Edith Cowan University

Research Online

Theses: Doctorates and Masters

Theses

1-1-2003

Emergency vehicle siren noise: A potential for hearing loss

Douglas A. Riach
Edith Cowan University

Follow this and additional works at: https://ro.ecu.edu.au/theses

Part of the Medical Education Commons

Recommended Citation

Riach, D. A. (2003). *Emergency vehicle siren noise: A potential for hearing loss*. https://ro.ecu.edu.au/theses/1294

This Thesis is posted at Research Online.
https://ro.ecu.edu.au/theses/1294

www.manaraa.com

Edith Cowan University

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study.

The University does not authorize you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following:

- Copyright owners are entitled to take legal action against persons who infringe their copyright.

- A reproduction of material that is protected by copyright may be a copyright infringement. Where the reproduction of such material is done without attribution of authorship, with false attribution of authorship or the authorship is treated in a derogatory manner, this may be a breach of the author's moral rights contained in Part IX of the Copyright Act 1968 (Cth).

- Courts have the power to impose a wide range of civil and criminal sanctions for infringement of copyright, infringement of moral rights and other offences under the Copyright Act 1968 (Cth). Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

المنارة للاستشارات

www.manaraa.com

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

www.manaraa.com

Title	**Emergency vehicle siren noise: A potential for hearing loss.**
Name	**Douglas A Riach**
Student ID number	**0975392**
University	**Edith Cowan University**
Degree	**Master in Health Science (Occupational Health and Safety)**
Supervisors	**Lorraine Gray** **Janis Mussett**
Faculty	**Communication, Health and Science** **School of Nursing and Public Health**
Date	**2003**

ABSTRACT

The purpose of this thesis was to critically investigate the noise produced by the sirens fitted to South Australian Police general patrol vehicles and calculate if this noise was of an intensity to cause noise induced hearing loss. Previous studies in Western Australia and in South Australia examined noise emissions from emergency vehicle sirens for the purpose of selecting the most suitable siren for emergency vehicles, this being the siren emitting the greatest intensity of sound. This study has researched emergency vehicle sirens from the perspective of employee exposure to siren noise. Noise levels were recorded from inside the police vehicles using a hand held digital sound level meter while the vehicle was driven under driving conditions of stationary, 60 km/h, 80 km/h and 100 km/h. Noise level readings were taken with the front windows closed and open.

South Australian police sirens have three distinct settings with differing noise outputs. The change in vehicle speed was found to affect the noise intensity within the vehicle for all 3 siren types. The peak noise level recorded was with the windows open and the vehicle travelling at 100 km/h (95, 94 and 97 dB(A) for the three sirens respectively).

Closing of the front windows when stationary and when driving at was found to reduce the noise intensity within the vehicle. The greatest reduction from closing the windows was recorded at 100 km/h. This reduction was 11, 9 and 7 dB(A) respectively for the three siren types.

Siren type one was the siren normally used by the South Australian police, consequently the majority of exposure by South Australian police employees is to siren type one. These sirens produced a peak internal vehicle noise intensity of 95 dB(A) at 100 km/h with the windows open and 84 dB(A) at 100 km/h with the windows closed.

The reading of 95 dB(A) is greater that the 90 dB(A) eight hour continuous exposure limit set by the South Australian Occupational Health Safety and

Welfare Act of 1986. The maximum exposure time for unprotected ears using the 90 dB(A) eight hour equivalent continuous A weighted sound pressure level ($L_{aeq, 8h}$) would be 2 hours and 30 minutes (150 minutes).

The assumption of this study was that noise intensity levels in excess of 90 dB(A) $L_{aeq, 8h}$ will cause noise induced hearing loss. Therefore the noise intensity recorded from the vehicle siren tests at 100 km/h with the windows open have the potential to cause hearing loss if the duration exceeds 150 minutes.

The review of existing records of vehicle pursuits showed that between January 1 1998 and December 31 2001, there were three instances where the exposure to siren noise exceeded the 150 minute exposure period.

This study found the closing of the windows to reduce the noise intensity at all speeds and all sirens types to below the 90 dB(A) $L_{aeq, 8h}$. It is therefore recommended that all police vehicles whilst using the sirens close all windows to reduce the noise intensity within the vehicle.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education:

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material

Signed

D. A. RIACH

1. 9. 2003

Acknowledgement

The assistance of the South Australian Police, especially the members of the Police Driver Training Unit is acknowledged.

Table of Content

		Page
Title page		1
Copyright and access declaration		2
Abstract		3
Declaration of originality		5
Acknowledgement		6
Table of contents		7
Chapter 1 – **Introduction**		
1.1	History of vehicle sirens	11
1.2	Problem.	11
1.3	Significance of study	12
1.4	Purpose of study	12
1.5	Study design	12
1.6	Study limitations	13
1.7	Research questions	13
1.8	Thesis assumption	14
1.9	Definitions and Terms	
1.9.1	Noise	14
1.9.2	Intensity	14
1.9.3	Immission	14
1.9.4	Emission	15
1.9.5	Decibel scale...	15
1.9.6	dB(A)	16
1.9.7	Eight Hour equivalent Continuous A Weighted ($L_{aeq,8h}$) Levels	16
1.9.8	Tinnitus	16
1.9.9	Presbycusis	17
1.9.10	Noise induced hearing loss	17
1.9.11	Acoustic trauma	17
1.9.12	Temporary threshold shift	17
1.9.13	Permanent threshold shift	17
Chapter 2 - **Literature review**		
2.1	Introduction	18
2.2	Structure of the human ear	18
2.3	Hearing mechanism of the human ear	21
2.4	How noise is transmitted	22
2.5	Noise induced hearing loss	23
2.6	Significance of noise induced hearing loss	24
2.7	Noise measurement	25

2.8 Standards and legislation 26
2.9 Noise trauma 26
2.10 Temporary threshold shift 27
2.11 Permanent threshold shift 27
2.12 Structural damage 27
2.13 Audible noise 28
2.14 Ultrasonic and infrasonic sound 29
2.15 Sound levels responsible for hearing loss 30
2.16 Overseas occupational studies 31
2.17 Australian occupational studies 32
2.18 Overseas emergency services studies 32
2.19 Australian emergency services studies 33
2.20 Literature summary 35

Chapter 3- **Methodology**

3.1 Research design overview 37
3.2 Validity 37
3.3 Reliability 38
3.4 Ethical considerations 38
3.5 Study setting 38
3.6 Vehicles 39
3.7 Sirens 40
3.8 Vehicle selection 42
3.9 Equipment and apparatus - noise recording equipment 43
3.10 Noise level recording position 44
3.11 Noise level testing 44
3.12 Testing protocol 46
3.13 Hearing protection 46
3.14 Collection of 1998 and 1999 exposure data 46

Chapter 4 – **Results**

4.1 Vehicle siren noise levels prior to activation of sirens 48
4.2 Noise levels produced by sirens 48
4.3 1998 to 2001 exposure data 49

Chapter 5- **Discussion and findings**

5.1 Research question one 51
5.2 Research question two 51
5.2.1 Siren one windows closed 51
5.2.2 Siren one windows open 52
5.2.3 Siren two windows closed 52
5.2.4 Siren two windows open 53
5.2.5 Siren three windows closed 53
5.2.6 Siren three windows open 53

5.3 Research question 3 54
5.3.1 Siren one 54
5.3.2 Siren two 54
5.3.3 Siren three 55
5.4 Research question four 55
5.5 Research question five 56
5.6 Generalisation 57
5.7 Transferability 57
5.8 Limitations
5.8.1 Traffic noise 57
5.8.2 Road noise 58
5.8.3 Vehicle suspension 58
5.8.4 Wind 58
5.8.5 Vehicle condition 58
5.8.6 South Australian Police data 59
5.9 Problems with noise standards 59
5.10 Presbycusis 61
5.11 Tinnitus 61
5.12 Extraneous noise 62
5.13 Extra auditory effect 62
5.14 Suggested further studies 62
5.15 Recommendations 63
5.15.1 Pre employment hearing tests 63
5.15.2 Exit tests 63
5.15.3 Hearing tests 63

Chapter 6 – **Conclusions**

6.13 Conclusion 65

References 66

List of Tables

1	Decibel scale	15
2	Table of test conditions	46
3	Vehicle noise level dB(A) sirens not operating	48
4	Siren noise levels	49
5	Exposure to siren noise recorded from vehicle pursuit data 1998 to 2001	50
6	Decrease in peak noise pressure dB(A) recorded when retested with the windows closed compared with windows open	55

List of Figures

1	Structure of the human outer ear	19
2	Structure of the human middle ear	20
3	Structure of the human inner ear	21
4	Police general duties patrol vehicle	40
5	Astra electronic siren control panel	41
6	Police vehicle with twin mounted speakers	42
7	Noise monitor	44

Chapter 1

INTRODUCTION

Emergency vehicles have sirens, which produce noise. In this introduction the problems of producing excessive noise in the work environment will be identified. The significance of work related, noise induced hearing loss will be stated and the common terminology explained.

1.1 History of vehicle sirens

Even before the use of motor vehicles by the South Australian emergency services, warning devises were used to warn people and road users of the approaching emergency vehicle. Prior to the introduction of motor vehicles, horse drawn fire engines were fitted with a bell, which was vigorously rung by a fireman when attending a fire.

The South Australian police introduced sirens on police motor vehicles in the 1950's. In the early 1970's sirens were replaced with under the bonnet-mounted twin alternating horns, which produced the distinctive "Hee Haw" noises. Although technically a combination of two horns, these devices were commonly referred to as sirens. In early 1980's there was a gradual replacement of the alternating horns with electronic sirens. Presently all South Australian police patrol vehicles and most other emergency services' vehicles are fitted with electronic sirens and roof mounted speakers.

1.2 Problem

The Police Service and the other emergency services use sirens on their vehicles to warn road users of the presence of emergency vehicles and to assist with negotiating traffic in urgent situations. The selection of siren types has obviously been related to noise output with an emphasis on warning other drivers of the emergency vehicle approach. At the time of commencing this

study the magnitude and the effect of exposure to the siren noise on the occupants of the emergency vehicles was not known.

1.3 Significance of the study

Noise induced hearing loss has been estimated as costing the Australian economy $35,000,000 per year with an annual rate of claims in excess of 10,000 (Worksafe Australia, 1990). In South Australia alone it is estimated that in excess of 900 claims will be received this year costing around $6,000,000 (WorkCover SA, 2002)

This thesis reports internal noise levels of 97 dB(A) from the South Australian Police vehicle sirens, when activated and the vehicle is travelling at 100 km/h. This noise level has the potential to cause hearing loss, thus increasing the cost to the Australian economy in compensation claims and lowering the quality of life for the exposed employees.

1.4 Purpose of the study

The purpose of the study was to determine if South Australian Police patrol vehicle sirens emit sufficient noise to cause hearing loss and if exposure to this noise was of a sufficient duration to be likely to cause hearing loss.
This study found that at speeds of 100 km/h all sirens tested produced noise intensities capable of causing noise induced hearing loss.

1.5 Study design

This study consists of two phases. The first was a quantitative field study recording vehicle siren noise immissions under simulated field conditions. The second phase was a review of 1998 to 2001 siren noise exposures from police records of vehicle pursuits with a quantitative review of exposures to siren noise using descriptive statistics to summarise the duration and number of exposures.

1.6 Study limitations

This research was conducted on a race track and not on a normal road. Although this is a variation from actual driving conditions it was considered the race track would actually cause a reduction in total recorded noise intensity due to the smoother and better maintained surface, reducing road and tyre noise.

The same consideration applies to traffic noise as the race track was void of other traffic. It is unlikely that a roadway would not contain traffic and other traffic noises. It was considered that traffic noise could only add to the total noise intensity in actual driving cases when compared to the quieter conditions on the racetrack.

1.7 Research questions

1. What is the noise intensity within South Australian Police patrol cars when the twin speaker, public address, amplified, warning sirens are activated?

2. Does the change in speed from stationary to 60, 80 and 100 km/h increase the noise intensity?

3. Is the closing of front vehicle windows effective in decreasing the noise intensity?

4. Considering the data gathered from the emergency vehicle sirens under the test conditions, what is the duration of exposure that, if exceeded, will cause noise induced hearing loss?

5. During the last four years have there been any documented cases of exposure to siren noise of sufficient duration to cause noise induced hearing loss?

1.8 Thesis assumption

The assumption of this study is that noise intensity levels in excess of 90 dB(A) (Laeq,8h), which is the exposure limit stated in the South Australian Occupational Health Safety and Welfare Act (1986) and Regulations (1995), will cause noise induced hearing loss. This assumption is supported by Robinson (1971), Burns (1973), United Kingdom Health and Safety Executive (1981), Mitchell (1992), Northern Territory Health Authority (2001), Australian Hearing Services (2002) and National Occupational Health and Safety Commission (2003).

1.9 Definitions and terms

1.9.1 Noise

All sound wanted or unwanted (adapted from Australian Standard 1269.0)

1.9.2 Intensity

Refers to the pressure or energy reaching the ear (Mathews, 1986; and National Occupational Health and Safety Commission (2003) recorded in pascals (Pa) or decibels (dB). The term loudness is also used to describe intensity of sound and refers to the force of sound waves against the inner ear.

1.9.3 Immission

Is the sound pressure levels recorded (received) at a particular location (Australian Standard 1269.0). The source of the sound pressure may be emitted from more than one source.

1.9.4 Emission

Is the radiation of sound from a source (Australian Standard 1269.0). Measurement of emissions identifies the sound pressure level radiating from a single source.

1.9.5 Decibel scale

A non-linear (logarithmic) scale used to measure the intensity of sound. The relationship of noise intensity to the decibel rating scale is indicated in Table 1. This intensity scale includes a range of frequencies similar to that commonly occurring in environmental noise and not merely single frequency tonal noise as produced in audiograms.

Table 1.
Decibel scale

Intensity	**dB**	**Example**
1	1	Hearing threshold
10	10	Quiet whisper
100	20	
1000	30	Subdued speech
10000	40	
100000	50	Normal conversation at 1 metre
1000000	60	
10000000	70	
100000000	80	
1000000000	90	South Australian official limit
10000000000	100	
100000000000	110	
1000000000000	120	
10000000000000	130	Pain threshold

(Adapted from ACTU National Occupational Health and Safety Unit, 1987)

1.9.6 dB(A)

Is the decibel scale in the range of frequencies to which the human ear is most sensitive (Mathews, 1986). The reading of 0 dB(A) is the threshold of hearing at 1,000 Hertz (Hz) for what is considered a normal young adult.

1.9.7 Eight Hour Equivalent Continuous A Weighted ($L_{aeq,8h}$) Levels

$L_{aeq,8h}$ are used when the exposure to noise is other than eight hours and it is necessary to normalise the exposure to an equivalent eight-hour exposure (Australian Standard 1269.1). This is necessary because the Australian noise exposure standards are designed for an 8 hour working day with the noise exposures considered as being continuous during this 8 hour period. Exposure to siren noise in this study is less than 8 hours.

1.9.8 Tinnitus

The word tinnitus comes from the Latin word *tinnire*, meaning to ring. Although often described as a ringing in the ears the noises can also include buzzing, roaring, whooshing, chirping, beating and humming. Tinnitus may be mild or severe, continuous or spasmodic and likely to differ in sound for each individual. Tinnitus usually persists despite surgical or other medical treatments. Tinnitus has long been associated with noise exposure and has also been documented as a result of single exposures of high intensity sound (Mayo, 1998).

1.9.9 Presbycusis

Hearing impairment due to the aging process. Hearing loss that increases with age and is not attributed to excessive noise exposure or other aetiology is referred to as presbycusis. The National Institute for Health (1990) and Burns (1973) agreed that Presbycusis was a characteristic of growing old but would not exclude the exposures to noise that had occurred during the lifetime. The

typical levels of Presbycusis at various ages are incorporated into annex A of the International Standards Organization, Standard 1999.2. This annex is used by audiologists to estimate the portion of overall hearing loss that is attributed to exposure to excessive noise.

1.9.10 Noise induced hearing loss

Hearing loss resulting from the exposure to excessive noise including acoustic trauma, temporary threshold shift and permanent threshold shift.

1.9.11 Acoustic trauma

Short term sound of sufficient intensity (gunshot or explosion in excess of 140 dB) may result in an immediate, severe and permanent hearing loss, which is termed acoustic trauma.

1.9.12 Temporary threshold shift

Temporary threshold shift is a non permanent hearing loss caused by exposure to excessive noise. The hearing loss is due to an increase in the threshold level of noise required to cause cochlea nerve stimulation.

1.9.13 Permanent threshold shift

With repeated exposure to high levels of sound there is a permanent need for an increase in noise intensity to stimulate the cochlea nerve.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Both published and unpublished material was sought and reviewed in the literature search as it was believed that emergency services had possession of unpublished research. Other Australian State Police Services were contacted as were South Australian Emergency Service organisations. A search of the University of South Australia and the South Australian WorkCover libraries were conducted. Lycos, Altavista, Excite and Yahoo search engines were used to conduct Internet searches.

2.2 Structure of the human ear

To comprehend noise induced hearing loss it is necessary to understand the structure of the human ear. The human ear consists of three main parts, the outer ear, the middle ear and the inner ear.

The outer ear consists of the pinna (earflap), the external auditory canal (ear canal) and the tympanic membrane (eardrum) which separates the middle and outer ear. The pinna is a cartilaginous shell shaped structure attached to the skull by muscles and ligaments, and covered by skin. The external auditory canal leads from the pinna to the tympanic membrane and is approximately 25 mm long with an average diameter of 8 mm at its entrance (adult). It is directed inwards, upwards and slightly forwards.

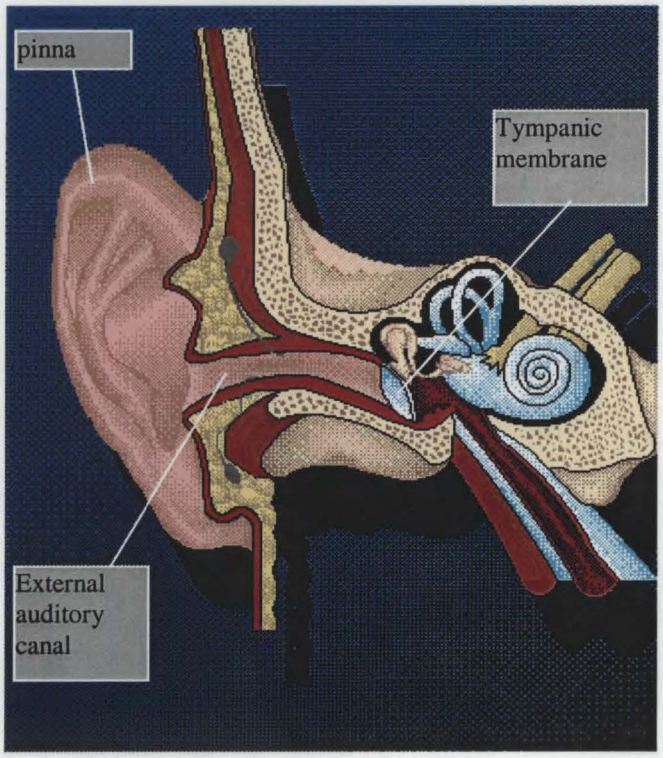

Figure 1.

The structure of the human outer human ear. (Tortora & Anagnostakos, 1987).

The middle ear is a small air filled cavity containing three small bones, the malleus (hammer), incus (anvil) and the stapes (stirrup). The malleus is firmly attached to the tympanic membrane and the stapes is connected to the oval window of the inner ear. The incus is the connector between the malleus and the stapes. The tympanic membrane is positioned at the internal end of the external auditory canal and forms an airtight and watertight barrier separating the middle ear from the external ear.

The eustachian tubes are air passages from the back of the nose and throat to the middle ears. The purpose of the eustachian tubes is to ensure that air pressure is equalised within the ears and the external environment.

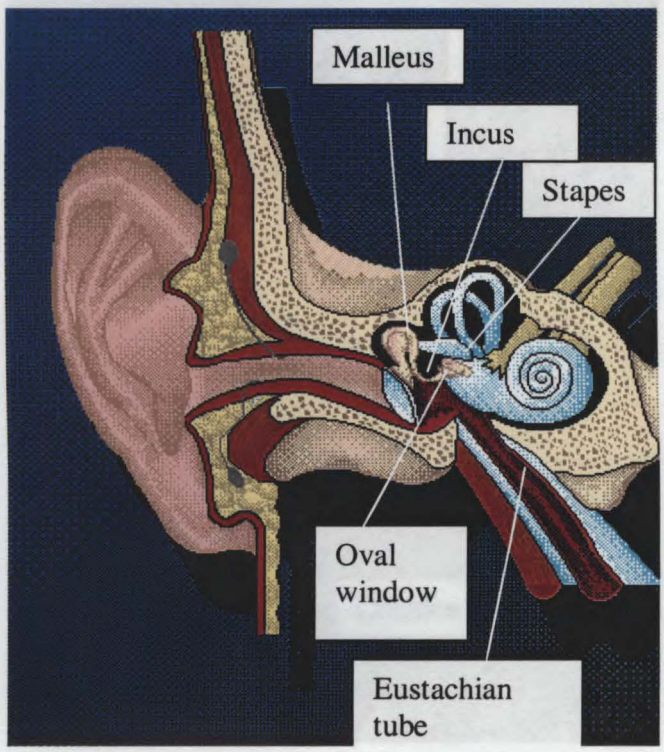

Figure 2.

The structure of the human middle ear. (Tortora & Anagnostakos, 1987).

The inner ear is a series of fluid filled bony canals. The oval window, the opening into the inner ear, separates the middle and inner ear. The oval window leads to the shell-shaped cochlea containing fluid and thousands of tiny nerve ending cilia (hairs). These nerve endings connect to the auditory nerve, which carries messages to the brain. Also in the inner ear are the semi-circular canals, set at right angles to each other, movement of fluid in these canals sends information to the brain to enable the body's balance to be maintained. This is the mechanism, which allows the brain to identify the body's position or kinesiology ie. standing up, lying down and position relative to the ground. The fluid filled canals can detect movement in any direction. The inner ear has two main functions, balance and hearing. This study is concerned with the hearing component only. Mechanical vibrations in the oval window cause movement of both fluid and cilia immersed in the fluid. Movement of the cilia stimulates the attached cells to send electric impulses along the auditory nerve to the brain.

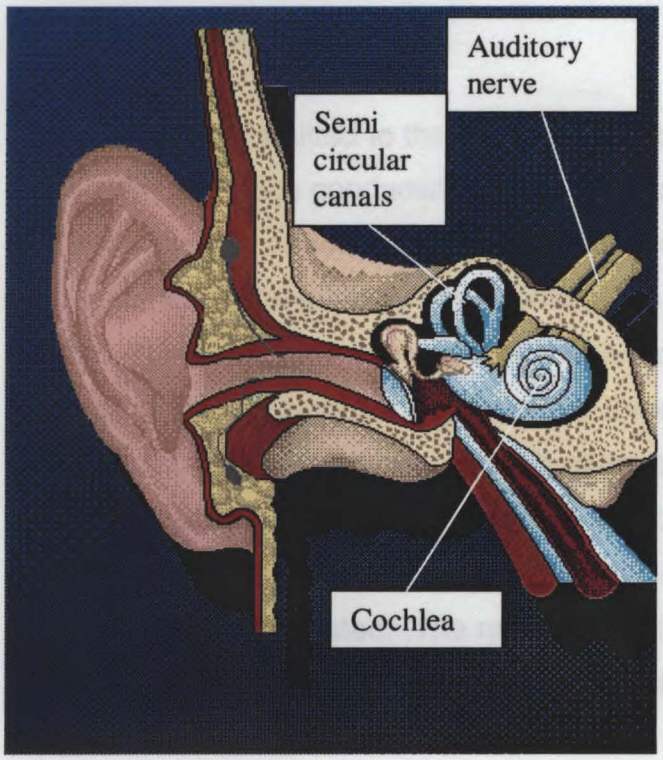

Figure 3.

The structure of the human inner ear. (Tortora & Anagnostakos, 1987).

2.3 Hearing mechanism of the human ear

Hearing is a series of events in which sound waves originating externally from the body produce internal electrical signals and cause nerve impulses to be sent to the brain where they are interpreted as sound. The pinna collects sound waves (vibrations) and channels them into the external auditory canal. Sound waves propagate along the auditory canal to the tympanic membrane. The tympanic membrane motion is transmitted via the tiny middle ear bones to the inner ear. Cilia inside the cochlea generate electrical impulses when stimulated. The impulses are transmitted along the auditory nerve to the brain. The ears themselves are not capable of hearing and understanding speech. The human hearing mechanism receives sound, modifies it, breaks it down into component parts and transmits that information to the brain. The brain is responsible for translating the information into meaningful speech, music, noise and other sounds.

2.4 How noise is transmitted

Noise can be transmitted to the inner ear in two separate pathways, air conduction and bone conduction. In air conduction sound waves are collected by the pinnas and directed into the external auditory canals. Sound waves propagate along the auditory canal, setting the tympanic membrane into motion. The tympanic membrane motion is transmitted and amplified via the malleus, incus and stapes to the inner ear through the oval window and into the fluid that fills the inner ear. The vibrations travel through the fluid in the cochlea containing the cilia. Membranes and cilia inside the cochlea are very sensitive to this vibration and generate electrical impulses when appropriately (threshold level) stimulated. The nerve impulses are carried via the auditory nerve to the brain where they are decoded and interpreted as sound. Different sounds move the population of cochlea cilia in different ways, thus creating varying electrical impulses allowing the brain to distinguish among various sounds, for example, different vowel and consonant sounds (National Institute of Deafness and other Communication Disorders, 1998).

Bone conduction is the term given to the pathway of sound conduction when the skull and or the ear canal walls are directly vibrated. This vibration is conducted via the bones of the skull, (the malleus, incus and stapes through the oval window) to the cochlea. Vibration of the skull can also directly stimulate the cochlea.

Electrical impulse production and nerve synapse is identical for both bone and air conduction pathways. Since most sound or vibration sources will excite both transmission paths the ear will usually receive both air and bone conducted signals simultaneously.

2.5 Noise induced hearing loss

Hearing loss resulting from dysfunction of the outer or middle ear, including the oval window, is referred to as "conductive hearing loss" and can often be corrected or improved with medication or surgery. Hearing aids and amplification have also been used successfully to restore some of the hearing ability.
Noise induced hearing loss has not been reported with causing "conductive hearing loss" (Clark & Bohne, 1999; Burns, 1973) and does not benefit from medication or surgery.

Hearing loss resulting from dysfunction of the inner ear or central hearing pathway is referred to as sensory neural hearing loss and can seldom be corrected or improved with medication or surgery (Mathews, 1986). This loss is due to a defect in the cochlea or the auditory nerve whereby nervous impulses from the cochlea to the brain are attenuated (Grant, 2000). Noise induced hearing loss has been reported as a primary cause of sensory neural hearing loss. Noise induced hearing loss is indicated by a loss of sensitivity in the high frequencies from 3, 000 to 6,000 Hz. This results in a characteristic "notch" on audiograms (National Institute of Health, 1990).

The earliest damage to hearing is reflected as a loss at 3,000, 4,000, and 6,000 Hz and there is always far more loss at 3,000, 4,000 and 6,000 Hz than at 1,000, 2,000 and 5,000Hz. The greatest loss usually occurs at 4,000 Hz. At stable noise exposure conditions losses at 3,000, 4,000 and 6,000 Hz will usually reach a maximal level in about 10 to 15 years (Orgler, 1987; American College of Occupational and Environmental Medicine, 1998; CCH, 2000).

Noise induced hearing loss (NIHL) can be considered in terms of mild, moderate, severe and profound.

- Mild NIHL is a high frequency hearing loss of between 20 and 40 dB;
- Moderate NIHL, between 40 and 60 dB
- Severe NIHL, between 60 and 80 dB

- Profound NIHL, greater than 80 dB

(New South Wales Department of Agriculture, 1999).

One of the frustrating facts of moderate NIHL (40 to 60 dB) is that higher frequency sounds such as s, sh, f, p, t, th, k and ch, in human speech may not be heard. For example, *fun* may be heard *sun* or *back* may be heard *bat*. The problem is amplified if there is any background noise such as from television or other people talking. Background noise interferes with the high frequency consonants. While there is the opportunity to view the speaker's face, a person with moderate noise induced hearing loss can fill in the spaces. This is a practice referred to as speech reading. Severe noise induced hearing loss will prevent the normal hearing of speaking voices even at close ranges.

2.6 Significance of noise induced hearing loss

Freeman (1999) referred to noise induced hearing loss as the number one industrial health hazard. In 1992, the Victorian Institute of Occupational Safety and Health VIOSH (Mitchell, 1992) estimated noise induced hearing loss costs Australia around $35 million per year on compensation claims alone.

Worksafe Australia (1990) publication "Noise Management at Work, Control Guide", supported the VIOSH estimation and reported an annual rate of 10,000 worker's compensation claims and $35 million paid in workers compensation claims per year.

The South Australian WorkCover Corporation reported that 27% of people with hearing loss suffered the loss as a result of exposure to excessively load noise (WorkCover, 2003).

In 2002 the South Australian WorkCover Corporation estimated the Australian annual cost in compensation claims due to noise induced hearing loss to be $35 million. The WorkCover estimate supported the earlier estimates by Mitchell (1992) and indicated there has not been a reduction in hearing loss

compensation over the 10 years 1992 to 2002. The South Australian The South Australian WorkCover Corporation also reported an excess of 900 noise induced hearing claims per year with an annual cost in excess of $6 million in South Australia (WorkCoverSA, 2002).

Berger (1983) reporting on the 1983 American statistics, found the cost of noise induced hearing loss to be $25 million for 5,535 claims under the Federal Employees' Compensation Act and a further $155 million which was paid to 62,436 claims by the Veterans' Administration to military personnel. Considering the number of claims reported by Berger (1983) and Bennett (1981) it is understandable that noise has been referred to as one of the most pervasive and serious health hazards in industry and the military (Axelsson, et al., 1996).

Bennett (1981) estimated the actual cost to be at least twice the reported costs owing to the additional factors such as lost productivity, staff replacements and costs of administering compensation claims.

The financial burden due to the compensation cost of noise induced hearing loss is only a fraction of the actual cost of the problem if the indirect costs associated with the problem are also considered. In the United States the number of people suffering hearing loss due to noise exposure has been estimated to exceed 10 million (National Institute for Health, 1990). Roof mounted emergency vehicle sirens are one such producer of excessive noise.

2.7 Noise Measurement

Australian Standard 1269.1 is the guidance document for occupational noise management within Australia and New Zealand. This Standard states that noise exposure is to be established in terms of: -

> "(i) Eight hour equivalent continuous A weighted sound pressure level or A weighted noise exposure; and
> (ii) the peak sound pressure level."

(Australian Standard1269.0, 1998, page 7)

This research has followed Australian Standard 1269.1 measurement protocols and recorded immissions in both peak sound pressure levels and the A weighted scale.

2.8 Standards and legislation

In South Australia the Occupational Health, Safety and Welfare Act (1986) and the Occupational Health, Safety and Welfare Regulations (1995) regulate noise exposures in the work environment. The Occupational Health Safety and Welfare Regulations of the South Australian Occupational Health, Safety and Welfare Act set the noise standard at 90 dB(A) for an 8 hour exposure and 140 dB(A) as a maximum permissible exposure. Australian Standard 1269.1 Occupational Noise Management sets the exposure standard at 85 dB(A) for the 8 hour continuous exposure. The Occupational Health, Safety and Welfare Act level of 90dB(A) is the enforceable noise level in South Australia.

2.9 Noise trauma

Short term sound of sufficient intensity (gunshot or explosion in excess of 140 dB) may result in an immediate, severe and permanent hearing loss, which is termed acoustic trauma (National Institute for Health, 1990; National Institute on Deafness and other Communication Disorders, 2000; American College of Occupational and Environmental Medicine, 1998).

Acoustic trauma is physical damage and can include stretching or tearing of delicate inner ear tissues beyond their elastic limits (Clark & Bohne, 1999). The greatest loss in acoustic trauma is centred around the 4000 Hz range (American College of Occupational and Environmental Medicine, 1998).

2.10 Temporary threshold shift

Temporary threshold shift (TTS) is the temporary loss or reduction in hearing as a result of exposure to excessive noise. Structural changes associated with TTS have not been fully established but may include subtle intracellular changes in sensory cells and swelling of the auditory nerve endings. Other potentially reversible effects include vascular changes, metabolic exhaustion and chemical changes within the hair cell. There is also evidence of decreased stiffness of the cilia, believed to result in a decrease in the cochlea nerve fibre stimulation thereby altering the hearing sensitivity (National Institute for Health, 1990; Scott-Brown, 1979).

2.11 Permanent threshold shift

Permanent threshold shift is permanent hearing loss. With repeated exposure to high levels of sound, damage to hair cells occurs and cochlear blood flow is impaired. With continued exposure the number of damaged hair cells increases. When sufficient numbers of hair cells are lost the nerve fibres to that region also degenerate with a corresponding degeneration within the central nervous system (National Institute for Health, 1990).

2.12 Structural damage

Virtually all of the structures of the ear can be damaged by noise, in particular the delicate sensory structure of the auditory portion of the cochlea (National Institute for Health, 1990). The most frequently reported structural damage is the loss of cilia (hair cells) within the cochlea (Rubel, 1994: National Institute on Deafness and other Communication Disorders, 2000).
When cilia are exposed to prolonged periods of damaging sound the basic structure of the hair bundles are destroyed and the important connections among hair cells are disrupted which leads to permanent hearing loss (National Institute on Deafness and other Communication Disorders, 2000).

Orgler (1987) and Australian Hearing Services (2002) considered the principal characteristics of occupational noise induced hearing loss are always sensory neural, affecting hair cells in the inner ear. Clark and Bohne (1999) disagreed with Orgler and concluded exposures to noise between 90 and 140 dB(A) damage the cochlea metabolically rather than mechanically. Clark and Bohne (1999) reported three separate stages of metabolic damage. In the first stage, sensory cells within the cochlea are killed by excessive exposure: these cells do not regenerate. In the second stage, after a period of time varying from weeks to years, the hearing loss can be detected by audiometric examinations. Whilst in the third stage, the patient becomes aware of the problem and has difficulty understanding human speech.

2.13 Audible Noise

Tonal frequency noise is sound with a single frequency such as those used in an auditory assessment (hearing test). Tonal noises are measured by the frequency (number of vibrations per second). The normal human ear is sensitive to frequencies between the range of 20 Hz and 20,000 Hz and particularly sensitive to the range 1,000 Hz - 4,000 Hz. Noise between 20 Hz and 20,000 Hz is often referred to as sound as it can be heard by the human hearing mechanism. Noise below the 20 Hz level is referred to as infrasound and sound greater than 20,000 Hz is called ultrasound. In the work environment single tonal frequencies are rare. The noise heard in these situations consists of many frequencies often covering the entire frequency spectrum (ACTU, 1987). The frequencies present in normal human speech can range from about 500 to 6,000Hz (CCH, 2000). Therefore in hearing prevention or hearing loss investigations the frequencies of the noise are less important than the total pressure of the noise (Australian Hearing Services, 2002).

2.14 Ultrasonic and Infrasonic

Although the range of audible frequency is classically defined as extending from 20 Hz to 20 KHz, sounds of significant intensity can be aurally detected at both lower and higher frequencies. The acoustical energy falling outside the audible range is designated as either infrasonic below 20 Hz or ultrasonic above 20 KHz.

Infrasound can be generated by both natural and man made events. Thunder, volcanic activities, winds, large waterfalls and impact of ocean waves are examples of natural sources. High powered aircraft, rocket propulsion systems, explosions, sonic boom, bridge vibrations, air heating and cooling equipment are man made sources of infrasound (Tempest, 1976). Infrasound frequencies have been the subject of limited research. One study of Mexican industries from 1990 to 1993 used "A" weighted sound pressure levels and measurements taken in accordance with official methodology (ISO 1999, 1975). However, the "A" range did not account for the recorded low performance, biological and psychological effects reported resulting from the exposure to low frequency sound (Garcia, 1994).

The US Army Corps of Engineers - Construction Engineering Research Laboratory, use the term "noise induced annoyance" in relation to aircraft acoustic energy. The army recognised that the dB(A) readings did not represent the level of annoyance caused by exposure to infrasonic sound frequencies. The conclusion drawn was that the infrasonic sound was different from typical community noise and caused an annoyance response (Schomer, 1989).

Ultra sonic sounds are naturally produced by bats and marine animals such as whales and dolphins. These creatures use the ultra sonic sounds for communication and navigation but little is known of the effect on humans.

Ultrasonic and infrasonic sounds have not been investigated in this study, however their importance in exposures to noise should be remembered,

especially in relation to diminished work performance. Ultrasonic and infrasonic effects on humans will be mentioned in the conclusion of this thesis.

2.15 Sound levels responsible for hearing loss

The association between noise and hearing loss is not a new concept, as early as 1946 (Murray & Reid) articles were published relating excessive noise levels to hearing loss. In 1965 Taylor conducted research on jute weaving in Scotland. The weaving of jute was an industrial process carried out in large noisy factories. Due to the lack of computerised processes in 1965 the machines were mechanical in nature and required a large volume of human input.
Taylor's (1965) data showed a reduction in hearing by workers particularly in the 2,000, 3,000 and 4,000 Hz frequency. The factory noise level was recorded as 100 dB(A). This early research although not stating the period of exposure to the noise by workers suffering hearing loss clearly identified a link between hearing loss at the 2,000, 3,000 and 4,000 Hz range and prolonged exposure to noise levels of 100 dB(A).

Robinson (1971) and Burns (1973) studied hearing loss of workers in noisy factory environments and concluded that regular exposure to noise levels in excess of 90 dB(A) will cause an identifiable and significant hearing loss in a sizeable portion of the exposed population. Robertson (1971) and Burns' (1975) results supported Taylor's (1965) conclusions of occupational noise induced hearing loss but lowered the level of intensity from 100 to 90 dB(A) as the level identified in the exposures resulting in noise induced hearing loss.

The United Kingdom Health and Safety Executive (1981) reported on noise levels for the duration of an employee's work life across a range of occupations and concluded that 11% of employees continuously exposed to levels equivalent to 90 dB(A) during their working life will suffer binaural hearing loss. This study also indicated that 50% of the workers surveyed suffered the hearing loss within a period of only ten years.

The United Kingdom Health and Safety Executive (1981) report did not look at occupational specific hearing loss but set a standard using continuous exposures to 90 dB(A). This report was non specific in occupations and did not identify exposure periods. However, the conclusions were drawn from a number of specific studies and did not contradict the work of Taylor (1965), Robertson (1971) or Burns (1973).

Mitchell (1992) studied noise induced hearing loss in the mining industry and investigated noise exposure for the duration of working life and the likelihood of noise induced hearing loss as a consequence of the noise exposure. Mitchell (1992), while using the 90 dB(A) standard, did not examine individual noise immissions or short term exposure effects. The findings of Mitchell (1992) supported the United Kingdom Health and Safety Executive (1981) results, that exposure to 90 dB(A) during working life resulted in a higher percentage of noise induced hearing loss cases than the workers in the sub 90 dB(A) work areas.

The Australian Council of Trade Unions (ACTU) is a non government organisation, which conducts workplace studies and funds research into workplace hazards. The ACTU National Health and Safety Unit (1987) report stated that regular day by day exposures to noise levels greater than 90 dB(A) will cause hearing damage over a period of time. The ACTU report also referred to the studies by NIOSH (1972), Guignard (1973), and the EPA (1974), who supplied ample data to support the conclusion that noise levels of 85 dB(A) and as low as 75 dB(A) will cause noise induced hearing loss to a small percentage of the exposed population.

2.16 Overseas occupational studies

Numerous occupational specific studies have been conducted since Taylor (1965) published the data from jute weaving factories. An American example is the investigation into a North Carolina sawmill (Lambeth, 1997). This study recorded noise exposure for sub groups of employees who used sawmill

equipment referred to as debarkers, head saws, sleds, edgers and gang saws. The noise exposure recorded ranged from 85 to 110 dB(A).

In a study of occupations using communication headsets, the University of Toronto (Kunov & Dajani, 1997) looked at air traffic controllers, telephone operators, reservation operators, telephone cable maintenance workers and airport ground crew. The sound level recording differed from the Australian Standard method used in this study as the measurement was with a miniature microphone placed in the ear and under the headsets. The results of the study were 64 to 81 dB(A) in quiet settings (office) and 77 to 88 dB(A) in noisy environments. This study did not examine the hearing loss of people exposed to the noise but recorded the noise level they were exposed to in the different work conditions.

2.17 Australian occupational studies

A comprehensive review and study (Leigh & Morgan, 1990) of the New South Wales mining industry was conducted from June 30 1985 to June 30 1988. This study used estimated noise exposure times (duration) from records of time spent on each job type and shifts worked. Employee audiograms were also conducted. The conclusion of this study was that 42% of miners employed during this time suffered noise induced hearing loss.

Skegg (1989) conducted field studies on New South Wales' sawmills. A peak reading of 107 dB(A) was recorded when the industry standard and state legislation of the time was 90 dB(A). This study did not look at noise induced hearing loss in the exposed population but studied the level of noise employee were exposed to.

2.18 Overseas Emergency Services Studies

In the United States of America the National Institute for Occupational Safety and Health (NIOSH) has conducted Health Hazard Evaluation and Technical Assistance (HETA) programs on fire fighters.

The first report (NIOSH, 1990) was from several metropolitan Fire Departments to determine the noise exposure levels. This noise survey involved fire fighters including volunteers wearing noise dose metres for a full shift. This study was not directly related to siren noise exposure and at the time the main concern was the proximity to noisy fire hose pumps. The average noise exposure was less than the recommended exposure limits, but there were brief periods where the noise levels exceeded the exposure limits. These high exposures were associated with emergency response runs in fire vehicles where the emergency vehicle sirens were operating (NIOSH, 1994). In this American study, the fire stations serviced a relatively small city district, thus the distance of travel to a fire or fire alarm was not excessive and the exposure to siren noise was not considered to be of sufficient duration to cause noise induced hearing loss.

The second HETA program on fire fighters was in 1994 at an American airport fire station. The noise dosimetry results were similar to the previous study with the time weighted average ranging from 60 to 82 dB(A). The data indicated that the code three responses conducted with warning lights and sirens operating reached a peak of 109 dB(A). However, because of the airport environment and the short distance travelled the period of exposure to the 109 dB(A) level of noise was not considered a hazard to hearing. This was due to the recorded exposures not exceeding one minute and infrequent exposure during an 8 hour working day (NIOSH, 1994). The activation of the fire vehicle sirens only occurred on emergency calls, which were not a common occurrence.

2.19 Australian Emergency Services Studies

The South Australian Ambulance Service (1996) conducted noise immission surveys with three different types of audible warning devices (sirens) fitted to ambulances. Peak readings of 89, 88 and 103 dB(A) respectively were recorded inside the vehicle with the windows down and the vehicle stationary. In this survey, readings were also taken with the windows closed and from in front of the vehicle at 10, 100 and 200 metres. In the siren testing with the

windows open and closed the three siren types produced differing results. Siren one recorded no change, 89 dB(A), when the windows were closed, siren two recorded a 6 dB(A) reduction from 88 to 82 dB(A) when the windows were closed and siren three recorded a reduction of 6 dB(A) reducing from 103 to 97 dB(A) as a result of closing the windows. The purpose of this testing was primarily to establish which device produced the greatest emission, a perceived benefit in consideration for subsequent selection for South Australian ambulances. This study was considering the warning of other road users of the presence of the ambulance of greatest importance and there is no reference in the surveys on noise induced hearing loss or employee exposures.

In 1995, the Western Australian State Emergency Service and the Western Australian Police Service (Peter, 1995) conducted noise immission and emission testing on various emergency vehicles. This study included three police patrol vehicles with various roof and under bonnet sirens. Noise immission and emissions were measured using a stationary vehicle with readings taken 3 metres in front of the vehicle and at the front passenger's position with the window closed. The peak dB(A) readings ranged from 90 to 114 dB(A). Although the health and safety of the occupants of the vehicle were considered in the Western Australian study the report placed greater emphasis on the need to alert the public of the presence of an emergency vehicle. Peter (1995) further discussed the potential for employer negligenc and specifically mentioned the need under Western Australian law for the disability suffered to be greater than 30% or a future economic loss of approximately $102,000, an event unlikely with noise induced hearing loss. Although this research carried out noise immission and emission testing, no recommendations were made on occupational noise induced hearing loss or prevention. It is important to note that in Western Australia the police service are exempt from the States occupational health and safety legislation.

South Australian law varies from that of Western Australia with the South Australian Workers Compensation and Rehabilitation Act controlling financial payments and the Occupational Health, Safety and Welfare Act regulating hearing loss prevention. In South Australia, negligence is not a specific

element to a prosecution or compensation. The comments by Peter (1995) relating to employer negligence, greater than 30% disability or future economic loss of $102,000 do not apply in South Australia and a claim for noise induced hearing loss resulting from siren noise exposure in South Australia is almost certain to be accepted and compensated financially.

The South Australian Police service has demonstrated a concern with exposure to noise in internal environments. An example of this is the 1996 noise survey undertaken into the noise levels within the State Mortuary within the Forensic Science building Divett Place Adelaide (Quality Safety Management, 1996). In this study noise emissions were recorded from operating equipment and general back ground noise as well as immissions monitored by personal noise dose meters worn by staff. The greatest noise was produced by the skull desoutter saw, 85 to 91 dB(A). However, the exposure time was limited to approximately 50 seconds per autopsy with a result of 75 dB(A) for a 8 hour exposure. This survey concluded that mortuary noise levels did not create a risk for occupational noise induced hearing loss.

2.20 Literature summary

Taylor, in his 1965 research on industrialised jute weaving, found noise levels of 100 dB(A) caused noise induced hearing loss. Robinson (1971) and Burns (1973) indicated that regular exposure to noise levels above 90 dB(A) can cause hearing loss. Noise levels of 85 dB(A) and as low as 75 dB(A) have also been found to cause noise induced hearing loss (NIOSH,1972; Guinard, 1973; and EPA, 1974)

Peter (1995) recorded noise levels of 90 to 115 dB(A) from Western Australian emergency and police service vehicles. The South Australian Ambulance Service (1996) noise survey on different siren brands produced noise levels of 89 to 103 dB(A).

Sound levels less than 75 dB(A) are unlikely to cause permanent hearing loss while sound levels of about 85 dB(A) with exposures of 8 hours per day will

produce permanent hearing loss after many years (National Institute for Health, 1990; National Institute on Deafness and other Communication Disorders, 2000). The intensity of noise is the important factor affecting hearing loss and the cause of the noise is often considered irrelevant. Sound levels below 140 dB(A) whether impulse (gunshot), impact (drop forge) or steady state (turbine) have been reported to produce the same hearing loss (National Institute for Health, 1990).

The South Australian Occupational Health, Safety and Welfare Act 1985 sets a maximum of 90 dB(A) for an eight hour exposure while at work. It is the assumption of this thesis that exposure to siren noise at or above 90 dB(A) for an eight hour equivalent will cause hearing loss. It is also recognised that a small percentage of the exposed population will suffer noise induced hearing loss when exposed to levels of 85 to 90 dB(A) for an eight hour continuous period. This is further supported by Australian Standard 1269, which states the recommended $L_{eaq,8h}$ to be 85 dB(A).

Chapter 3

METHODS

3.1 Research Design Overview

The first phase of this study was a quantitative field study recording the noise intensity of the three sirens types while stationary and driving at 60, 80 and 100 km/h. These readings were taken first with the windows open then repeated with the windows closed. Five separate vehicles were used for the siren tests and all were driven on the same section of track at the Mallala raceway. All sirens created a two tone noise, which gave a range of readings in dB(A) from the lowest to the highest tone. The readings for all five vehicles were averaged and the mean range for the two tone sirens have been stated.

Phase two of the research was the collection of exposure data from actual police records from 1998 to 2001 inclusive. These records revealed the details of high-speed pursuits undertaken with the sirens operating. This data was divided into categories of exposure duration to identify the frequency of the extended exposures to siren noise.

3.2 Validity

This study researched exposure of occupants in operational police vehicles to siren noise and the possibility of noise induced hearing loss occurring as a result of the exposure. Actual police general duty vehicles and sirens were used in the study to create a high level of validity. The recording of noise intensity was made from inside the vehicle from a position 0.1 metre from the ear canal of the front passenger: this recording position was chosen to give a valid measurement of the noise intensity that would have been received by the passenger's left ear.

3.3 Reliability

To obtain siren noise data with a high reliability, the noise intensity levels recorded from the siren noise was repeated with five different vehicles of the same year, make and model. The readings taken were within 1dB(A) for all sirens of the same type. The noise level meter was calibrated by the manufacturer prior to use on the day of testing and further checked against a known reference source of 86 dB(A), the first vehicle's horn. This calibration check was conducted pre and post every vehicle tested. At the completion of the siren testing the noise recording equipment was returned to the supplier for testing and calibration. The equipment remained within the manufacturer's specification.

3.4 Ethical considerations

To reduce the risk to participants during the field research phase of this study all driving was conducted on the Mallala racetrack to reduce the risk of an accident whilst driving at speed. No other vehicles were present on the racetrack and the back straight was used reducing the risk associated with bends and curves. The drivers of all test vehicles were driving instructors from the Police Driver Training Unit. These experienced drivers were familiar with the handling and performance of the test vehicles. The only passenger in the vehicle was the student researcher: both the driver and the researcher wore hearing protection during the siren testing and recording. Ethical approval was granted from the University of Edith Cowan Ethics Committee prior to conducting the research.

3.5 Study setting

In this research, noise intensity was recorded from inside the police vehicle from the front passenger's position. The majority of the South Australian police patrols are two person patrols and this position is the seat the second officer would occupy. The person in this seat is exposed to siren noise while the vehicle's emergency sirens are operating. This person would normally be an employee of the Police Service and therefore the State legislation on occupational health, safety and welfare would apply.

3.6 Vehicles

The South Australian Police use Holden Commodores as the general patrol vehicle. These vehicles are a production line vehicle known as a BAT1 Commodore. The Commodores are fitted with power steering, ABS braking system and limited slip differential. No changes to the roof linings, windows or other soundproofing are carried out at the factory by the suppliers of the vehicles, or by the Police Service. The vehicles used in the siren noise recording were actual South Australian Police general duty patrol vehicles, supplied by the South Australian Police Driver Training Section. These vehicles have previously been used by general duty patrols and will again be utilised for general duty patrols after the siren testing. All vehicles were the same current model in as new condition. The vehicles used by the Driver Training Section are supplied to operational police stations after driver training activities and when not required for driver training, thus the vehicles used in the siren testing for this research were actual general duty police patrol vehicles. Figure 4. illustrates the Holden Commodore used by the South Australian Police as a general duties police vehicle.

Figure 4.
South Australian Police general duties patrol vehicle

3.7 Sirens

The equipment of interest in the study was the "Arista" public address amplifier siren, fitted with twin roof mounted, 35 watt input, reflex horn speakers, with impedance of 8 Ohms. The public address amplifier has three settings; all settings sound different but are electronic automatic waving sirens. The first setting is the usual siren used by the South Australian Police and has a distinct two tone wave.

The second setting is identifiable by a shorter waving cycle than setting one. This siren also has a distinct two-tone alternating wave.

The third selection is a slower changing and longer duration waving noise, longer that either siren one or two.
A control panel between the front seats enables selection of siren type and therefore noise intensity (Figure 5).

Figure 5
Astra brand electronic sirens control panel

Sirens are mounted on the roof and directed forwards (figure 6).

Figure 6.
Roof mounted speakers

3.8 Vehicle Selection

The vehicles used in this research were supplied by the South Australian Police Driver Training Section. The Driver Training Section has a fleet of patrol vehicles which when not being used for driver training instruction are utilised for general duties policing. The five vehicles subjected to the siren noise testing were randomly selected from the Police Driver Training fleet of vehicles. This selection was made by selecting five sets of car keys from a bucket containing the keys to twelve vehicles. All vehicles were the same model with similar km on the odometer and in as new condition.

3.9 Equipment and Apparatus - Noise Recording Equipment

Noise immission levels were recorded by a hand held, digital sound level meter, 'Realistic' brand catalogue number 33-2050. This apparatus is capable of monitoring noise levels from 50 to 126 dB with an accuracy of + or - 2 dB at 114 dB. Figure 8. illustrates the sound level meter.

Figure 8.
"Realistic" sound level meter

The noise level meter used was calibrated by the manufacturer prior to use and was checked against a known reference source of noise at 86 dB(A) after every vehicle submitted to the siren testing. This assured that the data collected was reliable. The reference noise was the warning device (horn) of the first vehicle tested. Prior to vehicle siren testing the noise immission from the first vehicle's warning device (horn) was recorded. After every vehicle subjected to the testing protocols the digital sound level meter was checked against the known dB(A) from the warning device (horn). The field calibration checking against the vehicle's horn was conducted directly in front of the vehicle at a distance of 1 metre. Throughout the siren noise testing phase the results of the field calibration against the known reference noise level of the vehicle's horn remained constant and unvaried. At the completion of the siren testing the noise recording equipment was returned to the

supplier for testing and calibration. The equipment remained within the manufacturer's specification of + or – 2 dB at 114 dB.

3.10 Noise Level Recording Position

Recording of the siren noise was conducted with the microphone location at 0.1 metres horizontally from the entrance of the external canal of the left ear of the researcher sitting in the front passenger's seat. This seating position is that which the second police officer not being the driver would occupy in a South Australian Police general duties patrol. The recording protocol was consistent with Australian Standard 1269.1 (1998) that states "the recording is to be conducted between 0.1 and 0.2 metres horizontally from the entrance to the ear canal".

3.11 Noise Level Testing

Each vehicle selected was subjected to the thirty-two separate tests as listed in Table 2.

Table 2.

Table of Test Conditions

TEST	SPEED	SIREN TYPE	WINDOWS
1	Stationary	Nil - Motor running	Closed
2	Stationary	Nil - Motor running	Open
3	Stationary	One	Closed
4	Stationary	Two	Closed
5	Stationary	Three	Closed
6	Stationary	One	Open
7	Stationary	Two	Open
8	Stationary	Three	Open
9	60 km/h	Nil	Closed
10	60 km/h	Nil	Open
11	60 km/h	One	Closed
12	60 km/h	Two	Closed
13	60 km/h	Three	Closed
14	60 km/h	One	Open
15	60 km/h	Two	Open
16	60 km/h	Three	Open
17	80 km/h	Nil	Closed
18	80 km/h	Nil	Open
19	80 km/h	One	Closed
20	80 km/h	Two	Closed
21	80 km/h	Three	Closed
22	80 km/h	One	Open
23	80 km/h	Two	Open
24	80 km/h	Three	Open
25	100 km/h	Nil	Closed
26	100 km/h	Nil	Open
27	100 km/h	One	Closed
28	100 km/h	Two	Closed
29	100 km/h	Three	Closed
30	100 km/h	One	Open
31	100 km/h	Two	Open
32	100 km/h	Three	Open

3.12 Testing protocol

The digital sound level meter was activated at the commencement of the testing. In the non-stationary tests, recording was noted after the vehicle had reached and maintained the desired speed.

During the windows "open" tests the front driver's and the front passenger's windows were completely open. The rear windows were closed.

In the "closed" window tests all vehicle windows were completely closed.

Testing was conducted on the same section of track, the back straight of the Mallala raceway, travelling in the same direction on every occasion.

During the siren noise testing the police vehicles were driven by a South Australian police officer from the Driver Training Section.

3.13 Hearing protection

The driver of the police vehicle and the student researcher wore hearing protection during all siren testing.

3.14 Collection of 1998, 1999, 2000 and 2001 exposure data

The South Australian police have an internal system for monitoring vehicle pursuits referred to as urgent duty driving. The system involves the submission of a proforma document numbered and referred to as a PD101. This report form is submitted immediately after vehicle pursuits. The rationale behind the system lies in safety and supervision. All vehicles involved in high-speed pursuits are mechanically examined after the event. Police supervisors and managers review the report to ensure compliance with the Police Commissioner's instructions on urgent duty driving. At the end of these processes the forms (PD101) are centrally filed.

The Police Commissioner's instructions to police include the activation of the vehicle's emergency lighting and sirens in all cases of urgent duty driving and other occasions of non-compliance with the state traffic laws. Therefore during all reported vehicle pursuits noted on the internal report form (PD101) the sirens of the police vehicle were operating and the occupants exposed to the siren noise for the duration of the vehicle pursuit.

To gather the previous exposure data for this research, police records (PD101) for the calendar years of 1998 to 2001 were reviewed. The following information was retrieved from the records:

- Total exposures during the period
- Exposures less than 5 minutes in duration
- Exposures between 5 and 10 minutes
- Exposures between 10 and 20 minutes
- Exposures between 20 and 120 minutes
- Exposures between 120 and 150 minutes
- Exposures in excess of 150 minutes

Chapter 4

RESULTS

4.1 Vehicle noise levels prior to activation of sirens

Prior to activating the sirens of the test vehicles the noise levels within the vehicles were recorded for the two vehicle conditions, windows open and windows closed. This recording was conducted for the four test variables of speed, stationary, 60 km/h, 80 km/h and 100 km/h. Table 3. represents the mean noise levels recorded in this pre siren activation noise monitoring.

Table 3.

Vehicle noise levels dB(A), sirens not operating

Vehicle speed	Windows open	Windows Closed
Stationary (engine running)	56	<50
60 km/h	68	65
80 km/h	74	66
100 km/h	77	67

4.2 Noise levels produced by sirens

During the activation of the vehicle emergency sirens the noise levels were recorded for each siren type using the two vehicle conditions of windows open and windows closed. This recording was repeated for the four variables of speed (stationary, 60, 80 and 100 km/h). Table 4. lists the range of noise intensity recorded.

Table 4.

Siren noise levels

Vehicle Speed Km/h	Siren 1 window closed	Siren 1 window open	Siren 2 window closed	Siren 2 window open	Siren 3 window closed	Siren 3 window open
0	85-87	89-92	81-82	90-91	77-87	86-91
60	87-88	89-90	84-85	88-89	83-87	87-94
80	86-89	91-92	84-85	92-93	85-87	88-92
100	82-84	91-95	84-85	93-94	82-90	85-97

4.3 1998 to 2001 exposure data

Examination of South Australian Police records for the 4 year period 1 January 1998 to 31 December 2001 revealed documented evidence of 1,599 recorded vehicle pursuits where the sirens were activated, thus exposing the occupants of the police vehicle to siren noise. Table 5. lists the exposure data from these four years separated into periods of duration of continuous exposure. The first period is exposure lasting less than 5 minutes. The second period includes all recorded siren activation lasting more than 5 minutes and less than 10 minutes. The next exposure period is greater than 10 minutes and less than 20 minutes. The fourth period of exposure is greater than 20 minutes. The final exposure category for siren activation from the 4 year exposure data is for the period in excess of 2 hours and 30 minutes.

Table 5.

Exposure in minutes to siren noise recorded from vehicle pursuit data 1998 - 2001

Exposure Time	1998	1999	2000	2001
< 5 minutes	150	158	202	236
5 – 10 minutes	41	53	49	63
10 – 20 minutes	25	31	20	19
20 – 120 min	18	16	12	8
120 –150 min	1	0	0	0
> 150 minutes	0	1	0	2
Total	235	259	283	328

Chapter 5

DISCUSSION AND FINDINGS

5.1 Research question 1.

What is the noise intensity within South Australian Police patrol cars when the twin speaker, public address, amplified, warning sirens are activated?

The noise intensity within the test vehicles is stated in Table 4. The greatest noise intensity recorded in the test was from siren three at 97 dB(A) followed by siren one at 95 dB(A) and siren two at 94 dB(A). These reading were recorded at 100 km/h with the windows open.

At 80 km/h with the windows open siren two recorded a peak reading of 93 dB(A) while sirens one and three both recorded 92 dB(A).

All three siren types recorded levels in excess of 90 dB(A) at 80 and 100 km/h with the windows open.

Therefore all three sirens have the potential to cause noise induced hearing loss (Robinson, 1971; NIOSH, 1972; Burns, 1973; Guinard, 1973; EPA, 1974).

5.2 Research Question 2.

Does the change in speed from stationary to 60, 80 and 100km/h increase the noise intensity?

5.2.1 Siren one windows closed

The test results for siren one with the windows closed resulted in a 1 dB(A) increase from stationary to 60 km/h, a 1 dB(A) increase from 60 to 80 km/h and a 5 dB(A) reduction from 80 to 100 km/h. This meant that the 84 dB(A)

reading at 100 km/h was in fact lower than the three other test conditions of stationary, 60 km/h and 80 km/h.

In the case of siren one with the windows closed the change in speed from stationary to 60 and 80 km/h resulted in an increase of 1 dB(A) for each increase in speed. The increase in speed to 100 km/h did not cause an increase in noise intensity.

5.2.2 Siren one windows open

The test results for siren one with the windows open resulted in a decrease in 2 dB(A) from stationary to 60 km/h, a 2 dB(A) increase from 60 to 80 km/h returning the intensity to the 92 dB(A) recorded from the stationary position. A further 3 dB(A) increase was recorded when the speed was increased from 80 to 100 km/h.

Siren one with the windows open recorded an increase in noise intensity with the increase in speed to 80 and 100 km/h but not from the stationary position to 60 km/h.

5.2.3 Siren two windows closed

Siren two when tested with the windows closed recorded 82 dB(A) when stationary and increased 3 dB(A) to 85 dB(A) at 60 km/h. No change in noise intensity was recorded with the increase in speed to 80 km/h and 100 km/h. The reading at 60, 80 and 100 km/h remained at 85 dB(A).

In the tests on siren two with the windows closed the increase in speed from stationary to 60 km/h saw an increase in noise intensity but the additional increase in speed to 80 and 100 km/h did not produce an increase in the noise intensity.

5.2.4 Siren two windows open

Siren two when tested with the windows open first recorded a noise intensity of 91 dB(A) in the stationary position. When the speed increased to 60 km/h the noise level fell 2 dB(A) to 89 dB(A). With the further increase to 80 km/h the noise intensity rose by 4 dB(A) to 93 dB(A). With the increase in speed to 100km/h the noise intensity was recorded at 94 dB(A) which was a further increase of 1 dB(A).

Siren two when tested with the windows open did not record an increase in noise intensity from stationary to 60 km/h but did record increases in noise intensity when the speed was increased to 80 and 100 km/h.

5.2.5 Siren three windows closed

Siren three when tested in the stationary position with the windows closed recorded a noise intensity of 87 dB(A). This level remained constant even when the speed was increased to 60 and 80 km/h. Only at the 100 km/h speed did the noise intensity increase by 3 dB(A) to 90 dB(A).

For siren three with the windows closed the increase in speed from stationary to 60 and 80 km/h was not accompanied with an increase in noise intensity. With the increase in speed to 100 km/h there was a corresponding increase in noise intensity.

5.2.6 Siren three windows open

With the windows open siren three recorded 91 dB(A) in the stationary position. The noise intensity increased by 3 dB(A) to 94 dB(A) with the increase in speed to 60 km/h. However the increase in speed to 80 km/h saw a drop of 2 dB(A) to 92 dB(A). When the speed increased to 100 km/h the noise intensity increased by 5 dB(A) to 97 dB(A).

Siren three with the windows open recorded an increase in noise intensity from stationary to 60 km/h and from 80 to 100 km/h. However, the increase in speed from 60 to 80 km/h did not have a corresponding increase in noise intensity.

5.3 Research question 3

Is the closing of front vehicle windows effective in decreasing the noise intensity?

5.3.1 Siren one

Stationary, siren one recorded a decrease of 5 dB(A) when the windows were closed. At the 60 km/h speed the decrease was 2 dB(A). The 80 km/h speed recorded a decrease of 3 dB(A) and the 100 km/h speed recorded a decrease of 11 dB(A) when the windows were closed.

The closing of the windows was effective in decreasing the noise intensity for siren one, especially at the greater speeds.

5.3.2 Siren two

Siren two when tested with the windows open and stationary recorded 91 dB(A). The closing of the windows reduced this noise level to 82 dB(A), a reduction of 9 dB(A). At the 60 km km/h speed the closing of the windows saw a reduction of 4 dB(A), at 80 km/h a 8 dB(A) reduction was noted with the closing of the windows, while at 100 km/h the reduction was 9 dB(A).

The closing of the front windows is an effective strategy in decreasing the noise intensity for siren two, especially at the greater speeds.

5.3.3 Siren three

Siren three recorded a noise intensity of 91 dB(A) when stationary with the windows open. When the windows were closed the reading reduced 4 dB(A). At 60 km/h the noise level with the windows open was 94 dB(A): this level fell 7 dB(A) when the windows were closed. At 80 km/h with the windows open 92 dB(A) was recorded with a reduction of 5 dB(A) when retested with the windows closed. The 100 km/h speed and windows open condition recorded a reading of 97 dB(A). This level fell 7 dB(A) with the closing of the windows.

The closing of the front windows is an effective strategy in decreasing the noise intensity for siren three across all speeds.

Table 6. indicates the reductions in noise intensity recorded with the closing of the front windows under the various conditions of speed.

Table 6.

Decrease in peak noise pressure, dB(A) recorded when re-tested with windows closed compared with windows open

Vehicle Speed Km/h	Siren 1	Siren 2	Siren 3
0	-5	-9	-4
60	-2	-4	-7
80	-3	-8	-5
100	-11	-9	-7

5.4 Research question 4

Considering the data gathered from the emergency vehicle sirens under the test conditions, what is the duration of exposure that, if exceeded, will cause noise induced hearing loss?

At the 100 km/h speed test and the windows open, sirens one, two and three recorded peak readings of 95, 94 and 97 dB(A). Anecdotal evidence suggested that siren type one was the siren normally used by the South Australian police and that siren two was sometimes used when approaching an intersection and a change in siren type was desired. Siren three was not generally used because of the unpopular slow wailing noise emitted from this siren. Consequently it is believed that the most common exposure to siren noise will be that of siren one. Using siren 1 at 100 km/h with the windows open the reading was 95 dB(A).

Using the noise level in dB(A) based on $L_{aeq,8h}$ 90 dB(A) the exposure time at 95 dB(A) is 150 minutes (Australian Standard 1269).

5.5 Research question 5

During the last four years have there been any documented cases of exposure to siren noise of sufficient duration to cause noise induced hearing loss?

The data collected in relation to exposures to siren noise during vehicle pursuits was stated in Table 5. There has been a steady increase in recorded vehicle pursuit from 1998 to 2001 with the 1998 total of 235, 259 recorded in 1999, 283 in 2000, and 328 in 2001. There has also been an increase in longer duration pursuits lasting more than 150 minutes, with one pursuit recorded in 1999 and two in 2001.

As the calculated $L_{aeq,8h}$ at 95 dB(A) was 150 minutes in the three recorded exposures lasting more than 150 minutes, assuming the vehicle front windows were open, the occupants were subjected to a sufficient level of noise intensity to cause noise induced hearing loss.

5.6 Generalisation

As the research was orientated around the actual police general duties, Holden Commodore, patrol vehicles, with the normal siren configuration, it is believed that the results are highly transferable to situations of actual police driving with the sirens operating, in other general duties police vehicles of the same or similar type.

5.7 Transferability

This study is specifically directed at the South Australian police Holden Commodore vehicles that are fitted with external electronic sirens. However, all Australian Police Services and a number of other Emergency Services, (Fire, Ambulance and State Emergency) use external electronic sirens on their vehicles, the majority of which are roof mounted. A number of Emergency Services and Police Services use Holden Commodore vehicles.

Occupational noise induced hearing loss is an issue for all of the above mentioned services and the results obtained from this study could be applicable.

5.8 Limitations

5.8.1 Traffic Noise

It is recognised that traffic noise from other vehicles can be a contributing factor to sound pressure levels and for this reason testing was conducted at the Mallala Raceway away from other traffic noise. This produced noise levels related to vehicle sirens, speed traveled and window positions, which were not influenced by extraneous traffic noise. The introduction of external traffic noise can only increase the total noise pressure thus exposing the occupants of the police vehicle to even greater noise pressure levels.

5.8.2 Road Noise

The same section of road surface (racetrack) was used during the road testing and all vehicles were fitted with the same brand and type of tyres, inflated to the same pressure. This was done to standardise the noise created from the contact and movement of the tyres and the road surface. The tyres were the same type fitted to general duty police vehicles driven on the road. The tyre pressure levels used were the manufacture's and the police service's recommended inflation pressure. The racetrack was constructed of bitumen similar to South Australian roadways. However, the race track was relatively smooth compared to normal roads even in good condition and although not tested in this research, it is believed that the rougher finish of domestic roads will generate an increase in noise intensity when compared to the race track.

5.8.3 Vehicle suspension

The use of "as new" condition vehicles also ensured the suspension and wheel alignment was in good condition. The effect of worn or poor suspension or wheel alignment is an additional factor in noise production from the tyres and driving.

5.8.4 Wind

Wind velocity and wind noise was minimised by conducting the vehicle siren tests on a relatively calm and windless day. To reduce variation in results due to wind, all tests were conducted on the same day under the same environmental conditions, travelling in the same direction on the racetrack. This would not be the case for general duties driving and the total noise pressure would be increased with the increase of wind speed.

5.8.5 Vehicle conditions

The vehicles used in the siren testing were in good (new) condition. All door and window seals were in "as new" condition. None of the test vehicles had been involved in accidents and repaired. The age of the vehicles, age of door

and window rubber seals, would affect the vehicles sound proofing standards. Vehicles involved in accidents and repaired may also not have the same resistance to sound as a new vehicle. With age, use and accidents the level of sound entering the vehicle could be expected to be higher that in the new vehicles used in the siren testing.

5.8.6 South Australian police data

The exposure time recorded in the South Australian police vehicle pursuits data of this thesis was made available by the police. Exposure to excessive duration and noise intensity is based on this data. The police data was accepted as being accurate due to the nature of the recording and checking by supervisors. The start and finish times of the pursuits entered on the police forms (PD 101) was supplied by the digital recording equipment of the police communications centre. The data from the records of police pursuits 1998 to 2001 was considered reliable.

5.9 Problems with noise standards

Current scientific knowledge is inadequate to predict that any particular individual will be safe when exposed to hazardous noise (NIOSH, 1990). Research conducted by Murray and Reid (1946) showed that 28 single rifle rounds, fired several seconds apart produced substantial temporary threshold shifts, whilst the same number of shots from an automatic Bren gun in a much shorter period of time caused no significant changes. It is not currently known why both noises of equal intensity result in differing results.

When the exposure is less than a constant 8-hour exposure, difficulties arise in the calculation of exposure times. Australian Standard 1269.1 (1999) introduces the term "eight-hour equivalent continuous A weighted sound pressure level" which when calculated is believed to be equivalent to the 8 hour exposure. This is not however internationally accepted. Using the example of 88 dB(A) with a target of 85 dB(A) for 8 hours the exposure to 88 dB(A) should be limited to 4 hours. In 1969 the America, Walsh-Healey Act

was introduced which allowed for a 5 dB offset. For example the 88 dB(A) exposure reduced to a four-hour exposure and added 5 dB to allow a worker to be exposed to 93 dB for 4 hours. The basis for the American 5dB offset is that human hearing can tolerate short-term noise exposure to a greater extent than long term exposure. The offset rule was based on limited scientific evidence but allowed industry to operate with fewer restrictions.

Individual differences and sensitivity to noise exposure differ as much as 30 to 50 dB(A) temporary threshold shift and permanent threshold shift. Various factors are believed responsible for individual differences including the characteristic of ear canal and middle ear, drugs consumed and prior exposure to noise. Animal studies controlling variables suggest that inner ear anatomy and physiology may be a significant factor in sensitivity and resistance to noise induced hearing loss (NIOSH, 1990).

Ototoxic drugs including, Quinine and Chloraquine antimalarial drugs (Reynold, 1989), diuretics such as Frusemide or Thacrynic acid and other chemicals including certain antibiotics (Aminoglycosides) (Murphy, 1998) have been shown to exacerbate the damaging effects of noise exposure. High doses of aspirin are widely known to cause temporary threshold shift and tinnitus, although aspirin has not been shown to increase susceptibility to permanent noise induced hearing loss. The use of diuretics and antibiotics by members of the police service while exposed to siren noise can not be excluded. With this being accepted, the Leaq8h of 90 dB(A) or even 85 dB(A) is not a suitable predictor of noise induced hearing loss.

Solvent mixtures which have the chemical Toluene as a main component were also found to affect the hearing of workers when exposed to low noise levels which would not normally cause hearing loss without the presence of Toluene (Johnson, 1997).

Researchers have also documented findings of noise levels above 75 but below the accepted 85 decibels causing noise induced hearing loss (National Institute of Deafness and other Communication disorders, 2000).

The ISO Standard 1999 (ISO, 1997) uses the 90 dB(A) as does the South Australian legislation for an eight hour day while Australian Standard 1269 (1998) and the Swedish Standards use 85 dB(A). Which is the correct and safe level of exposure?

At the 90 dB(A) standard 4, out of every 10 people will suffer considerable hearing impairment (Zackrisson, 1996). It is a matter of acceptable risk. The risk or percentage of people suffering noise induced hearing loss from exposure to 85 dB(A) will be less than at 90 dB(A). However it has been shown that a small percentage will suffer hearing loss at 75 dB(A) (National Institute of Deafness and other Communication Disorders, 2000). Human susceptibility to noise and hearing damage has been shown to vary with a reported 96% having average susceptibility, 2% exhibiting high susceptibility and 2% having a low susceptibility to potential damage from noise exposure (CCH, 2000).

5.10 Presbycusis

Hearing loss due to age is considered a natural occurrence but the level of loss is a topic of longstanding interest. The International Standard on Acoustics (ISO, 1999) assumes a value in dB(A) which is to be added to an audiogram to compensate for age. This added value varies in individuals and has not been supported by laboratory animal studies (Mills, 1998).

5.11 Tinnitus

Tinnitus is associated with noise exposure but the level of exposure (intensity and duration of exposure) is less defined than in noise induced hearing loss. This study did not investigate tinnitus although the implementation of a hearing conservation program by emergency services should also address this problem.

5.12 Extraneous noise

When employees are exposed to work related noise some consideration should also be given to the effect of non-employment noise, prior to and after the working period, which may contribute to noise, induced hearing loss. Listening to loud music, car racing, shooting of rifles, pistols or shotguns and the exposure to traffic noises, prior to arriving at work, during work and departing from work will all contribute to the total level of noise exposure the employee may experience in one day. This non employment noise is normally unknown but when combined with workplace noise may increase the level of exposure the employee has been subjected to during that day, thus increasing the risk of noise induced hearing loss.

5.13 Extra auditory effect

Ultra sound and infra sound levels have not been measured in this study and their effects are generally not well understood. Reports of annoyance and irritability have been reported (Schomer, 1989) along with biological and psychological effects and lowered performance (Garcia, 1994) which would not be desirable effects on police or emergency service's officers generally and especially so during a period of high speed driving.

5.14 Suggested further studies

It is recommended that a longitudinal study of police officers exposed to siren noise and associated hearing loss be conducted to evaluate the long term effect of frequent but short duration exposure to siren noise.
It is a further recommendation that if further research was to be conducted on vehicle siren noise, that it be carried out in normal driving situations, rather than artificial conditions.

5.15 Recommendations

5.15.1 Pre employment hearing tests

The South Australian Police do not currently conduct pre employment audiograms. Therefore a benchmark hearing level prior to exposure is not known. It is recommended that successful employment applicants be given an ideogram prior to employment.

5.15.2 Exit tests

On retirement or resignation from the police service, audiograms are not conducted. Several noise induced hearing loss claims have been lodged by retired or ex police service members alleging a hearing loss was at least partly resulting from police service related exposure to noise. The conducting of exit audiograms would be of assistance in assessing such claims as well as providing longitudinal data.

5.15.3 Hearing tests

Members of the police service with the exception of 10 members of the Water Response Section (SCUBA divers) are not subjected to any form of hearing test during their employment. It is a recommendation that hearing tests be considered every two years for all police officers as part of a hearing conversation program. Due to the logistics of conducting the hearing tests on 2,500 officers, the cost involved and the slow onset of hearing loss, a greater frequency of hearing tests is not recommended.

Chapter 6

CONCLUSIONS

6.1 Conclusions from data recorded

The results of this study indicated peak noise levels from sirens in excess of the 90 dB(A) standard. This is consistent with the two Health Hazard Evaluations and Technical Assistance Programs (NIOSH, 1990; NIOSH, 1994) that were conducted on American fire service vehicles. In both these studies, emergency runs in fire vehicles with the sirens operating recorded peak noise levels in excess of 90 dB(A). In addition, the South Australian Ambulance Service (1996) testing of sirens produced a peak noise intensity in excess of 90 dB(A) with the windows open and the vehicle stationary. The Western Australian State Emergency Service and Western Australian Police Service also conducted tests of sirens (Peter, 1995) and recorded peak noise levels in excess of 90 dB(A).

The Health Hazard Evaluations and Technical Assistance Programs (NIOSH, 1990 and NIOSH, 1994), the South Australian Ambulance Service (1996) and the Western Australian Emergency Service studies (Peter, 1995) produced results supportive of the conclusions of this study, that the sirens fitted to South Australian general duties patrol vehicles can create a noise intensity in excess of 90 dB(A).

The assumption of this study was that noise in excess of 90 dB(A) can cause noise induced hearing loss. Therefore the research conducted supports the conclusion that the sirens fitted to South Australian Police general duties patrol vehicles do produce sufficient noise intensity to cause hearing loss.

6.2 Conclusions from exposure data

The relatively long period of exposure (150 minutes) is not commonly exceeded. The data for the 1998 to 2001 period contained only three such exposures. However, considering the unknown susceptibility of the vehicle occupants to noise induced hearing loss and the Australian Standard of 85 dB(A) for hearing conservation, not the 90 dB(A) stated in the South Australian Occupational Health Safety and Welfare Act, 1986, which was the standard used in this study, there are grounds for concern for the hearing conservation of vehicle occupants exposed to the siren noise for periods of less than 150 minutes.

The results of this study also indicate that the closing of the vehicle windows is a successful strategy in reducing the intensity (dBA) of the sirens recorded from inside the vehicle.

REFERENCES

American College of Occupational and Environmental Medicine. (1998). Position statement-occupational noise induced hearing loss. (on line). www.aceom.org/paprguid/papers/nihl.html (2000).

Australian Hearing Services. (2002). Sensorineural hearing loss. (on line). www.australianhearingservices.com.au. (2003).

Axelsson, A., Borchgrevink, H., Hamernik, R., Hellstrom, P. & Salvi, R.J. (1999). Scientific bases of noise induced hearing loss. London. Thieme Medral Books.

Australian / New Zealand Standard 1269 (1998). Occupational noise management. Homebush. Australia Standards.

ACTU. (1987). Noise control at work. Australia. ACTU National Occupational Health and Safety Unit.

Bennett, B. (1981). The cost of industrial deafness compensation. Proceedings of a national seminar of industrial deafness. Armidale. University of New England.

Berger, E. (1985). Workers compensation for occupational hearing loss. Indianapolis. EARLog 15. Aearo.

Burns, W. (1973). Noise and man. Philadelphia, Lippincott.

CCH electronic OHS library. (CD-ROM). (2000). Australia. CCH Publishing.

Clark. W. & Bohne. B. (1999). Effect of periodic rest on hearing loss and cochlear damage following exposure to noise. Journal of Acoustic Society of America. 82. 1264-65.

Clark. W. & Bohne. B. (1999) Effect of noise on hearing. Journal of American Medical Association. 281. 1658-59.

Chan, E. & Ulfendahl, M. (1998). Acoustic trauma causes reversible stiffness changes in auditory sensory cells. Neuroscience. 83(3). 961-8.

Davis, R., Cheever, M., Krieg, E. & Erway, I. (1999). Quantitative measure of genetic differences in susceptibility to noise induced hearing loss in two strains of mice. Hearing Research. 134. 9-15.

Environmental Protection Authority (EPA). (1974). Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin for safety. U.S.A. Office of Noise Abatement and Control. Report 55\9-74-004.

Freeman Centre for Audiology. (1999). Noise induced hearing loss. (on line) www.centre for audiology.com/conditions/noise/html. (2000).

Garcia, J. (1994) Noise levels in Mexican industry. Proceedings of the 128th ASA. Austin Texas. USA.

Grant, P. (1999). Sensory neural hearing loss. (on line) www.medicineau.netau/clinical/ent/snhl.html. (2000).

Guigard, J. (1973). A basis for limiting noise exposure for hearing conservation. Aerospace medical research laboratory report AMRL- TR-73-90. Ohio. U.S.A. Wright-Patterson Air Force Base.

International Standards Organization. (ISO). (1997). Acoustic determination of occupational noise exposure and estimate of noise induced hearing impairment. International Standards Organization.

Irwin, J. (1997). Occupational noise induced hearing loss. Occupational Medicine. (London). 47 (5). 313-5.

Ishii, E. & Tablott, E. Race / ethnicity differences in the prevalence of noise induced hearing loss in a group of metal fabrication workers. Journal of Occupational Environmental Medicine. 40 (8), 661-666.

Johnson, M. (1997). Effect of noise and solvents on hearing and its impact on the association. (on line). www.aiha.org/abs97/7 noise.html. (1999).

Kunov, H & Dajani, H. (1997). Measurement of noise exposure from communication headsets. University of Toronto. (on line). www.aiha.org/abs97/7noise.html. (2001).

Lambeth, J.D. (1997). Noise exposure reduction in a saw mill through unusual engineering controls. (on line). www.aiha.org/abs97/7noise.html. (2001).

Lataye, R. & Campo, P. (1999). Applicability of the L(eq) as a damage risk criteria: an animal experiment. Journal of Acoustic Society of American. March. (3). 1621- 32.

Leigh, J & Morgan, G. (1990). Hearing loss in the NSW coal mining industry. Journal of Occupational Health and Safety. 6. 387-91.

Harrington, J., Gill, F. & Gardiner, K. (1990). Occupational health. Oxford, England. Blackwell Science Ltd.

Health and Safety Executive, (1981). Protection of hearing at work. London. H.M.S.O.

Mathews, J. (1986). Health and safety at work. Sydney. Pluto Press.

Mayo Foundation for Medical Research. (1998). Head noise. (on line). www.medline.com. (2000).

Mayo Foundation for Medical Research. (2001). Hearing loss. (on line). www.Mayo.com. (2002).

Miller, J., Raphael, V. & Altschuler, R. (1998). Interactive effects of aging with noise induced hearing loss. Scandinavian Audiological Supplement. 48. 53-61.

Mills, J., Dubno, J & Boettcher, F. (1998). Interaction of noise induced hearing loss and presbyacusis. Scandinavian Audiological Supplement. 48. 117 -22.

Mitchell, T. (1992). Noise control in Industry: Cost effective management opportunities for the mining industry. VIOSH Working paper. Number 1,. Victorian Institute of Occupational Safety and Health.

Morata, T. & Franks, J. (1997). Effect of noise and solvents on hearing and its impact on the practice of industrial hygiene. (on line). www.aiha.org/abs97/7noise.html. (2002).

Murphy, W. (1998). Noise exposure in combination with ototoxic agents. (on line). www.aiha.org/abs98/8hear.html. (2000).

Murray, N. E., & Reid, G. (1946). Temporary deafness due to gunfire. Journal of Laryngology. 61. 92.

National Occupational Health and Safety Commission. (2003). Claims – sound and pressure. (on line). www.nohsc.info.au.com/site. (2003)

National Institute of Health. (1990). Noise and hearing loss. NIHL consensus statement. January. 8(1). 1-24. (On line). www.regimedia._hearing_loss.html. (2000).

National Institute on Deafness and other Communication Disorders. (1998). Noise induced hearing loss fact sheet. (on line). www.nih.gov/nided/noise.html. (2000).

New South Wales Department of Agriculture. (1999). Noise induced hearing loss.(on line). www.aghealth-farmsafe.nsw.gov.au/7htm. (2001).

NIOSH (1972). Criteria for a recommended standard occupational exposure to noise. US Department of Health, Education and Welfare. Report HSM 73-11001 (on line). www.cdc.gov/niosh/hearloss.html. (1999).

NIOSH (1990). Evaluation of noise induced hearing loss for fire fighters. Health hazard evaluation and technical assistance report 86-138-2017. (on line). Available www.cdc.gov/niosh/hearloss.html. (1999).

NIOSH (1994). Evaluating the risk of noise induced hearing loss for fire fighters in a metropolitan area. Health hazard evaluation and technical assistance report 88- 0290-2466. (on line).

NIOSH (1995). Evaluating the risk of noise induced hearing loss for fire fighters. Health hazard evaluation and technical assistance report 89-0026-2495. Washington DC. NIOSH.

Northern Territory Work Health Authority (2002). Noise and hearing loss. Darwin, Northern Territory. Northern Territory Government.

Orgler, G. (1987). Guidelines for the conduct of an occupational hearing conservation program. Journal of Occupational Medicine. 29. 981-89.

Oskam, J. & Mitchell, J. (1999). Noise exposure in agriculture. Okalahoma Agricultural Health Department. (on line) www. Cdc.gov.ni.sd/docs2/as63000.html. (2002).

Peter, P.R. (1995). Western Australian State Emergency Service and the Western Australian Police Service noise testing on various emergency vehicles. Unpublished paper. Perth. Australia. Western Australian Police Service.

Quality Safety Management. (1996). Noise survey report of state mortuary for SA Police. Unpublished report. Quality Safety Management (Aust) Pty Ltd.

Reynold, J. (Ed) (1989). The extra pharmacopoiea. London. Pharmaceutical Press.

Robinson, D. (1971). Occupational hearing loss. London. Academic Press.

Rubel, E. W. (1994). Hair cell regeneration. Society for Neuroscience. (on line). www.sfn.org/briefings/hair_cell.html. (1999).

Sallustio, V., Porlalatini, P., Soleo, L. & Cassano, F. (1998). Auditory dysfunction in occupational noise exposed workers. Scandinavian Audiological Supplement. 48. 95-110.

Schomer, P. D. (1989). On a theoretical interpretation of the prevalence rate of noise induced annoyance in residential populations-High amplitude impulse noise environments. Journal of Acoustic Society of America. 86, No 2. 835-836

Scott-Brown. (1979). Diseases of the Ear, Nose and Throat. Editors. Ballantyne, J. & Groves, J. London. Butterworths.

Skegg, D. (1989). Dealing with sawmill noise. Australian Safety News. 60. No 1. 48.

South Australian Ambulance Service. (1996). Audible warning devices. Unpublished paper. Adelaide. South Australian Ambulance Service.

Standards Australia. (1998). Australian Standard 1269. Sydney. Australia

Taylor, P. (1965). Study of noise and hearing in jute weaving. Journal of American Statistical Association. 38. 113

Tempest, W. (Ed).(1976). Effects of intense infra sound on man. New York. Academic Press..

Tortora. G. & Anagnostakos. N. (1987). Principles of anatomy and physiology. New York. Harper Row.

Workcover SA. (2000). Noise – the cost. (on line).
www.workcover.com/training/noisecosts. (2000).

Workcover SA. (2003). 2001 2002 Workcover corporation statistical review. (on line). www.workcover.com.au. (2003).

WorkSafe Australia. (1990). Noise Management at Work. Control Guide. Australian Government Publishing.

Zackrisson, G. (1996). Brat pain. The New Scientist. (on line).
www.newscientist/answers/lwa254.html. (1999).