-occupation noise and music on

a regular basis who are not part of any hearing conservation programme. In order for hearing loss preventive programmes to be effective, given the fact that hearing loss caused by noise, and music is gradual and subtle, so the individual will not be aware of the difficulty until it becomes serious enough to cause communication difficulties, we must make sure that a facility for hearing evaluation is accessible to everyone to prevent hearing loss in the general public, and hearing loss prevention should become a national priority; otherwise a significant amount of money will be required for rehabilitation.

### **13.3 Recommendation for future research**

This study has led to the following recommendations for future work:

- ✚ A comprehensive study to examine the personal sound exposure of children musicians (increased sample size) over the full 24 hours, which would include typical exposures at home and other musical activities outside the orchestra settings.
  
- ✚ A study to examine the personal sound exposure of youth musicians (increased sample size) over the full 24 hours, which would include typical exposures at home and other musical activities outside the orchestra settings.
  
- ✚ A study to examine the personal sound exposures of adult musicians (increased sample size) over the full 24 hours, which would include typical exposures at home and other musical activities outside the orchestra settings.
  
- ✚ Replication of this study would benefit from an increased sample size of each age group of musicians. An increased sample size of each type of musician may provide information relative to the effects of a specific instrument present in musical activities and average sound levels. The possibility exists that other orchestra musicians may experience substantially greater or lesser daily sound-level exposure than the subjects of this study.

- ✚ Replicating this study for different orchestras may provide information in support of the present findings.
- ✚ Future research that may be of value would be to extend the number of days of sound level exposure during typical musical activities. Because musicians' schedules vary from day to day within a week, measuring average sound levels across one full workweek may provide a more accurate representation.

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## Appendices

<b>A</b>	<b>Central Regional Ethics Committee Approval and Correspondence</b>
<b>B</b>	<b>Correspondence for Research Study (letters and communications)</b>
<b>C</b>	<b>Adult Consent Form and Letter for Musicians</b>
<b>D</b>	<b>Child Consent Form and Letter for Parents</b>
<b>E</b>	<b>Adult – Case History Form</b>
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<b>G</b>	<b>Children – Case History Form</b>
<b>H</b>	<b>Peer-reviewed Conference Presentation Directly Attributed to this Work</b>
<b>J</b>	<b>Sample doseBadge Monitoring Report</b>
<b>K</b>	<b>Copy of Hand-out on Personal Stereo and Hearing loss</b>
<b>L</b>	<b>Copy of Poster on Usage of Hearing Protection among Orchestra Musicians</b>

# Appendix A

## Central Regional Ethics Committee Approval

As the project involved the direct participation of children, youth and adult musicians, full Central Regional Ethics Committee approval was required. Approval was given (CEN/06/06/048). The special conditions and requirements of the committee were met in full.

- ✚ Researchers had to wear a name badge, be under full supervision of teaching staff at all times, and if possible, in their line of sight.
- ✚ All the musicians would be provided with complete explanations of the hearing test results/to the parents of the children, and preventive and treatment option will be provided to everyone who took part in this study.
- ✚ The doseBadges were intrinsically safe and did not emit any kind of radiation (like a mobile phone) or signal while they were in operation.
- ✚ A doseBadge would not be fitted to a child under seven years old. Badges would not be fitted to any children if likely to cause distress or anxiety.
- ✚ Full parental written consent of parents was required. A letter/information sheet was addressed to every parent explaining the project.
- ✚ Children were selected by the teachers to wear a badge, and a letter was sent to each parent explaining this part of the project in full and a consent form to sign. (Copies attached)
- ✚ No child would be required to wear a doseBadge, even if parental consent was obtained. They would be removed on request of the child.

All personal details of the participants and the names of the early childhood centres which participated in this study were kept strictly confidential and not disclosed, neither in this work nor in any other report.

The Central Regional Ethics Committee approved a number of model letters, information sheets and consent forms to be issued to the participants (i.e. governing bodies, parents, teachers etc). Two of these documents have been included below as examples.

# Appendix B

## Correspondence for Research Study (Letters and communications)

Date

Dear

**Comprehensive Study:** The effect of orchestra music on different age group of musicians.

I am very grateful for you giving me the opportunity to talk to you a couple of days ago about my Massey University PhD research project. As agreed, this follow-up letter is to explain who I am, and to give details of my research programme.

My name is Sargunam Sivaraj. I am a fully qualified and Registered Audiologist, and Head of the Audiological Services of Capital and Coast District Health Board (C&C DHB), working at Wellington Hospital. My PhD studies are supervised by Professor Philip Dickinson of the Institute of Food, Nutrition and Human Health in the College of Sciences, Massey University Wellington.

This research is to investigate the effect of orchestra music on different age groups of musicians. This will be the first comprehensive study of its kind in New Zealand following concern raised throughout the world about the increasing incidence of hearing loss in musicians.

The study involves taking sound measurements around individual instruments during practice sessions, measuring the sound exposure received by each musician using a small doseBadge situated near the ear, and performing a simple hearing test before and after the music session. I would also like to gain an idea of the sound levels across the orchestra during a dress rehearsal using inconspicuous microphones or doseBadges attached to the backs of music stands. I would be very grateful if you would ask your musicians if any would agree to help me by allowing me to undertake the following tasks.

**1. An interview with the musicians:** First of all, I would like to talk with individual musicians to obtain some idea of their hearing acuity and their exposure to sound from music, and this would be undertaken a few days before any sound measurements were made. The initial interview will include a case history - information will be collected regarding various ear related signs and symptoms such as: a history of hearing difficulty, ear infection, family history, ringing sensation, giddiness, systemic illness, medications taken and other type of noise exposure apart from music. This may take approximately 15 minutes.

**2. Otosopic examination:** I would then like to make a visual examination of the musician's ear drum and any formation of cerumen. This would take about 3 minutes, and is totally non-invasive and would not cause any discomfort at all.

**3. Hearing evaluation:** I would like to perform a comprehensive hearing evaluation only on volunteers. The test will give complete information regarding ear and hearing status of each volunteer. The total test procedure may take about 15 minutes.

**4. Personal sound exposure during the dress rehearsal:** This would involve, in the rehearsal/practice room, the fitting of a noise doseBadges to clothing at some convenient location close to the ears, of course with appropriate consent of the musician, and during a dress rehearsal the fitting of a small inconspicuous microphone or doseBadge to the music stand – again only with the appropriate consent of the musician. At the end of the sampling period, the doseBadge (or microphone) is removed and the information downloaded onto a computer. The doseBadge records only sound intensities and has no voice recording capabilities.

The equipment is manufactured to an international standard (IEC61 50081-1 (1992- Generic emission standard for residential commercial and light industry) which requires that the badge must be completely safe to use and does not emit or generate any kind of sound, microwaves, radio waves or any other signal while turned on and being worn. This is a requirement of the international standard under which the equipment is manufactured and tested.

This badge is small and light enough (50grams) not to draw the attention of the musicians or other people. However, if a musician did not wish to have it on the music stand we will not place the doseBadge there. I have enclosed information sheets on the doseBadge, which will be given to all the musicians.

I agree to:

- Maintain strict confidentiality by not identifying any individual musician or the orchestra in any publication and will not reveal to any third party or in any report or publication.
- To remove the badge at any time if the musician does not wish to participate.
- To be on site the whole time the badge is worn.
- To keep every musician informed of the results pertaining to the musician's participation.

Every musician has the right to:

- Decline the participation
- Withdraw from the study at any time up to sampling
- Ask any questions about the study at any time during participation.

All the musicians will be given access to a summary of the project findings when it is concluded. Please note that it is a requirement that all confidential information has to be kept in a secure storage with restricted access. Draft letters, information sheets and consent forms are enclosed.

The equipment used is robust but in the event of loss or damage, the orchestra or any individual will not be held in any way liable for whatever reason. This remains the sole responsibility of Massey University and its Insurers. However in the interests of all concerned, the researchers must remain on the premises at all times the equipment is in operation so as to respond to any requests of the musicians.

The Central Regional Ethics Committee requires the following participant's rights as part of the approval process. As an organisation you have the right to decline to participate or withdraw any of your centres from the study at any time.

Provide information only on the strict understanding that your organisational or participant musician will not be named or identified in any way (unless expressed permission is given to the researcher).

This project has been reviewed and approved by the Central Regional Ethics Committee. If you have any concerns about the conduct of this research, please contact Committee Administrators: Ms. Claire Yendoll and Ms. Jan Ostnes P: C/- Ministry of Health, 1-3 The Terrace, POBox-5013, Wellington, T:(04)4962405.

Email to: [claire\\_yendoll@moh.govt.nz](mailto:claire_yendoll@moh.govt.nz)

I sincerely thank you for your consideration in this important study. I have enclosed a consent form to be completed. I am happy to answer any further questions you may have, address any concerns and welcome any relevant comments or contributions you would like to make. Please feel free to contact me on 📞 (04) 9186656. Email: [sargunam.sivaraj@ccdhb.org.nz](mailto:sargunam.sivaraj@ccdhb.org.nz). I would value an opportunity to meet and discuss the project with you in person if this is possible at a time convenient to you. In this way we can discuss any immediate concerns and questions you may have.

This is a very important study that I believe will be of significant benefit to all the musicians and the Orchestra in the future, and your help in this would be very much appreciated.

Yours sincerely

Sargunamoorthy Sivaraj  
Team Leader  
Audiological Services of C&CDHB  
Wellington Hospital  
Wellington

# Effects of Music on Hearing

(PhD Study - Sargunamoorthy Sivaraj)

## CONSENT FORM (Orchestra Governing Body)

THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF FIVE (5) YEARS

Name of the

Orchestra:.....

I have read the attached letter and have had the details of the study explained to me. My questions have been answered to my satisfaction, I understand that I/Managers/Musicians can ask further questions at any time, and I am also aware that we as an Orchestra can withdraw from the study at any time.

I agree to participate in this study by allowing volunteer musician's participation as explained in the information sheet.

Signature:

Date:

Full Name - printed

# Appendix C

## Adult Consent Form and Letter for Musicians

**Letter to the individual musician who is part of the orchestra  
(This information is to be given along with the consent form)**

Dear Sir/Madam

My name is Sargunam Sivaraj, Team Leader for Audiological Services of Capital and Coast District Health Board (C&C DHB) working at Wellington Hospital. I am a PhD candidate of Massey University. I am sending this letter to explain my project.

This research is to investigate the effect of orchestra music on different age groups of musicians. This will be the first comprehensive study of its kind in New Zealand following concern raised throughout the world about the increasing incidence of hearing loss in musicians.

The study involves taking sound measurements around individual instruments during practice sessions, measuring the sound exposure received by each musician using a small doseBadge situated near the ear, and performing a simple hearing test before and after the music session. I would also like to gain an idea of the sound levels across the orchestra during a dress rehearsal using inconspicuous microphones or doseBadges attached to the backs of music stands. I would be very grateful if you would ask your musicians if any would agree to help me by allowing me to undertake the following tasks.

**1. Interview with the individual musicians:** First of all, I would like to talk to you to obtain some information regarding your hearing acuity and the exposure of sound from music. I would also collect some information regarding your awareness about music induced hearing loss and preventive measures being taken regarding various ear related signs and symptoms such as: a history of hearing difficulty, ear infection, family history, tinnitus, giddiness, systemic illness, medications taken and noise/sound exposure. It would take approximately 30 minutes and would be undertaken a few days before any sound measurements were made.

**2. Otoloscopic examination:** I would then like to make a visual examination of your ear drum and look for any impacted earwax in your ear canal, which can affect the hearing test results. This would take about 3 minutes, and is totally non-invasive and would not cause any discomfort to you.

**3. Hearing evaluation:** I would like to perform a comprehensive hearing evaluation only if you consent. This test will give complete information regarding ear and hearing status of each volunteer.

**4. Personal sound exposure during the dress rehearsal:** This would involve, in the rehearsal/practice room, the fitting of a noise doseBadges to clothing at some convenient location close to the ears, of course with appropriate consent of the musician, and during a dress rehearsal the fitting of a small inconspicuous microphone or doseBadge to the music stand – again only with the appropriate consent of the musician. At the end of the sampling period, the doseBadge (or microphone) is removed and the information downloaded onto a computer. The doseBadge records only sound intensities and has no voice recording capabilities.

The equipment is manufactured to an international standard (IEC61 50081-1 (1992- Generic emission standard for residential commercial and light industry) which requires that the badge must be completely safe to use and does not emit or generate any kind of sound, microwaves, radio waves or other signal while turned on and being worn. This is a requirement of the international standard under which the equipment is manufactured and tested.

The badge is small and light enough (50grams) not to draw people’s attention or cause any disturbance to the musician’s performance. However, if you do not wish to have it pinned to you during practice we could place it on the music stand. An information sheet is attached.

I agree to:

- Maintain strict confidentiality by not identifying your personal details or the test results to your management or the centre details to any third party or in any report or publication.
- Comply with all instructions of the management and not to interfere with any staff in the course of their duties.
- To keep you fully informed of all results pertaining to the interview.
- Not to take any sound recording of the interview.
- To allow you to inspect the interview sheet and notes at the end.

You have the right to:

- Decline to participate
- Decline to answer any particular question
- Withdraw from the study at any time from the date of this interview
- Ask any questions about the study at any time during participation
- Provide information on the understanding that your name or the centre in which you work will not be used under any circumstances unless you give expressed permission to the researcher
- Be given access to a summary of the project findings when it is concluded.

All the musicians will be given access to a summary of the project findings when it is concluded. It is a requirement that all confidential information will be kept in a secure storage with restricted access.

The equipment used is robust but in the event of loss or damage, the orchestra or any individual will not be held in any way liable for whatever reason. This remains the sole responsibility of Massey University and its Insurers. However, in the interests of all concerned, the researchers must remain on the premises at all times the equipment is in operation so as to respond to any requests of the musicians.

The researcher agrees to:

- Maintain strict confidentiality by not identifying the orchestra to any third party or in any report or publication.
- Comply with all instructions of the staff or management and not to interfere with any music performance or their duties.
- To keep the manager fully informed of all results pertaining to the Orchestra.
- Allow the manager to view and comment on any manuscripts prior to publication.
- To consult the manager and governing body before any press releases are made due to the anticipated high level of interest.

The Central Regional Ethics Committee requires the following participant's rights as part of the approval process.

This project has been reviewed and approved by the Central Regional Ethics Committee. If you have any concerns about the conduct of this research, please contact Committee Administrators: Ms. Claire Yendoll and Ms. Jan Ostnes P: C/- Ministry of Health, 1-3 The Terrace, POBox-5013, Wellington, T:(04)4962405,

Email to: [claire\\_yendoll@moh.govt.nz](mailto:claire_yendoll@moh.govt.nz)

Thank you for your consideration in this important study. I have enclosed a consent form to be completed. I am happy to answer any further questions you may have, address any concerns and welcome any relevant comments or contributions you would like to make. Please feel free to contact me 📞 (04) 9186656. Email: [sargunam.sivaraj@ccdhb.org.nz](mailto:sargunam.sivaraj@ccdhb.org.nz).

This is a very important study that we believe will be of significant benefit to all the musicians and the orchestra in the future, and your help in this would be very much appreciated.

Yours sincerely,

Sargunamoorthy Sivaraj  
Team Leader  
Audiological services of C&CDHB  
Wellington Hospital  
Wellington

**Effects of Music on Hearing**  
(PhD Study - Sargunamoorthy Sivaraj)

**CONSENT FORM**

**(For an individual musician, who is part of the orchestra)**

**THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF FIVE (5) YEARS**

I .....have read the information sheet and had the details of the study explained to me. My questions have been answered to my satisfaction, I understand that I may ask further questions at any time, and I am also aware that I can withdraw from the study at any time.

I agree to participate in this study under the conditions set out in the attached letter.

**Signature:** ..... **Date:** .....

**Full Name - printed** .....

# Appendix D

## Child Consent Form and Letter for Musicians

### Letter to the parents of the participating children (This information is to be given along with the consent form)

10 July 2006

Dear Parent

#### **Comprehensive Study: Inter-relationship between Music and Hearing**

My name is Sargunam Sivaraj, Team Leader for Audiological Services of Capital and Coast District Health Board (C&C DHB) working at Wellington Hospital. I am a PhD candidate of Massey University. I am sending this letter to explain my project.

In 2002-2003 we undertook a survey in the Department of Audiology, Wellington Hospital, to identify the number of young musicians with tinnitus and/or hearing loss. We found quite a few children with hearing loss and/or ringing sensation, and at least in some children the cause of the hearing loss could be attributed to music exposure. There are few reports relating to music induced hearing loss in children. Our findings warrant a more comprehensive study.

As currently there is no information on damage risk criteria for music on children, we would like to monitor the sound received by individual children in music activities at school. This will be the first ever comprehensive study of its kind in New Zealand, following concern raised throughout the world about hearing loss in musicians.

The project involves

**1. An interview with the Musicians:** First of all, I would like to talk with individual child musicians (5 yrs and above) and/or along with the parents to obtain some idea of their hearing acuity and their exposure to sound from music. This would be undertaken a few days before any sound measurements are made. The initial interview will include a case history - information will be collected regarding various ear related signs and symptoms such as: a history of hearing difficulty, ear infection, family history, ringing sensation, giddiness, systemic illness, medications taken and other type of noise exposure apart from music. This may take approximately 15 minutes.

**2. Otosopic examination:** I would then like to make a visual examination of the child musician's ear drum and look for impacted cerumen in the ear canal which may potentially affect the hearing test findings. This would take about 3 minutes, and is totally non-invasive and would not cause any discomfort at all.

**3. Hearing evaluation:** I would like to then perform a comprehensive hearing evaluation only on volunteers. The test will give complete information regarding ear and hearing status of each volunteer. The total test procedure may take about 15 minutes.

**4. Personal sound exposure during the musical event:** To do this we would have to fit a small noise dose badge to the clothing of the child (near their ears) and measure the sound received as they go about their activities as normal. The badges are small and light enough (50 grams) not to cause any discomfort or trouble to any child. However, if any child does not wish to wear a badge, it will not be fitted (or it will be removed if the child changes his/her mind).

The equipment is manufactured to an international standard (IEC61 50081-1 (1992- Generic emission standard for residential commercial and light industry) which requires that the badge must be completely safe to use and does not emit or generate any kind of sound, microwaves, radio waves or any other signal while turned on and being worn.

The equipment receives and stores the sound levels that the wearer would receive. The information collected is downloaded from the badge by plugging it into a reader unit only after it has been removed from the child.

We give a guarantee that while the equipment is robust, any loss or damage to the equipment for whatever reason remains the sole responsibility of Massey University. The children, parents, staff, or school have absolutely no liability for loss or damage however caused.

The researchers agree to:

- Maintain strict confidentiality by not identifying any child or the school he/she attends to any third party or in any report or publication.
- To remove the badge at any time if the child does not wish to wear it.
- To be on site the whole time the badge is worn.
- To keep you fully informed of the results pertaining to your child's participation.

You have the right to:

- Decline the participation of any child
- Withdraw from the study at any time up to sampling
- Ask any questions about the study at any time during participation.

You will be given access to a summary of the project findings for your child when it is concluded.

The Central Regional Ethics Committee requires the following participant's rights as part of the approval process.

This project has been reviewed and approved by the Central Regional Ethics Committee. If you have any concerns about the conduct of this research, please contact Committee Administrators: Ms. Claire Yendoll and Ms. Jan Ostnes P: C/- Ministry of Health, 1-3 The Terrace, POBox-5013, Wellington, T: (04)4962405. Email to: [claire\\_yendoll@moh.govt.nz](mailto:claire_yendoll@moh.govt.nz)

Thank you for your consideration in this important study. I have enclosed a consent form to be completed. I am not permitted to carry out research involving any individual child

participant unless full consent of the parents is obtained. I am happy to answer any further questions you may have, address any concerns and welcome any relevant comments or contributions you would like to make. Please feel free to contact me on 📞 9185132 or Email: sargunam.sivaraj@ccdhb.org.nz

Yours sincerely

Sargunam Sivaraj  
Team Leader  
Audiological Services of Capital & Coast District Health Board  
Wellington Hospital  
Wellington

**Effects of Music on Hearing**  
(PhD study - Sargunamoorthy Sivaraj)

**CONSENT FORM**  
**(Parent of the School Musician)**

**THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF FIVE (5) YEARS**

**Your Child's name:**.....

**School:** .....

I have read the attached letter and have had the details of the study explained to me. My questions have been answered to my satisfaction, I understand that I may ask further questions at any time, and I am also aware that I can withdraw my child from the study at any time. I agree to allow my child to participate in this study, as explained in the information sheet.

**Date:**

**Signature:**

.....

**Full Name - printed**

.....

# Appendix E - Adult Case History



## Research - Adult Case History

Date:.....

(Please note: Case history is the first and important step to understand your problem, hence we request you to fill in this form legibly and your answer shall be specific and complete to the question)

Name:..... Age/ Sex:.....

Phone No: (Home)..... (Office):.....

DOB:..... Organization:.....

Nature of Work/Works in the past: (Please specify number, years and months)

.....  
.....  
.....  
.....  
.....

### MUSIC EXPOSURE

(If relevant, do specify about Walkman usage, attending discotheque/night club/music hearing/gun shooting/bomb blast/fire crackers and/or any other type of unusual noise)

How long are/were you exposed to music (hours/days/months/years)?

.....  
.....

What are the musical instruments you play and how long have you been playing?

.....  
.....

When were you last exposed to noise/music?

.....  
.....

Have you had any other music exposure?

Walkman usage:.....  
Loud Car Stereo:.....  
Attending discotheque/night club:.....

### WHAT ARE YOUR HOBBIES?

.....  
.....  
.....

### NOISE EXPOSURE



**PREVIOUS HEARING EVALUATION** YES..... NO.....

Where:.....

When:.....

Remarks:.....

Do you have any ear specific symptoms, such as difficulty in using the phone?  
.....  
.....

**FAMILY HISTORY OF HEARING LOSS** YES..... NO.....

Who:.....

Remarks:.....

**HISTORY OF EAR PATHOLOGY/INFECTION** YES..... NO.....

Ears: Right..... Left..... Both.....

Age at onset:.....

Ear discharge/Drainage: Yes..... No.....

Pain: Yes..... No.....

Treatment:.....

Remarks:.....

**EAR SURGERY:** YES..... NO.....

Ears: Right..... Left..... Both.....

Date(s):.....

Type(s):.....

Remarks:.....

**TINNITUS** YES..... NO.....

(It means any kind of ringing buzzing or roaring sensation in the ear)

Ears: Right..... Left..... Both.....

Description:.....

Progressive: Yes..... No.....

Fluctuating: Yes..... No.....

Remarks:.....

**VERTIGO** YES..... NO.....

Rotary: Yes..... No.....

Light-headedness: Yes..... No.....

Nausea: Yes..... No.....

Remarks:.....

**HEAD INJURIES**

**YES**..... **NO**.....

Date(s):.....

Type(s):.....

Loss of Consciousness: Yes..... No.....

Affected hearing: Yes..... No.....

Remarks:.....

**SYSTEMIC ILLNESS**

Mumps..... Measles..... Diabetes..... Renal..... Infections..... Circulatory.....

Any other illness:

**MEDICATIONS**.....

**HEARING AIDS**

**YES**..... **NO**.....

Ear fitted: Right..... Left..... Both.....

Type: Body..... BTE..... In-the-Ear.....

Make:.....

Model:.....

First worn:.....

**AURAL REHABILITATION**

**YES**..... **NO**.....

Remarks:.....

**OTHER PERTINENT INFORMATION**

Thank you for your efforts in filling in this form

# Appendix F

## Questionnaire on Attitudes towards Hearing Loss in Musicians



### Research – Attitudes towards Hearing Loss in Musicians

Name:.....

Organisation/School:.....

Address:.....

Phone Number/s:.....

**Please note:** This information will be utilised to understand the general attitude of Musicians towards music and hearing loss and will help us in planning and regarding preventive steps to be taken to prevent hearing loss in Musicians.

1) Your Gender? Male  Female

2) Your Age?.....

3) What instrument/s do you play? :.....  
.....

4) Number of years playing instruments?:.....

5) Time spent per week playing instruments?:.....

6) Do you play acoustic/amplified?  Acoustic  Amplified  Both

7) Is music your job or leisure activity?:  Leisure activity  Job

8) Do you use a personal stereo?  Yes  No

9) If yes, how long do you use it for, and how loud do you prefer?

.....  
.....

Normal  Slightly loud  Very loud

10) What type of music do you play?:.....

11) If music is not your job, is your other employment noisy?  Yes  No  N/A

12) Are you aware that loud music can damage your hearing?  Yes  No  Not Sure

13) Have you ever experienced problems with your hearing after playing, such as muffled hearing, painful ears, ringing, and tinnitus?

Yes  No

14) How often has this happened?

Never  Rarely  A few times a year  once a month  more than once a month

15) Have you had a hearing test?

Yes  No

If yes, when.....

16) What was the result of the hearing test? What advice has been given?

.....  
.....

17) Are you aware that earplugs or other ear protection can protect your hearing?

Yes  No

18) Have you considered wearing hearing protection?

Yes  No

19) Have you ever worn hearing protection?

Yes  No  Only tried, but didn't use again

20) Do you wear hearing protection when you play?

Yes  No

21) If yes, did you find it comfortable with no loss of clarity?

Yes  No  N/A

22) Any comments about this?

.....  
.....

23) Do you think music needs to be played loud?

Yes  No

24) Has your hearing decreased as a result of exposure to loud sound?

I'm sure it has decreased  I think it has decreased  
 I'm sure it has not changed  I think it has not changed

25) Which group do you think would be most effective in educating musicians about hearing loss protection?

Health Professional

Government Agency (Ex: ACC)

Celebrity Spokesperson

Peer Group

Other

26) If you choose other, who do you think would be most effective?

.....  
.....  
.....

Thank you for your time and answers. If you would like to write any further comments please do so either here, or email me at [sargunam.sivaraj@ccdhb.org.nz](mailto:sargunam.sivaraj@ccdhb.org.nz)

.....  
.....  
.....

# Appendix G

## Children - Case History Form



### Children- Case history form

Date:.....

(Please note: A Case History is the first and important step to understand your problem, hence we request you to fill in this form legibly and your answer shall be specific and complete to the question)

Name:.....Age/Sex:.....

Phone No: (Home).....

DOB:.....Referral Source:.....

### MUSIC EXPOSURE

(If relevant, do specify about Walkman usage, attending discotheque/night club/music hearing/gun shooting/bomb blast/fire crackers and/or any other type of unusual noise)

How long are/were you exposed to music (hours/days/months/years).....

What are the musical instruments you play and how long have you been playing?

When were you last exposed to noise/music?

Do you have/had any other music exposure?

Walkman usage:.....

Loud Car Stereo:.....

Attending discotheque/night club:.....

### WHAT ARE YOUR HOBBIES?

### NOISE EXPOSURE

Have you had any type of noise exposure in the past?



Remarks:.....  
.....

Do you have any ear specific symptoms, such as difficulty in using the phone?  
.....  
.....

**FAMILY HISTORY OF HEARING LOSS**                      **YES**..... **NO**.....

Who.....  
Remarks:.....  
.....

**HISTORY OF EAR PATHOLOGY/INFECTION**      **YES**..... **NO**.....

Ears:    Right..... Left..... Both.....  
Age at onset:.....  
Ear discharge/Drainage:    Yes..... No.....  
Pain:    Yes..... No.....  
Treatment:.....  
Remarks:.....  
.....

**EAR SURGERY**    **YES**..... **NO**.....

Ears:    Right..... Left..... Both.....  
Date(s):.....  
Type(s):.....  
Remarks:.....  
.....

**TINNITUS**    **YES**..... **NO**.....

(It means any kind of ringing buzzing or roaring sensation in the ear)

Ears:    Right..... Left..... Both.....  
Description:.....  
Progressive:    Yes..... No.....  
Fluctuating:    Yes..... No.....  
Remarks:.....  
.....

**VERTIGO**    **YES**..... **NO**.....

Rotary:    Yes..... No.....  
Light-headedness:    Yes..... No.....  
Nausea:    Yes..... No.....  
Remarks:.....  
.....

**HEAD INJURIES**    **YES**..... **NO**.....

Date(s):.....  
Type(s):.....  
Loss of Consciousness:    Yes..... No.....  
Affected hearing:    Yes..... No.....

Remarks:.....  
.....

**SYSTEMIC ILLNESS**

Mumps.....Measles.....Diabetes.....Renal.....Infections.....Circulatory.....

**Any other illness:**

.....  
.....

**MEDICATIONS**

.....  
.....

**OTHER PERTINENT INFORMATION**

.....  
.....  
.....

Thank you for your efforts in filling in this form

## Appendix H

### Peer-reviewed Conference Presentation Attributed to This Work

Peer reviewed conference oral presentation on ‘Are we doing enough to prevent noise/music induced hearing loss in children in New Zealand’ at the Noise Induced Hearing loss in Children at Work & Play held on 19-20, October 2006 in Cincinnati, Ohio, USA.

Peer reviewed conference poster (following page) presentation on ‘Personal Stereo and Hearing loss’ at the Noise Induced Hearing loss in Children at Work & Play held on 19-20 October 2006 in Cincinnati, Ohio, USA.

Peer reviewed and accepted as poster (following page) presentation on ‘Usage of hearing Protection among Orchestra musicians’ at the American Academy of Audiology’s annual meeting, Audiology NOW 2011, held on 6-9 April 2011 in Chicago, USA.

Peer reviewed and accepted as oral presentation on ‘The Effects of Orchestra Music on hearing at various age groups’ at the American Academy of Audiology’s annual meeting, Audiology NOW 2011, held on 6-9 April 2011 in Chicago, USA.

Peer reviewed and accepted as oral presentation on ‘Longitudinal analysis of hearing loss development in orchestra musicians with increased years of music exposure’ at the EURONOISE 2012, to be held on 10–13 June 2012, Prague, Czech Republic.

Peer reviewed and accepted as oral presentation on ‘Influence of individual susceptibility to music induced hearing loss in orchestra musicians’ at the EURONOISE 2012, to be held on 10–13 June 2012, Prague, Czech Republic.

Peer reviewed and accepted as oral presentation on ‘Effects of orchestra music on hearing at various age groups of musicians’ at the EURONOISE 2012, to be held on 10–13 June 2012, Prague, Czech Republic.

Peer reviewed and accepted as poster presentation on ‘Orchestral musician's sound environment and the risk of hearing loss’ at the EURONOISE 2012, to be held on 10–13 June 2012, Prague, Czech Republic.

Peer reviewed and accepted as poster presentation on ‘Configuration/dips in pure-tone audiograms in various age groups of orchestra musicians’ at the EURONOISE 2012, to be held on 10–13 June 2012, Prague, Czech Republic.

# Appendix J

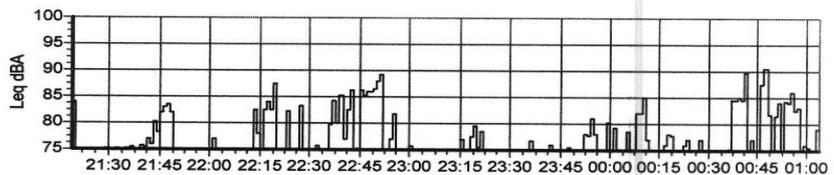
## Sample doseBadge Monitoring Report



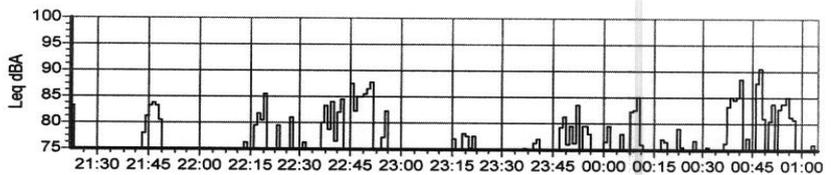
### Noise Dosimetry Report

Listing all measurements.

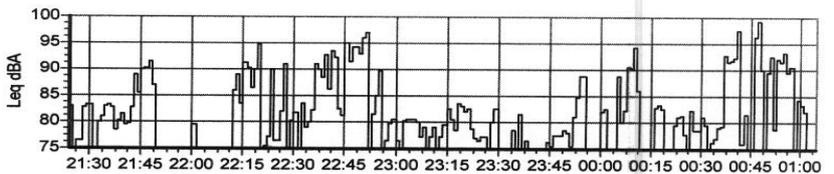
doseBadge 0451  
 Leq dBA 0  
 Dose % 11  
 Est.Dose % 23  
 Est.Exp Pa2h 0.2  
 Exposure Pa2h 0.1  
 Meas.Time 21:19 25/08/2008  
 Peak exceeded  
 Peak Level dBC 140



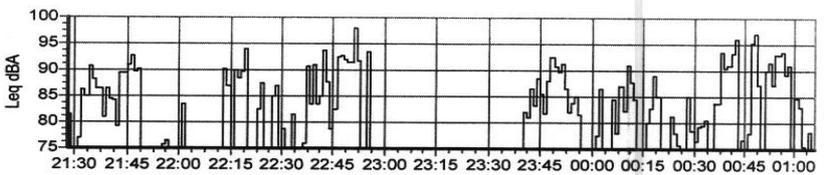
doseBadge 0454  
 Leq dBA 0  
 Dose % 9  
 Est.Dose % 18  
 Est.Exp Pa2h 0.1  
 Exposure Pa2h 0  
 Meas.Time 21:22 25/08/2008  
 Peak exceeded  
 Peak Level dBC 140



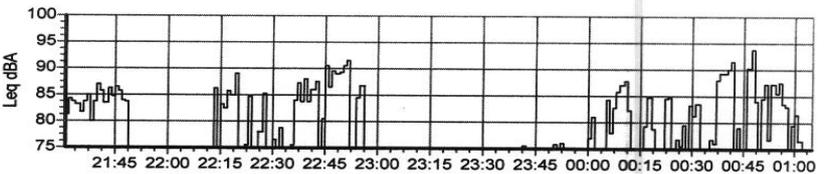
doseBadge 0450  
 Leq dBA 86.5  
 Dose % 63  
 Est.Dose % 137  
 Est.Exp Pa2h 1.3  
 Exposure Pa2h 0.6  
 Meas.Time 21:24 25/08/2008  
 Peak exceeded  
 Peak Level dBC 140



doseBadge 2301  
 Leq dBA 86.3  
 Dose % 60  
 Est.Dose % 132  
 Est.Exp Pa2h 1.3  
 Exposure Pa2h 0.6  
 Meas.Time 21:28 25/08/2008  
 Peak exceeded  
 Peak Level dBC 140



doseBadge 2302  
 Leq dBA 82.1  
 Dose % 22  
 Est.Dose % 50  
 Est.Exp Pa2h 0.5  
 Exposure Pa2h 0.2  
 Meas.Time 21:31 25/08/2008  
 Peak exceeded  
 Peak Level dBC 140





# Appendix K

## Copy of Hand-out on Personal Stereo and Hearing Loss

*Personal Stereo and hearing loss!!*

The massive popularity of portable music players could mean that many more people will develop hearing loss. A music library in the palm of your hand can thrill you, but it may be at a cost to your hearing.

**Who is at risk ??**  
Since systems vary in output it depends on many factors, so it is important to follow these simple steps to protect yourself from a permanent music induced hearing loss.



**WITH HIGH VOLUME AND LONG HOURS OF LISTENING- THERE IS A REAL RISK OF PERMANENT HEARING DAMAGE**

*The Simple Rules to follow :*

**The 60/60 rule:** Maximum listening level should be 60 minutes a day with the volume no higher than 60%.

**Turn it down:** Always maintain the volume as low as possible.

**Take a break:** Avoid prolonged, continuous listening by taking frequent breaks.

**Do not 'block out' noise:** Do not turn the volume up in a noisy situations.

**Automatic volume limiter:** Buy a system which limits the output to safe levels.

**Avoid:** Using personal stereo while exercising or if your daily work already involves noise/ music exposure.

**Do not interchange headsets with different systems:** Varying systems can often increase output volumes.

**Discontinue usage:** If you experience ringing sensation or speech sounds muffled, consult an audiologist and get your hearing checked.

**General:** Always choose tight fitting head phones. Ear muff head phones are better than the ear bud variety. The ear buds preferred by music listeners are more likely to cause hearing damage.

**Rule of thumb:** You should be able to hear other people talk when using your personal stereo. If others have to shout to be heard at one metre away..it means your volume setting is too high!!

*Get your hearing tested !!*

If you notice any ringing in your ears or speech sounds muffled after wearing a personal stereo system , discontinue its use and have your hearing checked by a qualified audiologist.

 Capital & Coast District Health Board  
Whenua o Te Kohu Haukeia

Audiological Services, Capital and Coast District Health Board (C&C DHB), Wellington South  
Sargunam Sivaraj M.Sc(So&H), CCC-A,FAAA,MNZAS, Team Leader of Audiological Services of C&C DHB.  
Presented at the "Noise-Induced Hearing Loss in Children at Work and Play Conference" held on October 19-20, 2006 at Cincinnati, Ohio, USA

 Massey University  
UNIVERSITY OF ADVANCE

