

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

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

**at Massey University, Wellington
New Zealand**

Sargunamoorthy Sivaraj

2011

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

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.

Acknowledgements

This Research project work has involved a large amount of cooperation and assistance from a number of people and organisations, which I wish to acknowledge.

First of all, I want to express my deepest gratitude to my supervisor, Prof. Philip Dickinson in the Department of Food and Nutrition and Human Health, Massey University, for his invaluable guidance and support, for sharing his considerable expertise and also for his constant help, encouragement and advice. And my co-supervisor, Mr. Graeme R Webster, Consultant Otolaryngologist and Head Neck Surgeon in Wellington Hospital for his support with this research work. In particular, I would like to acknowledge Professor Dickinson's direction with the preparation of this project work. I also want to express my sincere thanks and gratitude to my good friend Dr. Stuart McLaren for his support and time spent during the data collection and sharing his knowledge with me.

I would especially like to thank Ms. Sarah Glasgow, Human Resource Manager of New Zealand Symphony Orchestra (NZSO) for her support of this project. Special thanks are due to the Health and Safety Committee of the New Zealand Symphony Orchestra (NZSO) who supported this project.

I would also like to thank my great friends Daniel Grimmer and Mario Alexis Pereira for helping with reading the manuscript. I am also very grateful to the C&C DHB management for providing me with financial support during my years as full time staff and as a doctoral student. In particular, my thanks to Mrs. Adrienne Belchamber, for her continued support and encouragement. Further, I want to thank my staff of the Department of Audiology, at Wellington Hospital for their hard work during my absence from the department.

I would also like to thank all the musicians and the orchestras for their continued cooperation and assistance with the data collection.

I also want to thank Mrs. Janet Houghton, Head Audiologist and Manager of Courtney Hearing Centre, who has been providing hearing conservation Programme for the past many years for all the musicians, and also for sharing hearing test results, knowledge and expertise with me. I would like to thank Mr. Mervyn J Castle who assisted with the final reading of the thesis.

Lastly, but no means the least, I would like to thank my dear wife and colleague Aneeta Sargunam for all her encouragement and support for believing in me through the years of hard work, and my lovely children Nathan and Isaac for sacrificing the play time which was due to them.

Table of Contents

Abstract.....	iii
Acknowledgements.....	iv
Table of Contents.....	vi
List of Figures.....	xvii
List of Tables.....	xx
Glossary.....	xxiii
Chapter 1 : Introduction.....	1-1
1.1 Aims.....	1-5
1.2 Thesis Outline.....	1-6
Chapter 2 : Hearing loss – Overview.....	2-1
2.1 Introduction.....	2-1
2.2 Hearing Evaluation and Rehabilitation.....	2-3
2.3 Types of hearing loss.....	2-4
2.4 Incidence and prevalence of hearing loss.....	2-5
2.5 Attitudes towards hearing loss.....	2-7
2.6 Impact of hearing loss in social life.....	2-8
2.7 Hearing loss in children.....	2-10
2.8 Rehabilitation.....	2-11
2.9 Prevention of hearing loss – challenges.....	2-13
2.10 Current standards relationship between noise exposure and NIHL.....	2-14
Chapter 3 : Anatomy and Physiology of Human Ear.....	3-1
3.1 Introduction.....	3-1
3.2 External Ear.....	3-2
3.3 Middle Ear.....	3-4
3.3.1 The Eustachian Tube.....	3-6
3.3.2 The acoustic reflex.....	3-6
3.4 Inner Ear.....	3-7
3.4.1 Inner ear fluids.....	3-13
3.5 Vestibular Mechanism.....	3-16
3.6 Processing of auditory signals.....	3-18
3.7 Ear development.....	3-18
3.8 Hearing through air conduction.....	3-19
3.9 Hearing through bone conduction hearing.....	3-19
3.10 Thresholds of discomfort and pain.....	3-19
3.11 Types of Noise Induced Hearing Loss and Mechanisms of Injury.....	3-20

3.12 Physiology, Pathophysiology and Histopathology	3-21
3.12.1 Tuning Curve	3-25
3.12.2 Relationship-Temporary Threshold Shift and Permanent Threshold Shift	3-27
3.12.2.1 Equal energy Hypothesis	3-28
Chapter 4 : Studies of noise and hearing loss in musicians – A literature review	4-1
4.1 Introduction.....	4-1
4.2 Difference between music and noise	4-1
4.3 Studies finding that hearing loss is not a major issue among orchestra musicians	4-3
4.4 Longitudinal study or progressive hearing loss with increased music exposure	4-6
4.5 Studies finding better hearing than normal population.....	4-7
4.6 Studies explaining sound power of various instrument groups	4-7
4.7 Studies finding that hearing loss is a major issue among orchestra musicians	4-7
4.8 Studies in young musicians.....	4-11
4.9 Musicians and ear protection	4-16
4.9.1 Introduction.....	4-16
4.9.2 Musicians’ plugs with varied attenuation	4-17
4.9.2.1 Custom made musician ear plugs	4-17
4.9.2.2 Special filters with various levels of sound reduction (attenuation)	4-18
4.9.2.3 Non-custom made or standard musician plugs	4-19
4.9.2.4 Noise Reduction Rating (NRR)	4-20
4.9.3 Studies on usage of musicians’ ear plugs	4-22
Chapter 5 : Factors that influence music induced hearing loss in orchestra musicians	5-1
5.1 Introduction.....	5-1
5.1.1 Complex interaction of various factors.....	5-1
5.2 Middle ear problems and NIHL.....	5-2
5.2.1 Acoustic Reflex.....	5-2
5.2.2 Acoustic reflex threshold and protective factor	5-3
5.2.3 Acoustic reflex and time pattern	5-3
5.2.4 Fatigability	5-3
5.2.5 Protective effect	5-4
5.3 Conductive hearing loss and individual vulnerability	5-5
5.4 Aging and noise induced hearing loss	5-6
5.4.1 Presbycusis.....	5-6
5.4.2 Interaction between various aging and noise exposure.....	5-6

5.4.3 Changes in middle ear transmission with aging and the critical period for noise vulnerability.....	5-7
5.4.4 ISO Standards	5-8
5.4.5 Aging and individual susceptibility	5-9
5.5 Gender and noise induced hearing loss.....	5-10
5.6 Risk factors and noise induced hearing loss	5-11
5.6.1 Work load and noise exposure.....	5-12
5.6.2 Vibration and exercise	5-12
5.6.3 Smoking and noise induced hearing loss.....	5-13
5.6.4 Heat exposure and Noise Induced Hearing Loss	5-13
5.6.5 Ototoxic drugs and noise exposure.....	5-14
5.6.6 Noise and exposure to chemicals.....	5-15
5.6.7 Influence of loud noise exposure during post noise exposure	5-16
5.6.8 Noise exposure and efferent and sympathetic innervations.....	5-16
5.6.9 Anti-inflammatory drugs and its protective effects from noise induced damage	5-17
5.6.10 Drugs giving some protection from noise induced damage.....	5-17
5.6.11 Neurological factors and protective effects from noise exposure.....	5-18
5.6.12 Drugs and anti-apoptotic effects on noise induced hearing loss.....	5-18
5.6.13 Various other factors.....	5-18
5.6.14 Impulse noise	5-19
Chapter 6 : Rationale/Justification of the Research Project, Conceptual Framework, Study Design and Unanswered/Research Questions	6-1
6.1 Rationale/Justification of the Research Project	6-1
6.1.1 Noise induced hearing loss and prevention	6-1
6.1.2 Noise induced hearing loss and individual variability	6-2
6.1.3 Music induced hearing loss.....	6-2
6.1.4 Noise induced hearing loss in children	6-4
6.1.5 Industrial population and professional musicians.....	6-5
6.1.6 Controversies in hearing loss in musicians.....	6-5
6.1.7 Analysis of hearing loss development with increased years of music exposure	6-6
6.1.8 Usage of ear protection among musicians	6-7
6.1.9 Possible reasons for confusing results on presence of hearing loss in musicians.....	6-7
6.1.10 Drawbacks of the currently existing studies	6-8
6.2 Conceptual Framework.....	6-10
6.3 Study Design.....	6-11

6.4 Research questions.....	6-13
6.4.1 Hearing status of various group of musicians.....	6-13
6.4.2 Longitudinal hearing status with increased music exposure.....	6-14
6.4.3 Sound environment and hearing loss	6-14
6.4.4 Factors influencing the increased risk of hearing loss among musicians.....	6-15
6.4.5 General awareness and music induced hearing loss	6-15
6.4.6 Usage of ear protecting devices	6-16
6.4.7 Individual susceptibility and musicians.....	6-16
6.4.8 Damage risk criteria for music.....	6-16
6.4.9 Strategies to prevent noise levels and its effects on musicians' hearing	6-16
Chapter 7 : Research Methods	7-1
7.1 Introduction.....	7-1
7.2 Subjects	7-1
7.2.1 Exclusion criteria	7-1
7.3 Study development and rationale.....	7-2
7.4 Ethical requirements	7-3
7.5 Selection of orchestra musicians/music group.....	7-3
7.6 Physical environment.....	7-5
7.7 Physical environment.....	7-5
7.8 Instrument preparation	7-6
7.9 Classification of musical instruments	7-7
7.9.1 The Woodwind section:	7-7
7.9.2 The Brass section:	7-7
7.9.3 The Percussion section:.....	7-7
7.9.4 The Long Strings section:	7-7
7.9.5 The Short Strings section:	7-8
7.9.6 The Keyboard section:	7-8
7.10 Equipment used and data collected on music survey.....	7-8
7.10.1 Fixed sound level measurements	7-9
7.10.2 Personal sound exposure of musicians	7-10
7.11 Audiological evaluation	7-13
7.11.1 Completion of case history	7-13
7.11.2 Hearing evaluation.....	7-14
7.11.2.1 Ear examination	7-14
7.11.2.2 Impedance audiometry	7-15
7.11.2.3 Pure-tone audiometry	7-15
7.11.2.3.1 Classification of audiograms.....	7-16

7.11.2.4 Diagnostic Oto-acoustic Emission testing	7-16
7.12 Longitudinal analysis of hearing loss development.....	7-17
7.13 Drawbacks of this study	7-18
7.14 Statistical analysis of collected data	7-18
Chapter 8 : Results – Audiological evaluation performed on various age groups of musicians.....	8-1
8.1 Subjects.....	8-1
8.2 Classification of musicians	8-1
8.2.1 Adult orchestra musicians:.....	8-1
8.2.2 Youth orchestra musicians:.....	8-1
8.2.3 Children musicians:	8-1
8.3 Number of years of professional music activity	8-2
8.4 Daily time exposure to music	8-2
8.5 Orchestra musicians and various instruments played	8-4
8.5.1 Adult orchestra musicians and musical instruments played	8-4
8.5.2 Youth orchestra musicians and musical instruments played	8-4
8.5.3 Children orchestra musicians and musical instruments played	8-5
8.6 Mean hearing threshold of musicians of all age groups	8-6
8.6.1 Mean hearing threshold in the high frequency region of musicians of all age groups.....	8-7
8.6.2 Mean hearing thresholds of all musicians in terms of frequency range ...	8-8
8.7 Hearing loss in various groups of adult orchestra musicians.....	8-8
8.7.1 Adults orchestra musicians	8-9
8.7.2 Youth orchestra musicians.....	8-10
8.7.3 Children orchestra musicians.....	8-11
8.8 Asymmetry in hearing – orchestra musicians of various age groups	8-13
8.8.1 Asymmetry in hearing adult orchestra musicians.....	8-13
8.8.1.1 Ear specific data.....	8-13
8.8.1.2 Asymmetry in hearing: Mean hearing thresholds (dB HL) in adult violinists.....	8-14
8.8.1.3 Mean hearing thresholds for adult string players with hearing loss	8-15
8.8.2 Asymmetry in hearing youth orchestra musicians.....	8-15
8.8.2.1 Hearing threshold in both the ears	8-15
8.8.2.2 Ear specific data.....	8-16
8.8.3 Asymmetry in hearing children orchestra musicians.....	8-17
8.8.3.1 Hearing threshold in both the ears	8-17
8.8.3.2 Ear specific data.....	8-17
8.9 Gender difference in hearing loss in orchestra musicians	8-18

8.9.1 Gender difference (mean hearing thresholds) in adult orchestra musicians	8-18
8.9.2 Gender difference (mean hearing threshold) in youth orchestra musicians	8-19
8.9.2.1 Mean hearing thresholds (dBHL) in males and females of youth musicians.....	8-19
8.9.3 Gender difference (mean hearing threshold) in children orchestra musicians	8-20
8.10 Configuration of audiograms	8-20
8.10.1 Dips in pure-tone audiograms in adult orchestra musicians.....	8-21
8.10.2 Youth orchestra musicians – Dip in pure-tone audiograms.....	8-22
Comparison of right and left ear dips in the audiograms.....	8-22
8.10.3 Dips in pure-tone audiograms in children orchestra musicians	8-22
8.10.3.1 Dips in right ear	8-22
8.10.3.2 Dip in the left ear	8-23
8.11 Tinnitus and hearing loss in orchestra musicians	8-23
8.11.1 Tinnitus and hearing loss in adult musicians	8-23
8.11.1.1 Tinnitus and hearing loss in right ear.....	8-23
8.11.1.2 Relationship between tinnitus and hearing loss in left ear.....	8-24
8.11.2 Tinnitus and hearing loss in youth orchestra musicians	8-24
8.11.2.1 Tinnitus and hearing loss in right ear.....	8-24
8.11.2.2 Tinnitus and hearing loss in left ear.....	8-25
8.11.3 Tinnitus and hearing loss in children orchestra musicians	8-26
8.11.3.1 Relationship between tinnitus and hearing loss in right ear	8-26
8.11.3.2 Relationship between tinnitus and hearing loss in left ear.....	8-27
8.12 Family history of hearing loss.....	8-28
8.12.1 Family history of hearing loss in adult orchestra musicians.....	8-28
8.12.2 Family history of hearing loss in youth orchestra musicians.....	8-29
8.12.3 Family history of hearing loss in children orchestra musicians.....	8-29
8.13 History of ear infection and hearing loss in orchestra musicians	8-30
8.13.1 History of ear infection in adult orchestra musicians	8-30
8.13.1.1 Relationship between ear infection and hearing loss in right ear ..	8-30
8.13.1.2 Relationship between ear infection and hearing loss in left ear.....	8-30
8.13.2 History of ear infection in youth orchestra musicians	8-31
8.13.2.1 Relationship between ear infection and hearing loss in right ear ..	8-31
8.13.2.2 Relationship between ear infection and hearing loss in left ear.....	8-31
8.13 History of ear infection in children orchestra musicians	8-32
8.13.1 Relationship between ear infection and hearing loss in right ear	8-32

8.13.2	Relationship between ear infection and hearing loss in left ear.....	8-32
8.14	Youth orchestra musicians – Usage of personal stereo and hearing loss	8-33
8.14.1	Relationship between personal stereos and hearing loss in right ear....	8-33
8.14.2	Relationship between personal stereos and hearing loss in left ear	8-34
8.15	Youth orchestra musicians and other noise exposure	8-34
8.16	Musicians’ awareness of music induced hearing loss.....	8-35
8.16.1	Youth musicians’ awareness.....	8-35
8.16.2	Children musician’s awareness.....	8-35
8.17	Subjective hearing loss and actual hearing loss.....	8-36
8.17.1	Relationship between subjective and actual hearing loss in right ear...	8-36
8.17.2	Relationship between actual and subjective hearing loss in left ear	8-36
8.18	Visits to loud concerts.....	8-37
8.19	Usage of musician plugs	8-37
8.19.1	Adult musicians with hearing loss	8-37
8.19.1.1	Usage of ear protecting devices during rehearsal	8-37
8.19.1.2	Usage of Ear Protecting Devices (EPD) during performance	8-38
8.19.2	Adult musicians with normal hearing.....	8-38
8.19.2.1	Usage of ear protection devices during rehearsal	8-38
8.19.2.2	Usage of ear protection devices during performance	8-39
8.19.3	Youth orchestra musicians.....	8-39
8.19.4	Children orchestra musicians.....	8-40
8.19.5	Reasons for not Using Ear Protecting Devices (EPD).....	8-40
8.19.5.1	Adult musicians – Reasons for not using musician plugs.....	8-40
8.19.5.2	Youth musicians – Reasons for not using musicians’ plugs.....	8-41
8.20	Distortion Product Otoacoustic Emission (DPOAE) Test Results	8-41
8.20.1	DPOAE results in adult orchestra musicians.....	8-42
8.20.1.1	DPOAE Measurement at 8KHz.....	8-44
8.20.1.2	DPOAE with prolonged music exposure and age.....	8-45
8.20.2	DPOAE results in youth orchestra musicians.....	8-46
8.20.3	DPOAE results in children orchestra musicians.....	8-48
8.20.4	DPOAE as a tool to identify susceptibility to music/noise induced hearing loss	8-50
8.20.4.1	A young drummer	8-50
8.20.4.2	A young violinist.....	8-51
8.20.5	Summary of OAE Finding.....	8-52
Chapter 9	: Results – longitudinal analysis of hearing loss development.....	9-1
9.1	Introduction.....	9-1

9.2 Progression of hearing loss in a violinist with increased years of music exposure	9-1
9.2.1 Case 1: Series of audiograms of a violin player	9-1
9.2.2 Case 2: Series of audiograms of a violin player	9-3
9.2.3 Case 3: Series of audiogram of a violin player	9-3
9.2.4 Case 4: Audiogram of a violin player with well preserved hearing in both the ears	9-4
9.2.5 Case 5: Audiogram of a violin player with well preserved hearing in both the ears	9-5
9.3 Progression of hearing loss in a double bass player with increased years of music exposure.....	9-6
9.3.1 Case 1: Series of audiograms of a double bass player	9-6
9.3.2 Case 2: Series of audiograms of a double bass player	9-8
9.3.3 Case 3: Series of audiograms of a double bass player	9-10
9.4 Development and progression of hearing loss in a cello player with increased years of music exposure.....	9-12
9.4.1 Case 1: Development of hearing loss in a cello player.....	9-12
9.5 Development and progression of hearing loss in a flautist with increased years of music exposure	9-13
9.5.1 Case 1: Development of hearing loss in a flutist	9-14
9.5.2 Case 2: Development of hearing loss in a flutist (beginning effect of noise)	9-15
9.6 Development and progression of hearing loss in a percussionist with increased years of music exposure.....	9-15
9.6.1 Case 1: Development of hearing loss in a percussionist.....	9-15
9.7 Development and progression of hearing loss in a trumpet player with increased years of music exposure.....	9-17
9.7.1 Case 1: Development of hearing loss in a trumpet player	9-17
9.7.2 Case 2: Development of hearing loss in a French horn player	9-18
9.8 Progressive hearing loss with music exposure in children	9-19
9.8.1 Case 1: Combined effect of music exposure with previous history of ear infection and a family history of hearing loss.....	9-19
9.8.2 Case 2: Effect of music exposure with a family history of hearing loss.	9-22
9.9 Summary	9-25
Chapter 10 : Results of personal sound exposures of musicians and fixed time-average levels taken.....	10-1
10.1 Introduction.....	10-1
10.2 Adult orchestra musicians – Music Survey	10-1
10.2.1 Adult orchestra musicians – Measurement (1) during Rehearsal	10-1
10.2.2 Adult orchestra musicians - Measurement (2) during Rehearsal.....	10-3

10.2.3 Adult orchestra musicians – Measurement (3) during Rehearsal and Performance	10-6
10. 3 Youth orchestra musicians -Measurement during Rehearsal (1).....	10-7
10.4 Children musicians-Measurement during Rehearsal (1).....	10-9
10.5 Sound exposure during school discotheques	10-10
10.6 Assessment of whole day exposure for selected musicians.....	10-11
10.7 Summary	10-12
Chapter 11 : Discussion	11-1
11.1 Introduction.....	11-1
11.2 As a special group.....	11-4
11.3 Impact of hearing loss in musicians.....	11-4
11.4 Hearing Handicap	11-5
11.5 Hearing loss in various age groups of orchestra musicians	11-6
11.5.1 Hearing loss distribution among adult musicians-Sample size (n) = 61	11-8
11.5.2 Hearing loss distribution among youth musicians-Sample size (n) = 85	11-8
11.5.3 Hearing loss distribution among children musicians-Sample size (n) = 37	11-9
11.6 Longitudinal analysis of hearing loss	11-9
11.7 Tinnitus and orchestra musicians.....	11-11
11.8 Music Induced hearing loss (MIHL) and Asymmetry in hearing loss.....	11-13
11.9 Gender difference in music induced hearing loss	11-15
11.10 Music exposure and configuration of the audiogram	11-16
11.11 Personal stereo usage among young musicians	11-19
11.12 Individual susceptibility and music induced hearing loss.....	11-20
11.12.1 Ear susceptibility in an individual musician	11-22
11.13 Music induced hearing loss in children	11-23
11.14 Tests for susceptibility to noise induced hearing loss.....	11-25
11.15 Usage of Ear Protecting Device among musicians	11-26
11.16 Factors that may influence the prevalence of hearing loss among musicians	11-30
11.16. 1 Family history of hearing loss and music induced hearing loss	11-31
11.16.2 History of ear infection and music induced hearing loss.....	11-32
11.16.3 Musician’s awareness of music induced hearing loss.....	11-33
11.16.4 Youth orchestra musicians and other noise exposure	11-33
11.16.5 Visits to loud concerts.....	11-34
11.17 Distortion Product Oto-Acoustic Emission (DPOAE) test Results	11-35

11.18 Music Survey	11-37
11.18.1 Individual susceptibility based on music survey	11-38
11.18.2 Difficulty in calculating overall dosage and its effects on hearing...	11-39
11.18.3 Sound levels based on instrument played	11-40
11.18.4 Noise standards and music survey results.....	11-41
11.19 Acoustic Trauma with high impulse noise.....	11-42
11.20 Existing noise standards and inadequacies	11-43
11.21 Prevention and Early identification of hearing loss in musicians.....	11-45
11.21.1 Playing time	11-48
11.22.2 Seating arrangement.....	11-49
11.22.3 Importance of Music Survey.....	11-49
11.23 Original contribution to knowledge	11-49
11.24 Limitations to this Study.....	11-53
11.23.1 Fixed sound level measurements	11-53
11.23.2 Personal sound exposure of musicians	11-54
11.23.3 Self Selection bias.....	11-54
11.23.4 Musician's well trained ears	11-54
11.23.5 Responses to Questionnaire	11-55
11.23.6 Sound measurements and risk assessment.....	11-55
11.23.7 Sound measurements errors and uncertainties in measurements.....	11-55
11.23.8 Doubling exposure to assess risk assessment	11-56
11.23.9 Longitudinal analysis of existing audiometric data	11-56
11.23.10 Age and Gender correction were not undertaken	11-56
Chapter 12 : Conclusions	12-1
12.1 Introduction.....	12-1
12.2 Hearing status of various groups of musicians	12-1
12.3 Longitudinal hearing status with increased music exposure.....	12-5
12.4 Sound environment and hearing loss	12-6
12.5 Factors influencing the increased risk of hearing loss among musician.....	12-8
12.6 General awareness and music induced hearing loss	12-9
12.7 Usage of Ear Protecting Devices	12-9
12.8 Individual susceptibility in musicians.....	12-11
12.9 Damage Risk Criteria for music	12-12
12.10 Some other important findings.....	12-13
Chapter 13 : Recommendations	13-1
13.1 Strategies to prevent excessive noise exposure and its effects on musicians' hearing.....	13-1

13.1.1 Hearing loss prevention programmes must include:.....	13-2
13.1.1.1 Organisational measures	13-2
13.1.1.2 Engineering measures	13-2
13.1.1.3 Individual measures	13-3
13.1.1.4 Audiological evaluation	13-3
13.1.2 Youth Musicians	13-4
13.1.3 Children Musicians	13-4
13.1.3.1 Suggestions to the music teachers.....	13-5
13.2 Prevention of hearing loss in general public.....	13-5
13.3 Recommendation for future research.....	13-6
References.....	1
Appendices.....	26
Appendix A.....	27
Appendix B.....	28
Appendix C.....	32
Appendix D.....	36
Appendix E	40
Appendix F.....	44
Appendix G.....	47
Appendix H.....	51
Appendix J.....	52
Appendix K.....	54
Appendix L	55

List of Figures

Figure 3-1: Structure of the human ear	3-2
Figure: 3-2 Middle ear bones.....	3-4
Figure: 3-3 Bony labyrinth.....	3-8
Figure 3-4: Organ of Corti	3-9
Figure 3-5: Cross section of the Cochlea.....	3-11
Figure 3-6 Basilar membrane: analysis of sound frequencies	3-12
Figure 3-7 Hair cell activation in the Cochlea.....	3-14
Figure 3-8: Vestibular system.....	3-16
Figure 3-9 Auditory pathway (Neural) from the organ of Corti.....	3-17
to the auditory cortex in the brain	3-17
Figure 3-10: Physiology of human ear.....	3-21
Figure 3-11: Damage to Cochlea hair cells.....	3-23
Figure 4-1: Custom-made musician plugs with attenuation filters.....	4-18
Figure 4-2: Musician plugs (with various attenuation filters) and foam ear plug: mean attenuation (sound reduction) characteristics.....	4-18
Figure 4-3: ETY Plugs in two sizes	4-19
Figure 4-4: ETY Plugs and noise attenuation (reduction) in various frequencies... ..	4-20
Figure 4-5: Diagram of the ER-20/Hi-Fi earplug	4-20
Figure 5-1 Middle ear muscles	5-2
Figure 7-1 Typical orchestra seating arrangements for adult and youth orchestra musicians	7-5
Figure 7-2 Typical time history illustrations from fixed sound level measurements	7-10
Figure 7-3 DoseBadge with the reader unit	7-11
Figure 7-4 typical time-history from a doseBadge	7-13
Figure 8-1 Classification of adult orchestra musicians based on musical instrument	8-4
Figure 8-2 Classification of youth orchestra musicians based on musical instrument	8-5
Figure 8-3 Classification of children orchestra musicians based on musical instrument.....	8-5
Figure 8-4 Mean age-adult orchestra musicians with hearing status.....	8-9
Figure 8-5 Hearing status of youth orchestra musicians.....	8-11
Figure 8-6 Hearing status of children orchestra musicians.....	8-12
Figure 8-7 Adult musicians – Comparison of males and females mean hearing threshold.....	8-18

Figure 8-9 Adult musicians – Comparisons of dips in right and left ear.....	8-21
Figure 8-10 Youth musicians – Comparison of dips in right and left ear.....	8-22
Figure 8-11 Adult musicians – the reasons for not using musicians’ plugs	8-40
Figure 8-12 Youth musicians – the reasons for not using musicians’ plugs	8-41
Figure 8-13 Adult musicians – Ear difference in DPOAE	8-43
Figure 8-14 Adult musicians (31 musicians) – mean gender difference in DPOAE.....	8-44
Figure 8-15 DPOAE Measure-Example of Emission being absent at 8KHz	8-44
Figure 8-16 – DPOAE measure: 66 year old violinist (60 years of music exposure)	8-45
Figure 8-17 pure-tone audiometry results 66 year old violinist (60 years of music exposure).....	8-46
Figure 8-18 Youth musicians – Ear difference in DPOAE.....	8-47
Figure 8-19 Youth musicians – Gender difference in DPOAE	8-48
Figure 8-20 Children Musicians Ear difference in DPOAE	8-49
Figure 8-21 Children Musicians- Gender difference in DPOAE.....	8-49
Figure 8-22 DPOAE measure - 16 year old (male) drummer.....	8-50
Figure 8-23 Pure-tone audiogram – 16 year old (Male) drummers	8-50
Figure 8-24 DPOAE measure – 12 year old (male) violin player	8-51
Figure 8-25 Pure-tone audiogram – 12 year old male violin player	8-51
Figure 9-1 (Case 1) Development of hearing loss in a violinist (54 years old, male).....	9-2
Figure 9-2 (Case-2) Development of hearing loss in a violinist (53 years old, male).....	9-3
Figure 9-3 (Case 3) Development of hearing loss in a violinist (44 years old, male).....	9-4
Figure 9-4 (Case 4) Pure-tone audiogram of a violinist (46 years old, female)	9-5
Figure 9-5 (Case 5) Pure-tone audiogram of a violinist (51 years old, female)	9-6
Figure 9-6 Development of hearing loss in a double bass player (56 years old, male)	9-7
Figure 9-7 Development of hearing loss in a double bass player (62 years old, male)	9-9
Figure 9-8 Development of hearing loss in a double bass player (63 years old, female)	9-11
Figure 9-9 Development of hearing loss in a cello player (54 years old, male)	9-12
Figure 9-10 Development of hearing loss in a flutist (53 years old, female)	9-14
Figure 9-11 Development of hearing loss in a flutist (27 years old, female)	9-15
Figure 9-12 Development of hearing loss in a percussionist (52 years old, male).....	9-16
Figure 9-13 Development of hearing loss in a trumpet player (44 years old, male).....	9-17
Figure 9-14 Series of audiogram of a French horn player (60 years old, male).....	9-18
Figure 9-15 Development of hearing loss in a teenage musician (16 year old, male)	9-20

Figure 9-16 DPOAE Test results at 12 years of age	9-20
Figure 9-17 DPOAE (left ear) results of teenage musician (at 16 years of age)	9-21
Figure 9-18 DPOAE (right ear) results of a teenage musician (16 years old, male)	9-22
Figure 9-19 Development of hearing loss in a teenage musician (15 years of	9-23
Figure 9-20 DPOAE Test results at 11 years of age	9-24
Figure 9-21 DPOAE (left ear) results at 15 year	9-24
Figure 9-22 (Right ear) DPOAE results at 15 years of age	9-25
Figure 10-1 Instrument setup for music survey (D-DoseBadge and M-Sound level meter)	10-2
Figure 10-2 Adult orchestra musicians – Average dosage for various groups of musicians (during rehearsal) – measurement (1)	10-3
Figure 10-3 Adult Orchestra musicians – Average dosage for various	10-4
groups of musicians (during rehearsal) - measurement (2)	10-4
Figure 10-4 Adult Orchestra musicians – Average double dosage for various	10-5
groups of musicians (during rehearsal) – measurement (2)	10-5
Figure 10-5 Adult orchestra musicians – Average dosage for various groups of musicians (during rehearsal and concert performance) – measurement (3)	10-7
Figure 10-6 Youth Orchestra musicians – Average dosage for various	10-8
groups of musicians – measurement during rehearsal	10-8
Figure 10-7 Youth orchestra musicians-double dosage – Average dosage for various groups of musicians – measurement during rehearsal	10-9
Figure 10-8 Sound Level measurements taken during a School disco	10-11
Figure 11-1 DPOAE and pure-tone audiometry test results - Violin player (Female, 9yrs old)	11-15
Figure 11-2 – Pure-tone audiograms of Violin players	11-23

List of Tables

Table 4-1 Recommended musician ear plugs by musical instrument type	4-22
Table 7-1 Table of equipment used and descriptors of data obtained during music survey...	7-8
Table 8.1: Subjects participated in this study	8-2
Table 8-2 Mean hearing threshold (dB HL) of musicians of all age groups [dB, (SD)]	8-6
Table 8-3 Mean hearing threshold (dB HL) of 183 (61 adult, 85 youth and 37 children) orchestra musicians in the high frequency region	8-7
Table 8-4 Mean hearing threshold (dBHL) in various frequency range	8-8
Table 8-5 Hearing status – adult orchestra musicians in different musician groups	8-9
Table 8-6 Mean age – adult orchestra musicians with and without hearing loss	8-9
Table 8-7 Hearing status – Youth orchestra in different musician groups	8-10
Table 8-8 Mean age – Youth orchestra musicians with and without hearing loss	8-10
Table 8-9 Hearing status – Children orchestra in different musician groups	8-11
Table 8-10 Mean age – child orchestra musicians with and without hearing loss	8-12
Table 8-11 Difference in mean hearing threshold (dB HL) between the ears	8-13
Table 8-12 Hearing status in right ear in adult musicians	8-13
Table 8-13 Hearing status in left ear in adult musicians	8-14
Table 8-14 Hearing status in right and left ear in adult musicians	8-14
Table 8-15 Mean hearing threshold of adult violinist in right and left ear	8-14
Table 8-16 Mean hearing threshold of adult violinists with hearing loss.....	8-15
Table 8-17 Mean hearing thresholds of youth musicians in both ears	8-15
Table 8-18 Hearing status in right ear in youth musicians	8-16
Table 8-19 Hearing status in left ear in youth musicians	8-16
Table 8-20 Hearing status in right and left ear in youth musicians	8-16
Table 8-21 Mean hearing thresholds of children musicians in both ears	8-17
Table 8-22 Hearing status in children musicians (Number of musicians).....	8-17
Table 8-23 Adult musicians – gender difference in mean hearing thresholds (dB HL).....	8-18
Table 7-24 Youth musicians – gender difference in mean hearing thresholds.....	8-19
Table 8-25 Children musicians – gender difference in mean hearing thresholds (dB HL)..	8-20
Table 8-26 Children musicians – Dips in the pure-tone audiogram of right ear	8-22
Table 8-27 Children musicians – Dips in the pure-tone audiogram of left ear	8-23
Table 8-28 Adult musicians – Tinnitus and hearing loss in right ear	8-23
Table 8-29 Tinnitus and hearing status of musicians in left ear	8-24
Table 8-30 Youth musicians – Tinnitus and hearing status of musicians in right ear	8-25

Table 8-31 Youth musicians – Tinnitus and hearing status of musicians in left ear	8-26
Table 8-32 Children musicians – Tinnitus in right ear	8-27
Table 8-33 Children musicians – Tinnitus and hearing status of musicians in left ear	8-27
Table 8-34 Adult musicians – Family history of hearing loss and hearing status	8-28
Table 8-35 Youth musicians – Family history of hearing loss and hearing status	8-29
Table 8-36 Children musicians – Family history of hearing loss and hearing status	8-29
Table 8-37 Adult musicians – ear infection and hearing in right ear	8-30
Table 8-38 Adult musicians – ear infection and hearing in left ear.....	8-30
Table 8-39 Youth musicians – ear infection and hearing in right ear	8-31
Table 8-40 Youth musicians – ear infection and hearing in left ear.....	8-31
Table 8-41 Children musicians – ear infection and hearing in right ear	8-32
Table 8-42 Children musicians – ear infection and hearing in left ear.....	8-32
Table 8-43 Youth musicians – personal stereo usage and hearing status in right ear	8-33
Table 8-44 Youth musicians – personal stereo usage and hearing status in left ear.....	8-34
Table 8-45 Youth musicians – other noise exposure and hearing status.....	8-34
Table 8-46 Youth musicians – Awareness on Music Induced Hearing Loss	8-35
Table 8-47 Youth musicians – Awareness on Music Induced Hearing loss	8-35
Table 8-48 Youth musicians - subjective and actual hearing loss in right ear	8-36
Table 8-49 Youth musicians – subjective and actual hearing loss in left ear.....	8-36
Table 8-50 Adult musicians with hearing loss – usage of ear protection devices during rehearsal.....	8-38
Table 8-51 Adult musicians with hearing loss – usage of ear protection devices during performance.....	8-38
Table 8-52 Adult musicians with normal hearing – usage of ear protection devices during rehearsal.....	8-39
Table 8-53 Adult musicians with normal hearing – usage of ear protection devices during performance.....	8-39
Table 8-54 Adult musicians (31 musicians) – Ear difference in DPOAE.....	8-42
Table 8-56 Youth musicians (34 musicians) – Ear difference in DPOAE	8-47
Table 8-57 Youth musicians (34 musicians) – Gender difference	8-47
Table 8-58 Children musicians (28 musicians) - Oto-acoustic emission test results	8-48
Table 8-59 Children musicians (28 musicians) - Mean gender difference in DPOAE	8-49
Table 9-1 Double bass player - Development of hearing loss in the right ear (56 years old, male).....	9-7
Table 9-2 Double bass player - Development of hearing loss in the left ear (56 years old, male).....	9-7

Table 9-3 Double bass player – Development of hearing loss in the right ear (62 years old, male).....	9-9
Table 9-4 Double bass player – Development of hearing loss in the left ear (62 years old, male).....	9-9
Table 10-1 Adult orchestra musicians – Time average level measurements (1).....	10-3
Table 10-2 Adult orchestra musicians – Time average level measurement (2) details	10-4
Table 10-3 Adult orchestra musicians – Average measurement (3) details (during Rehearsal and Concert Performance).....	10-6
Table 10-4 Youth orchestra musicians – Average measurement details (During rehearsal)	10-8
Table 10-5 Children orchestra musicians – Average measurement details (during rehearsal)	10-10
Table 10-6 Children Orchestra musicians – Average dosage for various groups of musicians during rehearsal	10-10
Table 10-7 Measurement details (whole day sound exposure) for selected musicians).....	10-11
Table 11-1 Distribution of hearing loss among adult orchestra musicians	11-8
Table 11-2 Distribution of hearing loss among youth orchestra musicians	11-8
Table 11-3 Distribution of hearing loss among children orchestra musicians	11-9

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 ($L_{Aeq} 8h = 85dB$).

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^2s), but in industry it is more convenient to use pascal squared hours ($Pa^2 h$).

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 induced 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_{avg}: A metric for monitoring noise proposed by US Occupational Safety and Health Administration (OSHA) standard. The L_{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_{Peak}: 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_{Amax}): 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_{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_{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_{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 (Pa^2s) but can also be quoted in pascal squared hours (Pa^2h).

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_{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.