UniServices
Auckland UniServices Limited

POSTAL ADDRESS
c/- The University of Auckland
Private Bag 92019, Auckland, New Zealand

STREET ADDRESS
Level 10, UniServices House
70 Symonds Street, Auckland

TEL +64 9 373 7522
FAX +64 9 373 7412
WEB www.uniservices.co.nz

FINAL REPORT

Prepared for

Noise Induced Hearing Loss

Report prepared by Professor Peter R Thorne

On behalf of:
Auckland UniServices Ltd
Private Bag 92019
Auckland
New Zealand

For:
ACC
P O Box 242
WELLINGTON

Attn: John Wallart
Project Manager, Injury Prevention

Best practice in noise-induced hearing loss management and prevention

A review of literature, practices and policies for the New Zealand context

Report prepared for the Accident Compensation Corporation

This document was compiled by:

Mr Nicolas Reid, Research Assistant, Section of Audiology, University of Auckland

Nicolas Reid has a MSc in Psychology (Ergonomics) with first class honours from the University of Auckland and a research background in ergonomics. He has recently been working as an ergonomics consultant and occupational psychologist, responsible for developing and implementing health and safety policies in industry and managing "graduated-return-to-work" programmes for injured employees.

Under the direction of a steering group:

Professor Peter Thorne, Section of Audiology, School of Population Health, University of Auckland

Peter Thorne holds a personal chair in Audiology at the University of Auckland. He heads the Section of Audiology in the School of Population Health within the Faculty of Medical and Health Sciences. He has broad research interests in the field of hearing science but a predominant focus on the diagnosis and mechanisms of hearing loss, particularly that arising from excessive noise exposure. He is also involved with the National Foundation for the Deaf, a national community organisation concerned with increasing awareness of deafness and advocating for improved services for the hearing-impaired, and is the current President of the NFD Council.

Associate Professor Shanthi Ameratunga, Injury Prevention Research Centre, University of Auckland

Shanthi Ameratunga is an injury epidemiologist with dual qualifications in public health medicine and paediatrics. She trained at the Johns Hopkins School of Public Health and completed her PhD in injury-related disability at the University of Auckland. She has a particular interest in the broader determinants of injury and finding solutions that could prevent the occurrence as well as disabling consequences of hazardous events.

Mr Warwick Williams, National Acoustics Laboratories, NSW, Australia

Warwick Williams is a Senior Research Engineer at the National Acoustic Laboratories, Chatswood, NSW, Australia and has research interests specifically in the areas of noise exposure and the prevention of occupational hearing loss. He is currently chairman of the Standards Australia committee "AV/003 Acoustics – Human effects" responsible for the combined "Australian/New Zealand Standard AS/VZS 1269: 2005 Occupational noise management".

Associate Professor Suzanne Purdy, Speech and Language Therapy, Department of Psychology, University of Auckland

Suzanne Purdy has a background in psychology [MSc(Auck)] and audiology [DipAud(Melb), PhD(Iowa)]. She is an Associate Professor and currently heads the Discipline of Speech Science in the Psychology Department at the University of Auckland. She is also a Research Associate of National Acoustic Laboratories, Sydney, Australia and an Honorary Associate of Macquarie University Linguistics Department, Sydney, Australia. Dr Purdy's research interests include auditory processing disorders, auditory evoked potentials, cochlear implants and hearing loss prevention.

Dr George Dodd, Acoustics Research Centre, University of Auckland

George Dodd is a Senior Lecturer in Acoustics at the Acoustics Research Centre, School of Architecture and Planning. Having graduated in mathematics he subsequently studied Physics and Acoustics and as a mature student completed a Diploma in Audiology at the University of Southampton. His current research interests include all matters to do with noise control and subjective acoustics. Dr Dodd has served as a board member of the International Commission on Acoustics and is currently NZ representative on ISO for acoustics standards.

Table of contents

Preface

This review of literature was conducted for the Accident Compensation Corporation to assist in the development of immediate and long-term interventions for reducing the incidence of noise-induced hearing loss as well as directing potential future research.

There is a very extensive body of literature on noise-induced hearing loss (NIHL) including the clinical manifestations, pathology and mechanisms and the relationship of the hearing loss to the physical parameters of the noise. However, the body of information regarding the practical avoidance of noise-induced hearing loss in the population is more limited. Any attempt to review and evaluate national and international best practice for interventions to reduce noise-induced hearing loss is thus confounded by the fact that no real established and validated best practices appear to exist.

Many approaches are piecemeal, targeting a very specific industry location or population, and almost always being based upon a restrictively short timeframe in regards to the years of exposure that typically induce noise-induced hearing loss. Follow up assessments to assess the permanence of intervention outcomes, even six months or a year later, are noticeably absent.

The majority of attempts for interventions are unpublished, unverified and frequently unevaluated, even by those that developed and delivered the intervention. Consequently, it is almost impossible to evaluate the effectiveness of most interventions, particularly as examples of even the structure, nature and delivery methods are conspicuously absent from most citations of such work.

Furthermore most interventions do not in fact attempt to reduce noise-induced hearing loss, but rather measure some more immediate and quantifiable indicator that is assumed to be related to hearing preservation. For example, a number of studies use either employee self-report of hazard knowledge and safe noise behaviours or hearing protector usage rates as their dependent variable. Obviously the validity and efficacy of such studies pivot entirely on the assumptions that increased risk knowledge or hearing protector usage will result in lower rates of noise-induced hearing loss: assumptions that some research indicates may not always be reasonable. Likewise several pieces of research use temporary noise-induced hearing loss (temporary threshold shift) as an analogue for permanent noise-induced hearing loss, based on the generally unverified assumption that temporary threshold shift directly precedes permanent threshold shift.

Theory abounds in this area, some of which is well validated in research and practice, whereas others are novel and emergent. All are hindered by substantial ethical considerations for the experimentation on hearing loss in humans, either in the laboratory or in the field.

Thus to establish the best practice for noise-induced hearing loss interventions requires a constructive approach. Where it is not possible for any one study, report, theory or experience to provide the ‘gold standard’ for such a complex and interactive phenomenon as is the prevention of noise-induced hearing loss, one must catalogue and evaluate all available information on the topic, and from this synthesis extract the clear trends and factors that lead to successful reduction in incidence and extent.

While there are many individual parts to the problem of noise-induced hearing loss and the strategies to reduce it, to view the sum of these parts in context allows us a greater view of the issue than all of the parts viewed in isolation.

Introduction

Hearing loss from excessive or loud sound exposure has been identified as an occupational hazard since at least the time of antiquity. For example, Pliny the Elder (29-79AD), a Roman naturalist and historian writing during the early first century, noted that noise was a workplace risk for fishermen of the upper Nile. A high rate of deafness among these workers was attributed to the constant noise produced by the rapids and waterfalls that the fishermen worked and lived amongst (Rosen, 1974).

Noise-induced hearing loss was seen in the Middle Ages among miners and bell ringers, who were known to become deaf in their later years as a result of their work (WHO, 1997).

During the Victorian era, the affliction of noise-induced hearing loss was known as blacksmiths' or boilermakers' deafness (E. E. Holt, 1882). During this period the Industrial Revolution introduced mechanisation and mechanically powered equipment to factories throughout the developed world, making high levels of noise exposure a daily reality for much of the working class.

While originally seen as an unavoidable consequence of employment or even a natural form of protection from further noise (Weston & Adams, 1932), noise-induced hearing loss is now viewed as both undesirable and, to a considerable extent, preventable.

However, despite the knowledge of the primary cause and effect relationship of occupational deafness for over two millennia, noise-induced hearing loss still exists and is very much a modern problem.

Purpose, scope and objectives

The purpose of this document is to review the current body of knowledge surrounding noise-induced hearing loss in order to identify current best practice for reducing the incidence, extent and personal impact of this problem. Published literature and, scientific information and data from academic sources were reviewed, as well as informal information, practices and positions from industry, professionals and the public.

The need for this work has resulted from concern that the incidence and cost of noise-induced hearing loss in New Zealand is apparently on the increase.

It is intended that this document provide a reference point for those that make recommendations regarding a strategy to reduce noise-induced hearing loss in the community. It is not intended to recommend a solution alone, but rather to be a starting point where best practices can be identified and strategies developed by the ACC Strategy Group. It is not intended to inform ACC policy decisions.

The document is structured in the following way. The first section provides an overview of noise-induced hearing loss, including its pathology and the clinical picture, while the second attempts to codify the incidence rate and economic costs of this disorder both in New Zealand and internationally.

The third section describes the current legislation and laws surrounding occupational noise exposure in New Zealand, and compares these to international standards and criteria. Here the conventions for describing sound levels and limiting occupational exposure are also identified.

The fourth section describes and evaluates the historical measures undertaken to combat noise-induced hearing loss, the hearing conservation program, and presents and evaluates an alternate paradigm.

The fifth section covers the design, use and efficacy of personal hearing protection devices, the key component of most common noise reduction efforts. In this section key physical and psychological barriers to protector usage are also discussed.

The sixth section identifies factors that may compound or potentiate noise-induced hearing loss in the industrial setting, while the seventh outlines issues with certain occupations and other groups that have been identified as at a higher risk of noise-induced hearing loss.

Section eight deals with recreational noise and the entertainment industry, as well as other non-occupational sources of sound exposure that can also cause noise-induced hearing loss.

Section nine is a summary of this document with conclusions and an identification of further research needs. This is followed by an appendix of noise control methods and international noise standards.

Research methodology

Data for this report was gathered from a wide variety of academic literature as well as unpublished and private documents, websites and discussion with relevant specialists, individuals and organisations.

To identify and access scholarly articles online databases such as Ovid Medline and Psychinfo were utilised. A variety of search terms and combinations were used such as ‘noise’, ‘sound’, ‘hearing loss’, ‘deafness’, ‘noise-induced hearing loss’, ‘occupational disease’, ‘hearing conservation’, ‘hearing protectors’. Articles on more specific topics within the realm of noise-induced hearing loss were found using search terms relevant to each topic. In addition recent issues of key journals related to hearing, noise and occupational medicine were monitored for new relevant publications.

A significant number of further unpublished reports and other such ‘grey literature’ documents were gained from the library at the National Acoustics Laboratory in Sydney and from the private collections of the staff there. This was also a source of works in progress and yet-to-be-published experimental results that represented the state of the art.

Noise and hearing loss specialists within the University of Auckland and at the University of Otago were contacted directly and provided a source of opinion, references, articles, data and unpublished reports.

ACC provided access to their internal library and data files on noise-induced hearing loss claim rates and costs, in addition to discussion with ACC staff who deal directly with hearing loss claims.

Internet web search engines were used to locate the websites of a number of groups and organisations as noted below. This was a key source of basic information such as standards, codes of best practice, statutes and guidelines, as well as a representation of the views and practices of the organisations. Representatives of the Department of Health and the Ministry of Education were also contacted directly.

In addition to these organisations, discussion was held with an informal group composed of Auckland acoustic engineers and members of related industries and their feedback and opinions were recorded. Similarly a presentation of preliminary findings was given to the ACC noise-induced hearing loss strategy group and their feedback was incorporated.

Air New Zealand was visited as an example of a high noise risk industrial stakeholder and components of the organisation’s hearing conservation and audiometry program was observed in practice.

Stakeholders and industry groups

Part of the brief for this document was to include the views and practices of relevant ‘stakeholders’ and industry and professional groups. A list of national and international organisations that were contacted as part of this project is included at the end of this section.

The organisations’ websites were scanned for relevant pages and documents, while contact personnel (usually a communications officer or secretary) were identified and contacted via telephone, email or post to request further information and a statement reflecting that organisation’s attitude toward noise-induced hearing loss and its prevention.

Most official and governmental organisations had a short written policy statement on noise-induced hearing loss while a few also provided academic papers or research results that were incorporated into the body of this document.

Societies and foundations representing hearing impaired and deaf persons or professionals in the industry typically provided a policy or statement on noise-induced hearing loss also. However, this was often delivered as a verbal or email statement from a representative reflecting the general position and opinion of the organisation or its members, rather than being a specific written policy or guiding principle.

Whilst organisations contacted indicated a concern about noise-induced hearing loss and the need to reduce its incidence, there was typically little information regarding what else should be done or specifically why current attempts at controlling the issue were ineffective, or even what the organisations' current methods actually are. Thus generally these statements were little more than a declaration of the existence of a noise-induced hearing loss problem that was of concern for that organisation.

Data and reports on noise-induced hearing loss were recovered from the Accident Compensation Corporation (ACC) and Department of Labour Occupational Safety and Health Service (OSH) in New Zealand, the National Institute of Occupational Safety and Health (NIOSH) in USA and the National Acoustics Laboratory (NAL) in Australia.

New Zealand based organisations contacted:

ACC – Accident Compensation Corporation
www.acc.co.nz

OSH – Department of Labour Occupational Safety and Health service
www.osh.govt.nz

NOHSAC – National Health and Safety Advisory Committee
www.nohsac.govt.nz

Hearing Association Inc New Zealand
www.hearing.org.nz

New Zealand Audiological Society
www.audiology.org.nz

National Foundation for the Deaf
www.nfd.org.nz

The New Zealand Society of Otolaryngology, Head and Neck Surgery
www.orl.org.nz

Australia:

National Occupational Health and Safety Commission (Now called the Australian Safety and Compensation Council)
www.nohsc.gov.au

State work cover and health and safety organisations
http://www.nohsc.gov.au/OtherRelatedSites/

Australian Hearing
http://www.hearing.com.au/

National Acoustics Laboratory
www.nal.gov.au

Australian Deafness Forum
http://www.deafnessforum.org.au

Australian Association of the Deaf, Inc.
http://www.aad.org.au/

SHHH Australia (Self Help for Hard of Hearing people)
http://www.shhhaust.org/

United States:

NIOSH –National Institute for Occupational Safety and Health
http://www.cdc.gov/niosh/noisepg.html

OSHA -Occupational Safety and Health Administration, Dept. of Labor
www.osha-slc.gov/SLTC/noisehearingconservation/index.html

MSHA – Mine Safety and Health Administration, Dept. of Labor
http://www.msha.gov/1999noise/noise.htm

Labourers Health and Safety Fund of North America
http://www.lhsfna.org/

National Institute on Deafness and other Communication Disorders *http://www.nidcd.nih.gov/health/hearing/index.asp*

Canada:

Canadian [National] Centre for Occupational Health and Safety
http://www.ccohs.ca/

CanOSH government information website
http://www.canoshweb.org/en/about.html

United Kingdom:

HSE -Health and Safety Executive/Commission
http://www.hse.gov.uk/index.htm

Royal National Institute for the Deaf
http://www.rnid.org.uk/

European Union:

European Agency for Safety and Health at Work
http://ew2005.osha.eu.int/

International Organisations:

ISO, the International Standards Organisation
http://www.iso.org/iso/en/ISOOnline.frontpage

WHO- World Health Organisation
http://www.who.int/topics/noise/en/

What is noise-induced hearing loss?

Clinically, noise-induced hearing loss (NIHL) is a permanent form of hearing loss that occurs because of exposure to intense sound. After a single exposure there are initial temporary changes in hearing that are reversible, but if the sound is intense enough or repeated, permanent irreversible hearing loss occurs, which is referred to as a permanent threshold shift (Dobie, 2001). In short, noise-induced hearing loss is the deafness that occurs when the ears are exposed to sounds in excess of what they can handle.

Sound, noise and hearing

From a physical standpoint sound is composed of pressure waves passing through a medium and can vary in amplitude/intensity (wave height), frequency (number of waves/second) and complexity. These three properties of the sound waveform translate to the perceptual sound characteristics of loudness, pitch and timbre respectively. Psychologists define ‘sound’ as pressure waves travelling through a medium that carry some sort of information, signal or communication. On the other hand ‘noise’ is defined as unwanted sound, sound that doesn’t carry useful information and is generally considered undesirable or unpleasant.

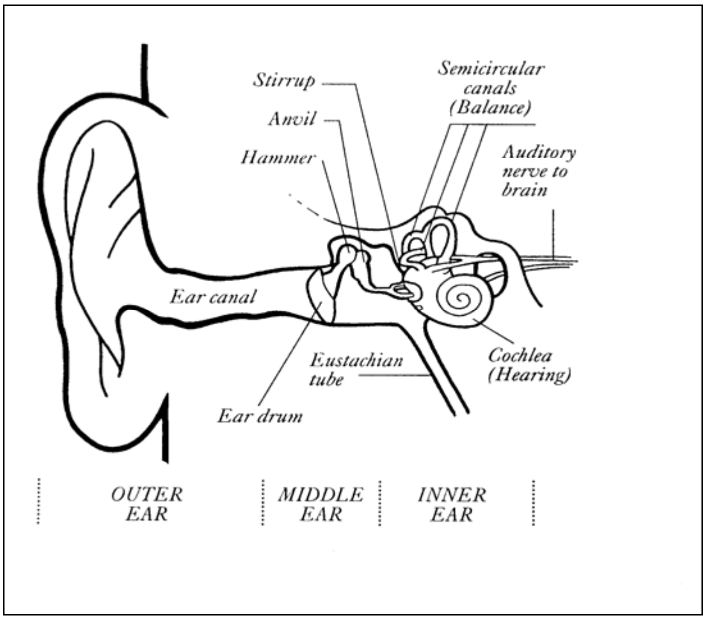
However in terms of the physics of sound waves and energy there is no such distinction; both sound and noise are analogous (Dobie, 2001). It is the physicist’s definition of noise that is relevant to noise-induced hearing loss, as any sound can contribute to the disorder regardless of its source or whether it is perceived as desirable or not. In terms of hearing loss, mechanical noise, music, machinery and speech are all potentially as risky as each other. The intensity, duration and cumulative exposure to a sound determine its pathological impact upon the ear. While sounds from certain sources tend to be longer and more intense than others, if any sound/noise is intense enough or long enough it can cause damage to the ears resulting in a loss of hearing ability.

Yet the psychological distinction between noise and sound must be taken into account when considering noise-induced hearing loss. Despite the fact that the two relate to the same physical phenomenon and generally affect the ear in the same way, the difference in attitude that people create between noise and sound can influence their hearing safety and noise-avoidance behaviours. For example, studies have shown that people consider loud music to be ‘good’ sound, where more volume adds to the enjoyment (Serra et al., 2005). This is in contrast to say industrial noise, which is generally seen as a ‘bad’ sound where more volume is undesirable (eg Crandell et al., 2004, Ologe et al., 2005).

Hearing is the perceptual response by the brain to sound waves that are received by the ears. The ear consists of three main divisions as can be seen in Figure 1.

The external ear serves to funnel sound waves into the internal parts of the ear, and also provides a limited amount of assistance to spatial localisation of sounds due to its shape. The collected waves travel along the ear canal through to the tympanic membrane (commonly known as the eardrum) causing it to vibrate. The middle ear is composed of structures that transfer the vibration of the eardrum into fluid movement in the adjacent sensory organ in the inner ear called the cochlea. Within the cochlea there is a network of fine sensory hair cells that are moved accordingly and it is this motion that causes the hair cells to create impulses in the auditory or hearing nerve. This translates the incoming pressure changes into neural signals, which are then sent via brainstem auditory centres to the primary auditory centres in the cortex of the brain. It is the hair cells that are affected by loud sound exposure leading to noise-induced hearing loss.

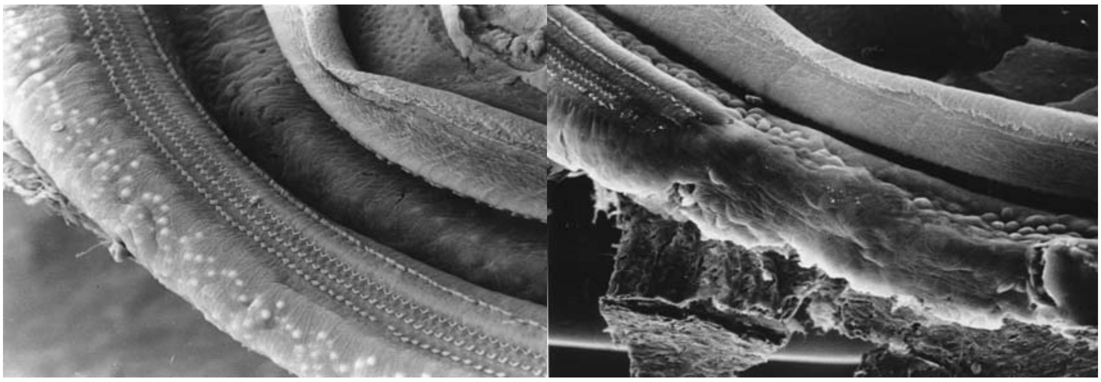
Figure 1: Divisions and mechanisms of the ear (Williams, 2005a)


Stirrup
Semicircular canals (Balance)
Anvil
Auditory nerve to brain
Hammer
Ear canal
Eustachian tube
Cochlea (Hearing)
Ear drum
OUTER EAR
MIDDLE EAR
INNER EAR

How does noise-induced hearing loss occur?

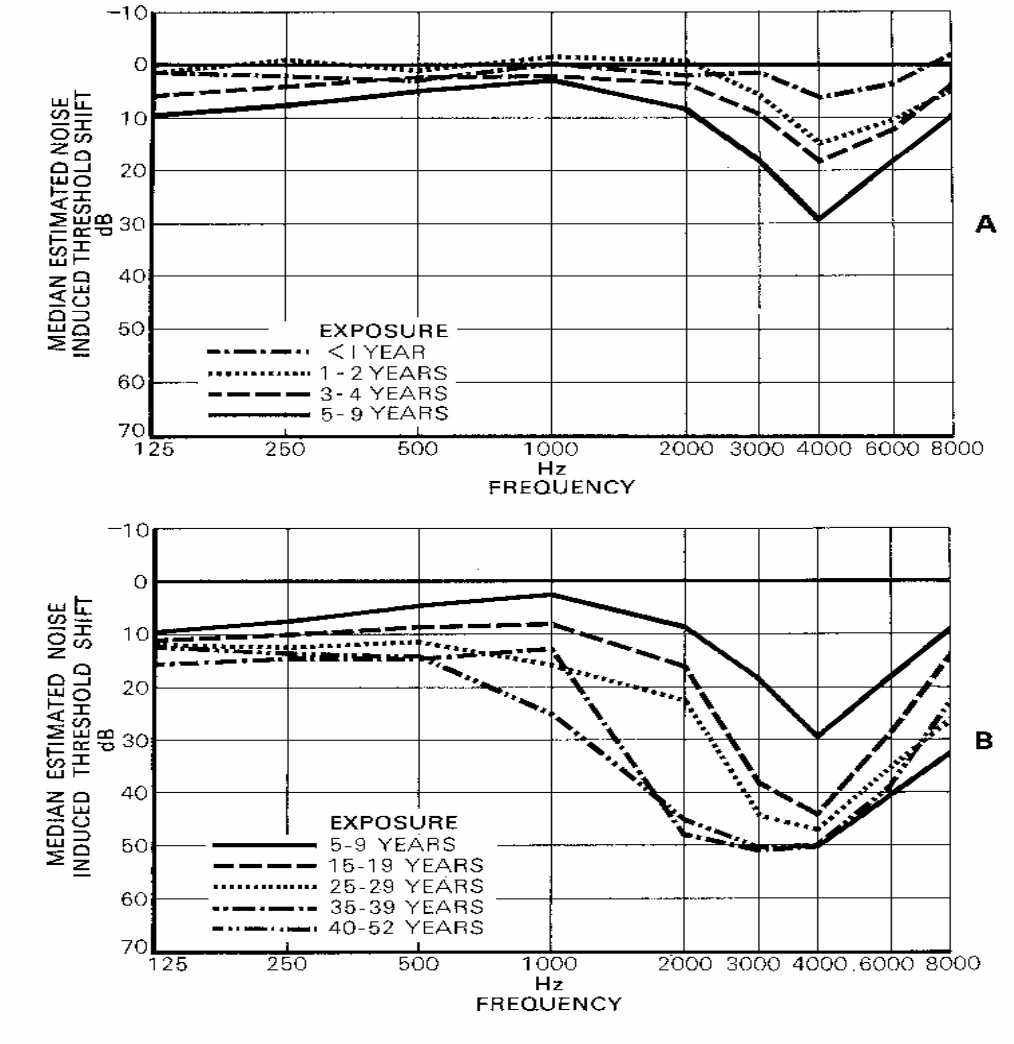
Hearing loss from loud sound exposure occurs because of damage to structures in the cochlea. The predominant damage occurs to the hair cells and their associated nerves leading to the hearing loss. Hair cells along the cochlea respond to different frequencies of sound. That is to say they map directly to the frequencies that humans can hear, with certain cells responding to low frequencies (low pitch sounds), others to high frequencies or high pitch sounds. When hair cells are repeatedly exposed to excessive stimulation from intense sound, they become fatigued and fail to respond properly. This manifests as a temporary hearing loss or 'dullness' of hearing after noise exposure (known as temporary threshold shift or TTS), which recovers within 16-24hrs of the exposure. If the excessive stimulation is repeated or sustained for long enough the hair cells will become permanently damaged or die and the threshold shift becomes permanently established. This type of permanent damage is visible in Figure 2. In the image on the left the three rows of outer hair cells and the additional row of inner hair cells are intact and clearly visible in a healthy cochlea. In the image on the right of a noise-damaged cochlea, almost all of the hair cells have been destroyed. Hair cells cannot regenerate and they currently cannot be repaired or replaced by treatments, meaning that noise-induced hearing loss is permanent.

Figure 2: Healthy (left) and noise damaged (right) cochlear hair cells



Because the hair cells are specialised for frequency, the frequency of the loud sound exposure influences which cells become damaged, which in turn influences the frequencies of the hearing loss. Damage from noise in occupational settings mostly occurs to those cells that detect higher frequencies of sound. Thus the characteristic noise-induced hearing loss is a loss of high frequency hearing particularly between 3 and 6 kHz (Dobie, 2001).

Figure 3: Audiograms showing onset and progression of noise-induced hearing loss: First a 'notch' appears in the 3-6kHz region, then the notch broadens over time with continued exposure (From Burns, 1968,).

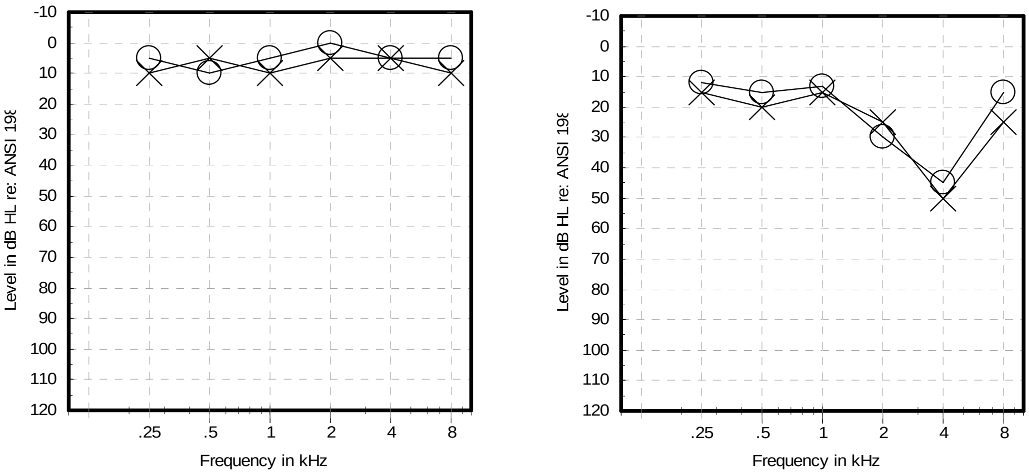


Audiometry and the measurement of hearing loss

Hearing ability can be evaluated by a number of behavioural tests including testing of hearing thresholds at sounds of different frequencies. The hearing thresholds (the intensity of the softest sound that can be detected) can be graphically displayed in an audiogram, which charts the threshold at each hearing frequency (Figures 3 and 4). Noise-induced hearing loss begins with an elevation in hearing threshold around the 3-6kHz region of the audible spectrum leading to a 'notch' in the audiogram which spreads across the other frequencies of human hearing if sound exposure is maintained. This progression can be seen in

Figure 3, while an example of an audiogram of normal hearing is compared to an audiogram showing characteristic patterns of noise-induced hearing loss in Figure 4 below.

Figure 4: Audiograms showing normal hearing (left) and slightly reduced hearing with characteristic notch of noise-induced hearing loss (right)



Evoked otoacoustic emissions

Otoacoustic emissions (OAEs) are sounds originating in the inner ear that can be measured in the ear canal after the ear has been stimulated by sound. The OAE is generated by healthy outer hair cells in the inner ear and if these cells are not functioning the OAE is absent or reduced in amplitude Kemp, 2002). OAEs can be measured very easily and are used clinically as a quantitative index of inner ear function (Kemp, 2002; Shafer et al., 2003). There are different types of emission which are categorised by the type of sound stimulus. These are the transient OAE (TEOAE) which are produced in response to an acoustic click or pure tone and the Distortion Product OAE (DPOAE) which occurs in response to two simultaneously presented pure tones.

There has been a lot of interest in using OAE as an objective measure of damage from noise exposure (Attias et al., 1998; Fraenkel et al., 2003), particularly early damage. Research in Australia by LePage and associates suggests that permanent hearing damage from chronic (repeated) noise exposure occurs in two phases, a “pre-clinical” phase where damage is done but no hearing loss results, followed by a clinical phase where a significant permanent change in hearing threshold is detectable (see AS/NZS 1269.4:2005 Appendix H). Standard audiometric monitoring can only identify hearing damage from the later clinical phase, however click-evoked otoacoustic emissions measurably decline in the pre-clinical phase (Chan, Wong, & McPherson, 2004). As a result a procedure has been developed to test these emissions to give an approximate measure of the risk for hearing deficit before any hearing loss has occurred (LePage & Murray, 1993). This test procedure has not been validated.

Unfortunately, as yet these tests cannot accurately determine the threshold of hearing and are unable to consistently differentiate between slight, moderate or severe levels of hearing loss. Because they are likely to be absent in individuals who already have significant hearing loss they may be of little use for identification and documentation of hearing loss in the majority of occupationally noise-exposed populations that exhibit existing permanent threshold shifts. Likewise OAEs may not effective for informing strategies to conserve and manage the hearing of already affected individuals, except they may provide information about changes in hearing at unaffected frequencies in the audiogram. However otoacoustic emissions testing does have the potential to identify auditory damage before any measurable hearing loss has occurred, and therefore could be a useful tool in parallel to threshold audiometry to identify individuals who are especially prone to, or at imminent risk of developing hearing loss (eg Zhang et al., 2004). They are also an objective measurement of inner ear function and thus can be useful to verify the hearing loss if a person is suspected of malingering. Otoacoustic emissions testing takes approximately four minutes per subject, and unlike a standard audiogram test it require only conditions of relative quiet (<45 dBA) rather than a closely controlled acoustic environment or sound booth. Additionally the process is low cost, relatively simple and testers can be easily trained, so there are few practical barriers to the inclusion of otoacoustic emissions testing in hearing conservation and noise management programs.

The use of OAE testing in management of NIHL is an area that needs further research.

Effects of noise-induced hearing loss

The result of excessive noise exposure is typically a binaural (in both ears) sensorineural hearing loss caused by damage to the sensory system that results in a substantial hearing handicap for the individual (Alberti, 1987; Neuberger et al., 1992). In addition to a loss of hearing in the high frequencies a person will show a loss of ability to discriminate (separate) speech sounds and may also have an intolerance to loud sounds. Commonly a person with noise-induced hearing loss will complain of tinnitus which is the phantom perception of sound in the absence of any physical sound (Baguley, 2002). For many in the early stages of noise-induced hearing loss the tinnitus is the most distressing symptom (Axelsson, 1985; Neuberger et al., 1992). Naturally such a handicap places a significant burden on an individual physically and psychologically, but hearing loss also has substantial social and interpersonal consequences.

The consequential handicaps that arise from the hearing loss include an inability to hear soft sounds, severe difficulty in hearing in the presence of background noise and a loss of clarity of sounds, particularly in the high frequency portion of the speech spectrum that creates great communication difficulties (Hetu & Getty, 2001).

Not only does this greatly influence the quality of the afflicted individual's life through limiting interpersonal communication, entertainment and employment opportunities, but also translates into a handicap for the individual's immediate family and friends (Williams, 2005a).

The negative consequences of uncorrected hearing loss have been well studied and are reviewed by Arlinger (2003). People have problems recognizing speech, especially in difficult listening environments. Uncorrected hearing loss results in poorer quality of life, social isolation, and a feeling of being excluded that leads to a higher prevalence of symptoms of depression. Hearing impaired individuals can experience fatigue from the effort of having to listen closely. They can lose self-esteem through a fear of being characterised as 'deaf' or 'handicapped', or through feeling like a burden to their family or loved ones (Jubb-Toohey, 1994). The concern that one may be missing out on important verbal communications can cause stress, particularly in environments with high background noise, and a tendency to avoid situations where one may have trouble hearing can lead to a feeling of isolation and reduced social contact (Jubb-Toohey, 1994).

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

From an employment perspective noise-induced hearing loss can significantly reduce an individual's ability to undertake job tasks that require the use of auditory signals or verbal communication (eg aviation, http://www.caa.govt.nz), placing limits on the kinds of employment an affected individual can take and reducing their utility in others. Within the workplace a partially deafened individual could be perceived and labelled as incompetent, inattentive or 'difficult' due to their communication handicap, causing social isolation in the workplace and impacting upon team work and group productivity. This could be especially so in the earlier stages of hearing loss where neither individuals nor their peers have yet realised that they have reduced hearing ability. In the absence of an identifiable external handicap, communication difficulties may be attributed to the individual's personality or intellect (Westbrook, Hogan, Pennay, & Legge, 1992). Individuals can adapt or acclimatise their social and work habits 'subconsciously' for some time and substantial hearing losses will largely go unidentified due to this behavioural adjustment, while friends and colleagues can attribute the effects of the noise-induced hearing loss to behavioural problems.

From an organisational perspective these problems can manifest as high levels of lateness and absenteeism from affected workers, increased turnover and reduced tenure of staff, reduced job satisfaction from the affected worker or their peers, and lower productivity from teams that include deafened individuals. The fact that noise-induced hearing loss is most pronounced in older age could prevent some noisy industries from retaining highly skilled and experienced staff who have been forced into early retirement due to hearing loss.

Overall, hearing loss (noise-induced hearing loss) is a disorder that can have greatly debilitating psychological, social and economic outcomes for the individual and those around them. In a world made for those that can hear properly, deafness can strongly impact upon all facets of an individual's life.

Noise-induced hearing loss:
What is the nature of the problem?

International estimates of the scale of the problem

In 1999 Leigh calculated a worldwide incidence (new cases) of noise-induced hearing loss of 1,628,000 cases per annum (Leigh, Macaskill, Kuosma, & Mandryk, 1999). However, because of the incremental nature of the disability it is not generally possible to attribute the onset of NIHL to one specific point in time, which makes cataloguing onset of the disorder difficult. Indeed it is suggested that affected individuals may experience significant impact upon their lives for several years before they are considered to be suffering from noise-induced hearing loss.

According to the [US] National Institute on Deafness and Other Communication Disorders, in 1999, 28 million Americans (or 10% of the population), were hard of hearing, and of these cases approximately one third (3-4% of total population) were primarily the result of noise exposure (National Institute on Deafness and Other Communication Disorders, 2005). Furthermore it was estimated that a further 30 million Americans were exposed to injurious noise levels on a daily basis. Together these statistics reveal that around 13-14% of the total population of the USA, some 39-42 million people, either currently experience noise-induced hearing loss or are at a high risk of developing it (whether occupationally caused or not) (National Institute on Deafness and Other Communication Disorders, 2005).

A review of academic sources conducted by Crandell et al. (2004) puts the estimate slightly higher, at 11 million Americans currently exhibiting some degree of permanent noise-induced hearing loss and 40 million in at-risk occupations. Additionally they identify that 50 million Americans are at risk of noise-induced hearing loss due to their regular use of firearms (Crandell, Mills, & Gauthier, 2004).

European data on noise induced hearing loss and extent of noise exposure in the workplace is provided by The European Agency for Safety and Health at Work (European Agency on Safety and Health at Work, 2005). This supports the European Risk Observatory which provides an overview of health in the workplace in European member states, a description of the trends and underlying factors. The methodology varies among the different countries but generally relies on self-reports and questionnaire surveys. These data are summarised here and more detail can be obtained from the Agency's website.

Noise exposure is deemed to be a continuing risk within European countries. Data collected during the period 1990 to 2000 showed that over a quarter of the European workforce (29%) was exposed at least a quarter of the working time to high level noise; approximately 20% of workers were exposed half or more of their working time to noise loud enough that they had to raise their voice to talk to other people; and around 10% of the workers are exposed (almost) permanently to high-level noise. Countries in the survey reported an increasing number or percentage of people exposed to noise in the workplace over this period or beyond although there was a 10% decline in the percentage of the workforce in Germany that reported being exposed to noise between 1992 and 1999 (European Agency on Safety and Health at Work, 2005).

According to the European Union occupational diseases statistics, in 2000, about 7% of European workers consider that their work affects their health in form of hearing disorders. Overall workers report more hearing problems due to their work since 1995. According to the European Survey on Working Conditions (Paoli and Merllié, 2001), the proportion of workers experiencing loud noise in the workplace had increased and workers in all occupations showed more hearing problems in 2000 (7%) than in 1995 (6%), except the professionals, clerks, skilled agriculture workers and armed forces, which reported a decrease. However, the situation does differ between countries as described in the following from individual country reports (European Agency on Safety and Health at Work, 2005).

A survey of workers in the Czech Republic showed that approximately 11.4% of workers reported hearing problems. The number had decreased by about 40% between 2000 and 2002 but in 2003 had increased to be higher than that reported in 1996.

The number of recognised cases of occupational deafness in Germany has stabilised since 1995 but the severity of the hearing loss is decreasing. In 1999, 4% of the workers reported that they have hearing problems and it is highest in workers in older workers (about 7% of the workers above 45 years of age reported hearing problems). The highest incidence of noise induced hearing loss was found among metalworkers, mechanics and construction workers.

The number of notification of noise related hearing loss in Denmark has steadily decreased since 1993 although the authors report that the large fall in the period up to 2000 cannot directly be related to noise reducing efforts as new restrictions on the obsolescence of notifications had been introduced in this time and would have substantially reduced the number of notifications. Noise exposure rates were regarded as a significant problem and were higher for workers in manufacturing, construction and agriculture. Interestingly the authors reported an increasing trend for notifications among schoolteachers and day care workers.

The number of reported cases of noise-induced hearing loss in Finland has decreased substantially from about 2000 cases in 1987 to 821 in 2002. The reason for the substantial decline over this period was not discussed.

The number of compensated cases of noise-induced hearing losses in France has decreased since 1988 and the incidence of hearing loss among workers in Italy is reported to be decreasing across sectors except for the construction sector where it has increased between 1985 and 1999. These data are based on survey and self-reports and detailed statistics were not available. In contrast, the number of cases of noise-induced hearing loss in the Netherlands is increasing.

Estimates of the prevalence of noise-induced hearing loss in the UK varies from 509,000 (Palmer et al., 2001, Medical Research Council (MRC) survey in 1997-98), to 81 000 according to the Self-reported Work-related Illness (SWI) survey conducted by the Health and Safety Executive in 2003-2004 or 170,000 people between 35 and 64 years of age in a more recent survey. Interestingly, in the latter study about 266,000 men and 84,000 women in this age band have persistent tinnitus that can be attributed to noise. The number of cases of disablement benefit for noise-induced hearing loss in the UK has changed little since the late 1990's, following a long-term decline since at least the 1980s.

According to the UK Health and Safety Executive (HSE) over 2 million workers are regularly exposed to loud noise at work and about 1.7 million workers are exposed above levels that are considered safe. In 2001, approximately a third of men and 11% of women had worked in a noisy job for a year or longer, with 16% of men and 3% of women reporting more than 10 years of such exposure. Six (6%) of men and 3% of women reported that work tasks left them with ringing in their ears or a temporary feeling of deafness at least every week, and 3% of men and 2% of women said this sensation was daily. Despite the apparent decline in claims hearing loss caused by work-related noise exposure to noise at work continues to be a significant occupational problem in the UK.

In Australia in 2001/2002, there were 4510 compensation claims for noise-induced deafness with an average cost of $6711 per claim, representing approximately $30 million of noise related compensation over the same period. However it is estimated that compensation costs may be only 10% or less of the total costs of noise in Australia. (NOHSAC, 2004). Up to one million Australian workers (12% of the workforce) are expected to be exposed to hazardous noise, (Waugh, 1986).

Based on the more stringent WHO definition for substantial or significant hearing loss (average of 41 dB loss for 500, 1000, 2000 and 4000 Hz), an estimated one sixth (16%) of hearing loss worldwide is attributable to occupational noise exposure alone (WHO, 2002). This figure of 16% is corroborated by an American assessment of the contribution of occupational noise exposure to total deafness rates, giving a range from 7% in the most developed nations to 21% in developing regions (Nelson, Nelson, Cocha-Barrientos, & Fingerhut, 2005). Given current estimates of total deafness rates, this indicates at least 90 million persons worldwide are currently suffering substantial hearing loss as a result of occupational noise exposure.

To broadly extrapolate all of these results to the global population, depending on the criteria used, somewhere in the region of 180 million persons worldwide could currently be affected by at least some degree of noise-induced hearing loss. Furthermore, if the NOHSAC criteria are expanded to the global population, more than 600 million more could be at risk of developing it.

Estimates of prevalence and incidence in New Zealand

Likewise in New Zealand it is difficult to identify exactly how many people are affected by noise-induced hearing loss, and how many are at risk.

On average, eleven more New Zealanders receive compensation for noise-induced hearing loss every day.

From 1992 to 1998, there were 2,411 validated cases (95% male) of noise-induced hearing loss reported to the Notifiable Occupational Diseases System (NODS), a voluntary register maintained by the Occupational Health and Safety Service (Driscoll et al., 2004). From 1998 to 2000 there were a further 709 notifications (Statistics New Zealand, 2000). While these voluntary reports cannot be taken as any reliable indication of the actual prevalence of occupational noise-induced hearing loss, they do place noise-induced hearing loss as the second most *voluntarily* reported occupational disease in the country (after ‘occupational overuse syndrome/osteoarthritis’), and with more cases reported than all the remaining categories of occupational diseases combined.

It is estimated that currently around a quarter of the New Zealand workforce of 1.47 million workers are affected to some degree by harmful noise at work (McBride, 2005). The 2003 ACC Annual Report states that despite knowledge of effective controls and guidelines the prevalence of noise-induced hearing loss shows no sign of decrease.

The most recent data from ACC indicate 4081 new claims for noise-induced hearing loss in 2004/05 (Tables 1 and 2). This translates to around 11 New Zealanders successfully claiming compensation for a new case of noise-induced hearing loss each day. As can be seen in Table 2, the number of these claims has been steadily increasing over the last ten years, with a noticeable increase between 1995-99 and 2000-2004. This increase is obvious in the fact that the number of noise-induced hearing loss claims paid out in 2004 (4009) was almost double the number paid just four years earlier (2095). However, this does not necessarily represent a doubling in the actual incidence of noise-induced hearing loss over the same period, due to changes in claim and compensation structure over this timeframe.

Table 1 shows the number and percentage of all noise-induced hearing loss claims registered with ACC over the last decade by job grouping. This shows that agriculture and fisheries workers, trades workers and machine operators and assemblers are the most at-risk occupations. Over 95% of claims are made by men.

Table 1: Distribution of all noise-induced hearing loss claims to ACC by employment type

Unknown	Unknown (Not Collected)	Legislators, Administrators, & Managers	Professionals	Technicians & Associate Professionals	
15,082	2,291	1,742	2,076	1,438	
36.97%	5.62%	4.27%	5.09%	3.53%	
Service & Sales Workers	Agriculture & Fishery Workers	Trades Workers	Plant & Machine Operators	Elementary Occupations	
1,225	4,934	4,123	5,303	2,109	
3.00%	12.10%	10.11%	13.00%	5.17%	

The vast majority of claims for noise-induced hearing loss in New Zealand are lodged in middle age or later, with few before the age of thirty. Analyses of these data indicate a large bubble of claims is visible from those entering retirement. This is not to suggest that young persons are not susceptible to noise-induced hearing loss. However the long onset of the disease from chronic noise exposure (greater than ten years typically), combined with the fact that most people do not seek medical care or compensation until they have a substantial hearing loss means that the problem tends to only become visible as the individual ages.

Estimates of cost in New Zealand

Compensation and rehabilitation directly cost the country almost $43 million in 2004/05.

The latest statistics from ACC (data provided by ACC) indicate that $23,388,433 was paid out on 4081 new cases of noise-induced hearing loss in the 2004-2005 financial year, representing an average first year cost of $5731.05 per claim (see Table 2). Over the same period a further $19,537,746 was spent on 8,977 ongoing noise-induced hearing loss claims. Thus overall, in the 2004-2005 year the rehabilitation costs directly related to noise-induced hearing loss totalled almost 43 million dollars.

Over the last decade ACC has met 28,805 claims for noise-induced hearing loss, at a total cost of $218,402,445. Furthermore, over the last decade the costs of noise-induced hearing loss have increased by an average of 20% each year. While these growth rates for claims do not necessarily mean that the actual incidence of noise-related hearing loss is increasing, they do indicate that there is a significant financial burden upon the Accident Compensation Corporation. No detailed analysis has been undertaken of the ACC data (this was not part of the brief for this review).

Table 2: Number and costs of new and ongoing noise-induced-hearing loss claims to ACC, 1995-2005

Financial Year	Number of New Claims	Number of Ongoing Claims	New Claim Costs	Total Costs
1995/1996	1658	180	$4,013,805	$7,497,030
1996/1997	2469	294	$7,264,318	$11,075,331
1997/1998	2901	241	$10,200,310	$15,186,275
1998/1999	2617	272	$10,275,920	$16,047,061
1999/2000	2834	321	$12,208,468	$17,611,402
2000/2001	2891	592	$13,288,620	$19,745,421
2001/2002	2628	2002	$13,324,906	$21,106,695
2002/2003	3304	4964	$18,210,607	$30,029,710
2003/2004	3422	6825	$19,649,509	$37,177,341
2004/2005	4081	8977	$23,388,433	$42,926,179
Total	**28805**	**24668**	**$131,824,896**	**$218,402,445**

Issues with noise-induced hearing loss data

Numerous issues exist regarding the calculation of the local and global impact or burden of noise-induced hearing loss. There are variations across countries in the audiometric criteria for defining the degree of hearing loss and in the methods or criteria for attributing the proportion of hearing loss that is due to noise exposure rather than age or other disease. Data are based on a variety of methods such as self-reports, questionnaires and the numbers receiving compensation. The latter data will vary substantially across jurisdictions because of differences in criteria that are used by the issuing authority to identify hearing loss as compensable.

For example, in New Zealand a claim for NIHL is based on a history of noise exposure and evidence of a hearing loss that can be managed with hearing aids. There is no absolute audiometric criterion for determining the severity of noise-induced hearing loss and it is possible for someone to be classified as having noise-induced hearing loss regardless of degree of hearing ability. Meanwhile in the United Kingdom a worker must have a binaural equivalent hearing loss of 50dB before they are eligible for a disablement benefit noise-induced hearing loss (Health & Safety Executive, 2004). This criterion represents a substantial hearing impairment, and therefore statistics from some United Kingdom sources would exclude people with losses less than 50dB that would generally be classified as a hearing impairment. Additionally this also excludes the incidence of non-occupational hearing loss (such as recreational noise exposure) which is not compensable under the majority of schemes worldwide, but which is covered in New Zealand by ACC.

Data on the scope, scale and impact of noise-induced hearing loss upon the people and economy of New Zealand is required to understand the extent and effect of this problem. This is noted by the chair of the National Occupational Health and Safety Advisory Committee in its 2005 report to the Minister of Labour, when discussing occupational disease and injury surveillance in general:

"Effective occupational disease and injury surveillance systems are an essential part of an effective national occupation health and safety strategy. If we cannot measure occupation disease and injury, we cannot validly identify priorities, or prevent occupation disease and injury occurring, or measure how effective any prevention strategies are.

Sadly, the systems used in New Zealand for the surveillance of occupational disease and injury fail to meet these basic expectations and fall far short of internationally accepted practice, especially for the surveillance of occupational disease."

P1 (Pearce et al., 2005)

The main concerns NOHSAC has for such data are based on an identified lack of common definitions and coding of disease, injury and occupation, a poor capture of occupational history and inadequate or non-existent coding of the occupational history information that is collected, and a lack of a single entity responsible for the collection coding and analysis of occupational disease and injury in New Zealand.

ACC has a somewhat unique position as the primary government funded compensation and rehabilitation provider for the whole country. This means that the data sets available from claims are comprehensive than an academic study or private health insurance company could hope to find, however they are far from perfect and are indeed subject to the concerns noted above.

Furthermore, it is expected that reported rates after 2001 have increased due to fee changes around that period. It is also not possible to accurately separate the incidence of occupational noise-induced hearing loss from non-occupational sources in the data or to attribute some ratio between them. Also, ACC funding figures cover rehabilitation, compensation and maintenance costs from work-related accidents causing hearing loss, in addition to long term acquired noise-induced hearing loss from excess noise exposure. For these reasons the increase in incidence rates and costs visible over the last decade of ACC data cannot be taken as direct evidence for an actual increase in the incidence of noise-induced hearing loss in New Zealand, however they do indicate that at the least the problem is not going away on its own.

Summary

Noise-induced hearing loss is identified as a significant public health issue worldwide. There is some evidence that the number of new cases is declining in some European countries, but increasing in others. Interestingly consistently in the surveys there is apparent increase in the number of people who believe that they are exposed to dangerous noise levels in the workplace. While it is difficult to precisely define and catalogue the disorder, somewhere in the region of 180 million people worldwide may currently be affected with a further 600 million at a high risk of developing it due to excessive noise exposure levels. Construction, agriculture, manufacturing and metalworking industries show a higher prevalence of noise-induced hearing loss and the greatest losses are consistently among men above the age of 45 years.

It is also difficult to make decisive conclusions on the incidence rate in New Zealand from the data available. However the ACC data does indicate an increase with 4081 new claims in the 2004/05 financial year. There are certainly no signs of decrease in the number of claims over the last decade despite established knowledge of effective controls.

The rehabilitation and compensation costs of this condition to ACC are high and increasing each year. The total cost was almost $43 million in 2004/05, over double those just five years earlier. These claims were not distributed evenly among the population. Only one in twenty claims were lodged by females, while agriculture and fisheries worker, trade worker and machine operator were the occupations most commonly listed by claimants. The vast majority of claims for noise-induced hearing loss are lodged in middle age or later.

A lack of an effective national register for noise-induced hearing loss, variation in definitions of the disorder and flexible compensation criteria make it difficult to accurately define the nature, extent and impact of noise-induced hearing loss in New Zealand.

Across the variety of industry, academic, narrative, and government sanctioned sources on noise-induced hearing loss, one clear thread is evident: that noise-induced hearing loss is a significant and widespread public health issue, it leads to substantial negative impacts upon the lives of those that are afflicted, and while there is no cure for those that are already affected, the condition itself is regarded as essentially preventable.

Despite this near unanimous agreement on the problematic nature of noise-induced hearing loss, little epidemiological evidence exists on the true extent of the problem in New Zealand. It appears that while there is general agreement, particularly in industry that noise-induced hearing loss is a serious problem, exactly how much of a problem it is remains inconclusive.

Workplace noise exposure legislation

Based upon the knowledge that exposure to excessive noise levels can cause temporary and permanent damage to hearing, legislation and standards have been developed to control the level of sound to which workers are exposed. As reviewed below, legislation in most jurisdictions around the world is based upon specifying the limit for continuous and peak noise that a worker may be exposed to, the measures that must be undertaken if noise exposure is above these limits, and requirements for monitoring and minimisation of hearing loss.

Continuous and peak exposure limits in New Zealand

The New Zealand national standard for exposure to noise in the occupational environment is an eight-hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,8h}$) of 85dB(A), while the maximum peak level permitted is ($L_{C,peak}$) of 140dB(C). This is set in law by regulation 11 of the Health and Safety in Employment Regulations (1995) which defines these limits as:

The noise exposure level, $L_{Aeq,8h}$, is the level of the daily noise exposure normalised to a nominal 8 hour day, in dB(A) referenced to 20 micropascals; that is to say, it is the steady noise level that would, in the course of an eight hour period, cause the same A-frequency-weighted sound energy as that due to the actual noise over the actual working day; and

The maximum peak noise level, $L_{C,}$peak, is the highest C-frequency-weighted peak sound pressure level in the place of work in decibels referenced to 20 micropascals, measured using sound measuring equipment with ``P'' time-weighting, as specified in the Australian Standard numbered AS 1259.1-1990 and entitled ``Sound level meters Part 1: Non-integrating''; and

The levels of noise referred to in sub clause (1) of this regulation shall be measured and assessed in accordance with the Australian Standard numbered AS 1269-1989 and entitled "Acoustics – Hearing conservation''.

This means that over a continuous eight hour working day, an individual may not be exposed to a sound level in excess of the equivalent of 85 decibels of steady state sound pressure over the same period that has been measured according to the weighting of the 'A' scale. The A scale was devised to weight the frequencies of the sound spectrum in relation to the capacities of the healthy human ear, as the ear is not evenly sensitive to all frequencies (Bies & Hansen, 1996). If noise exposure levels are in excess of this, steps must be taken to reduce the noise, protect the workers ears and monitor their hearing. The peak noise levels are measured with the C-frequency weighting because the C-weighting provides an approximation to a flat response thus not limiting the peak values when measured by a sound level meter (Haughton, 2002).

> **The national standard for occupational noise exposure is an eight-hour equivalent continuous sound pressure level of 85dB(A).**

Note that this standard does not state that individuals cannot be exposed to a single sound over 85 decibels, but rather that the *average* of their total exposure taken over the whole day should not exceed this level. Under most circumstances the noise exposure experienced over a working day is made up of a variety of sound intensities, durations and frequencies. Thus effective measurement of noise dose must consider the total sound exposure over the exposure period. Another approach used in the USA is the calculation of the Time-weighted average (TWA; OSHA 1910.95, Occupational Noise Exposure Industry Standard, OSHA 2006) which is the average of each of the different exposure levels during any exposure period. As an example for noise with a 90dBA exposure limit and a 5dB exchange rate (ie the US standard), the TWA is calculated according to the following formula:

TWA = 16.61Log$_{10}$(D/100) + 90 where D = dose

The "noise dose" can be calculated from tables. The maximal permissible dose is 100% and is equivalent to 90dBA for 8hrs (equivalent to a L_{Aeq8hr} of 90dBA). Details of the method of calculating the TWA are in the OSHA 1910.95 Standard available from the US Department of Labour Occupational Health and Safety Administration (OSHA, 2006).

Furthermore, it should be noted that this limit of 85dBA is based upon a 'trade-off' between practicability and protection, and that it is based upon population statistics and not individual data. As noted throughout this document, there is great variation in real world noise exposure durations, working conditions, recreational noise, individual susceptibility to noise-induced hearing loss and other factors. Because of this the 85dB $L_{eq,8h}$ does not guarantee that a person exposed to noise below this level for their working life will not suffer from noise-induced hearing loss.

Rather, this limit is based upon a statistical analysis of risk. For example: at an equivalent continuous A-weighted sound pressure level over an 8-hour day of 85dB(A), 95% of the exposed population would not be expected to have a hearing loss that exceeds 10dB over a working lifetime, while 5% would have greater than 10dB loss (Standards Australia/Standards New Zealand, 2005). This indicates that even when noise exposure is kept to the recommended limit most exposed individuals could expect a little or no loss of hearing threshold, while one in twenty individuals could experience a small loss.

For peak noise, the national standard is a C-weighted peak sound pressure level ($L_{C,peak}$) of 140dB(C). This means that no individual may be exposed to a single sound level peak in excess of 140dB (measured on the 'C' scale) at any time, regardless of their other sound exposures. Unlike the 85dB limit explained above, this peak limit is not related to continuous exposure but rather refers to the absolute upper permissible limit of any sound at any time. This limit reflects the fact that a single burst of noise of sufficient intensity can cause instantaneous damage to the ear and immediate permanent hearing loss. The C weighting is chosen to give an essentially flat response (it relates to the 100phon loudness curve) that cheaper measuring equipment can meet and hence gives a consistent measurement across a range of sound meters (Haughton, 2002).

The calculation of the standard for average exposure is based upon an eight hour working day, with the assumption that the individual works five days a week, fifty weeks of the year. Additionally it is assumed that the individual is only exposed to significant levels of noise during the eight hour working day and not after hours, and that they take two days in a row per week for a weekend also with no substantial noise exposure. This point is significant in that the pattern and duration of recovery time, the quiet periods between noise exposures that provide 'rest' for the ears, has been implicated as a factor in noise-induced hearing loss in addition to the pattern and duration of the noise exposure itself (ISO, 1990).

Obviously this standard does not exactly reflect the working habits of a proportion of New Zealand workers, particularly those that undertake shift-work, overtime or contract work, those that work part time or multiple jobs, or persons that do not take their days off as a typical two day weekend. Yet for the majority of people this standard may be adequate, and it is an internationally standardised and accepted method for estimating noise exposures (See Appendix II). In the future there may be some potential to move to a different noise exposure measure that better accounts for all workers and sources of exposure (such as the twenty-four hour average adopted by the US Coast Guard, for example (United States Coast Guard, 1982)). However currently there appears to be nothing that is more valid and reliable than the existing standard.

The decibel scale

The decibel scale is a logarithmic scale of ratios that compares the sound intensity of interest to a reference level (Haughton, 2002). The reference level is the softest sound intensity that can be heard at a 1000 Hz by the normal hearing population. According to the decibel scale a sound of 10dB is ten times more intense; a sound of 20dB is 100 times more intense than the standard. A 3-decibel increase equates to a doubling of the sound intensity. Likewise to reduce a noise emitted from a noise source by 3dB actually requires the sound intensity to be halved. This 3dB doubling factor is known as the exchange rate (Dobie, 2001). In the USA a 5dB exchange rate is used because it is assumed that sounds workers are exposed to are not continuous but are intermittent.

While the use of the decibel scale is an elegant solution for engineers and mathematicians, the use of a log scale to describe sound intensities can be very problematic for the majority of persons who do not have a working knowledge of logarithms. Most people are far more familiar with simple linear scales with absolute reference points. For example, to the untrained observer a change from 85dB to 91dB may appear minor or just discernable, as linearly this is a mere 7% increase. However due to the non-linearity of the decibel scale this in fact represents a quadrupling of sound intensity, or in other terms a 400% increase in energy. Indeed most people perceive an increase of 10dB to be approximately ‘twice as loud’, despite this being an increase of ten times in the sound energy.

A further part of this confusion is that that the decibel scale is not an absolute one, but rather it is based upon the typical capabilities of the human ear (Bies & Hansen, 1996). Thus a sound level of zero decibels does not mean that no sound exists, but rather this is the threshold of audibility for 50% of young individuals with otologically normal hearing. Correspondingly, it is perfectly possible for sound levels to be less that 0dB, and indeed individuals with acute hearing can hear sounds below zero decibels. To compare sound levels in relation to zero as an absolute reference point is erroneous, and again this concept may be confusing for the majority of the general public who would assume that zero decibels represent no sound at all.

The equal energy hypothesis

The $L_{eq\ 85\ 8h}$ for noise exposure is based upon the equal energy principle of noise-exposure, also known as the total energy theory (Behar et al., 2000). This principle states that the amount of hearing loss caused by a sound is directly proportional to the average amount of sound energy received over time. Therefore if the total sound intensity is doubled (i.e. increased by 3dB), halving the exposure time will result in the same amount of energy reaching the ear. For example, an eight hour exposure at an average of 85dB and a four hour exposure at an average of 88dB would create the same amount of sound energy, and according to the principle would result in the same level of hearing loss (Behar et al., 2000). Conversely if one wished to double the amount of time they spend exposed to a noise, the intensity of the noise must be halved to maintain the same level of sound energy, and to maintain the same effect on hearing.

This is summarised succinctly in the extract below from an Ontario Noise Regulation Special Advisory Committee report:

Noise-induced hearing loss (or more precisely the average hearing loss within a representative population) is simply defined by the total amount of A-weighted sound energy received by the ear. Permanent damage is immediate and irreparable though, on a daily basis, generally immeasurably small and the rate at which damage accumulates is proportional to the sound intensity. This means that a doubling of intensity, corresponding to a 3 dB increase in sound level, can be offset by a halving of the exposure time.

(Shaw, 1985) p4

While the equal energy principle is generally accepted as the 'best available' method for conceptualising and calculating the effect of sound exposure on hearing loss (I-INCE, 1997), there are a number or issues with it that must be considered.

Firstly, this hypothesis considers sound simply as a single averaged level over the total exposure period, and assumes that a given amount of sound energy translates directly into a corresponding amount of hearing loss. However in the vast majority of occupational settings the sound exposure is not constant and of a single intensity, but rather it is composed of a variety of sound sources at a variety of intensities, frequencies and complexities that stop, start, pulse and otherwise vary considerably across a given exposure period. While the use of an average sound level simplifies measurement and calculation significantly it may gloss over certain significant characteristics of a sound exposure. This is particularly with high sound pressure levels where this 'linear' energy relationship may break down (Williams, 2005a).

For example it is implicit in this theory that intermittency of sound offers no benefit. However, there is evidence to suggest that regular quiet periods between noise events may have a recovery effect that results in less hearing loss than a single sustained noise of equivalent intensity maintained across the same period, however recovery time within a single exposure period is not taken into account by this principle (Ward, 1991). As noted below a number of authorities worldwide (eg USA) use a 5dB exchange rate to account for the typical intermittency of occupational noise exposure, however this appears to be a somewhat arbitrary correction factor and still does not result in any further measurement or description of the actual noise in question. More recently its validity has been questioned and a 3dB exchange is now recommended (NIOSH, 1998: American Academy of Audiology, 2003).

Likewise there is also evidence to suggest that high speed pulsating or repetitive impact noise may cause more damage than simpler exposures depending upon the rate and intensity (Price, 1974), and indeed many jurisdictions in the world have separate sound limits for impact noise (see Appendix II). Furthermore it is established that high frequency noise is generally more harmful to hearing than lower frequencies at a given intensity. While the "A" scale weights such differing frequencies to have approximately the same hazard at a given intensity, narrow band pure tones and broad-spectrum sounds are treated the same by this hypothesis despite the fact that pure-tones are more hazardous (Dobie, 2001).

Interestingly, despite its extensive use the equal energy hypothesis has not really been validated across the range of exposure parameters experienced in the workplace. Indeed a number of population (Bies and Hansen, 1990) and animal studies (Lataye and Campo, 1996; Hamernik et al., 2003; Harding and Bohne, 2004) have questioned its use as a unifying principle. There may be some validation of its use within certain critical levels of continuous noise exposure but because the level of injury is dependent on frequency and the particular turn of the cochlea affected it cannot be used as a generalised principle (Harding and Bohne, 2004). It is also not applicable to impulsive noises (eg Roberto et al., 1985).

Regardless of these issues the equal energy hypothesis is a useful tool and no better method has so far been developed, and indeed for the majority of situations with typical steady-state noise exposures it may be accurate (I-INCE, 1997). However in the more extraordinary situations like those noted above, the efficacy of the total energy hypothesis may be reduced and further consideration of the type, duration and nature of the sound exposure in question could be beneficial for further preventing hearing loss.

The health and safety in employment act and regulations

As noted above, the Health and Safety in Employment Regulations of 1995 state that:

Every employer shall take all practicable steps to ensure, in relation to every place of work *under the control of that employer, that no employee is exposed to noise above 85 dB(A) over an eight hour period or any peak noise above 140 dB,* whether or not the employee is wearing a personal hearing protection device*.*

In parallel to this, the Health and Safety in Employment Act (1992) requires employers to take all practicable steps to ensure the safety of employees at work, and to provide a safe working environment. The text of this act, outlined below, indicates that it is the employer's responsibility to identify hazards, assess whether they are significant and control any significant hazards via elimination, isolation or harm minimisation. Furthermore the employer is also required to monitor the health of employees who have been exposed to a significant hazard, and to provide information and training supervision for staff in relation to hazards in the workplace.

In terms of noise exposure, this translates into a requirement to conduct preliminary noise surveys to identify possible hazards followed by detailed noise surveys of identified noise hazards to assess if they are a significant risk. After this, employers are required to investigate, and if practicable, control the noise at the source and isolate noise sources away from employees. Where it is considered not practicable to eliminate or isolate the hazardous noise source, employers must provide hearing protectors. The requirement for monitoring employee health means that employers must arrange audiometry hearing test for all employees working in an area of hazardous noise, once when the employee starts work and again at intervals not more than twelve months after. In addition employers must provide information, training and supervision for workers to identify noise hazards and for the safe use of plant, equipment and hearing protectors (OSH, 1996).

This law forms the basis for the current hearing conservation paradigm that is described in the next chapter. The text states clearly that the primary requirements of the law are the identification and elimination of noise hazards, followed by the isolation of noise hazards if this is not possible. It is only when these steps are not 'practicable' (or while they are still being undertaken) that the provision of protective equipment such as hearing protectors is considered a suitable and compliant solution. However, this clause based upon 'practicability' potentially provides a convenient "opt-out" from the more effective noise control methods, and provides a basis for a legally compliant noise management program based largely on the use of hearing protectors. This is particularly so as there is no strict definition of what constitutes practicability. Therefore a complete noise control program as specified in the Act can potentially be passed over on the grounds of difficulty or expense, as it is often true that the provision of hearing protectors is a lot easier and cheaper than modifying equipment, the environment or work processes to lower noise output. These issues are covered in greater detail in the following chapters.

HEALTH AND SAFETY IN EMPLOYMENT ACT 1992

PART 2 – Duties relating to health and safety in employment

Duties of employers in relation to hazard management

7. Identification of hazards

Every employer shall ensure that there are in place effective methods for:

Systematically identifying existing hazards to employees at work; and

Systematically identifying (if possible before, and otherwise as, they arise) new hazards to employees at work; and

Regularly assessing each hazard identified, and determining whether or not it is a significant hazard.

8. Significant hazards to employees to be eliminated if practicable

Where there is a significant hazard to employees at work, the employer shall take all practicable steps to eliminate it.

9. Significant hazards to employees to be isolated where elimination impracticable

Where there is a significant hazard to employees at work; and

Either:

There are no practicable steps that may be taken to eliminate it; or

All practicable steps to eliminate it have been taken, but it has not been eliminated,

The employer shall take all practicable steps to isolate it from the employees.

10. Significant hazards to employees to be minimised, and employees to be protected, where elimination and isolation impracticable

Where:

There is a significant hazard to employees at work; and

Either:

There are no practicable steps that may be taken to eliminate it; or

All practicable steps to eliminate it have been taken, but it has not been eliminated; and

Either:

There are no practicable steps that may be taken to isolate it from the employees; or

All practicable steps to isolate it from the employees have been taken, but it has not been isolated,—

The employer shall take the steps set out in subsection (2) of this section.

The steps are:

To take all practicable steps to minimise the likelihood that the hazard will be a cause or source of harm to the employees; and

To provide, make accessible to, and ensure the use by the employees of suitable clothing and equipment to protect them from any harm that may be caused by or may arise out of the hazard; and

To monitor the employees' exposure to the hazard; and

To take all practicable steps to obtain the employees' consent to the monitoring of their health in relation to the hazard; and

With their informed consent, to monitor the employees' health in relation to exposure to the hazard.

An employer does not comply with subsection (2)(b) by:

Paying an employee an allowance or extra salary or wages instead of providing the protective clothing or equipment; or

Requiring an employee to provide his or her own protective clothing or equipment as a pre-condition of employment or as a term or condition in an employment agreement.

However, an employer does not have to comply with subsection (2)(b) in relation to protective clothing if:

An employee genuinely and voluntarily chooses to provide his or her own protective clothing for reasons of his or her comfort or convenience; and

The employer is satisfied that the protective clothing is suitable in terms of subsection (2)(b).

An employee who has chosen to provide his or her own protective clothing under subsection (4) may, after giving reasonable notice to the employer, choose that the employer provide protective clothing under subsection (2)(b) instead of providing it himself or herself.

Nothing in subsections (4) or (5) derogates from the responsibility of the employer under subsection (2)(b).

Exposure limits and legislation worldwide

The level and criterion of average noise exposure limits, the exchange rate, and maximum or peak levels for a selection of key national and international jurisdictions are described in Appendix II. New Zealand is included for comparison.

It can be seen that like New Zealand most authorities worldwide use an 85dB(A) main criterion with a 3dB exchange rate. However this level is certainly not universal and there are some notable exceptions. The USA features a variety of limits between 77 and 90dB(A) due to a complex mix of state and federal jurisdictions, and likewise the levels used in China vary between 70 and 90dB(A) depending on the industry in question. A 5B exchange rate is used in some jurisdictions of the USA and Canada, and in Chile and Israel.

One distinguishing feature of the new regulations of the European Union and the United Kingdom is the existence of a *first and second action level* which define sound levels at various stages of monitoring and protection must take place. Similarly a number of other nations and jurisdictions have separate levels at which monitoring, hearing conservation and noise control must begin.

A 140dB(C) limit for peak noise is most common but again not universal. Many make a distinction between a maximum daily level and a maximum peak level, some specify different limits for protected versus unprotected peak exposures or for first and second action levels, while many also specify a maximum permissible number of impacts or provide different peak sound levels for different impact rates.

Almost all levels are based upon an eight hour day although the US Coast Guard uses a 24 hour criterion, while the Norwegian offshore industry uses a 12 hour one. These levels presumably better represent the nature of noise exposure in those industries. The efficacy of the eight-hour criterion for non-eight hour days has been questioned in literature (Williams, 2005a), and AS/NZS 1269.1 includes a scale for reducing the $L_{Aeq\ 8h}$ by 1 to 3 dB to accommodate shift lengths of up to 24 hours.

In comparison to international exposure limits, the New Zealand criterion, exchange rate and peak levels appear consistent with international best practice. However the potential for introducing into New Zealand legislation a strata of action levels similar to those recently introduced in Europe and the United Kingdom could be investigated to reinforce the current NZ standards. For example a lower action level at 80dB(A) where training and the provision of information is required could compliment the existing 85dB(A) criterion for hearing conservation. Likewise an upper action level at 90dB(A) where noise control measures become mandatory would similarly reinforce the existing standards.

Additionally limits on the number of permissible impacts or impulse noises, or correspondingly lower criterion levels for high impact environments, could be introduced. For specific situations of shift work and atypical work patterns in New Zealand, an alternate criterion based upon a 24 hour exposure period for applicable industries could also be investigated.

Summary

The New Zealand national standard for continuous noise exposure is an ($L_{Aeq,8h}$) of 85dB(A) with an exchange rate of 3dB, while the maximum peak level permitted is ($L_{C,peak}$) of 140dB(C). These standards are based upon statistical calculations of risk and do not guarantee the protection of an individual. These legal limits are consistent with those used in most jurisdictions worldwide however New Zealand does lack some of the measures that some other governments have, such a system of action levels or specific controls on impact noise.

The standards are calculated using the decibel scale and according to the equal energy hypothesis. Both of these can be confusing to the untrained observer, while the hypothesis may not be totally suitable for unorthodox conditions despite it generally high level of utility. No better methods of calculating suitable levels of noise exposure were identified.

Beyond the noise exposure limits, New Zealand law specifies that employers must identify, eliminate or isolate noise hazards wherever practicable, and to provide hearing protection devices until this is achieved. The issue of ‘practicability’ potentially allows employers to rely on the inferior option of hearing protection alone as the basis for their noise-induced hearing loss control efforts. This could be done by labelling noise control methods as impracticably expensive or difficult, even if they are significantly more effective in the long run than a hearing protector program.

Hearing conservation programs

Hearing conservation programs are designed to protect individuals in noisy occupational settings from developing occupational noise-induced hearing loss. Under most legal jurisdictions worldwide employers are required to undertake a hearing conservation program when daily noise exposure exceeds a given level as described in the previous chapter, typically as the first course of action.

Generally a hearing conservation program consists of a noise survey of the workspace to establish exposure levels and 'noise hazard areas', the issue of personal hearing protectors and education on their correct fitment and use, and some form of engineering noise control. This is undertaken in conjunction with regular and standardised audiometry administered to all noise-exposed personnel, the results of which are monitored to identify any threshold shift to evaluate the effectiveness of the program (NOHSC, 1991; Williams, 1993b).

The Australian/New Zealand Standard on Occupational Noise Management (AS/NZ 1269-1998 OSH, 1996b) identifies four distinct purposes for conducting pure tone threshold audiometry in individuals exposed to noise at work:

The identification and documentation of existing hearing loss.

The early detection of any deterioration of hearing in persons exposed to excessive noise.

The direction of those individuals who are identified as having a hearing loss to an appropriate rehabilitation program.

The supply of any special communication or warning system that may be required within the workplace for an individual with a hearing loss.

The Acoustical Society of America recommends that the audiometric testing component of hearing conservation programs be administered yearly wherever possible, and at no more than two yearly intervals elsewhere so that established criterion ranges remain equitable (Acoustical Society of America, 2002). More frequent audiometric testing is desirable at high noise exposures (e.g. 8 hour averages in excess of 100dBA), where workers are exposed to impulse noise, or where job conditions change frequently (Standards Australia/Standards New Zealand, 2005). It is also recommended that each successive year's audiograms be compared to those preceding it, rather than to an initial baseline measure, to avoid placing undue precedence on the accuracy of the first audiogram (Acoustical Society of America, 2002). As such this approach requires accurate and reliable assessment to identify the beginnings of hearing loss over a relatively short timeframe. However this practice could lead to a 'creeping' hearing loss that is not seen between one year and the next due to a gradual onset over several years.

Audiometric data can become corrupted by inadequate acoustics of the test environment, by inaccurate audiometer calibration or by inconsistent test techniques. Such factors can produce variability indicative of threshold shift in the test population, and careful scrutiny is required to identify the true cause of such results (American Academy of Otolaryngology, 1988). It should be noted that due to the inherent variability in the audiometric testing process, in typical practice any change in threshold level is not considered an indication of hearing loss unless it is in excess of 15dB loss of hearing (Standards Australia/Standards New Zealand, 2005). As a 15dB change could represent a significant hearing loss depending upon the baseline hearing ability, this level of test variability could mask the onset of noise-induced hearing loss until it is in an advanced stage.

Efficacy of hearing conservation programs

Several studies have attempted to empirically assess the efficacy of traditional hearing conservation programs.

One series of studies conducted during the early 90's in industrial plants concluded that a hearing conservation program including the effective use of hearing protectors *and a reduction of noise emission levels* can eliminate noise-induced hearing threshold shifts (Bruhl, Ivarsson, & Toremalm, 1994). Similarly, a major survey of 48 companies in the United

Hearing conservation programs require strong commitment from management to be effective.

Kingdom concluded that organisations that were committed to the process of implementing noise regulations could find practical solutions (Leinster, Baum, Tong, & Whitehead, 1994). These authors found that the most important factor in the successful implementation of such projects was a strong commitment from senior management.

These two studies indicate that with the right organisational support it can be possible to implement a successful hearing conservation program, and if these programs are implemented in their entirety they can be effective at controlling hearing loss.

However, Dobie (1995) conducted a methodological analysis of these and other studies claiming to measure the efficacy of hearing conservation programs and found that none featured randomised clinical trials and that all suffered from one or more methodological shortcoming such as a failure to match treatment and control groups for age, previous exposure, existing hearing loss and the inclusion of subjects that had already experienced sustained occupational noise exposure. These issues led the author to conclude that: *"Although noise reduction for individuals obviously can prevent noise-induced hearing loss, to my knowledge, no single study offers convincing evidence of the efficacy of occupational hearing conservation programs, primarily due to methodologic flaws." (Dobie, 1995)5,* p385).

Reports of declining rates of NIHL or occupational hearing loss in some jurisdictions (such as Finland and the UK) could be interpreted as indicating that good hearing conservation practice and attention to controlling personal noise exposure in the workplace has reduced the incidence of noise related hearing loss in these countries. However, some caution needs to be exercised in interpreting these data. It was not possible in this review to determine whether these changes are related to real reductions in the incidence, differences in reporting over time and the criteria for assessing severity of hearing loss or a combination. It should also be pointed out that the numbers of reported cases has stabilised in the UK and Finland and in some other countries is increasing, suggesting that the impact of any measures may have reached a limit.

Given these findings, it is difficult to find any strong scientific evidence that hearing conservation programs can totally eliminate occupational noise-induced hearing loss. While the evidence suggests that conservation programs can be effective at identifying, monitoring and lessening the severity of noise-induced hearing loss, it appears that they cannot be considered a total and perfect solution. The factors that may affect the effectiveness of hearing conservation programmes and ways to improve them are discussed in the next section.

Hearing conservation programs and NIHL prevention

The effectiveness of hearing conservation programs as a means of preventing hearing damage from noise exposure has been questioned and is considered in this section.

Because of the use of hearing loss as the index of effectiveness, hearing conservation programs can be thought of as being designed to "conserve" the hearing of at-risk populations rather than preventing hearing damage occurring in the first place. These programs are designed to monitor the hearing of workers exposed to potentially dangerous levels of noise and this monitoring is only an effective tool once it identifies a significant permanent threshold shift. The existence of temporary threshold shifts and tinnitus are considered an early indicator of hearing damage, but currently temporary threshold shifts cannot be used to accurately predict permanent threshold shifts. Furthermore there is evidence that inner ear damage may occur before a hearing loss is detectable (LePage and Murray, 1993). Indeed this is recognised in the AS/NZS Standard #1269 'Purposes for Conducting Workplace Audiometry', which states that there is 'evidence that inner ear damage caused by noise exposure accumulates prior to the onset of the threshold impairment'. Thus audiometry is generally only of use once an individual already exhibits a measurable degree of hearing loss that can be attributed to a history of noise exposure. Furthermore it is suggested that the likelihood of measuring a significant threshold shift using annual tests is very small (Hetu, Tran Quoc, & Dugay, 1990). On the other hand audiometry can be useful to identify programs that are effective, for example if audiometry identifies no loss of hearing amongst a population of workers this could indicate an effective hearing conservation program. However the use of audiometry to identify an occupational hearing risk and develop a noise management program is a false economy, as it relies on the destruction of hearing as the dependent test variable, the very thing one is trying to avoid (Williams, 2005a).

In terms of close monitoring to detect hearing loss, audiometry can be of limited value unless it is performed almost perfectly (Waugh, 1993). As noted above, variation in definitions, thresholds, test conditions and test administrators can create variability between successive tests that limits the conclusions that can be gained from them (American Academy of Otolaryngology, 1988). Furthermore, irregular implementation of test programs and the movement of staff between organisations can mean that the audiometry is sometimes never undertaken in the first place. When audiometry is undertaken regularly and correctly it can be used to observe the progression of noise-induced hearing loss in an individual, however it is of little use in preventing the loss (Williams, 1993b). In this regard otoacoustic emissions may potentially provide a better assessment of "pre-clinical" noise exposure or damage before it is manifest as a hearing loss, but the development of such procedures needs further research and refinement.

Hearing conservation programs based on audiometry or assessment of hearing damage can be seen as a remedial method to reduce the severity of noise-induced hearing loss, rather than a proactive measure to prevent it from occurring. Conservation programs are used to identify the onset of noise-induced hearing loss and to reduce the severity of further hearing loss (Waugh, 1993). As such some degree of hearing loss is inherently expected, even with a program with perfect uptake and compliance.

For this simple reason typical hearing conservation programs cannot be seen as 'best practice' for noise-induced hearing loss *prevention,* however they are still a widely used and suitable method for controlling the severity of noise-induced hearing loss in the workplace. This does lead to the question of whether hearing threshold is the best outcome measure to use to identify noise-induced hearing loss, or for the monitoring of program effectiveness. It has been suggested that additional tests should be undertaken in conjunction with audiometry (NIOSH, 1998), where some behavioural or 'functional' measure of hearing ability may be more appropriate.

There is also a difference between the plan of a hearing conservation program and what is actually achieved in the field. It has been suggested that hearing conservation programs are typically reduced to hearing assessment schedules combined with the promotion of personal hearing protection and a little token noise-reduction on an engineering level (Dobie, 1995; Moretz, 1990; Williams, 1993b), although the extent that this happens in New Zealand is unknown. This would be problematic as it would place the source of the problem and the failure to prevent the hearing loss squarely onto the individual worker, rather than the workplace or work culture.

For example, if the workers' personal hearing protection is seen as the sole means of reducing the effect of noise then there is the potential that a change in hearing is viewed as the individual's problem (ie 'your audiogram' identifies a loss in 'your hearing') for not complying with the use of hearing protection. Such an approach leads to the idea that the development of noise-induced hearing loss from occupational exposure is the worker's fault, and not the responsibility of management or the organisation as a whole (Williams, 1993b). It can be argued that it frames the issue as the problem of the noise 'receiver', rather than that of the noise 'creator'. This can lead to a management attitude that any deafness occurring in a noise-exposed worker is due to the worker's personal failure to protect themselves properly from a noise hazard, despite management direction to do so. *"You didn't wear your hearing protectors frequently/adequately/properly even though we told you that you had to, now your audiogram shows that you have hearing loss as a result."*

There is increasing recognition that safety solutions based around individualistic controls without the corresponding safety management systems and organisational support are likely to fail (Gallagher, 1997; Williamson, Feyer, Cairns, & Biancotti, 1997).

Best practice appears to place personal hearing protection as the lowest rung on the hierarchy of noise control measures, a last resort technique that gives 'protected exposure' to dangerous noise, rather than protecting the individual from exposure to the noise in the first place (OSH, 1994; Shaw, 1985; Standards

Personal hearing protectors provide 'protected' exposure to a noise hazard, but do not remove or isolate the hazard itself.

Australia/Standards New Zealand, 2005; WorkCover NSW, 1996) (see also Appendix I: Hierarchy of methods of noise control). However, in contrast the typical hearing conservation program effectively places personal hearing protection as the paramount means for controlling hearing loss related to noise exposure (Dobie, 1995; Moretz, 1990; Williams, 1993b).

It would seem that for a hearing conservation program to be an effective *prevention method,* the focus needs to shift from the individual to the organisation, and from personal exposure *protection* to general exposure *prevention*. The individual certainly has a large role to play in their own hearing safety, however they cannot be expected to shoulder the full burden of a problem that goes well beyond the control of any one worker.

This difference between conservation and prevention is noted by the National Institute of Occupational Safety and Health in the USA. As noted in the preamble to a NIOSH (NIOSH, 1996) guide to hearing loss prevention, this change in paradigm is significant both in terms of the outcomes it can achieve and the changes that must be implemented:

"The shift from conservation to prevention is not minor. Conserving means to sustain the hearing that is present, regardless of whether it is impaired or not. Prevention means to avoid creating hearing loss"

(NIOSH, 1996).

Barriers to successful implementation of a hearing conservation program

In a recent review Lipscomb, an American hearing conservationist reflects his frustration with the ineffectiveness of hearing conservation programs over the forty-year course of his career (Lipscomb, 2005). He states that that if hearing conservation programs were effective and well applied, there would be very few new cases of noise-induced hearing loss in the United States today, given that OSHA regulations regarding hearing conservation programs in industry have been in place for over twenty years. However, he reports that this is obviously not the case.

In the review, Lipscomb (Lipscomb, 2005) provides an economic perspective on the implementation of hearing conservation programs, stating that there are several barriers to effective hearing conservation program implementation, particularly a reluctance to follow the full course of a program including pre and post employment testing and regular sound measurement data. Also noted is the attempt by many American companies to avoid compensating hearing loss claims by blaming non-occupational noise, military service, exposure in previous employment and age-related hearing loss for the workers deafness, an approach that is apparently effective in such litigation.

The universality of this opinion, especially how it relates to New Zealand cannot be determined as such research has not been undertaken in this country and is beyond the scope of this review. While this focus upon such legal issues may not be directly relevant to the New Zealand situation because of the role of ACC, the statement that the personal and financial costs to individuals and organisation far outweigh the costs of implementing such programs is potentially relevant and should be considered in a review of the effectiveness of NZ hearing conservation programs. Furthermore, the implication that after approximately twenty years of legislative mandate such conservation programs remain inconsistently, and in some cases poorly, implemented and largely ineffective internationally suggests hearing conservation programs as currently structured should not be promoted as the sole answer to the noise-induced hearing loss problem.

Hearing conservation program or personal hearing protection program?

It has been suggested that in practice what are commonly referred to as hearing conservation programs are in fact merely personal hearing protection programs (Dobie, 1995; Waugh, 1993). This is due to the common focus upon the promotion of hearing protection combined with audiometry to identify hearing loss, without the focus upon noise control and hazard training that should be undertaken in parallel. Waugh states that most hearing conservation programs in Australian workplaces are simply hearing protection programs (and usually inadequate ones at that), so to ask if hearing conservation programs are effective amounts to little more than asking 'is hearing protection an effective noise control method?' From this review of current literature and investigation of practice this statement seems apt both in New Zealand and elsewhere in the world.

Two main categories for the apparent failure of hearing protection programs to *prevent* noise-induced hearing loss are identified. Firstly in practice hearing protectors typically do not provide the wearers with enough actual sound attenuation to protect their hearing. Reasons for this include failure to supply each individual with a suitable and correctly fitting protector, failure to obtain correct placement of the protector every time it is worn, and failure to maintain protectors in perfect operating condition (National Acoustic Laboratories, 1998).

It is suggested (Arezes and Miguel, 2002) that these issues can be mediated by carefully selecting and fitting hearing protection to each worker individually to suit their anatomical variability (while avoiding the bulk purchase

In practice many hearing conservation programs lack noise control measures and rely exclusively on personal hearing protection.

of ‘one size fits all’ earplugs or muffs), by providing suitable training on the correct use and placement of protectors, and by ensuring that protectors are well maintained and replaced when necessary, which itself requires some training to identify when hearing protectors become ineffective.

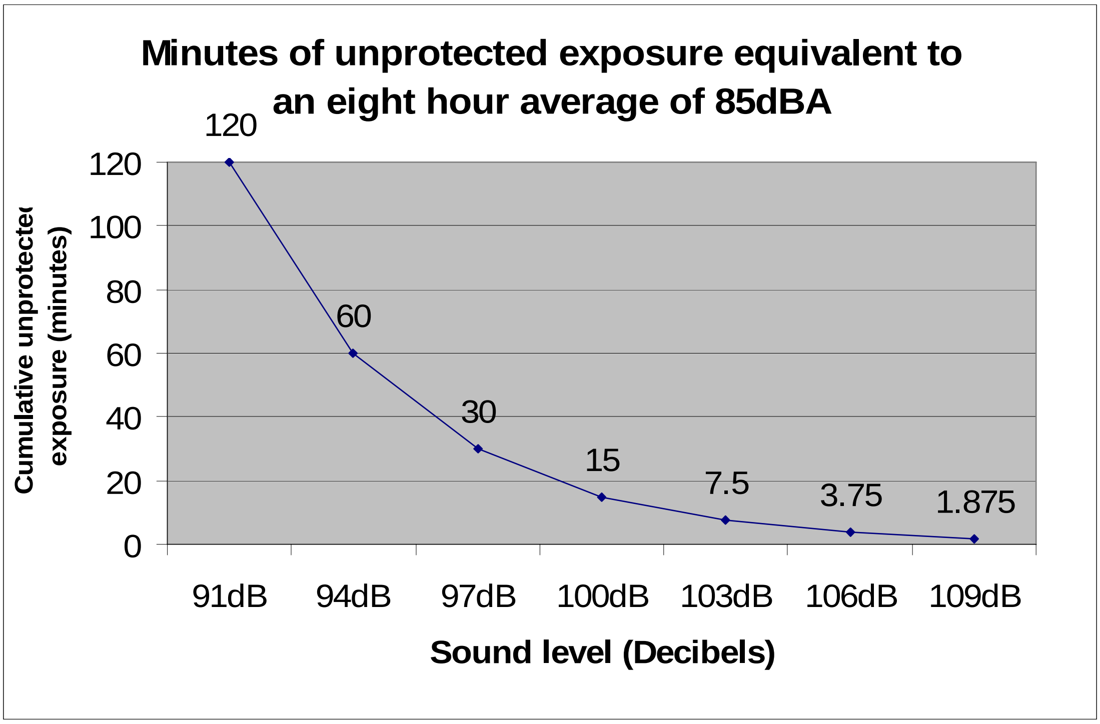
Secondly it is noted that hearing protectors are very frequently not worn for the entire duration of exposure (Lusk & Kelemen, 1993). The reasons for this can be based upon the perception of discomfort, interference with work tasks or a reduced ability to communicate or attend to warning sounds (Melamed, Rabonowits, Feiner, Weisberg, & Ribak, 1996). Furthermore it is suggested that the use of such protection is a matter of awareness, attitude and experience, and that some individuals may simply choose to take a risk over wearing protection, regardless of their knowledge of the consequences (Lusk & Kelemen, 1993). Noise-induced hearing loss is a largely invisible disorder without any obvious immediate indicators that appears gradually according to varied time course. Because of this it is suggested that workers are generally not motivated to do anything independently regarding noise at work (Henderson & Saunders, 1998; ISO, 1990; Robinson, 1991).

While a hearing protector wearing rate of 100% is required for such programs to be perfectly successful, numerous studies have indicated that rates of around 50% are more typical (Lusk & Kelemen, 1993; Waugh, 1993). As noted elsewhere in this document, because of the intensity/time relationship as little as a few minutes unprotected exposure in a high noise environment can effectively render several hours of protected exposure useless. For example, if a set of ear muffs rated at 30dB attenuation is not worn for ten minutes out of one hour of exposure, the effective noise-exposure reduction offered by the protection for the whole hour is equivalent to only 8dB (Standards Australia/Standards New Zealand, 2005). If a level of attenuation approaching 30dB is required then this 8dB capacity will do little to protect the wearer’s hearing.

It should be noted that the unprotected exposure does not have to be all in one session as periods of a few minutes unprotected exposure throughout the day can easily accumulate. This is due to the non-linearity of noise risk. This is contrary to the use of a ‘linear’ protection device such as a hardhat that most workers would be more familiar with. To protect one’s head for half the time reduces the risk of a head injury by 50% over that period, but to wear earmuffs for half the time exposed to noise does not halve the risk to hearing.

As can be seen in Figure 5, the time required to receive the equivalent amount of sound energy of eight hours at the limit of 85dBA decreases rapidly as the sound level increases. For example, at 100dB the total permitted daily noise dose is achieved in only 15 minutes. In terms of hearing protection, this means that even if a worker were to wear a pair of perfectly fitted and maintained earmuffs of sufficient attenuation to protect them from 100dB, more than 15 minutes of unprotected exposure over a whole eight hour day could render the other 7 hours 45 minutes of diligent protection largely ineffective. That is after 15 minutes the person would have received a damaging noise exposure. Note that this equates less than two minutes per hour without the hearing protection fitted correctly, and as noted above the unprotected periods are cumulative over the whole day. Furthermore as the time of unprotected exposure increases the effect upon hearing increases exponentially, 30 minutes of unprotected exposure at 100dB is equivalent to two whole days at 85dBA, while a whole week worth of sound energy would be received in only ten minutes at 109dB.

Figure 5: Minutes of unprotected exposure equivalent to an eight hour average of 85dBA



A particular problem can occur when individuals apply their hearing protection shortly after entering a high noise environment and remove them shortly before leaving, rather than ensuring that their entire period in the exposed environment is protected. This is perhaps one of the fundamental flaws of hearing protection, individuals will only act to don their protection after a high noise situation has been identified (NIOSH, 1996; Sexias & Nietzel, 2004). If this identification comes from the noise itself rather than some form of advanced warning (e.g. signage or a verbal warning) some level of unprotected exposure will always occur.

Naturally it is better for an at-risk worker to wear protection for 50% of the working day than having no protection at all as it should reduce the overall extent of the hearing loss, but depending upon the conditions such a compliance rate could severely compromise the effectiveness of any hearing conservation program. To improve on this level of compliance requires extensive management effort and to achieve the theoretically required 100% compliance may be impossible in practice.

Behaviour based prevention

The idea that the extensive use of hearing protectors is a solution to workplace noise exposure creates a behaviour-based prevention program based around the idea that 'if people were more careful, there wouldn't be a problem'. However as Waugh notes, to expect people to be perfectly safe is akin to expecting them to be perfectly intelligent, perfectly beautiful and perfectly healthy, an expectation that is beyond the reality of the human condition (Waugh, 1993). While many people will take sensible precautions when given suitable information regarding hazards, risks and precautionary measures, not every person behaves this way even when the risks are great (Lusk, Ronis, & Kerr, 1995; Melamed, Rabonowits, Feiner, Weisberg, & Ribak, 1996). The continued existence of smoking, dangerous driving and other such behaviours in the face of widespread knowledge of the risks involved is evidence of this. Furthermore, attempting to change existing behaviour is notoriously difficult, particularly where such behaviour (or the lack of it) has become an ingrained part of the individual's core beliefs or routine (Katz, 2001).

It has been stated that the most common attitude toward the management of occupational heath and safety is to 'leave it up to the workers', a stance that presents major obstacles for the enforcement of hearing protector usage (Eakin, 1992). Many employers in the Eakin study indicated that they thought their egalitarian relationship with their employees would be compromised if the were to dictate to them in regards to their own personal safety. This focus on the personal use of hearing protection avoids addressing the true cause of the problem, the noise itself, and as noted above can easily lead to victim-blaming of the affected individual. While it may be true that "earmuffs and earplugs are the most *simple and cost-effective* solution to workplace noise" (Lipp, 1992), the use of personal hearing protection is far from the most *effective* solution overall, and in the long term may actually be very costly in both financial and human terms. To control a hazard by elimination or reduction to safe levels is the most basic and effective way to reduce the risk of harm (OSH, 1994; Waugh, 1993).

Re-conceptualising the problem

Although a reduction or elimination of the noise source is part of a hearing conservation program and the underlying legislation or regulations, in practice it would appear that these programs generally focus on the outcome of the problem, hearing impairment, rather than on the noise exposure as its cause. In practice they aim to identify why workers don't wear their hearing protection and attempt to implement procedures to convince them to do so. While this approach is certainly more effective than none at all, it fails to give due precedence to addressing the root of the problem.

However, it has been suggested that by conceptualising the problem as 'noise management' the focus is placed squarely on the source of the hazard (Williams, 1993b). This places the onus of avoiding exposure on the whole organisation rather than on the individual alone, and draws attention to the noise exposure properties of equipment, the environment and task design. Such an approach is consistent with the ergonomic mantra of designing the plant, environment and tasks of a work system to suit the capacities of the worker, rather than trying to modify the worker to suit a poorly designed work system (Bridger, 2003).

There is a common idea that as long as the amount of noise reaching a worker's ears is below a given criterion they will be safe from hearing loss, regardless of whether this is due to reduced noise or due to attenuation from hearing protection. This idea holds true in theory, but to base an assessment of protection on just the laboratory-assessed attenuation levels of particular hearing protection devices is erroneous (National Acoustic Laboratories, 1998). Rather the assessment of how much protection a particular device affords should be based upon real-world usage, taking into account the placement of the device, its condition and most importantly for how much of the exposure period the hearing protection is actually worn (WorkCover NSW, 1996). When these factors are taken into account, it can often be impossible for personal hearing protectors to provide the total level of attenuation and exposure protection required (Waugh, 1993). The efficacy of hearing protector usage is covered more extensively in the following chapter. Furthermore, as noted previously all concepts of a threshold for 'safe' levels of exposure are based upon statistical averages across populations of people, and cannot guarantee a specific risk to hearing (or lack of) for any one individual.

Noise management programs, a realistic alternative?

Noise management programs differ from *hearing conservation* programs in that they attempt to control noise exposure on all levels, primarily via noise elimination and exposure reduction but also secondarily via the use of hearing protection where higher level strategies are not yet implemented. This is the approach suggested in the Australia/New Zealand Standard for Occupational Noise Management, which states:

A cost-effective way to manage noise is to apply noise control measures to existing noisy equipment and thereby minimize occupational noise-induced hearing impairment.

For some workplaces, reducing noise levels may require the application of noise management policies, planning and budgeting over a number of years. While these noise control measures are being formulated and implemented, people need to be protected from the effects of excessive noise through hearing protection programs.

To be effective, such programs should be carefully managed… as an interim measure for those people at risk.

Section 0, page 5 (Standards Australia/Standards New Zealand, 2005)

This standard firmly establishes hearing protector programs as temporary measures to be undertaken until a more permanent solution is found. Additionally the position of this standard realistically identifies that reducing noise levels takes time, effort and expense. However it also states that noise control can be a cost-effective measure.

The NSW Code of Practice for Noise Management (Appendix I) lists a hierarchy of measures to control noise which is more aligned to the Standard described above. First on this hierarchy of effective noise control procedures are engineering controls that treat the source of the noise (e.g. quieter machinery, acoustic isolation of plant), followed by the engineering controls that treat the transmission path or reception point of the noise (e.g. sound barriers, low-noise booths). The next most effective controls are the use of personal hearing protectors, and the use of administrative controls. Administrative controls modify work organisation to minimise the number of individuals exposed, such as shift rotation of workers through high exposure tasks, scheduling high exposures outside of normal working hours, and the establishment of low noise periods. These treat the problem of sound at the location of the receiver. This last set of controls is likely less effective due to the non-linearity of noise exposure (i.e. a very long period of quiet is required to account of even a brief period of high noise exposure, while a brief period of non-compliance in a high noise environment can render hearing protection ineffective).

This hierarchy of approaches is also explicit in the Health and Safety in Employment Act ("Health and Safety in Employment Act", 1992), which states that once a hazard has been identified:

Significant hazards to employees are to be eliminated if practicable.

Significant hazards to employees are to be isolated where elimination impracticable.

Significant hazards to employees are to be minimised, and employees to be protected, where elimination and isolation impracticable.

Any attempts to reduce noise and protect the worker from exposure must be part of a comprehensive program involving all levels of organisation including upper and middle management as well as general workers (Saari, 2005), with a focus on education and monitoring to identify noise hazards and equip staff with the means to address them (Williamson, Feyer, Cairns, & Biancotti, 1997). The reality of the situation is that hearing protection will likely continue to be a significant part of any noise-induced hearing loss reduction program in the foreseeable future. However, the recent literature would support a change in approach that avoids total reliance on fallible personal hearing protection devices as the most effective solution to reducing NIHL.

Overall it would appear that there is a trend internationally to shift from a focus on '*hearing conservation'* programs to *'noise management'* programs in order to provide the conceptual change required to further develop the avoidance of dangerous noise exposure in the workplace (Waugh, 1993). This generally reflects the purpose and intent of legislation in most jurisdictions but a such a change of focus may place more emphasis on reducing the hazard foremost and then minimising any risk that remains rather than reducing the risk while leaving the hazard in place, (Williams, 1993b).

Summary

Hearing conservation programs consist of workplace noise surveys to establish exposure levels and ‘noise hazard areas’, engineering noise control methods to reduce noise levels, and the issue of personal hearing protectors and education on their correct fitment and use to mitigate any noise that remains. This is undertaken in conjunction with regular and standardised audiometry administered to all noise-exposed personnel, the results of which are monitored to identify any threshold shift to evaluate the effectiveness of the program.

Hearing conservation programs can be effective at preventing further escalation of noise-induced hearing loss in noise exposed workers when undertaken correctly and in their entirety with support from management and workers alike.

However it has been suggested that the core noise control components of a complete hearing conservation program are very frequently ignored on the grounds of difficulty or expense, often leaving the use of personal hearing protection devices as the first and, sometimes, only component of the program that is implemented.

Personal hearing protection devices are an imperfect solution to excessive noise exposure on their own. There are a number of ways in which they can fail to provide the total amount of protection they afford, particularly when used incorrectly or for less time than necessary. The key issue with hearing protectors is that their use does not prevent the exposure to a noise hazard from occurring, but rather they provide (some) protection from a hazard that the individual remains exposed to.

There is a general consensus among the reviewed literature that hearing protector users practically never achieve the 100% usage rate under exposure conditions that is required to be totally effective. This is particularly problematic as noise does not present a linear hazard exposure profile: a very small period of unprotected exposure to intense noise can negate the effects of a much longer period of full protection.

Furthermore a reliance on hearing protectors can have a socio-organisational impact on hearing loss prevention, framing the issue as one of personal hearing loss resulting from a personal failure to adequately protect oneself. This avoids the fact that noise hazards are the result of much broader organisational processes, and it places the need to deal with it squarely on the individual rather than on the organisation as a whole.

Additionally a hearing conservation program based upon the use of personal hearing protection creates a behaviour based program, where the level of hearing protection is contingent upon consistent and compliant hearing protection behaviours. To expect this level of ‘perfect’ behaviour from a typical human may be unreasonable, and attempting to change existing behaviours to comply is also notoriously difficult.

Conservation programs use pure tone audiometry to identify the onset of noise-induced hearing loss and to inform measures to reduce the severity of further hearing loss. However in terms of close monitoring to detect hearing loss, audiometry can be ineffective unless it is performed almost perfectly. When audiometry is done regularly and correctly it can be used to observe the progression of noise-induced hearing loss in an individual, however it is of little use in preventing or limiting the loss once it is identified.

Audiometry uses permanent and noticeable hearing loss as the test variable. As such some degree of hearing loss is inherently expected, except where a complete lack of loss could indicate a program with perfect success. For this reason a hearing conservation program cannot be considered a total solution to noise induced hearing loss prevention, but rather that it can be an effective tool for minimising the outcomes if delivered correctly.

As an alternative to a hearing conservation program, noise management programs have been proposed. These incorporate a wider organisational approach with a reduction in noise at the source a key component and less reliance on personal hearing protection. While a reduction of noise levels is an integral part of a textbook hearing conservation program, a redefinition of approach may be needed to place noise control at the centre of common practice noise-induced hearing loss control efforts.

Overall a shift from a focus on ‘hearing conservation’ programs to ‘noise management’ programs would provide the conceptual change required to further develop the avoidance of dangerous noise exposure in the workplace. This would change the philosophy from reducing the risk while leaving the hazard in place, to reducing the hazard foremost and then minimising any risk that remains.

Personal hearing protection devices

Introduction

This section reviews the nature and use of personal hearing protection devices (PHPs). The use of personal hearing protection devices has been identified as an insufficient substitute for the reduction of noise at the source or the treatment of noise transmission, and is best used as a temporary measure until such more effective noise control measures have taken place (Standards Australia/Standards New Zealand, 2005; WorkCover NSW, 1996). Irrespective of this, hearing protection is by far the most common method of dealing with hazardous noise and often the first and only step taken by employers (Dobie, 1995; Moretz, 1990; Waugh, 1993).

Types and use of personal hearing protection

Give the attenuation of PHPs and the variance in attenuation. hearing protectors in common use fall into two broad categories, examples of which can be seen in Figure 6. The first category, here referred to as 'earmuffs' or 'muffs', are those devices that are worn on the outside of the head around the external ears. They take the form of solid cups of plastic or a similar material fitted with a padded core and inner edge and connected with a flexible head band so that they form a seal against the side of the head. With such an arrangement the entire structure of the outer ear is contained within a sealed space formed by the skull and the external device, thus limiting the amount of sound energy that can reach the ear.

> **Hearing protectors that are fitted and worn correctly and properly maintained can provide over 30dB of attenuation.**

The effective attenuation of a set of earmuffs depends upon the thickness, density and integrity of the shell, the sound deadening properties of the cup lining and the effectiveness of the seal between the muff and the wearer's skull. The quality of this seal depends upon a number of factors, including the shape and material of the sealing pad, the condition of the padded material, the correct fitment of the device and the shape of the skull itself. Correctly fitted and worn earmuffs in good condition can provide very high levels of sound attenuation. However their use is ultimately limited by the fact that at extreme levels of sound exposure sound will be conducted through the material and through the bone of the wearers' skull, bypassing the protective properties of the hearing protector.

The second category of hearing protectors are devices that are designed to be inserted into the ear canal. These devices are commonly referred to as ‘earplugs’ or simply ‘plugs’, or by a number of trade names. They are usually disposable items taking the form of small cylinders of pliable foam or flexible cones of moulded rubber. However, custom-made devices are available that are moulded to the exact shape of the users ear canals and are intended to be cleaned and reused.

The attenuation of earplugs is dependent upon the density of the material they are made of and how effectively they block the ear canal. To be effective a perfect seal between the plug and the canal is required as any gap allows sound to enter the canal. Incorrect fitting (such as only partially inserting the plug into the middle ear), damaged or dirty plugs, old plugs that have lost their elasticity, atypically shaped ear canals and cerumen (earwax) build up can all lead to an ineffective seal.

Figure 6: Examples of common personal hearing protection devices

Clockwise from top left: Standard earmuffs, radio earmuffs, canal caps, Earplugs have the potential to impact cerumen (earwax) deep in the ear canal against the eardrum or can introduce bacteria or fungi into the ear leading to outer ear canal infections. Additionally there is the possibility of direct trauma to the internal ear if the earplugs are fitted or withdrawn too forcefully. However if the individual is aware of the correct method for insertion and washes their hands and earplugs before fitting, such outcomes are very unlikely.

Custom fitted reusable plugs provide the best fit, comfort and attenuation, however they are substantially more expensive than disposable models and require regular cleaning and careful fitment.

Canal caps are a less common variety of personal hearing protectors that are somewhat of a cross between earmuffs and earplugs. They are like a pair of earplugs supported by a flexible band designed to seal the entrance to the ear canal. They are not designed to be inserted totally into the outer ear as the spring band keeps them in place like with earmuffs to provide a seal against noise. This means they are easier to apply and remove than traditional earplugs and do not require clean hands to fit, yet they are not nearly as bulky, heavy or potentially hot as earmuffs can be. However it has been suggested that they may often not provide such a good seal as required to be effective. Furthermore the band worn either at the front or the back of the neck can be uncomfortable or interfere with clothing or other safety gear, and if bumped or rubbed can transmit loud sounds directly into the ear, which can be extremely irritating (National Acoustic Laboratories, 1998).

Selection, fit and correct use of hearing protectors

Information in this section is adapted from “Attenuation and use of Hearing Protectors”, 8th edition, published by the Australian Commonwealth Government (National Acoustic Laboratories, 1998) and (Dobie, 2001).

The first point that is stressed by most literature regarding the use of hearing protection is that one size does not fit all as individuals can have vastly different size and shape of the head and external ear. This is particularly an issue with female employees or ethnic groups as most earmuffs are designed with the typical dimensions of white European males in mind, however even within a mostly homogenous group there is sufficient individual variation to cause problems (National Acoustic Laboratories, 1998). Earmuffs that do not totally enclose the outer ear and seal properly against the side of the head are largely ineffective. Likewise earplugs that do not form a total seal within the ear will do little to protect the wearer’s hearing.

Hearing protectors are not ‘one size fits all’. They need to be individually selected to ensure an effective fit.

Therefore hearing protectors need to be fitted to the individual or at the least a range of sizes and options should be made available so the individual can select one that fits well. Naturally this also requires a sufficient level of information and training regarding the correct selection of suitable protection.

While there are economic incentives for a company to purchase a bulk order of one particular size or model of protector, this approach could easily lead to a number of staff receiving inadequate protection.

Even with a functional and effective seal, the need for a comfortable fit must also be taken into account. If a particular set of hearing protectors is uncomfortable the individual will be much more inclined to remove them at any available opportunity, or to not even put them on in the first place (Melamed, Rabonowits, Feiner, Weisberg, & Ribak, 1996). Because of this, one needs to also consider the temperature and humidity of the working environment, as wearing earmuffs in a hot environment can make the worker feel hot, sweaty and very uncomfortable. There is anecdotal evidence of individuals drilling holes in their earmuffs to alleviate extreme heat issues and naturally in the process rendering them ineffective at blocking noise. Where heat is an issue, earplugs are often a better option as they do not trap heat around the ears like earmuffs can.

To further ensure consistent compliance, hearing protectors should not interfere with any other equipment or the workers environment. This is a particular issue in construction and similar industries when workers must simultaneously wear hard hats, eye goggles, breathing apparatus or other ‘head mounted’ safety or protective gear. Not only could any interference result in an ineffective fit or a compromised seal, but a conflict between hearing protection and a other gear such as a hard hat would often result in the hearing protectors being removed. This is because protecting the hearing is often seen as a much lower priority than protecting ones body from immediate physical trauma (Sexias & Nietzel, 2004).

Another key point with hearing protectors is that one attenuation does not fit all either, and care should be taken to not “over protect”. While at first this may appear counter to common sense, it is important to not automatically buy the protective device that provide the greatest attenuation available. Rather a device should be selected to suit the level of attenuation demanded by the actual noise exposure that is experienced, rather than blocking as much sound as possible. Typically this consists of selecting the lowest class of hearing protector that would reduce the noise experienced to below the 85dB threshold. The purpose of this is to improve compliance, as people can feel disconnected and separated from their co-workers and the world when their hearing is over attenuated. Hearing is important for communication both on a personal and an operational level, and also for receiving warnings or information. High noise environments place strain on hearing ability as it is. If an individual’s hearing ability is further reduced more than is necessary by excessive hearing protection, they will be less likely to wear them in the first place, and more likely to remove them frequently to communicate (Milhinch & Dineen, 1997).

There are models of earmuff available to improve communication in excessively noisy environments. These include two way radio communication between co-workers and team members.

In addition to providing the workforce with suitable hearing protection devices, education and training on the correct fitment and placement must also be made available (Lusk et al., 2003). It cannot be assumed that each individual knows how to select and fit their protection correctly. Likewise information should be available on how to inspect, clean and maintain hearing protectors to a good working standard. Beyond having staff care for their own equipment, a regular inspection and maintenance schedule should also be part of any hearing protector program. Tailored, personalised programmes that encourage workers’ to take personal responsibility for selection, care and usage of personal hearing protectors increases their use (Lusk et al., 2003).

Earmuff seals are vital to the function of the unit and often require replacement at yearly intervals or even more frequently earmuffs with deteriorated seals can have highly reduced attenuation to the point where they offer little protection at all (National Acoustic Laboratories, 1998). Likewise custom-fitted earplugs loose their efficiency when they become old, dirty, misshapen or brittle, and similarly disposable or foam plugs must be replaced regularly to be effective.

Overall, the maximum level of attenuation that can be achieved with hearing protection (using a combination of both ear plugs and muffs) is an equivalent SLC_{80} of around 35dB, due to the sound conducting properties of the human skull and protector materials as noted previously. Above this the amount of sound energy travelling to the inner ear via the bones of the skull and through the protectors themselves renders any further blocking of the path between the environment and the tympanic membrane ineffective.

This functional limit of attenuation combined with the 85dBA criterion for acceptable exposure creates a maximum limit for the use of hearing protection at 120dBA. Above this it is not theoretically possible to attenuate the sound exposure to an acceptable limit and other measures must be taken to reduce the sound level. In practice such a limit may be reached at a substantially lower level of exposure due to the inefficiencies of hearing protectors, and according to the literature best practice would involve the introduction of other methods to reduce sound energy before such a maximum level is reached.

Workplace attitudes to hearing protection

An extensive study was conducted recently by the United Kingdom's Health and Safety Executive (Hughson, Mulholland, & Cowie, 2002) to identify the factors relating to workers' attitudes towards noise risks and the use of hearing protection and to develop interventions to improve use and compliance.

This study was based initially on a series of surveys completed by 280 employees and 18 representative managers selected from eighteen factories and construction companies in the United Kingdom that were classified as small, medium and large workplaces. Based upon these initial results four of the companies were selected for a tailored active intervention study and follow up assessments were conducted at eight weeks following the completion of the intervention program.The questionnaires covered areas such as noise-related working practices, risk perception, awareness and knowledge of noise exposure and legislation, general safety attitudes and organisational issues. This extensive and systematic study was conducted under legal conditions largely similar to the New Zealand workplace. The results, particularly those relating to attitudes and behaviour, could have significant implications for local interventions designed to increase the usage of personal hearing protection devices or those that aim to increase the noise-risk awareness of employees and management alike. For this reason the results of the study are summarised here.

Attitudes to wearing hearing protection

There was a large variation in hearing protector usage across the various companies, with between 10% and 100% compliant usage observed in existing 'ear protection zones'. This is consistent with findings from other studies that workers only use hearing protection in readily identifiable, very high noise environments. (Williams, Forby-Atkinson, Purdy, & Gartshore, 2002).

Workers in large (>250 employees) and medium sized (26-250 employees) companies were more likely to be exposed to noise all or most of the time, while workers in small companies were more likely to have occasional noise exposure. The most common sources of noise was constant work processes of the whole workplace, followed by intermittent noise created when the worker was using a machine and intermittent noise when another worker was using a machine.

Around half of the employees surveyed reported wearing hearing protection 'all of the time', while the remainder wore it 'some of the time' with a small proportion reporting never protecting their ears when exposed to workplace noise. Based on the tendency to overestimate personal safety behaviours in self report questionnaires (Lusk, Ronis, & Baer, 1995; McBride, Firth, & Herbison, 2003), it is expected that considerably less than 50% of workers actually wore their hearing protection every single time they were exposed to a high noise environment. Similar to other studies the most commonly reported reasons for not wearing them were perceived difficulties created in hearing for communication, feelings of discomfort while wearing the equipment and perceived inability to hear warning signals.

Perception of risk and effects of reduced hearing

Similar to other reports Hughson et al. (2002), found that personal hearing loss or knowledge of hearing problems made the individual no more likely to wear hearing protection. This identifies a key attitudinal problem and a lack of understanding of the true nature of hearing loss.

Workers were categorised into high, medium and low 'risk perception' based upon their responses to a number of questionnaire items. Overall 76% were categorised as having a high perception of risk, 23% as medium and 1.5% (4 individuals) had low risk perception. Three quarters of all respondents indicated that they knew they could become deaf if they didn't wear hearing protection, two thirds (37%) thought their chances of this happening were quite likely if that were the case, and more than three quarters thought that getting industrial deafness would 'ruin their life in later years'. Almost 60% of those with high risk perception reported wearing their hearing protectors all the time, while only 3% reported never wearing them. This indicates that there is likely to be a strong correlation between the perception of noise-risk and the use of devices to abate that risk. However the existence of the 3% who never use hearing protectors despite being highly conscious of the risks of noise exposure, and likewise the 37% that only used them sometimes, indicates that there are other factors that strongly influence the use of hearing protection beyond the simple ability to perceive and understand the risk of not using them.

All four individuals with low risk-perception stated that they never wore hearing protection. (It should be noted that while these individuals did not identify themselves as at risk or lacked the ability to make this distinction, noise surveys conducted by the researchers showed that they were indeed exposed to hazardous levels of noise in their workplace, like all other workers in the study). While these four individuals represent only a very small proportion of an otherwise mostly risk aware and self-protecting sample, they may represent a 'hardcore' minority of workers that perceive no risks and take no precautions. Such individuals would be at a very high risk of developing noise-induced hearing loss, and interventions designed to specifically target this small sector of highly at-risk workers could be very effective to avoid some of the most severe cases of noise-induced hearing loss.

Knowledge of hearing protector issues

In regards to knowledge of issues to do with noise exposure Hughson et al. (2002) found that around two thirds had medium levels of knowledge and one third had high levels, with only 2% being judged to have low knowledge of noise exposure issues. This shows that almost all workers surveyed had at least a basic overall knowledge of noise related issues, however knowledge of certain particular aspects were found to be lacking. For example, less than 4% of all respondents could name the 85dB level at which they should wear hearing protection, and less than 10% knew that a sound level of 93dB was twice the level of exposure as 90dB.

Knowledge scores were found to correlate fairly strongly with risk-perception scores, and both correlated with a general factor of ‘general attitude to safety’. This suggests that knowledge of the issues of noise exposure and hearing loss leads to an increased tendency to accurately perceive the true severity of the risk of unprotected noise exposure. However once again they could not be taken as the sole factor, and indeed it is more likely that noise safety perceptions, attitudes and behaviours are part of a complex and interactive system with many factors and processes (Lusk et al., 2003).

Impact of organisational size on perception and behaviours

Overall workers in large companies had greater perceived risk awareness and levels of knowledge of hearing loss and the impact of nosies exposure. This may relate to the fact that larger companies (85%) had hearing protection programs that their employees were aware of, while this was less that 50% for medium and small sized companies. Similar rates were reported in regards to the dissemination of information about noise at work.

Workers from large companies were almost twice as likely to report having received information about noise exposure at work from their managers as those in medium or small companies. Furthermore, approximately fifty percent of those in the smaller businesses that did report receiving such information said that it was within the last year, compared to 80% from the large companies. This indicates that not only are large companies substantially more likely to disseminated information regarding noise in their workplace, but this also suggests that such dissemination occurs much more frequently than in smaller organisations and as a result the information received is also far more likely to be up to date.

These readily observable differences between large and small organisations has significant implications for noise-risk and hearing protection attitudes in the New Zealand workforce, where an estimate 97% of business representing 42% of all paid workers would fall into the 'small' category used in this study. As a further 22% of workers are self employed, only 36% of workers in New Zealand work for large organisations (Barker, 2005).

Information dissemination and recall

Interesting results were found when comparing management and worker questionnaire responses. The management of all companies reported making 'information' available to employees regarding where and how to obtain hearing protection and the legal requirements of employers and employees relating to noise at work. However, 56% percent of all employees from the same companies reported not receiving any information. Likewise from the ten companies that reported providing information specifically on the risks of deafness due to exposure to noise at work 53% of employees did not identify that any such information had been received. Similarly only 39% of workers from companies that reported using leaflets to disseminate information said they received information from leaflets or information sheets.

It is understandable that management are more likely to have greater recall of such information delivery than employees, as it is management that would have developed and implemented the information dispersal while workers may have only been exposed to the end product very briefly. However these large discrepancies between reported delivery and reported reception suggest problems, either these media are largely ineffective at reaching all workers, or management are overly confident about the effectiveness of their information delivery. Overall this appears to show that the typical means for providing information to workers can be far from satisfactory. Such information delivery should be an integral part of a wider noise-control program and feature regular updates and revisions. According to the authors this would be of greater effect than if delivered in isolation and would allow up to date information to be remembered and understood more readily.

Attitudes toward hearing protector use

Several key attitudes regarding the use of hearing protection and noise safety were identified.

Workers were found to have higher rates of hearing protector usage if there was a strong association between their use and the task at hand. This was particularly so where regular and predictable high noise from a specific machine established hearing protection as a part of the routine of operating that machine, i.e. where there is an obvious hearing health hazard. This has also been found elsewhere in construction (Milhinch & Dineen, 1997) and agriculture (McBride, Firth, & Herbison, 2003). Furthermore higher rates of protection were observed in those that had established a personal habit of wearing protection, regardless of whether on not the protection was actually required. This was often reported as the result of frequent reinforcement from co-workers, leading to a well learned behaviour over time. It is suggested that while workers will ultimately make decisions to use personal protective equipment themselves, a high level of risk awareness and support from a strong safety culture with peer approval will increase the probability of the right decision.

The authors of this study noted a number of reasons that made workers much more likely to wear hearing protection. These were:

If they understand the physiological effects of noise exposure

Where noise levels are highest

Where the noise levels are constant

Where the process conditions are unchanging

Where the job or task is routine

Where they are actively involved in a noisy task

Where they are directly supervised

Where management demonstrated commitment to hearing conversation

Where there is positive support form peer groups

(Hughson, Mulholland, & Cowie, 2002) p35

From the above list, three key factors for regular hearing protection usage can be identified. The first is that the individual understands the risks of noise exposure, and identifies their level of exposure as a problem. The second is that using hearing protection is a considered a regular and integral part of their job (and that their job tasks are not so variable that this attitude does not develop). The third factor is that there is sufficient commitment and support from peers, supervisors and management to wear hearing protection.

Summary

To summarise the preceding findings, for optimal hearing protector usage a workplace should have:

Accessible protection: That hearing protectors are freely available and in good working condition, and that workers are aware of how to correctly fit and wear them without any conflict from other equipment or objects.

Identifiable hazard: Workers have the knowledge to identify the existence of hazardous noise and be made aware that noise hazards do exist in their workplace.

Safe attitude: Workers understand that noise exposure is a hazard, that exposure should be avoided and that avoiding exposure is an important action for them to take.

Cultural-Organisational support: A hearing-safe culture exists in the workplace with active support for hearing protector usage from all levels of organisation, including managers and peers.

Therefore, effective interventions to increase the use of hearing protection in industry should include effective training and accessible information on the selection and proper use of hearing protection and the implementation of a regular maintenance and inspection program. Furthermore training and information regarding excessive noise exposure as a risk to hearing, health and lifestyle is required, as is functional training to identify what kinds and amounts of noise exposure constitute a risk to hearing.

For larger organisations, cultural-organisational support would be best dealt with through existing organisational structure and health and safety processes and staff. For smaller companies that cannot afford such health and safety ‘infrastructure’, the above requirements must be integrated into standard operating procedures and responsibility must be taken by managers, foremen and general staff alike.

Compounding and potentiating factors of noise-induced hearing loss

This section provides an overview of the factors that interact with noise exposure to affect the course and severity of NIHL.

Presbyacusis and the effects of age

Age-related hearing loss is the most common form of hearing impairment, and can be distinguished from noise-induced hearing loss by a different audiometric pattern (Toppila, Pyykko, & Starck, 2000). While many hearing-related diseases are prevalent in the elderly, such as ear infections, otosclerosis and Menière's disease, the term presbyacusis (literally 'old man's hearing') is used to describe hearing loss that is attributable to 'the process of ageing alone'. The most salient difference is that unlike noise-induced hearing loss which predominately affects the sensory hair cells, presbyacusis can be due to the degradation of a number of different elements of the cochlea and auditory system, causing different patterns of hearing loss (Dobie, 2001).

The audiometric profile of presbyacusis varies according to the pathology (Schuknecht, 1993) but the classical profile is a progressive threshold shift where the highest frequencies are first and most severely affected. This compares with the 'notch' in the audiogram at 3-6 kHz that is characteristic of noise-induced hearing loss.

It is the conclusion of a number of studies that the factor of 'age' is a significant predictor of noise-induced hearing loss, second only to noise exposure itself (Stephens, 1982; Toppila, Pyykko, & Starck, 2000). However this is simply due to the fact that total exposure to other hearing loss causing factors and confounders naturally increases as time progresses. Therefore a distinction must be made between the basic factor of 'age' and the more specific factor of 'age-related hearing loss'.

While they feature different pathologies and causes, the effects of noise exposure and ageing upon hearing can be difficult to separate.

The relationship between presbyacusis and noise-induced hearing loss is not clearly established. In general and this is the basis of the ISO 1999 standard, it is suggested that age-related permanent threshold shift and noise-induced permanent threshold shift have an additive effect. That is to say that age-related deafness progresses at the same rate regardless of previous noise-induced hearing loss (Macrae, 1991), and vice versa (Welleschik & Raber, 1978), and that the total hearing loss is the sum of the hearing loss from age and noise exposure in dB There is also some research to suggest that age may have a slightly overlapping effect on noise-induced hearing loss, particularly where total hearing loss is above 40dB (Mills, 1992). This potential for overlap is identified in current ISO and ANSI standards for calculating the relative contributions of age and noise to total hearing loss. The rationale for this is that the damaging effects of age and noise overlap in the cochlea, and when one agent has destroyed a large proportion of hair cells there is simply less opportunity for the other to cause damage (Dobie, 2001). Others have suggested that the total hearing loss from presbyacusis and noise-induced hearing losses is best determined by adding the intensities of the losses rather than dB (Humes and Jesteadt, 1991, Mills et al., 1997) but this has been disputed and it is suggested that the addition in dB is a reasonably accurate prediction of the interaction (Boettcher, 2002).

Interestingly, observations from the Framingham Heart Study suggest that if the ear has suffered some damage from noise exposure hearing loss from age progresses at a faster rate at the frequencies adjacent to the noise-induced hearing loss (Gates et al., 2000). Thus the noise exposed ear appears to ages at a different rate than the non-exposed ear and the damage may continue after the exposure has ceased (Gates et al., 2000). Kujawa and Liberman recently tested this in animals and showed if mice were exposed to a single traumatising sound when very young they developed far more severe hearing loss and cochlear damage as they aged then animals who aged but were not exposed to the noise (Kujawa and Liberman, 2006). This suggests an early exposure to noise during development precipitates the effect of aging. Collectively these data have important public health implications and imply that the noise and aging effects cannot simply be added together.

Ototoxic chemicals

Some chemicals can cause hearing loss. These “ototoxins” cause hearing loss by damaging the cochlea and/or the auditory pathways at a variety of locations, not only the hair cells as is the case with noise.

Potential ototoxins include solvents and fuels such as toluene, white spirit, xylene, butanol, heptane and n-hexane, metals such as arsenic, lead, manganese, mercury and organic tin, exhaust fumes in the form of carbon monoxide, fumigants and herbicides like hydrogen cyanide and paraquat, and organophosphate fertilisers, among many others (Fechter, 2004).

Many of these chemicals are in common usage in a variety of industrial and agricultural occupations and can present a potential risk to the hearing of individuals in these positions. Many of these compounds show synergism with noise exposure in experimental animals and the true extent of the effect of such substances upon hearing in humans is not fully recognised (Sliwinska-Kowalska et al., 2005). . However it is suggested that while ototoxins present only a moderate risk to hearing when individuals are exposed to them alone, a combination of toxins or toxins in conjunction with noise can have an additive or even synergistic effect (Fechter, 2004). One study reported that Brazilian printers exposed to high levels of toluene and noise developed substantially more hearing loss than printers with similar noise exposure but no toluene exposure (Morata, Dunn, Kretschmer, Lemasters, & Santos, 1991). Some earlier studies have shown that concurrent noise and ototoxin exposure leads to hearing loss that is no greater than would be expected from noise alone (Jacobsen, Hein, Suadicani, Parving, & Gyntelberg, 1993), while other studies indicate at least an additive effect (Morata, Dunn, Kretschmer, Lemasters, & Keith, 1993). These mixed results are due in part to the wide variety of ototoxic effects each with a potentially unique toxicology and effect on hearing; methodological issues regarding animal testing, varied exposures and sample populations and difficulty isolating independent variables; and a gulf between clinical and epidemiological evidence.

A recent study has stated that the current body of knowledge is now sufficiently developed to support the claim that ototoxins can indeed have a synergistic effect with noise, and even suggests that certain non-ototoxic chemicals may catalyse noise-induced hearing loss (Sliwinska-Kowalska et al., 2005). While in a similarly recent review it is noted that organic solvents tend to have an additive effect, while asphyxiants have a truly synergistic effect (Fechter, 2004).

A recent report published by the Australian National Occupational Health and Safety Commission states that there is limited awareness in the Australian occupational health community of the chemical hazards to hearing (NOHSAC, 2004). There is nothing to indicate that this is not also the case in New Zealand. Furthermore it suggested that typical hearing conservation practices do not take into the account the risk of ototoxic exposure alone, and most certainly have no special provision for such exposure in combination with noise.

Further research is greatly needed in this area, particularly to identify what levels and combinations of ototoxin exposure commonly exist in New Zealand industry, the nature of noise exposure that is typically concurrent with this, and the best approach to reduce the hearing loss that results from combined exposure.

Ototoxic drugs

One subset of ototoxic substances is drugs and medicines that cause hearing loss. They are identified separately here because exposure to them is typically deliberate and regulated according to medical advice, rather than being somewhat uncontrolled as an occupational hazard. Examples of such ototoxic drugs are the cytotoxic compounds used as anti-cancer treatments like cisplatin, the aminoglycoside range of antibiotics (gentamicin, neomycin and others), diuretics such as furosemide and even large doses of aspirin (OSH, 1994).

Again, like the chemicals identified above, these substances have been shown to have a variety of different additive, synergistic and even attenuating effects on hearing loss when combined with noise exposure, particularly in animal studies. However it is still tenuous to try and identify the specific contribution that such medicines have on total hearing loss, and indeed much of these have been identified by their potential to cause temporary threshold shift or tinnitus in high doses, rather than long term permanent hearing loss (Lawton & Robinson, 1989).

Whilst awareness of the interactions between drugs and noise is important, Dobie (2001) has noted that in reality the combined effect of drugs and noise on hearing is probably of relatively little concern for noise exposure in an occupational setting. The consumption of such medicines would generally be limited to short specific periods of illness, periods where the individual is likely to be absent from work and therefore not concurrently exposed to high levels of noise. In the case of cancer treatment the drug exposure may be intense and sustained and patients would not be expected to continue working during such intensive therapy.

On the other hand there is a potentially greater risk from medications that are taken regularly for long periods while the individual is able to work or be otherwise exposed to sustained high levels of noise (Lawton & Robinson, 1989). For example, there have been concerns about the interaction of aspirin, which has been shown to potentiate noise-induced temporary threshold shift in humans (Lawton & Robinson, 1989) although it may ameliorate the effect of noise on the cochlea in animals through its ant-oxidant propoerties (Kopke et al., 2000; Yamashita et al., 2005). There is no evidence that aspirin enhances the severity of NIHL. Indeed the risk of exacerbating hearing loss is likely to be slight in comparison to the risks of heart attack, and studies have suggested that only a high dose of aspirin (six or more tablets per day) would have this effect (Lindgren & Axelsson, 1985).

There is little evidence to suggest that ‘normal’ doses of any drug over a limited time period presents a particular additional risk to hearing. However it is recommended that any individual taking a course of a known ototoxic drug, particularly in high doses or for an extended period, avoid potentially hazardous noise exposure during dosage and for two weeks after their last dose (Dobie, 2001). Further research in this area should be directed toward medications that are typically taken in large doses of for an extended period while the individual is still capable of working in a high noise environment, and toward any newly developed drugs that are intended to be taken daily by a largely healthy individual.

Vibration

High levels of vibration are not uncommon in the workplace and frequently produced in conjunction with noise by machinery and power tools with oscillating or cyclically moving parts. Vibration can cause objects and surfaces to resonate and emit noise, and high levels of noise can make surfaces vibrate. It is largely established that vibration alone does not cause hearing loss (Boettcher, Henderson, Gratton, Danielson, & Byrne, 1987).

However whether vibration can potentiate the hearing effects of noise exposure during simultaneous exposure to both factors is not clear. One animal study demonstrated greater temporary and permanent threshold shift in chinchillas exposed to noise and vibration at their body resonant frequency than with noise exposure alone, along with concurrently higher levels of hair cell loss (Boettcher et al., 1989). A laboratory study using human subjects showed similar results, with a greater noise-induced temporary threshold shift where the subjects were concurrently exposed to whole body vibration at 5 Hz (the approximate body resonant frequency of humans), however as always the link between temporary threshold shift and permanent hearing loss is tenuous (Manninen, 1983). Additionally these animal and human experiments have been criticised as lacking ecological validity, due to their exposure of the subjects to levels of both vibration and noise that are both well in excess of typical exposures and legal limits (Lawton & Robinson, 1989).

Epidemiological studies in industrial populations have suggested a possible link between 'vibration induced white finger' and permanent threshold shift in forestry (Iki, Kurkmatani, Hirata, & Moriyama, 1985) and mining (Szanto & Ligia, 1999). However it should be noted that such a correlation would be expected due to the common co-existence of noise and vibration in industrial applications as noted above. As vibration in the absence of noise is comparatively rarer in industry than noise and vibration together, it is suggested that finding a suitable control population for such retrospective studies would be almost impossible (Lawton & Robinson, 1989).

Currently there appears to be insufficient evidence to suggest that concurrent vibration provides a significant additional risk to hearing but the above studies show some potential for an additive effect although the effect sizes are small and validity is questionable. Other studies have furnished mixed results, indeed some have even suggested a slightly protective effect (Lawton & Robinson, 1989).

Therefore in terms of protecting individuals exposed to both noise and vibration from harm, resources would be more efficiently allocated to reducing the noise itself (assuming any vibration is suitably controlled according to existing guidelines for vibration exposure). However, where individuals are exposed to significant whole-body vibration it may be prudent to implement further noise reduction measures or set a lower limit of acceptable noise, particularly if the vibration is close to the 5Hz body resonant frequency of humans.

Vascular effects

Like any part of the human body, the cochlea and hair cells cannot function or survive without adequate blood supply. It is for this reason that vascular changes have been implicated as one of the possible contributing mechanisms for noise-induced hearing loss and a potential compounding factor (Hawkins, 1971). Furthermore it has been suggested that individuals with vascular diseases such as diabetes or hypertension that create poor general blood flow may be at greater risk of noise-induced hearing loss due to poor blood flow to the cochlea (Dobie, 2001). However again research in this area has been limited, with typically mild and contradictory effects and there is as yet no real evidence to support the above hypothesis (Saunders, Dear, & Schneider, 1985). While this remains an area for further study with potentially great gains to be made in understanding the mechanics of noise-induced hearing loss, currently resources could be better spent addressing the more salient factors of noise-induced hearing loss, namely noise exposure itself.

Smoking, alcohol and exercise

A number of population studies have identified a positive relationship between cigarette smoking and hearing loss (Cruickshanks, Klein, Klein, Wiley, & Nondahl, 1998; Rosenhall, Sixt, Sundh, & Svanboug, 1993). This implication that tobacco smoking is hazardous to hearing holds true even when adjustments have been made for other factors such as age and noise exposure (Itoh, Nakashima, Arao, Wakai, & Tamakoshi, 2001). This effect maybe due to impact that carbon monoxide and other toxins in cigarettes have on cochlear blood supply, but the precise mechanism is unconfirmed (Ferrite & Santana, 2005).

Animal studies have shown that concurrent exposure to carbon monoxide exacerbates noise-induced hearing loss and that this maybe due to the production of free-radicals (Fechter, 2004). Despite this, studies in humans looking at the combined effects of concurrent smoking and noise exposure on permanent threshold shift have been more limited in number and scope. Generally such studies show an additive effect between the two factors, identifying noise exposed smokers as having more adverse effects than their non-smoking counterparts (Mizoue, Miyamoto, & Shimizu, 2003; Uchida, Nakashima, Ando, Niino and Shimokata, 2005). The interaction is not seen to be synergistic or beyond the sum of the individual contributions of each factor, however there is some evidence that synergism may occur between noise exposure, smoking and age (Ferrite & Santana, 2005).

Although cigarette smoke contains a number of organic solvents and metals that have been proposed to cause synergism with noise, the concentrations of these toxins in smoke is likely to be well below that experienced during occupation exposure to the same chemicals. Paradoxically one experimental study identified a possible protective effect of smoking on temporary hearing loss (Dengerink, Lindgren, & Axelsson, 1992), but as stated above it appears that the opposite is true for permanent threshold shift.

As with other factors identified in this section, the independent effects of smoking upon hearing are substantially lower than the damage caused by excessive noise exposure. Again where deafness is the concern it would be much more effective to use resources to reduce noise levels and promote hearing safety than to attempt to reduce smoking.

In addition to smoking, there is some indication that alcohol consumption may have an effect on noise-induced hearing loss. One recent experiment has shown that moderate alcohol consumption and moderate physical activity prior to noise exposure has a protective effect on temporary threshold shift (Strasser & Irle, 2002). This was thought to be because of the alcohol-induced capillary vasodilatation and an increased heart rate due to exercise resulting in increased blood flow to the cochlea. In contrast, other studies involving higher levels of physical exercise independent of noise-exposure have reported adverse effects on hearing (Engdahl, 1996; Landstrom, Bystrom, & Olofsson, 1999).

These results are based upon a few isolated experiments with a small sample sizes, and thus the actual impact of alcohol or exercise on noise-induced hearing loss is unknown, if any such interaction actually exists.

Individual and genetic susceptibility

There is much discussion regarding individual susceptibility to noise-induced hearing loss. In large population based studies much variation is seen between individuals, even when noise exposure, age, disease and other potentially influential factors are controlled for. Attempts to describe this variability via non-auditory factors have shown only small amounts of this variance can be accounted for (Henderson, Subramaniam, & Boettcher, 1993).

It appears that like most human conditions, the extent of noise-induced hearing loss in the individual is to some extent determined by some form of individual susceptibility. Research has aimed to identify factors such as gender or ethnicity that may be used to predict this susceptibility (Dobie, 2001), as well attempts have been made to characterise individuals with 'tough' or 'tender' ears based upon temporary threshold shift, yet so far such studies have given little predictive power (National Institutes of Health, 1990). Genetic and environmental factors affect susceptibility to hearing loss with age (DeStefano, Gates, Heard-Costa, Myers & Baldwin, 2003). Genetic differences appear to account for some of the difference in susceptibility (Davis, Kozel & Erway, 2003; Heinonen-Guzejev, Vuorinen, Mussalo-Rauhamaa, Heikkila, Koskenvuo & Kaprio, 2005) but this does not seem to be related to genetic differences in the ability to cope with oxidative stress (Carlsson, Van Laer, Borg E, Bondeson, Thys, Fransen, 2005). Men have much greater rates of noise-induced hearing loss than females but the question of whether this is due to inherent or environmental differences is not resolved. Interestingly female chinchillas develop less high frequency hearing loss from noise exposure than male chinchillas suggesting a gender difference rather than environmental difference (McFadden, Henselman & Zheng, 1999).

A greater understanding of what personal characteristics may create a susceptibility to hearing loss could be most beneficial in developing interventions to target those individuals that are most at risk. However in the absence of reliable data in this area, targeting individuals or groups as susceptible to noise-induced hearing loss based upon expected noise exposure would be a more far more effective approach in the short term.

Summary

Age-related hearing loss is the most common form of hearing impairment, and clearly different from noise-induced hearing loss in terms of its pathology. However the effects of 'age' on hearing are not always clear-cut: it may often be difficult to isolate the hearing loss that is due to the ageing process alone from other deafness-causing factors that also correlate with age.

In general it is suggested that age-related permanent threshold shift and noise-induced permanent threshold shift have an additive effect, however there is also some research to suggest that age may have a slightly overlapping effect with larger losses.

There is some evidence that very young persons are more susceptible to noise exposure. However, because of the compounding effect of age-related hearing loss the impact of a given noise exposure may be greater in an older person. While it is key that hearing loss prevention begins in youth, the hearing of older, already exposed populations also require conservation from further loss.

Ototoxic chemicals can cause hearing loss by damaging the cochlea and/or the auditory pathways at a variety of locations, not only the hair cells as is the case with noise.

Potential ototoxins include solvents, fuels, metals, carbon monoxide, fumigants and herbicides and fertilisers. Many of these chemicals are in common usage in a variety of industrial and agricultural occupations and can present a risk to the hearing of individuals in these positions. Industries using organic solvents, herbicides and fertilisers are also frequently associated with concurrent excessive noise levels.

Research indicates that while ototoxins present only a moderate risk to hearing with isolated exposure, a combination of toxins or toxins in conjunction with noise can have an additive or even synergistic effect. Typical hearing conservation practices do not take into the account the risk of ototoxic exposure alone, and most certainly have no special provision for such exposure in combination with noise. However, the level of understanding of the interactions between ototoxins and noise exposure is limited and to make any concise conclusions is difficult. Further research is greatly needed in this area, particularly to identify what levels and combinations of ototoxin exposure commonly exist in New Zealand industry, the nature of noise exposure that is typically concurrent with this, and the best approach to reduce the hearing loss that results from combined exposure.

Some drugs and medicines can cause hearing loss. Examples of ototoxic drugs are some cancer treatments, antibiotics, diuretics, and high doses of aspirin. Some of these substances have been implicated as have additive or synergistic effects on hearing loss when exposure is in conjunction with excessive noise.

High levels of vibration are not uncommon in the workplace and frequently produced in conjunction with noise by machinery and power tools. It is largely established that vibration alone does not cause hearing loss, however there is current debate as to whether vibration can potentiate the hearing effects of noise exposure during simultaneous exposure to both factors. Currently there is insufficient evidence to suggest that concurrent vibration provides a significant additional risk to hearing, however where individuals are exposed to whole-body vibration it may be prudent to implement further noise reduction measures, particularly if the vibration is close to the 5Hz body resonant frequency of humans.

A number of population studies have identified a positive relationship between cigarette smoking and hearing loss when other factors such as age and noise exposure have been adjusted for. The general consensus it that this effect is due to the impact that carbon monoxide and other toxins in cigarettes have on vascular blood supply, however the precise mechanism is unconfirmed.

Like most human conditions, the extent of noise-induced hearing loss in the individual is to some extent determined by individual susceptibility. Research has aimed to identify personal or genetic factors that could be used to predict susceptibility to noise-induced hearing loss, yet so far such studies have given little predictive power.

A greater understanding of what personal characteristics may create a susceptibility to hearing loss could be most beneficial in developing interventions to target those individuals that are most at risk. However in the absence of reliable data in this area, targeting individuals or groups as susceptible to noise-induced hearing loss based upon expected noise exposure would be a more far more effective approach in the short term.

While many of these secondary factors can cause hearing loss alone and possibly have synergistic effects in combination with noise exposure, the reviewed literature indicates that none come close to accounting for as much hearing loss as noise exposure alone. Hearing loss prevention strategies should focus on reducing noise levels foremost, but further consideration should be made in situations where high levels of noise are experienced in combination with another agent.

Noise-induced hearing loss in high risk groups

Exposure to high levels of noise and noise-induced hearing loss rates are far from equally distributed across the general population. For example in New Zealand, of the 25,710 successful ACC claims for noise-induced hearing loss over the last decade where occupational grouping was known, over 55% were tradespersons, machine operators or workers in the agricultural sector. By contrast just 15% of claimants were listed as technicians, clerks or professionals. Likewise as noted elsewhere in this document, it is primarily males who are affected by noise injury and rates are substantially higher in older individuals than youth, mainly because of the cumulative exposure.

Naturally individuals who work in occupations where noise exposure is commonplace are at a much higher risk of developing hearing loss. However the risk of developing hearing loss in a noisy environment is also compounded by accessibility and use of hearing protectors or other noise control methods that may differ across groups and industries. For example it is noted that "*construction and farming are characterized by small independently operated enterprises: few* [workers in these occupations] *are included in hearing loss prevention programs"* (Kerr, McCullagh, Savik, & Dvorak, 2003, p1).

Assessing the particular risk of certain occupational and demographic groups should facilitate the development of specific interventions to target groups of individuals who are most at risk. Two key occupations have received recent attention due to the high rates of noise-induced hearing loss among workers and are reviewed here.

Agricultural workers

The agricultural industry and particularly pastoral farming has received considerable attention both internationally and in New Zealand. According to the ACC statistics, a substantial number of claims comes from this industry.

A recent study of 586 Southland farmers indicated that the median daily L_{eq} exposures derived from a noise exposure survey of mainstream farming activities lay between 84.8 and 86.6 dBA (McBride, Firth, & Herbison, 2003). This is typical of moderate industrial exposure and mostly in excess of the New Zealand standard of 85 dBA. However it is noted by the authors that a significant minority of exposures exceeded 90 dBA, indicating intermittent higher exposures. They cite such activities as chainsaw operation (120dBA), pig feeding (105dBA) and operating cab-less tractors (100dBA) as substantial contributions to the average daily exposure. Furthermore it was stated that observed hearing loss in the same sample of farmers was consistent with this level of exposure.

Of a smaller group of 60 individuals that were observed directly, 8.3% were observed to wear hearing protection 'most of the time', 16.7% 'some of the time' while the clear majority were not observed to wear hearing protection at all (76.7%). Approximately three quarters of the sample undertook three or more different farming activities a day, some of which resulted in noise exposure and some which did not. It is likely that this varied mix of quiet and noisy activities is one of the main causes for such inconsistent hearing protector usage. Also the lack of a need to always wear protection may have reduced compliance when there was an identifiable noise hazard because of the practical issues of remembering to apply protection when changing tasks. For example hearing protector usage was most common with very high noise chainsaw usage, but significantly less common with relatively lower noise tractor operation, even though both were often significantly above the recommended exposure limit. Furthermore comparison of observations and self-reported hearing protector usage indicated that farmers overestimated their use of hearing protection. This indicates that self-report measures of hearing protection are likely to be unreliable, and that perhaps farmers own conceptions of what constitutes effective and timely use of hearing protection may be inconsistent with what is actually required for them to be effective.

McBride et al. (2003) concluded that the common everyday sources of noise in farming are high but not intense, however because of this the effects can be subtle and the onset of hearing loss insidious.

Everyday sources of noise in farming are high but not intense, so their effects can be subtle and insidious.

They noted that noise reduction or isolation at the source is best practice, yet in the agricultural context this may be impracticable, leaving hearing protection as the easiest control option. The fact that greater hearing protector usage was observed with higher noise activities indicates that there is as least some knowledge of the hazard that excessive noise presents in farming, and that some level of link exists between risk perception and risk-mediation behaviours.

Further knowledge of the efficacy of hearing protection and the intensity of typical noise levels in the agricultural sector could lead to great improvements in noise-induced hearing loss rates among farmers.

A screening study conducted with an Australian population found an elevated risk of hearing loss in farm workers and a similar pattern of hearing protector usage in a farm setting (Williams, Forby-Atkinson, Purdy, & Gartshore, 2002).

These studies identify that a potentially significant barrier to optimal hearing protector usage in agricultural settings may be a failure to identify all excessive noise sources as a hazard. This points out the need to disseminate the concept that any noise or sound can be hazardous if it is of sufficient intensity or duration, and furthermore that in terms of hazards to hearing the terms ‘noise’ and ‘sound’ are synonymous.

A later study of 808 young adult farmers aged 15-24 years from New South Wales, Queensland and Tasmania conducted over seven years showed a visible decline in hearing threshold when data was compared across two year age blocks (Franklin, Challinor, Depczynski, & Fragar, 2002). In addition there was a strong correlation between the audiometric thresholds and participants’ subjective evaluation of their hearing ability. This study indicates that, in the Australian setting at least, new cases of noise-induced hearing loss are forming in young agricultural workers in a manner consistent with the observed noise exposure levels and limited protective practices. This survey identified similar sources of potentially hazardous noise exposures to those seen in other agricultural studies with the majority or respondents reporting the use of workshop tools (89.9%), chainsaws (82.4%) and firearms (78.7%).

Again, inequalities were observed in reported hearing protector use for a number of tasks that all represented a possible noise exposure risk. For example, a large proportion of respondents reported always using hearing protectors when operating a chainsaw (31.5%) or driving a tractor without a cabin (22.8%), yet a smaller proportion would always use them when using workshop tools (17.8%) or operating firearms (9.7%). Perhaps more disturbing are the results that show close to half of the sample never wore hearing protection even with easily identifiable high noise tasks such as chainsaw operation. These results suggest that in this study self-reported hearing protector usage was generally inadequate, and particularly so for activities that may not be undertaken regularly or be seen as a typical ‘noisy job’. One particular concern is the apparently consistent lack of hearing protection with firearm use, indicating a perception that firing guns is not a risk to hearing. This is perhaps due to the fact that such exposures are brief, irregular and intermittent (unlike those that come from tractors or chainsaws), and despite the fact that such high intensity impulsive noises can often cause immediate damage to the ear (Odes, 1972).

In summary the authors concluded that in Australia young adult farmers already show signs of noise related deafness, and if noise avoidance and hearing protection behaviours are not changed then the hearing of farmers will continue to decline overall. They state that further work needs to be done to increase the number of young farmers wearing hearing protection, particularly wearing protection in all noisy situations, for all the time exposed to noise.

Farmsafe Australia, a partnership of industry and government agencies, has published a strategy for noise injury prevention for the Australian farming community (Farmsafe Australia, 2004). Their approach to managing noise-induced hearing loss is threefold:

Reducing the incidence: To prevent noise injury occurring.

Reducing the severity: Intervention at an early stage to reduce the degree of hearing loss.

Reducing the impact: management, rehabilitation, appropriate education and funding to lessen the impact of existing hearing loss upon the quality of life of the effected person and their family.

In addition to this they suggest a strategy comprised of:

Establishing a national framework for action

Identification of key noise exposure risks and other risk factors

Identification of effective controls for selected problems

Education and training

Legislation, regulations and standards

Monitoring of peoples hearing

Awareness and promotion of strategies

Access to services and devices for people with hearing impairment

Identification of further research needs

Identification of the implementation of strategy

Similar results to those above have been found in agricultural populations in the United States. One older study notes that of twenty pieces of specialist farm equipment assessed in 1968, such as tractors, grain dryers and chain saws, thirteen exceeded the 85dB average level at 0.5, 1 and 2 kHz (Jones & Oser, 1968). While design evolution has led to a quietening of equipment, comparison of these levels to those observed in more recent studies (eg McBride et al., 2003) suggests that sound output levels of some farm machinery may not have altered substantially. Furthermore, it is likely that in some places equipment several decades old is still in use. From one assessment of farming noise in Wisconsin, measurements of noise levels in 155 tractors on 36 farms indicated 75% of cab-less tractors produced noise levels at the operators seat of 90dB or greater, while even inside the cab of enclosed tractors some 18% still exceeded this figure (Holt, Broste, & Hansen, 1993). It should be noted here that this study was conducted according to the 90dB OSHA limit for the American agricultural industry, a limit that represents a sound energy level greater than the 85dBA limit used in New Zealand.

A number of studies have shown a high rate of hearing loss among American farmers similar to those observed in New Zealand and Australia. For example, in a Missouri study 47% of farmers reported hearing loss versus 32% of non-farmers from the same locality (Thelin, Joseph, Davis, Baker, & Hosokawa, 1983), while in rural New York, 65% of tested dairy farmers had hearing loss at 3, 4 and 6kHz compared to 37% of their non-farming peers (Marvel, Pratt, Regan, & May, 1991). The discrepancy between the hearing loss rates of general farmers in Missouri and dairy farmers in New York is no doubt largely due to differences in testing methods and criteria between the two studies, however these differences may also indicate inequalities in hearing loss and noise risk between the various sectors of the farming industry. Such a difference in risk between farmers undertaking different activities on a daily basis would not be surprising, and indeed has been observed at some level in both the New Zealand (McBride, Firth, & Herbison, 2003) and Australian settings (Franklin, Challinor, Depczynski, & Fragar, 2002). An informal audiological survey in 2005 of 400 attendees at the Field-days Agricultural show at Mystery Creek in New Zealand revealed high numbers of farm workers with substantial hearing loss (Thorne personal comm.). Currently the specific contribution of ‘farming type’ to noise-induced hearing loss rates is uncertain, and further research in this area could be most beneficial to for the design of interventions targeting the agricultural industry.

Construction workers

Like agricultural workers, construction workers have been identified as one sector of industry that is at great risk of noise-induced hearing loss. This is due to the frequent use of power tools, tasks that involve impacts and other high noise activities, coupled with the fact that most construction workers are self employed or work in small organisations on a variety of worksites, often without the resources or inclination to establish hearing protection procedures (Kerr, McCullagh, Savik, & Dvorak, 2003).

A report on noise and hearing in the Australian construction industry was published in 1997, following a substantial study of the workers of the expansive Crown Casino development in central Melbourne (Milhinch & Dineen, 1997).

There were three main findings of this study. Firstly it was confirmed that the sound levels measured on this construction site were indeed hazardous. 23 out of 29 workers for whom detailed noise exposure time surveys were conducted had average exposures above the 85dBA threshold, with six individuals with a daily average exposure above 94dBA. The average eight hour Leq for all individuals was 89.9 dBA, representing more than double the recommended average sound intensity. These stemmed from a variety of personally and externally generated sources (including hand operated power tools and machines, air blowers and jack hammers), and often contained intense peaks or occurred within reverberant areas. 75% of workers were exposed to multiple episodes of impulse sounds exceeding the safe exposure limit of 140 dB.

Secondly, the construction workers on the site saw their workplace as hazardous in many ways, including a risk of fatal injury or a risk of loosing employment through incapacitation. Hearing was viewed as extremely important in terms of vigilance and necessary for awareness of dangers and for communication, yet despite this the risk of damaging ones hearing had a much lower priority than other workplace hazards that could lead to immediate physical trauma or death. Not surprisingly then, any restriction in hearing ability such as the use of hearing protection was seen as a risk to safe and efficient work practices. Both ear muffs and ear plugs were freely available on site, yet despite this 65.5% of the 26 observed workers did not use hearing protection at all during the work day. The remaining 34.5% used hearing protection when they considered that it was required for the particular task at hand, while no worker wore protection throughout the entire day. This indicates that the usage of hearing protection on construction sites is strongly linked to a perceived risk arising from the personal use of very noisy equipment, rather than a perception of a risk to hearing overall.

"Well, it's good to be able to communicate with whoever's working around you. I mean, if you can't do that, either if it's too noisy or you've got your hearing protection on, then something could be falling down and he's going 'Look out! Look out!' and you're going 'What? What?'"

Construction worker from 'Group 7', p25 (Kerr et al, 2003)

The third finding in this study was that although workers were aware of the harmful effects of excessive noise on hearing they did not exhibit the corresponding knowledge of its effects on their own hearing. It appears that the workers were aware of the risks of noise exposure, but did not equate their own situation as being consistent with such a risk. Continued exposure to excessive noise was seen as inevitable due to a number of factors, including the perceived threat to continued employment if they were to complain, a fear of failing to hear danger or not be able to communicate if wearing hearing protection, and doubts about how significant a hearing loss risk was presented.

In a similar large scale study conducted in Washington state over five years from 1999 to 2004, seven hundred and thirty construction workers were interviewed and assessed and there was a full-shift dosimetry survey conducted across a variety of commercial construction sites (Sexias & Nietzel, 2004). The primary findings were that construction workers were exposed to over the 85dBA NOISH daily exposure standard in about 70% of the work shifts that were assessed by personal noise dosimetry.

Furthermore, it was noted that even supposedly 'quiet' trades like electricians still had a substantial portion of measured work shifts in excess of the standard, and all trade types on site featured some individuals with highly excessive exposures. This indicates that while some particular trades may be at a higher risk than others (e.g. iron workers, labourers, carpenters and masons), all workers of any trade had a significant potential to experience damaging levels of noise on a daily basis. Of all the construction workers surveyed, hearing protection was worn on average less than 20% of the time when exposure levels were above the 85dBA limit. As a result of this poor compliance, the average actual protection level gained by using hearing protectors was less than 3dB, with the figure varying substantially between individuals and occupations.

Overall, less than one in five exposed shifts were brought below the recommended level. This means that even where noise levels were above the recommended level and hearing protection was worn, their use was ineffective at preventing hearing-damaging levels of exposure in over 80% of cases. Nearly 50% of workers sampled reported that they ‘always’ wore hearing protectors when necessary, yet these same workers were only observed using them for about one third of the time they were exposed above 85dBA. This indicates that workers self-reported estimates of hearing protector usage were grossly overestimated, suggesting that either they consistently fail to identify when noise exposure levels are actually hazardous, or that some form of subjective recall bias was in action.

From these results, the authors concluded that the low hearing protection use rates were a combination of inadequate worker education, unavailability of appropriate protection devices, over attenuation and perceived barriers to their use. To remedy these factors, they suggest the following actions:

Better hearing loss prevention training, covering when and where workers might be overexposed to noise, and what they can do to reduce their own exposure.

Additional training on the selection, use and correct fitment of protective devices.

Free provision of at least two different types of device (such as earmuffs and plugs) at convenient locations at each job site, so that workers can select the device of their preference.

Posting of signs around areas or operations where hearing protection is required.

Strict enforcement of hearing protector use during high noise exposures.

(Sexias & Nietzel, 2004) p10

While these measures may indeed increase the use of hearing protection in construction, just how much improvement they would promote is debateable given the extensive literature on the barriers to effective use of hearing protectors. This is not to say that hearing protection devices are useless or that improving compliance with their use would not reduce the incidence and severity of noise-induced hearing loss, but rather that any solution that intends to totally prevent noise-induced hearing loss in the construction industry should include a combination of hearing protection, noise reduction and noise isolation.

Other occupations

As noted in the introduction to this section, in any occupation where there is sustained excessive noise over 85dBA there is the risk of noise-induced hearing loss. In noisy occupations where there are further potentiating factors or a typical lack of noise awareness and hearing protection the risk is even more so.

One such occupation is fire fighting. It has been suggested that a fire fighters exposure to noise on the job can indeed exceed recommended limits (Tubbs, 1995a), and that the much more immediate risk of physical trauma and death in the extreme physical environment of a building-fire greatly overshadows any concerns that may be held for one's hearing (Walton, Conrad, Furner, & Samo, 2003). As such it is suggested that fire fighters hearing may be at risk and little is being done to protect it. Furthermore the fact that fire fighters work irregular shifts across rotating rosters (Orris, Meluis, & Duffy, 1995) may mean that the standard 85dBA average for a typical working day is an unsuitable criterion.

However, recent research has suggested that while fire fighters are sporadically exposed to excessive noise and may indeed lack effective hearing loss prevention practices, that overall the noise exposure experienced by fire fighters across a working week does not pose a particularly great threat (Clark & Bogl, 2005). This is due in part to the large portion of the day that fire fighters spend in relatively quiet recreation between bouts of noise exposure. In support of this the study also claims to have found no difference between fire fighters hearing loss rates and those of a matched sample of non-occupationally exposed control subjects over a seven year period when age related hearing decline was taken into account.

A second occupation that fits the criteria of high noise exposure and limited hearing loss prevention activity is workers in hospitality venues where loud amplified music is commonplace. One sample of the sound volume in eight live music clubs in New York City indicated very high noise levels during performances (Gunderson, Moline, & Catalano, 1997). Dosimeters worn by an investigator standing in a position adjacent to that occupied by bar staff revealed average sound levels between 94.9 and 106.7 dBA during performances and ambient levels 83.7 to 97.1 dBA. This indicates that staff and patrons in such environments are at risk, and subjective reports of tinnitus and hearing loss from staff members correlated with sound level between clubs. Despite most ambient noise levels and all 'performance' noise levels being in excess of the local 90dBA limit, 84% of employees surveyed reported rarely or never using hearing protection at work. No further hearing conservation measures are reported, however it is implied that none existed. Routine inspection by health and safety authorities of sound levels in the clubs surveyed was non-existent. Anecdotal evidence suggests that this is mainly the case in New Zealand.

The authors (Gunderson et al., 1997) concluded that there is a great need to educate the employees of music clubs about the risks of noise-induced hearing loss and the means to prevent it in order to avoid hearing loss in this substantial group of workers. While it is the workers who regularly and consistently exposed to this source of excessive noise, extending this education to the relatively irregular patrons of music clubs may also be beneficial in reinforcing the message that ‘any form of sound can be hazardous if it is loud and sustained’.

It would be impractical to outline herein the evidence for all occupations that may have high levels of noise exposure and poor hearing loss prevention practices, and indeed it could be argued that almost all prevention activities in any occupation can be equally inadequate. Overall it appears that there are many occupations that are in need of task and workplace specific assessment to identify the true extent of noise exposure and hearing loss, barriers to preventative practices, and the best measures to address these issues.

Age groups

As noted in the previous section on presbyacusis and the effects of age, it is clearly established that older individuals are most likely to present with noise-induced hearing loss due to the cumulative nature of noise exposure on the cochlea and the ear inability to repair or replace damaged hair cells. The behavioural effects of noise-induced hearing loss in the elderly are further compounded by the potential for concurrent age-related auditory decline to cause a more severe loss of hearing overall. Furthermore it is often suggested that due to relatively non-existent noise management and hearing protection practices prior to the 1970’s, currently aged and retiring workers are more likely to show the symptoms of noise-induced hearing loss and require compensation and rehabilitation than those that are entering the workforce today.

An interesting study by Kujawa and Liberman (2006) described earlier, showed that mice exposed to a traumatising noise when young developed far greater age-related hearing loss than unexposed mice. This implies that early exposure to noise, perhaps during a critical period of development influences the development of presbyacusis and demonstrates an interaction between noise and aging.

There is some recent evidence that suggests that noise-induced hearing loss in children and young adults may be more of a public health problem than currently recognised. This is based upon the idea that while occupational exposure of young people to excessive noise is typically limited (especially with those that have yet to properly enter the workforce), non-occupational noise exposures from concerts, stereos, toys, lawn mowers and fireworks may be much higher in youth that in adults (Niskar et al., 2001). Contrary to this the literature reviewed in the next section does suggest that non-occupational noise exposures are typically only a minor component of overall hearing loss. However it must be noted that almost all studies in this area deal with an adult population for whom recreational noise exposure may be relatively limited, and occupational exposure much more significant, than in a population of children or teens.

This lack of typical occupational noise hazard exposure in young persons means that currently few, if any, interventions are in place to protect the hearing of youth. They miss out on the occupationally based measures that do exist, therefore if safe hearing knowledge and practices are to be adopted by youngsters they must be specifically targeted to them independent of employment. This perhaps points to a lack of legislation protecting individuals from excessive noise exposures in non-occupational settings.

There is some indication that students at school can be exposed to noise levels comparable to industrial occupations (Serra et al., 2005). It is suggested by some authors that this combination of noisy classrooms, loud recreational activities such as discotheques and perhaps part time work in high noise environments could be causing some hearing loss in the general public even before they have entered the workforce (Biassoni et al., 2005).

Barring specific exposures to extreme noise events that can cause immediate deafness, noise-induced hearing loss is cumulative, usually the result of repeated exposure to excess noise over a large portion of an individual’s lifetime. Due to this cumulative long-term nature, no major threshold shift would be generally expected in the early phases of ones life. Yet while this early life noise exposure may not manifest directly into an observable hearing loss or significant disability on its own, it may be the case that moderate overexposure to noise when young makes the ears more susceptible to greater noise-induced hearing loss in later life. Therefore to prevent any excessive noise exposure until an individual enters the workforce could perhaps delay the onset of noise-induced hearing loss in noise exposed occupations by several years.

In terms of building knowledge and awareness of hearing loss issues it would be desirable to begin before the individual enters the workforce, so that they have a developed concept of hearing safety prior to exposure to any significant occupational noise hazards. Additionally it is usually much easier to learn and adopt positive behaviours in the first instance, than to attempt to modify or supersede existing negative behaviours that have become entrenched (Katz, 2001). It could therefore be more effective to teach people to value and protect their hearing while young than to attempt to regulate their behaviour in later life, as such behaviour then may be inconsistent with their personal beliefs regarding noise, hearing, work and entertainment.

For these two reasons it may be desirable for any substantial public health campaign intending to reduce noise-induced hearing loss to target school aged children and young adults directly with education and awareness building strategies. Not only would this allow younger persons to make more informed choices about their current noisy activities, potentially reducing their exposure to noise while young, it would also serve to prepare them for the future by instilling protective and cautious attitudes towards noise exposure and hearing loss.

Summary

Noise exposure and noise-induced hearing loss rates are far from equally distributed across the general population. Individuals who work in occupations were noise exposure is commonplace are at a much higher risk of developing such hearing loss, while inequalities also exist between groups in regards to the accessibility and use of hearing protectors or other noise control methods.

There is a large potential for noise-induced hearing loss in the agricultural sector. The combination of a variety of tasks with varying noise levels and a variety of dispersed worksites make farmers susceptible to unprotected exposure to excessive noise. Everyday sources of noise in farming are high but not intense, because of this their effects can be subtle and the onset of hearing loss insidious.

It is noted that noise reduction or isolation at the source in the agricultural context may be perceived as prohibitively impracticable, leaving hearing protection as the easiest control option. However, the reviewed literature indicated that agricultural hearing protector usage was generally inadequate. This was particularly so with activities that are not undertaken regularly or seen as a typically ‘noisy job’. One paper reported that almost one quarter of those surveyed never wore hearing protection under any circumstances.

The fact that greater hearing protector usage was observed with higher noise activities indicates that there is as least some knowledge of the hazard that excessive noise present in farming, and that some level of link exists between risk perception and risk-mediation behaviours.

Construction workers have been identified as potentially at great risk of noise-induced hearing loss due to the frequent use of power tools and tasks that involve impacts and other high noise activities. This high risk of noise exposure is coupled with the fact that most construction workers are self employed or work in small organisations on a variety of worksites, often without the resources or inclination to establish hearing safety procedures.

Hearing was viewed as extremely important by construction workers for awareness of danger and for communication, yet hearing loss was given a much lower priority than other workplace hazards that could lead to immediate physical trauma or death. Any restriction in hearing ability such as the use of hearing protection was seen as a risk to safe and efficient work practices.

The usage of hearing protection on construction sites is strongly linked to a perceived risk arising from the personal use of very noisy equipment, rather than a perception of a risk to hearing overall. Construction workers are often aware of the risks of noise exposure, but they do not necessarily equate their own situation as being consistent which such a risk.

Continued exposure to excessive noise on the construction site was perceived as inevitable due to a number of factors, including the perceived threat to continued employment if they were to complain, a fear of failing to hear danger or not be able to communicate if wearing hearing protection.

Workers in other noisy occupations such as fire fighters and hospitality workers are at risk of noise-induced hearing loss due to the high levels of noise that can occur in these industries. There is also an indication of common lack of the use of hearing protection in these non-industrial jobs. While the total time such workers remain exposed to excessive intensities may be less than in factories or similar occupations, a greater lack of information and awareness regarding safe hearing practices is suggested in these atypically noisy jobs.

As noted in the previous section older individuals are more likely to present with noise-induced hearing loss due to the cumulative nature of noise exposure on the cochlea and by the potential for concurrent age-related auditory decline to cause a more severe loss of hearing overall.

Due to relatively non-existent noise management and hearing protection practices prior to the 1970's, currently aged and retiring workers may be at a greater risk of experiencing the symptoms of noise-induced hearing loss than those that are entering the workforce today.

There is some recent evidence to suggest that noise-induced hearing loss in children and young adults may be more of a public health problem than currently recognised. Occupational exposure of young people to excessive noise is typically limited but non-occupational noise exposures from concerts, stereos, toys, lawn mowers and fireworks may be much higher in youth that in adults.

There is also some indication that students at school can be exposed to noise levels comparable to industrial occupations. Currently few, if any, interventions are in place to protect the hearing of youth outside occupational settings.

Due to this cumulative long-term nature of noise-induced hearing loss, no major threshold shift would be generally expected in the early phases of ones life. However, preventing excessive noise exposure before an individual enters the workforce could perhaps delay the onset of noise-induced hearing loss in noise exposed occupations.

Recreational noise-induced hearing loss and the entertainment industry

While the current focus on noise-induced hearing loss is firmly placed upon the regular and sustained noise exposure that is experienced in the workplace, more attention is now being paid to exposure to excessive sound during recreation and home life. Since the advent of the transistorised electronic circuit in the 1950's the widespread use of amplified sound and music has become commonplace in homes and entertainment venues throughout the world, while more recently the introduction of digital technology and miniaturisation of audio devices has enabled the development of the portable personal music player. In addition to this motorised recreation such as motorcycles has become increasingly accessible to the general public, as has live music and performance, while hunting and sports shooting remain as popular as ever. Although the brief for this report did not require an extensive review of leisure and recreational noise exposure this is included here briefly to provide context.

Personal music players

Personal music players present a potential noise hazard because of the potentially high sound levels that they can achieve and their portability enables long duration exposures. A number of studies have been undertaken to determine the specific sound levels produced by these devices and to assess the risk of hearing damage. A recent study of Sydney rail commuters' use of personal music players conducted by the Australian National Acoustics Laboratory indicated that approximately one quarter of devices examined were set at a level in excess of 85 dBA when the user was invited to participate outside a central city railway station (Williams, 2005b). This means that approximately 25% of users of these devices may be at risk of developing noise-induced hearing loss if the exposure is of long enough duration. However, it must be noted that the criteria in this study was the absolute level of 85dBA, rather than an average daily measure of sound exposure. Certainly if these 25% used their music players at this volume for eight-hours-a-day, five-days-a-week for a decade, then the expected rates of noise-induced hearing loss would likely be comparable to any other occupational noise exposure at this level.

In early 2006 a law suit was filed against Apple Corporation on the grounds that the iPod is a dangerous and defective device (BBC News Brief, 2006). This was on the basis that the volumes produced could reach over 115 decibels, which could cause hearing damage in as little as 30 seconds use. It was noted also that each device does carry the warning that permanent hearing loss could occur if it is used at high volumes. Additionally this article reported that there is a mandatory decibel limit of 100dB in France and models for that market are restricted to this level.

Research conducted in 1998 by LePage and Murray on 1724 subjects indicated that users of personal music systems had lower otoacoustic emission strength than non users (LePage & Murray, 1998). Additionally people exposed to industrial noise exhibited reduced OAE strength than those not exposed, while persons with both kinds of exposure had the most reduced overall, indicating an additive effect between personal music players and industrial noise exposure. Furthermore, the size of decline in OAE strength was reported to be proportional to exposure, based upon a self report measure placing individuals into low, moderate and heavy categories of personal music system use.

The authors noted that the use of pure tone audiometry had failed to show any marked effect between amplified music and hearing loss in young people (Carter, Murray, Khan, & Waugh, 1984; Carter, Murray, & Bulteau, 1985). However they suggest that this was due to the inability of audiometry to identify pre-clinical hearing loss, particularly in young persons with limited exposure history. The major limitation of this study was a failure to control for noise exposures other than from industrial or personal music systems. The authors suggested that users with high personal stereo use may also be likely to experience high levels of exposure from radios, live concerts or other forms of amplified music or entertainment. While this does limit the potential to attribute the pre-clinical decline in OAE strength directly to personal music players, it may identify a sector of the population that is at risk of hearing loss from amplified music in general.

While these reports indicate the potential for personal music players to permanently damage hearing, it is obvious that in the vast majority of cases the time spent listening to such personal music devices would be substantially less than eight hours per day every day. As such the actual contribution of personal stereo systems to population hearing loss rates may be minor, but it is one area that could be targeted readily with education and/or output controls.

However, given the evidence for an interactive effect between occupational exposure and personal stereo use, it is reasonable to suggest that using personal music players at high volume during non-work times could negate the recovery function that such recreational periods are assumed to provide. While the research and understanding of the recovery effects of quiet periods on noise exposure is currently insufficient (ISO, 1990), it should be noted that the average 85dbA daily limit is based on the assumption that no significant noise exposure occurs outside of work hours. If workers are receiving a substantial amount of intense noise exposure during their non-work time from music or recreation, then this assumption would obviously be violated. If this was the case then the 85 decibels limit for the eight hour working day would need to be lowered (or the work day shortened), for the same level of protection from hearing loss to be afforded. Attempts have been made to develop 24 hours noise exposure limits to take this idea of a 'global sound dose' into account (e.g. the US Coast Guard criterion), yet so far none have been accepted as a suitable replacement for the established standard.

Therefore despite the recent media coverage surrounding the fact that up to one quarter of people listening to personal music players may have them at the volume of power tools, the issue of the potential hearing damage needs further investigation because of the relatively limited exposure time.

Bars, nightclubs and live music

Due to concern that the noise levels in local nightclubs were damaging, an informal noise survey was recently conducted by the Hearing Association in Nelson ("Turn down music in bars, says hearing group", 2005). While the association was refused permission by nightclub owners to conduct precise noise assessments, they did undertake an unofficial review of four nightclubs visited between 8.30pm and midnight. They found that the average noise exposure across all locations was 97.4dB, rising at times to 120dB. The Hearing Association described the workplace as a 'toxic noise environment', noting that while tobacco smoking in bars was now severely limited to protect the health of employees almost nothing was done to enforce noise levels.

The attitude of club owners toward the situation was dismissive. One owner suggested *that "It's not an issue with staff, they are the ones who enjoy the music, and the customers are the same"* while another noted that *"It's certainly not an issue. You can't be too loud anyway, the staff need to hear to serve".* Furthermore it was suggested that no owner would prevent their workers from wearing hearing protection if the wanted to, yet this indicates that they did not actively promote hearing protection either.

These two quotes indicate three concerning attitudes toward noise levels in hospitality environments. The first is that owners and managers may not believe that loud noise is a problem at all, or at least that it is not a problem in their establishment. The second attitude is that loud music is only a problem when it impacts upon task performance, despite the fact that humans are adaptable and quite capable of working in excessive noise environments well beyond the level that is hazardous to hearing. Furthermore this indicates that managers may only be concerned about noise levels restricting profitability, rather than the health of their employees.

The third attitude is that if the noise source is enjoyed by those who are exposed, then there is no need for hazard control. This is perhaps the most insidious factor when the noise in question is from a musical source. Unlike many other noise sources and hazards in general, loud music is frequently enjoyed by those who are exposed to it, while some individuals believe that the louder the music the more enjoyable it is. The important point is that any sound of sufficient level and duration is capable of causing hearing damage.

A further point from this article is that one club owner noted that his bar complied fully with noise levels at the boundary, a condition of licensing and resource consent. This noise at boundary limit is regularly assessed by authorities, with the possibility of the venue being shut down if this was found to be excessive. Additionally there are measures in place for local residents to report a venue that they believe may be putting out too much noise. However the owner noted that the authorities never took sound level readings inside the bar, and therefore interior noise levels were not a concern for him. While specific legislation exists in New Zealand regarding both noise levels at boundaries and the noise levels that a worker can be exposed to in the workplace, it appears that in the entertainment industry it is only the first noise issue that is regularly enforced and as such it is only exterior noise that is of any concern to owners and operators.

Anecdotal evidence collected by the report writer among Auckland venues supports this assertion. One manager who was contacted stated that "*We have OSH through all the time, and they've never said anything about noise inside the bar… if it was a problem then they would have said something*". This is despite the fact that he also reported regularly having to shout to communicate with staff right next to him, indicating that noise levels would be high. Furthermore he noted that they had never made hearing protection available to staff and did not know of any bar or club that did, suggesting that earplugs were only necessary for staff at '*big rock concerts and stuff like that, not in a bar like this*'. This indicates a lack of understanding among hospitality operators regarding what constitutes hazardous noise levels, how to identify them, and what they need to do when noise is excessive. Additionally these attitudes seem to indicate again that individuals are only aware of noise as a problem when it is extremely excessive rather than simply hazardous.

There appears also to be a need for specific research in this area: while it is established that noise levels within hospitality venues can frequently exceed safe limits, the actual effects of this exposure upon staff's hearing is unknown.

Hunting and shooting

50 million Americans routinely use firearms for hunting or sport (Crandell, Mills, & Gauthier, 2004), while it is estimated that only 1% of American hunters use hearing protection while shooting (Kramer & Updike, 1991). Not surprisingly recreational firearm noise has been cited as a primary cause of noise-induced hearing loss incurred during leisure activity in the United States (Clark, 1991), and indeed a number of American studies have identified increased high-frequency hearing loss in recreational shooters compared to a matched non-shooting control sample (Nondahl et al., 2000).

Smaller calibre weapons such as a .22 usually deliver less than 140dB peak sound pressure to the users ears, however larger bore rifles, pistols and shotguns frequently deliver up to 170dB peak (Odes, 1972). While the smaller weapons can cause temporary threshold shift and contribute to permanent noise-induced hearing loss, the more powerful varieties of firearm can cause sudden and permanent threshold shift due to acoustic trauma (Dobie, 2001). Hearing protection is the primary method for reducing hearing loss from firearms. Unfortunately, as noted above, hearing protection usage rates may be very poor.

Noise-induced hearing loss from rifles and shotguns are typically asymmetrical (Johnson & Riffle, 1992) because the ear closest to the barrel receives the bulk of the noise energy, while the right ear is protected by the 'noise shadow' created by the head (Dobie, 2001).

American studies have suggested an interactive effect between recreational shooting and occupational noise exposure. Recreational shooters who worked in high noise environments were found to have higher levels of permanent threshold shift and greater asymmetry to their hearing loss than their peers who received occupational exposure to noise alone (Stewart, Konkle, & Simpson, 2001). These results point to the benefit that could be gained by delivering interventions to occupationally exposed workers that treat noise/sound exposure as a total concept, so that they would become aware not only of the effects of noise at work, but also of the compounding effects of additional noise in their leisure time.

These is no real data regarding the incidence of firearm related hearing loss in New Zealand and this is an area that should be studied further.

Other sources

In the American study of construction workers outlined previously, non-occupational activities were assessed along with workplace noise exposures (Sexias & Nietzel, 2004). It was concluded that, for most construction workers, non-occupational activities made little contribution to the workers total annual noise dose. Apart from a small fraction of those sampled who has relatively quite jobs and spent a lot of time in noisy recreation, the impact of recreational noise upon a tradesman's hearing was said to be negligible.

It should be noted however that this survey did not take into account the use of firearms, beyond noting that persons who shoot firearms were more likely to undertake other noisy recreation as well. Overall this indicates that, in the construction trades at least, the occupational component of total noise exposure is by far the greatest contributor to noise-induced hearing loss and interventions to address this source of noise would be more effective than those targeting out-of-work noise exposures.

Summary

While the current focus on noise-induced hearing loss is firmly placed upon the regular and sustained noise exposure that is experienced in the workplace, attention is now also being paid toward exposure to excessive sound during recreation and home life. The trend toward motorised, mechanical, amplified or explosive recreation has prompted some to suggest that a greater risk of hearing loss is being placed upon the ears of the public.

Undertaking high noise activities during recreation time could negate the recovery function that non-work periods are assumed to provide by current conceptions of noise dose. This could mean the current 85dB (A) daily limit for sound exposure could be less suitable under these conditions.

Most personal music players are capable of producing sound intensities that can cause noise-induced hearing loss, and research has indicated that approximately 25% of users of personal music players set them to a volume that may be contributing somewhat to noise-induced hearing loss.

However given the relatively short exposure periods, it is suggested that under normal use such devices alone will not cause their users to acquire noise-induced hearing loss. Nevertheless such devices can easily contribute to an individuals total noise dose, particularly in conjunction with a noisy occupation or other high noise exposure recreation.

Many bars and live music venues also have noise levels that can easily cause damage to the hearing of exposed individuals if the exposure is sustained and repeated over a long period of time. While this is of less concern to patrons who would experience such exposures sporadically, for an employee who works regular hours in such an establishment these noise levels could present a serious risk to their hearing.

There is an indication that excessive noise is not identified as a hazard in the entertainment industry, or that the hazard is identified but ignored. This may be supported by a the perception that sounds sources such as music are ok as long as they are enjoyable, regardless of the actual level of exposure.

Recreational firearm noise has been cited as a primary cause of noise-induced hearing loss incurred during leisure activity in the United States. This is due to the extremely high impulse noises experienced, limited opportunities to reduce noise and poor hearing protector rates. Smaller arms can contribute to noise-induced hearing loss in general, while larger weapons with sound peaks of up to 170dB can cause immediate hearing damage. The applicability of American data to the New Zealand context is not established.

The extent to which recreational noise exposures alone, other than firearm use causes noise-induced hearing loss under typical conditions is not clear and needs further study. However, recreational exposures can contribute to the total noise dose an individual receives, particularly when these are in conjunction with occupational noise exposure. Additionally persons employed in the recreation or entertainment industries could be a much greater risk than the casual patron due to their regular and sustained exposure. These results point to the benefit that could be gained by delivering interventions to occupationally exposed workers that treat noise/sound exposure as a total concept, so that they would become aware not only of the effects of noise at work, but also of the compounding effects of additional noise in their leisure time.

Summary and conclusions

This review of the literature has highlighted that NIHL remains a significant health problem internationally despite decades of interventions to prevent it. The review has highlighted that there are substantial variations around the world in the strategies and practices to reduce NIHL although the main approaches are similar and centre around identification of the source of the damaging sound and prevention or restriction of its exposure through a mixture of engineering controls and personal protection. The efficacy of these approaches has been reviewed and areas of success and failure highlighted. The salient points and conclusions from the review are discussed in this section.

Incidence and prevalence of NIHL in New Zealand

Data regarding the true prevalence and incidence rates of noise-induced hearing loss in New Zealand are poor. Estimates of prevalence are derived from household and census surveys which are principally based on self-report measures. Whilst these provide estimates of the prevalence of hearing loss, these do not provide the data to define the cause and configuration of the hearing loss. Thus these data do not indicate the prevalence of noise-induced hearing loss per se nor can they be used as a basis for determining any change in prevalence over time.

The number of claims to ACC (only of occupational noise exposure) shows a steady increase over the last decade. Whilst this provides an indication of the number of notified occupational noise-induced hearing loss cases and can give some estimate of the number of new cases (4081 in 2004), it is difficult to determine trends in the incidence as the criteria have altered over time. Such incidence rates are also based upon the individual seeking assistance and thus cannot provide a true indication of the incidence rate. It is also important to realise that there is a long lag between the time the hearing loss may start and the lodgement of a claim.

Similarly international estimates of the prevalence and incidence vary wildly, largely because of a variety of definitions and criteria. This lack of basic criteria standardisation also hinders attempts to describe noise-induced hearing loss epidemiology in terms of ethnicity, employment or similar factors.

Conclusion: **It is not possible to establish the true incidence or prevalence rates of NIHL in New Zealand. A better understanding of the incidence and prevalence of NIHL in the New Zealand community is essential as a foundation for monitoring effectiveness of future strategies to reduce the impact of noise exposure on hearing which could only be achieved by focussed epidemiological studies.**

Legislation

Internationally, best practice for noise-induced hearing loss prevention includes strong legislative support that lays down criteria for acceptable noise levels and acceptable noise control procedures, as well as close monitoring that the legislative requirements are being met.

There is sufficient legislation to control occupational noise exposure and to prevent noise-induced hearing loss in New Zealand, and it is in line with international best practice. However the implementation and enforcement of this legislation may be insufficient.

Noise reduction is almost universally recognised as the most effective measure to prevent noise induced hearing loss, and this position is reflected in New Zealand regulations and standards. However, such regulations also allow a wide berth to rely on simpler but much less effective methods such as hearing protection on the grounds of ‘practicability’. A more precise definition and stricter controls on what is considered impracticable may prevent the preferred option of noise reduction from being dismissed so readily.

Internationally, such as in the recent UK legislation and guidelines, there is the precedent for the introduction of *action levels* in addition to the single noise level criterion that currently exists in New Zealand legislation. This would introduce a requirement for some additional preventative measures to be introduced in high noise environments and as risk of hearing damage increases. For example a *first action level* or trigger level could be implemented at a lower sound level when monitoring and basic strategies must be undertaken, while a *second action level* could place additional controls on workplaces with extreme noise exposures.

***Conclusion:* Some review of the New Zealand legislation and the effectiveness of its implementation should be undertaken. This should include a review of the adequacy of the legislation, the effectiveness of its implementation and monitoring of the legislative requirements, and whether changes such as the introduction of action levels could enhance its effectiveness.**

Hearing conservation

Current practices throughout the world are based around the concept of a hearing conservation program, the basis for which is enshrined in law along with the standards and regulations for exposure.

Best practice for hearing conservation includes annual audiology evaluations by trained staff using consistent systems and adhering to testing guidelines, combined with an accurate database of results to monitor hearing levels and a policy of noise control as the primary intervention in conjunction with strong management support for hearing conservation. Details of an example of good practice are provided in Appendix 1.

There is some evidence to suggest that more sensitive audiological tests using otoacoustic emissions could provide a better method of identifying "pre-clinical" damage, but this still in development.

In theory a hearing conservation program should be effective due to a combination of audiological monitoring, noise reduction and protection from noise. Yet it appears that typically in practice not all components of the program are undertaken, particularly the noise reduction, due to perceptions of cost and difficulty.

A significant problem with current hearing conservation programs is a reliance on personal hearing protection as a method of noise exposure management as this is neither foolproof nor consistently effective. This, in combination with the great responsibility it places on the individual to use them unfailingly to achieve sufficient levels of protection, can create a flawed behaviour-based protection strategy.

There is no best practice to deal with this other than having very strict and tight controls over hearing protector usage coupled with extensive monitoring of compliance. The efficacy of a hearing protector program can be improved by ensuring ready access of suitable and well maintained protectors, while a high level of staff training and education with management support could establish a culture of safe and frequent use of hearing protection. Yet modifying and controlling individual behaviour is notoriously difficult, particularly when near perfect compliance is required, and such actions still do not prevent the individual's exposure to the noise.

Any reliance on leaving the noise hazard in place while attempting to force individuals to protect themselves from it has been criticized as a fundamentally flawed approach.

***Conclusion:* Hearing conservation programs can only be effective if there is strong management support and commitment, consistent high quality noise and audiology monitoring and strict adherence to the use of hearing protectors. In the end though any reliance on the use of hearing protectors as a primary means of protection against noise-induced hearing loss in industry is unlikely to deliver the expected protection.**

Hearing loss prevention or noise management programs

Because of the apparent failures of the established concept of *hearing conservation* to sufficiently combat noise-induced hearing loss over preceding decades, there is currently a strong move internationally to the idea of *hearing loss prevention* as a replacement. This requires a paradigm shift from the conservation of hearing and minimisation of hearing loss to one of the prevention in the first instance. This new approach has been labelled the *noise management program*.

Noise management is achieved by a strong focus on the elimination and isolation of noise, preventing noise exposure occurring in the first place through a variety of engineering and organisational methods. The reliance on personal hearing protection is greatly reduced with a focus on reducing noise at the source, while the concept of hearing protection as a suitable sole solution to noise exposure is discredited.

Furthermore noise exposure is seen as a company-wide issue, while a reduction in noise-induced hearing loss is a key organisational outcome. Responsibility for prevention lies with all levels of the organisation, not simply the affected individual. A noise-safe culture is established through policy and practice when the prevention of noise exposure is integrated into management systems and work processes. In turn, the safety culture supports a reduction in noise exposure and hearing loss. Preventing noise-induced hearing loss is seen as an integral goal of the business, rather than an undesirable product that is treated remedially.

Best practice with noise management programs is not yet available, as there has yet been no widespread implementation of the new paradigm to allow these to establish. However, the core components of noise management (such as strong management-organisational support, effective noise control and reduced dependence on hearing protection), are established as necessary features of any successful occupational deafness prevention program as they address the major shortcomings of the hearing conservation approach.

Conclusion: **a shift from a *hearing conservation approach* to a *hearing loss prevention approach* or *noise management program has been touted as a potentially* more effective method of reducing the incidence of noise-induced hearing loss in industry.**

Directions for future research and action

Three key areas have been identified for future research into the prevention of noise induced hearing loss and actions to prevent it. The first is a need to address current shortcomings with **incidence and prevalence data** that prevent a full understanding of the epidemiology of noise-induced hearing loss in New Zealand. The second area is related to improving the **efficacy of current practices and implementing a new preventative model**. The third relates to **education, public understanding of noise and hearing loss and the establishment of a sound-safety culture.**

1. Data and incidence

More extensive epidemiological research is required to determine the true extent of the noise-induced hearing loss problem in New Zealand. The lack of a detailed characterisation of the problem of noise-induced hearing loss in New Zealand hinders efforts to combat this problem effectively and efficiently.

A focussed epidemiological study combined with analysis of current databases (e.g. ACC claims) is required to provide an indication of the extent of noise-induced hearing loss and its demographic distribution in New Zealand. There are some health databases (military and some industry records) that could be accessed to determine any changes in hearing loss over time and effectiveness of hearing conservation programs, although their use may be questionable because of variations in the quality of audiometry procedures over time.

An analysis of actual levels of noise exposure and frequency of high noise tasks in industries would be useful and it is acknowledged that this data is available in some industries.

The establishment of an inclusive and extensive national noise-induced hearing loss and noise exposure register could be beneficial. This would serve as baseline data for future studies and help to inform any political process required to enhance legislation to reduce noise levels in industry.

An assessment could be undertaken of how well industries are complying with current legislation, and the effectiveness of the current legislative framework for NIHL.

In general, more extended term longitudinal studies are needed, with suitable controls in a variety of industries and locations to learn more about the natural history of NIHL. The pathology of noise-induced hearing loss is complex and occurs over several decades, but little research uses enough participants to cover the complexity or a long enough time to track the true development of the disorder.

Additionally further investigation into the use of otoacoustic emissions testing as a predictive alternative to pure tone audiometry is suggested.

To establish the validity of international data on occupational noise exposure and hearing loss (particularly American) for the New Zealand context would be beneficial, as this would allow one to see which results can be used to inform local strategies directly and to indicate areas where local research must be undertaken.

2. Prevention model and improving current practice

There is room for improvements to be made with existing practices of hearing loss prevention and minimisation. This could be achieved via research into the barriers to the reduction of the impact of noise exposure on hearing in the New Zealand setting. This would focus on the barriers to reducing noise levels in industry, barriers to effective use of personal hearing protection, and barriers to improving personal awareness of noise hazards in industry.

Furthermore an outcome-focussed study on methods to change behaviour in industry and individually to improve compliance with initiatives to reduce noise levels would help develop interventions to improve current practices. The field regarding the psychological and personal barriers to safe hearing behaviours is lacking, particularly in regards to measures beyond the use of hearing protection.

A change of central concept from 'hearing conservation' to 'hearing loss prevention' or 'noise management' has been proposed as a possibly more effective way of reducing noise-induced hearing loss, too. This would view NIHL as a 'sound injury' and promote the view that any sound that is of sufficient intensity and duration can be harmful or injurious. There are parallels here with skin cancer prevention programmes which highlight the need to avoid direct sun exposure in order to prevent cancer whilst considering the use of sun creams as a secondary preventative measure. This is a fundamental shift from a *conservation paradigm* to a *prevention paradigm* which will no doubt be difficult and create substantial barriers to change. However, it is consistent with ACC's approach to injury prevention overall and it could be useful to draw on the experience of ACC with other injury prevention campaigns (e.g. WorkSafe, FarmSafe, etc). Research is required to establish how such a shift could take place within the existing socio-political and legislative framework that surrounds occupational noise-induced hearing loss, and to identify what the major barriers to such a change would be.

With ACC's experience in mind the establishment of a 'sound safety' culture is one potential way to reduce noise-induced hearing loss in industry. Identifying it as a campaign such as **'SoundSafe'**, which is safety around sound) may be a useful method which has parallels with other ACC campaigns and is a well recognised "brand". However, there is a caveat as there is not yet any real evidence to suggest that a change in culture can be reliably achieved, or that this will lead to the actual outcome to reduce noise exposure or increase noise-induced hearing loss avoidance behaviours. While the concept of a cultural change at all levels of organisation in conjunction with legislative and procedural support is strong in theory, some evidence is required that it would work. Some ideas on what would be needed to determine the suitability and methods to implement such a change are outlined below.

A focus upon hearing loss prevention and noise reduction should be substantially more effective in reducing the personal and economic burden of noise-induced hearing loss in the long term, despite the possibility that a focus on hearing conservation and noise protection may give greater immediate results. Interventions in industry could stress these long term benefits over short term gains. Research to establish the long term efficacy, ease of implementation and economy of a noise-reduction and engineering approach to excess noise over a hearing protector approach could provide an economic rationale for a complete noise control program. This could give businesses a financial incentive to prevent hearing loss in addition to the altruistic benefits.

Occupational interventions should identify all levels of the organisation as key stakeholders in the hearing health of the company, including workers, support staff and middle and upper management. While this is not to absolve the worker of individual responsibility, it is to identify noise-induced hearing loss as an organisational problem and to instil safe hearing practices within workplace culture. To develop an environment where noise reduction and hearing safety is an integral part of the workplace culture could be significantly more effective than attempting to force such noise and safety controls upon the workplace from an external source.

Viewing NIHL as an injury from too much sound exposure (a 'sound injury'), and hence sound as a potential hazard, would enable prevention policy to be developed utilising other models of injury prevention. A widely accepted conceptual framework in the field of injury control – a matrix postulated by William Haddon (Runyan, 2003) emphasizes the need to consider the spectrum of opportunities and countermeasures for preventing an injury and its consequences. This matrix is consistent with current thinking on an inclusive multi-directional approach to reducing noise-induced hearing loss and could be utilised as a framework to identify additional means for noise reduction strategies and to identify further research needs.

In particular, the matrix draws attention to interventions that can be applied along two axes: (1) at the level of the host (e.g. behavioural interventions directed at individuals at risk including use of personal hearing protection devices), the vector (e.g. engineering interventions relating to the source of noise), and the physical and social environment (e.g. workplace and organisational policies); and (2) at different phases relating to the injury (prior to, during, and after exposure to noise).

•	• Host (indi vidu	• Agent / vehicle (source of	• Physical environmen t (industry	• Social environment (community norms,

	al)	noise)	design)	policies)
• Pre-exposure	•	•	•	•
• During exposure	•	•	•	•
• Following exposure	•	•	•	•

Haddon also promoted the value of considering strategies that counter potential hazards across 10 domains:

Prevent the creation of the hazard

Reduce the amount of hazard brought into being

Prevent the release of the hazard

Modify the rate of release of the hazard

Separate the hazard from that which is to be protected by time and space

Separate the hazard from that which is to be protected by a physical barrier

Modify basic relevant qualities of the hazard

Make what is to be protected more resistant to damage from the hazard

Begin to counter damage done by the hazard

Stabilise, repair, and rehabilitate the object of damage

While noise-induced hearing loss is rarely the consequence of a single (acute) exposure, the analogy and need to consider a broad-based intervention approach may provide a path to developing a novel prevention process.

3. Education, understanding and safety culture

In support of the proposed paradigm shift to prevention and the introduction of a Sound Safe culture, a public awareness campaign could be conducted to inform the public on key noise-induced hearing loss issues, particularly on the point that any kind of sound can be hazardous if it is long or intense enough. This would require research into the current public understanding of noise and hearing issues.

Effective campaigns to educate workers and the general public should concentrate on providing a moderate level of useful and functional information to allow individuals to identify problems and formulate solutions, rather than bombarding them with a lot of unnecessary information such as complex logarithmic scales and weighted daily exposure limits. As noted previously the scales used to describe noise and hearing loss can be confusing so there is a need to use pragmatic or realistic measures. Research into a more suitable method of communicating how to identify noise hazards would be important and could build on the experience of other campaigns such as the melanoma and UV exposure campaign.

To rename the disorder from noise-induced hearing loss to ‘sound injury deafness’ or similar may create a better public understanding of the nature of this problem. Replacing ‘noise’ with ‘sound’ avoids the common but erroneous distinction people make between noise (‘bad’) and sound (‘good’). Changing from ‘hearing loss’ to ‘injury’ actively frames it as a physical injury that is caused by sound exposure.

Learning suitable knowledge of noise and hearing issues through childhood and early adulthood may be an effective way of creating a culture of hearing safety in our society and preventing the onset of noise-induced hearing loss in later life. This could work by priming the individual with ‘bottom-up’ awareness and behaviour to support later ‘top-down’ controls and regulation, and is consistent with idea that it is much easier to learn good behaviours in the first instance that to attempt to modify existing behaviour.

For community interventions, hearing safety and noise awareness programs could be effectively applied as part of education curricula from a young age. While this would have the positive effect of targeting a group that has been identified as possibly at risk of noise-exposure (schoolchildren), the greatest benefit would be to instil safe hearing concepts into the general population from a young age.

It would be simple to integrate basic noise exposure awareness skills into existing health and personal development curricula, however it could be more effective to introduce such concepts into physics, biology or workshop classes so that they are viewed and understood in context.

Interventions should focus upon the fact that while hearing loss is basically permanent and irreversible, it is potentially preventable.

Giving due regard to the social handicap and difficulties hearing loss places upon ones family life this could be more effective for the general population than focussing on economic or business outcomes. However it is also important to avoid negatively framing the whole intervention as this can be ineffective in the long term.

References

Acoustical Society of America. (2002). *Evaluation the Effectiveness of Hearing Conservation Programs through Audiometric Data Base Analysis* (No. ANSI S12.13 TR-2002): American National Standards Institute,.

Alberti PW (1987). Noise and the ear. In AG Kerr and D Stephens (Eds) *Scott-Brown's Otolaryngology, vol 2 Adult Audiology*, Butterworth, London pp594-642.

American Academy of Audiology (2003). *Preventing noise-induced occupational hearing loss.* www.audiology.org/NR/rdonlyres/64A07CE5-E466-4765-8D8D-999B6AF7DBFC/0/niohlprevention.pdf

American Academy of Otolaryngology. (1988). *Guide for Conservation of Hearing in Noise* (revised ed.). Washington, DC: American Academy of Otolaryngology -Head and Neck Surgery Foundation Inc.

Arlinger, S. 2003. Negative consequences of uncorrected hearing loss – a review. *International Journal of Audiology*. 42, 2S17-20.

Arezes PM and Miguel AS (2002). Hearing protector acceptibility in noisy environments. *Ann Occ Hyg,* 46: 531-536

Attias J, Bresloff I, Reshef I, Horowitz G, Furman V. Evaluating noise induced hearing loss with distortion product otoacoustic emissions. *British Journal of Audiology*. 1998;32(1):39-46.

Axelsson A, Sandh A. (1985) Tinnitus in noise-induced hearing loss. *British Journal of Audiology*;19(4):271-6.

Baguley DM. (2002)Mechanisms of tinnitus. *British Medical Bulletin*; 63:195-212.

Barker, R., Hon. (2005). *Address to Massey University Small Business Research Symposium, The Museum Building Wellington*. Retrieved 9/09/2005, 2005, from http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=22222

BBC News Brief. (2006, February 2nd). *Man sues over iPod 'hearing risk'. BBC News Online*.

Behar A, Chasin M. and Cheesman M. (2000). *Noise control: a primer*. Singular Publishing Group, San Diego.

Biassoni, E. C., Serra, M. R., Richter, U., Joekes, S., Yacci, M. R., Carignani, J. A., et al. (2005). Recreational noise exposure and its effects on the hearing of adolescents. Part 2: Development of hearing disorders. *International Journal of Audiology, 44*, 74-85.

Bies, D. A., & Hansen, C. H. (1996). In E. F. Spon (Ed.), *Engineering Noise Control: Theory and Practice*. London: Chapman & Hall.

Boettcher, F. A. (2002). Susceptibility to acoustic trauma in young and aged gerbils. *Journal of the Acoustical Society of America, 112*, 2948-2955.

Boettcher, F. A., Henderson, D., Gratton, M. A., & Byrne, C. D. (1989). Recent advances in the understanding of noise interactions. *Archives of complex environmental studies, 1*, 15-21.

Boettcher, F. A., Henderson, D., Gratton, M. A., Danielson, R. W., & Byrne, C. D. (1987). Synergistic interactions of noise and other ototraumatic agents. *Ear & Hearing, 8*(4), 192-212.

Bridger, R. S. (2003). *Introduction to Ergonomics* (2nd ed.). London, New York: Taylor & Francis.

Bruhl, P., Ivarsson, A., & Toremalm, N. (1994). Noise-induced hearing loss in an automobile sheet-metal pressing plant. A retrospective investigation covering 25 years. *Scandinavian Audiology, 23*(2), 83-91.

Burns, W (1968) *Noise and Man*. John Murray, London

Carlsson, P. I., Van Laer, L., Borg, E., Bondeson, M. L., Thys, M., Fransen, E., et al. (2005). The influence of genetic variation in oxidative stress genes on human noise susceptibility. *Hearing Research, 202*(1-2), 87-96.

Carter, N., Murray, N., Khan, A., & Waugh, R. (1984). A longitudinal study of recreational noise and young people’s hearing. *Australian Journal of Audiology, 6*, 45-53.

Carter, N., Murray, N. M., & Bulteau, V. (1985). Amplified music, recreational noise and hearing in people aged 16-21 and 28-33 years. *Australian Journal of Audiology, 7*, 79-83.

Chan, V. S. W., Wong, E. C. M., & McPherson, B. (2004). Occupational hearing loss, screen with distortion-product otoacoustical emissions. *International Journal of Audiology, 43*, 323-329.

Clark, W. W. (1991). Noise exposure from leisure activities. *Journal of the Acoustical Society of America, 90*, 175-181.

Clark, W. W., & Bogl, C. D. (2005). Hearing levels of firefighters: risk of occupational noise-induced hearing loss assessed by cross-sectional and logitudinal data. *Ear & Hearing, 26*, 327-340.

Crandell, C., Mills, T. L., & Gauthier, R. (2004). Knowledge, behaviours, and attitudes about hearing loss and hearing protection among racially/ ethnically diverse young adults. *Journal of the National Medical Association, 96*(2), 176-186.

Cruickshanks, K. J., Klein, R., Klein, B. E. K., Wiley, T. L., & Nondahl, D. M. (1998). Cigarette smoking and hearing loss: the epidemiology of hearing loss study. *Journal of the American Medical Association, 279*, 1715-1719.

Davis, R. R., Kozel, P., & Erway, L. C. (2003). Genetic influences in individual susceptibility to noise: a review. *Noise & Health, 5*(20), 19-28.

Dengerink, H. A., Lindgren, F., & Axelsson, A. (1992). The interaction of smoking and noise on temporary threshold shift. *Acta Otolaryngol, 112*, 932-938.

DeStefano, A. L., Gates, G. A., Heard-Costa, N., Myers, R. H., & Baldwin, C. T. (2003). Genomewide linkage analysis to presbycusis in the Framingham Heart Study. *Archives of Otolaryngology Head & Neck Surgery, 129*(3), 285-289.

Dobie, R. A. (1995). Prevention of noise-induced hearing loss. *Archives of Otolaryngology - Head and Neck Surgery, 121*(4), 385-391.

Dobie, R. A. (2001). *Medical-Legal Evaluation of Hearing Loss* (2nd ed.). San Diego: Singular/Thompson Learning.

Driscoll, T., Mannetje, A., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., et al. (2004). *The burden of occupational disease and injury in New Zealand: Technical Report*. Wellington: NOHSAC.

Eakin, J. M. (1992). Leaving it up to the workers: sociological perspective on the management of health and safety in small workplaces. *International Journal of Health Services, 22*(4), 689-704.

Engdahl, B. (1996). Effects of noise and exercise on distortion product otoacoustic emission. *Hearing Research, 93*(1-2), 72-82.

European Agency for Safety and Health at Work, 2005. www.osha.europa.eu/riskob/noiseexposure/xxx_index_html/view?searchterm=noise-induced%20hearing%20loss

Farmsafe Australia. (2004). *Noise injury prevention strategy for the Australian farming community*. Moree: Farmsafe Australia.

Ferrite, S., & Santana, V. (2005). Joint effects of smoking, noise exposure and age on hearing loss. *Occupational Medicine, 55*, 48-53.

Fechter, L. D. (2004). Promotion of noise-induced hearing loss by chemical contaminants. *Journal of Toxicology and Environmental Health, Part A, 67*, 727-740.

Fraenkel R, Freeman S, Sohmer H. Use of ABR threshold and OAEs in detection of noise induced hearing loss. Journal of Basic & Clinical Physiology & Pharmacology 2003;14(2):95-118.

Franklin, R. C., Challinor, K., Depczynski, J., & Fragar, L. J. (2002). *Noise exposure, hearing protection and noise injury in young adult farmers*: Australian Centre for Agricultural Health and Safety.

Gallagher, C. (1997). *Health and Safety Management Systems: An Analysis of System types and Effectiveness*. Melbourne: Monash University.

Gates GA, Schmid P, Kujawa SG, Nam B, D'Agostino R. Longitudinal threshold changes in older men with audiometric notches. Hearing Research 2000;141(1-2):220-8.

Gunderson, E., Moline, J., & Catalano, P. (1997). Risks of developing noise-induced hearing loss in employees of urban music clubs. *American Journal of Industrial Medicine, 31*, 75-79.

Hamernik, R.P., Qiu, W., Davis, B. 2003. The effects of the amplitude distribution of equal energy exposures on noise-induced hearing loss: the kurtosis metric. *Journal of the Acoustical Society of America* 114, 386-95.

Harding, G.W., Bohne, B.A. 2004. Noise-induced hair-cell loss and total exposure energy: analysis of a large data set. *Journal of the Acoustical Society of America* 115, 2207-20.

Haughton P (2002). *Acoustics for Audiologists*. Academic Press, London.

Hawkins, J. E. (1971). The role of vasoconstriction in noise-induced hearing loss. *Annals of Otology Rhinology and Laryngology, 1971*(80).

Health & Safety Executive. (2004). *Statistics: Noise-Induced Deafness*, 2005, from www.hse.gov.uk/statistics/causdis/noise.htm

Health and Safety in Employment Act (1992).

Heinonen-Guzejev, M., Vuorinen, H. S., Mussalo-Rauhamaa, H., Heikkila, K., Koskenvuo, M., & Kaprio, J. (2005). Genetic component of noise sensitivity. *Twin Research & Human Genetics: the Official Journal of the International Society for Twin Studies, 8*(3), 245-249.

Henderson, D., & Saunders, S. S. (1998). Acquisition of noise-induced hearing loss by railway workers. *Ear & Hearing, 19*, 120-130.

Henderson, D., Subramaniam, M., & Boettcher, F. (1993). Individual Susceptibility to Noise-Induced Hearing Loss: An Old Topic Revisited. *Ear & Hearing, 14*(3), 152-168.

Hetu, R., & Getty, L. (2001). The nature of the handicaps associated with occupational hearing loss: implications for prevention. In National Occupational Health and Safety Commission (Ed.), *Occupational Noise-induced Hearing Loss* (pp. 64-85). Sydney: Worksafe Australia.

Hetu, R., Tran Quoc, H., & Dugay, P. (1990). The likelihood of detecting a significant hearing threshold shift among noise-exposed workers subhected to annual audiometric testing. *Annals of Occupational Hygiene, 34*(4), 361-370.

Holt, E. E. (1882). Boilermakers Deafness and Hearing in a Noise. *Trans Am Otol Soc, 3*, 34-44.

Holt, J. J., Broste, S. K., & Hansen, D. A. (1993). Noise exposure in the rural setting. *Laryngoscope, 103*(258-262).

Hughson, G. W., Mulholland, R. E., & Cowie, H. A. (2002). *Behavioural studies of people's attitudes to wearing hearing protection and how these might be changed* (No. 028). Edinburgh: Health & Safety Executive.

Humes, L. E., & Jesteadt, W. (1991). Modeling the interactions between noise exposure and other variables. *Journal of the Acoustical Society of America, 90*, 182-188.

I-INCE. (1997). *Technical Assessment of Upper Limits on Noise in the Workplace*: International Institute of Noise Control Engineering.

Iki, M., Kurkmatani, N., Hirata, K., & Moriyama, T. (1985). An association between Raynaud's phenomenon and hearing loss in forestry workers. *American Industrial Hygiene Association Journal, 46*(9), 509-513.

ISO. (1990). *ISO 1999: Acoustics -- Determination of occupational noise exposure and estimation of noise-induced hearing impairment*: International Organisation for Standardization.

Itoh, A., Nakashima, T., Arao, H., Wakai, K., & Tamakoshi, A. (2001). Smoking and drinking habits as risk factors for hearing loss in the elderly: epidemiological study of subjects undergoing routine health checks in Aichi, Japan. *Public Health, 115*, 1920196.

Jacobsen, P., Hein, H. O., Suadicani, O., Parving, A., & Gyntelberg, R. (1993). Mixed solvent exposure and hearing impairment: an epidemiological study of 3284 men. The Copenhagen male study. *Occupational Medicine, 43*, 180-184.

Johnson, D. L., & Riffle, C. (1992). Effects of gunfire on hearing level for selected individuals of the Inter-Industry noise study. *Journal of the Acoustical Society of America, 72*(4), 1311-1314.

Jones, H. H., & Oser, J. L. (1968). Farm equipment noise exposure levels. *Amercian Industrial Hygiene Association Journal, 29*(146-151).

Jubb-Toohey, W. (1994). Too Noisy to Hear. *Better Hearing,* p1.

Katz, D. L. (2001). Behaviour modification in primary care. *Preventive Medicine, 32*, 66-72.

Kemp, D.T. (2002). Otoacoustic emissions, their origin in cochlear function and their use. *British Medical Journal,* 63: 223-241

Kerr, M. J., McCullagh, M., Savik, K., & Dvorak, L. A. (2003). Perceived and measured hearing ability in construction labourers and farmers. *American Journal of Industrial Medicine, 44*, 431-437.

Kopke RD, Weisskopf PA, Boone JL, Jackson RL, Wester DC, Hoffer ME, et al. Reduction of noise-induced hearing loss using L-NAC and salicylate in the chinchilla. *Hearing Research* 2000;149(1-2):138-46.

Kramer, W., & Updike, C. (1991). *Recreational shooters and their use of hearing protection.* Paper presented at the American Speech-Language-Hearing Association, Seattle, Washington.

Kujawa SG, Liberman MC. Acceleration of age-related hearing loss by early noise exposure: evidence of a misspent youth. *Journal of Neuroscience* 2006;26(7):2115-23.

Landstrom, U., Bystrom, M., & Olofsson, B. (1999). Temporary impairment of hearing in connection with physical exercise and exposure to noise/music. *Archives of complex environmental studies, 11*(1-2), 9-19.

Lataye, R., Campo, P. 1996. Applicability of the L(eq) as a damage-risk criterion: an animal experiment. *Journal of the Acoustical Society of America* 99, 1621-32.

Lawton, B. W., & Robinson, D. W. (1989). *The effects upon hearing of noise in combination with other agents: A critical review of the literature*. Southampton: Health & Safety Executive.

Leigh, J., Macaskill, P., Kuosma, E., & Mandryk, J. (1999). Global burden of disease and injury due to occupational factors. *Epidemiology, 10*(5), 625-531.

Leinster, P., Baum, J., Tong, D., & Whitehead, C. (1994). Management and motivational factors in the control of noise induced hearing loss (NIHL). *Annals of Occupational Hygiene, 38*(5), 649-662.

LePage, E. L., & Murray, N. M. (1993). Click-evoked otoacoustic emissions: comparing emission strengths with pure tone audiometric thresholds. *Australian Journal of Audiology, 15*(1), 9-22.

LePage, E. L., & Murray, N. M. (1998). Latent cochlear damage in personal stereo users: a study based on click-evoked otoacoustic emissions. *Medical Journal of Australia, 169*, 588-592.

Lindgren, F., & Axelsson, A. (1985). Temporary threshold shift induced by noise exposure and moderate salicylate intake. *Scandinavian Audiology Supplement, 26*, 41-44.

Lipp, J. (1992). Ear protection simple and effective. *WorkCare Issues, 2*(1), 3.

Lipscomb, D. M. (2005, 16 August). *An Exercise in Futility: Frustrations of a Hearing Conservationist*. Retrieved 25/08/2005, from http://www.audiologyonline.com/articles/arc_disp.asp?id=1371

Lusk, S., & Kelemen, M. (1993). Predicting use of hearing protection: a preliminary study. *Public health Nursing, 10*(3), 189-196.

Lusk, S., Ronis, D., & Baer, L. (1995). A comparitive study of multiple indicators. Observations, supervisors report, and self-report as measure of workers' hearing protector use. *Evaluation and the Health Professionals, 18*(1), 51-53.

Lusk, S., Ronis, D., & Kerr, M. (1995). Predictors of hearing protection use among workers: implications for training programs. *Human factors, 37*, 635-640.

Lusk SL, Ronis DL, Kazanis AS, Eakin BL, Hong O, Raymond DM (2003). Effectiveness of a tailored intervention to increase factory workers' use of hearing protection. *Nursing Research*, 52: 289-295

Macrae, J. H. (1991). Presbycusis and noise-induced permanent threshold shift. *Journal of the Acoustical Society of America, 90*, 2513-2516.

Manninen, O. (1983). Studies of combined effects of sinusoidal whole body vibrations and noise fo varying bandwidths and intensities on TTS in men. *International Archives of Occupational and Environmental Health, 51*(3), 273-288.

Marvel, M. E., Pratt, D. S., L.H, M., Regan, M., & May, J. J. (1991). Occupational learing loss in New York dairy farmers. *American Journal of Industrial Medicine, 18*(333-337).

McBride, D. (2005). Unpublished document (pp. 11): University of Otago.

McBride, D., Firth, H., & Herbison, G. P. (2003). Noise exposure and hearing loss in agriculture: A survey of farmers and farm workers in the Southland region of New Zealand. *Journal of Occupational and Environmental Medicine, 45*(12), 1281-1289.

McFadden, S. L., Henselman, L. W., & Zheng, X. Y. (1999). Sex differences in auditory sensitivity of chinchillas before and after exposure to impulse noise. *Ear & Hearing., 20*(2), 164-174.

Melamed, S., Rabonowitz, S., Feiner, M., Weisberg, E., & Ribak, J. (1996). Usefulness of the protection motivation theory in explaining hearing protection device use among male industrial workers. *Health Psychology, 15*, 209-215.

Milhinch, J., & Dineen, R. (1997). *Noise and Hearing in the Construction Industry: A Study of workers' views on noise and risk on a Victorian site*: Incolink.

Mills, J. H. (1992). Noise-induced hearing loss: Effects of age and existing hearing loss. In A. L. Dancer (Ed.), *Noise-Induced Hearing Loss*. Philadelphia: B.C. Decker.

Mills, J.H., Boettcher, F.A., & Dubno, J.R. (1997). Interaction of noise-induced permanent threshold shift and age-related threshold shift. *Journal of the Acoustical Society of America, 101*, 1681-1686.

Mizoue, T., Miyamoto, T., & Shimizu, T. (2003). Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers. *Occupational and Environmental Medicine, 60*, 56-59.

Morata, T. C., Dunn, D. E., Kretschmer, L. W., Lemasters, G. K., & Keith, R. (1993). Effects of occupational exposure to organic solvents and noise on hearing. *Scandinavian Journal or Work and Environmental Health, 19*(4), 245-254.

Morata, T. C., Dunn, D. E., Kretschmer, L. W., Lemasters, G. K., & Santos, U. P. (1991). *Proceedings of the fourth international conference on the combined environmental factors*, Baltimore.

Moretz, S. (1990). Decibel damage. *Occupational Hazards, 52*, 41-44.

National Acoustic Laboratories. (1998). *Attenuation and use of Hearing Protectors* (8th ed.). Chatswood, NSW: Commonwealth of Australia.

National Institute on Deafness and Communication Disorders, 2005. www.nidcd.nih.gov/health/statistics/hearing.asp

National Institutes of Health. (1990). Consensus conference: Noise and hearing loss. *Journal of the American Medical Association, 263*(23), 3185-3190.

Nelson, D. I., Nelson, R. Y., Cocha-Barrientos, M., & Fingerhut, M. (2005). The global burden of occupational noise-induced hearing loss. *American Journal of Industrial Medicine, 48*, 446-458.

Neuberger M, Korpert K, Raber A, Schwetz F, Bauer P. (1992) Hearing loss from industrial noise, head injury and ear disease. A multivariate analysis on audiometric examinations of 110,647 workers. *Audiology*.;31(1):45-57.

NIOSH. (1996). *Preventing Occupational Hearing Loss - A Practical Guide*. Cincinnati, Ohio: National Institute for Occupational Safety and Health, US Department of Health and Human Services.

NIOSH. (1998). *Criteria for a Recommended Standard - Occupational Noise Exposure - Revised Criteria 1998*. Publication 98-126.

Niskar, A., Kieszak, S., Holmes, A., Esteban, E., Rubin, C., & Brody, D. (2001). Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: The third national health and nutrition examination survey, 1988-1994, United States. *Pediatrics, 108*(1), 40-43.

NOHSAC. (2004). *National prevention of occupational noise induced hearing loss* (No. 1/8): National Occupational Health and Safety Commission.

NOHSC. (1991). *Noise Management at Work - Control Guide*. Sydney: National Occupation Health and Safety Commission.

Nondahl, D. M., Cruickshanks, K. J., Wiley, T. L., Klein, R., Klein, B. E. K., & Tweed, T. S. (2000). Recreational firearm use and hearing loss. *Archives of Family Medicine, 9*, 352-357.

Odes, J. S. (1972). Acuostic trauma of spartsman hunter due to gun firing. *Laryngoscope, 82*(11), 1832-1839.

Orris, P., Meluis, J., & Duffy, R. (1995). Firefighters' safety and health. In *Occupational Medicine: State of the Art Reviews* (Vol. 10). Philadelphia: Hanley & Belfus, Inc.

OSH. (1994). *Noise-Induced Hearing Loss of Occupational Origin*. Occupational Health and Safety Service, Department of Labour, Wellington

OSH (1996). *Control guide. Management of Noise at Work.* Occupational Health and Safety Service, Department of Labour, Wellington

OSH (1996b) *Approved Code of Practice for Management of Noise in the Workplace.* Occupational Health and Safety Service, Department of Labour, Wellington

OSHA (2006). Department of labour Occupational Health and Safety Administration, http://www.osha.gov

Paoli P and Merllié D (2001). *Third European Survey on Working Conditions.* European Foundation for Improvement of Living and Working Conditions, Dublin.

Palmer KT, Coggon D, Syddall HE, Pannett B, and Griffin MJ (2001). *Occupational exposure to noise and hearing difficulties in Great Britain.* Health and Safety Executive, Norwich.

Pearce, N., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., & Wagestaffe, M. (2005). *Surveillance of occupational disease and injury in New Zealand: Report to the Minister of Labour*. Wellington: NOHSAC.

Price, G. R. (1974). Transformation function of the external ear in response to impulsive stimulation. *Journal of the Acoustical Society of America, 56*(1), 190-194.

Roberto, M., Hamernik, R.P., Salvi, R.J., Henderson, D., Milone, R. 1985. Impact noise and the equal energy hypothesis. *Journal of the Acoustical Society of America* 77, 1514-20.

Robinson, D. W. (1991). *Tables for the estimation of hearing impairment due to noise for otologically normal and typical unscreened populations of males and females* (No. HSE contract research report no 29/1991). London: Health & Safety Executive.

Rosen, G. (1974). A Backward glance at noise pollution. *American Journal of Public Health, 64*(5), 514-517.

Rosenhall, U., Sixt, E., Sundh, Y., & Svanboug, A. (1993). Correlations between presbyacusis and extrinsic noxious factors. *Audiology, 32*(234-243).

Runyan, C. (2003). Introduction: Back to the future - revisiting Haddon's conceptualization of injury epidemiology and prevention. *Epidemiologic Reviews, 25*, 60-64.

Saari, J. (2005). *Accident Prevention Today*, from http://agency.osha.eu.int/publications/magazine/4/en/index_2htm

Saunders, J. C., Dear, S. P., & Schneider, M. E. (1985). The anatomical consequences of acoustic injury. *Journal of the Acoustical Society of America, 78*(3), 833-860.

Serra, M. R., Biassoni, E. C., Minoldo, G., Franco, G., Abraham, S., Carignani, J. A., et al. (2005). Recreational noise exposure and its effects on the hearing of adolescents. Part 1: An interdisciplinary long-term study. *International Journal of Audiology, 44*, 65-73.

Sexias, N., & Nietzel, R. (2004). *Noise exposure and hearing protector use among construction workers in Washington state*. Seattle: University of Washington.

Schucknecht HF (1993), ed. *Pathology of the Ear.* 2nd ed. Philadelphia: Lea and Febiger

Shaffer, L. A. Withnell, R. H. Dhar, S. Lilly, D. J. Goodman, S. S. Harmon, K. M. (2003). "Sources and mechanisms of DPOAE generation: implications for the prediction of auditory sensitivity." *Ear & Hearing* 24(5): 367-79.

Shaw, A. G. (1985). *Occupational Noise Exposure and Noise-Induced Hearing Loss: Scientific Issues, Technical Arguments and Practical Recommendations APS 707* (No. NRCC/CNRC No 25051). Ottawa, Canada.

Sliwinska-Kowalska, M., Zamysolwska-Szmytke, E., Szymczak, W., Kotylo, P., Fiszer, M., Weslolwski, W., et al. (2005). Exacerbation of noise-induced hearing loss by co-exposure to workplace chemicals. *Environmental Toxicology and Pharmacology, 19*, 547-553.

Standards Australia/Standards New Zealand. (2005). *Occupational noise management* (No. AS/NZS 1269:0:2005).

Statistics New Zealand. (2000). *Occupational Safety and Health*, 2005, from www.stats.govt.nz/quick-facts/govt-services/occupational-safety-health.htm

Stephens, S. G. D. (1982). Clinical investigation of hearing loss in the elderly. In S. G. D. Stephens (Ed.), *Scott Brown's Otolaryngology* (Vol. II, pp. 1421-1443). London: Buttorworths.

Stewart, M., Konkle, D. F., & Simpson, T. H. (2001). The effect of recreation gunfire noise on hearing in workers exposed to occupational noise. *Ear, Noise & Throat Journal, 80*(1), 32-40.

Strasser, H., & Irle, H. (2002). Physiological costs of the hearing due to noise exposure, additional physical stress, and combined exposure to alcohol and cigarette smoke. *Human factors and ergonomics in manufacturing, 12*(3), 279-296.

Szanto, C. S., & Ligia, S. (1999). Correlation between vibration induced white finger and hearing loss in miners. *Journal of Occupational Health, 41*(222-237).

Thelin, J. W., Joseph, D. J., Davis, W. E., Baker, D. E., & Hosokawa, M. C. (1983). High-frequency hearing loss in male farmers in Missouri. *Public Health Reports, 98*(98), 268-273.

Toppila, E., Pyykko, I., & Starck, J. (2000). Age and noise-induced hearing loss. *Scandinavian Audiology, 30*, 236-244.

Trevithick, P. (1995). What it's like living with a deaf person. *Better Hearing, June*.

Tubbs, R. L. (1995a). *Evaluation risk of noise induced hearing loss for firefighters* (No. HETA 89-0290-2460). Cincinnati, Ohio: National Institute for Occupational Safety and Health.

Turn down music in bars, says hearing group. (2005, 7/12/2005). *The Nelson Mail*.

United States Coastguard (1982). Recommendations on control of excessive noise http://www.uscg.mil/hq/g-m/nvic/12_82/n12-82.pdf

Uchida, Y., Nakashimat, T., Ando, F., Niino, N., & Shimokata, H. (2005). Is there a relevant effect of noise and smoking on hearing? A population-based aging study. *International Journal of Audiology, 44*(2), 86-91.

Virginia Department of Health. (2000). *Noise-Induced Hearing Loss: A Study Prepared in Response to HJR 371*: Virginia Department of Health and Virginia Department of Deaf and Hard of Hearing.

Walton, S. M., Conrad, K. M., Furner, S. R., & Samo, D. G. (2003). Cause, type and workers' compensation costs of injury to fire fighters. *American Journal of Industrial Medicine, 43*, 454-458.

Ward, W. D. (1991). The role of intermittence in PTS. *Journal of the Acoustical Society of America, 90*, 164-169.

Waugh, R. (1986). *A national strategy for the prevention of noise- induce hearing loss* (No. NAL 113): National Acoustics Laboatories.

Waugh, R. (1993). *Do hearing conservation programs really work?* Paper presented at the

National Seminar on Noise Management in the Workplace, Melbourne, Australia.

Welleschik, B., & Raber, A. (1978). Influence of exposure time and age on noise-induced hearing loss: Observations of 25,544 industrial workers. *Laryngology, Rhinology and Otolaryngology, 57*(12), 1037-1048.

Westbrook, M., Hogan, H., Pennay, M., & Legge, V. (1992). Workers' reactions to their noise-induced hearing loss: acknowledgement versus avoidance. *J Occup Health safety - Aust NZ, 8*(3), 237-242.

Weston, H., & Adams, S. (1932). *The Effects of Noise on the Performance of Weavers* (No. 65 (II)). London: Industrial Health Research Board.

WHO. (1997). *Prevention of Noise-Induced Hearing Loss, Report of an Informal Consultation held at the World Health Organization*. Geneva: World Health Organisation.

WHO. (2002). *The World Health Report, Chapter 4: Selected Occupational Risks*, 2005, from http://www.who.int/whr/2002/chapter4/en/index8.html

Williams, W. (1993a). *Managing noise: Demystifying noise control.* Paper presented at the National Seminar on Noise Management in the Workplace, Melbourne, Australia.

Williams, W. (1993b). *Occupational Noise Management*. Sydney: National Acoustic Laboratories.

Williams, W. (2005a). *Barriers to occupational noise management*.Unpublished manuscript.

Williams, W. (2005b). Noise exposure levels from personal stereo use. *International Journal of Audiology, 44*(5), 231-236.

Williams, W., Forby-Atkinson, L., Purdy, S., & Gartshore, G. (2002). Hearing loss and the farming community. *Journal of Occupational Health and Safety - Australian and New Zealand, 18*(2), 181-186.

Williamson, A., Feyer, A.-M., Cairns, D., & Biancotti, D. (1997). The development of a measure of safety climate: The role of safety perceptions and attitudes. *Safety Science, 25*, 15-27.

WorkCover NSW. (1996). *Code of Practice for management and protection of hearing at work*. Sydney.

Yamashita D, Jiang HY, Le Prell CG, Schacht J, Miller JM. Post-exposure treatment attenuates noise-induced hearing loss. *Neuroscience* 2005;134(2):633-42.

Zhang, Y., Zhang, X., Zhu, W., Zheng, X., Deng, X. 2004. Distortion product of otoacoustic emissions as a sensitive indicator of hearing loss in pilots. *Aviation Space & Environmental Medicine.* 75, 46-8.

Appendix I:
Hierarchy of methods of noise control

Adapted from the New South Wales code of practice for noise management and protection of hearing at work (WorkCover NSW, 1996), and (Williams, 1993a).

Current noise control concepts are based around the idea of a hierarchy of three approaches based around the 'source-path-receiver' model of conceptualising how noise reaches the ear. These three components are:

Elimination or reduction of noise at the source

Elimination or disruption of the noise transmission path

Isolation or insulation of the receiver from the noise

Inherent in this hierarchy is the idea that the most effective method of noise control is to have no excessive noise at all, followed by preventing excessive noise from reaching people while the least effective method is to protect people from noise that they are exposed to. This last form of protection typically requires behavioural change, changing behaviour permanently is very difficult making this last measure often ineffective.

Note that these lists are arranged so that the actions that typically lead to the greatest drop in sound levels are ranked first. Depending on the particular situation, any of these actions could be very beneficial, and the action that will provide the most benefits should be implemented first.

1. Reduce noise at the source: Most effective

Eliminate the noisy process entirely (is the process actually necessary for production?)

Substitute a quieter process for the noisy process (for example, spot welding to join metal components rather than using impact rivets or driving screws rather than hammering nails)

Replace noisy plant/machinery with equipment designed to operate at quieter levels (upgrade to newer machinery with a lower acoustic output)

Modify specific components of a task or machine to avoid causing unnecessary noise (e.g. replace gear drives with belts or fit rubber bumpers between impact points)

Separate noisy components from the rest of the plant (e.g. pumps and compressors need not be located in the immediate vicinity of the machines they power)

Correct specific noisy elements of a machine if the whole item cannot be treated. (consider each component of a machine as an independent noise source, and treat the loudest components first)

Maintain all tools and equipment to a high standard to prevent additional noise being created (e.g. replace worn or loose parts, ensure proper lubrication and balancing of moving parts, firmly secure panels and covers against vibration)

Reduce the operating speed of machines to the lowest required to meet production targets (i.e. avoid running fast and loud if not necessary)

In environments with more than one noise source (like most workplaces), it is by far more effective to reduce the noise from loudest source before targeting other areas. This is called ranking noise sources.

If one particular noise source is 3dB or more above the rest (in reality twice as loud) this problem should take priority, if you reduce the other sources and leave this one as-is there will be no appreciable change in noise level. However if all sources are within 3dB of each other quietening just one will make very little difference, while quieting a source that is already 10dB less than another adjacent will have a negligible impact. Either all sources need to be reduced or other methods such as distance and isolation should be implemented.

2. Reduce transmission of noise between the source and the receiver

Establish distance between the noise source and the worker (there is a 6dB drop in sound energy with a doubling of distance between the source and the receiver. This represents a quartering of sound energy every time distance is doubled. For example moving something two meters away instead of one quarters the sound levels, move it four meters and the sound reaching the individual is only 1/16th of that at the source)

Erect a noise barrier such as a wall between the source and the worker, (the denser and heavier the material, the better the sound barrier e.g. lead, steel, concrete and brick. A barrier is most effective when it totally seals the path, i.e. anywhere air can flow, noise can too)

Apply noise absorbing material to surfaces facing the noise source, or to barriers between the source and the receiver. (good sound absorbers are materials such as foams, fibreglass and thick pile carpet)

Minimise resonances of walls and enclosures, which will transmit sound to the protected area at the resonant frequency. (reinforce and brace strategic areas during design or modification)

Reduce the reverberation of the room where noise is generated (use sound absorbing material on floors, ceilings, walls and other surfaces)

Note that materials that are good noise barriers are very poor noise absorbers, and vice versa. Therefore when the goal is to block noise from reaching the worker, dense solid materials are best. When the aim is to lessen the noise in a worker's environment, linings should be made of 'soft' sound absorbent materials. It reality most sound barriers would be made of a hard core to prevent the transmission of noise, with an absorbent lining to deaden reflected and resonant sound. The main principle is absorb-block-absorb: absorb sound close to the source, block its transmission and absorb it close to the receiver.

3. Reduce noise reception at the receiver: Less effective

Acoustically isolate the worker. (establish control rooms away from noise sources, or develop low noise booths within high noise areas)

Use personal hearing protection devices, such as ear plugs and ear muffs. (note that this approach may only reduce the severity of the noise exposure, the worker is still exposed to the sound)

Please note: In reality it is almost impossible to modify the receiver (the human) to lessen the impact of noise, so technically the methods listed above also constitute a reduction in noise transmission on the path between the source and the receiver. However these methods have been included under a separate section to provide a simpler and more functional structure to the noise control framework.

4. Administrative controls

When it is not practicable to comply with legislative standards for noise exposure solely through the above engineering controls, administrative controls may also be used to limit individual noise exposure times. These measures include such things as shift rosters that are designed to expose as few workers to noisy tasks as possible and rotation of staff between high and low noise exposure operations.

Furthermore arranging all high noise operations to be undertaken at specified 'high noise periods' can increase the uptake and efficacy of hearing protectors and other methods by clearly identifying when there is a high risk to hearing and when protective measures must be taken. Conversely planning regular 'low noise periods' throughout the day in a typically noisy environment may not only reduce overall noise exposure but can have the further beneficial effect of allowing recovery time between bouts of high noise.

Administrative controls are the same as moving the noise spatially or temporally from the workers, but their effectiveness can vary greatly. For example for shift rotation to be effective a very long quiet period must follow even a short period of high noise, to the point where such staff rotation may be organisationally impossible. Scheduling high noise tasks out of normal working hours so that only a skeleton crew is exposed to the noise can be effective at lowering the total workplace noise exposure level. It is also effective at protecting those staff not involved in the high noise task, but this action itself does nothing to reduce the noise exposure of the staff that are required to run the operation.

Administrative controls must be undertaken with other noise reduction, avoidance or protection methods as part of a noise management program, they will generally have little effect independently.

Appendix II:
International exposure limits and exchange rates

The following table describes the level and criterion of average noise exposure limits, the exchange rate, and max or peak levels for a selection of key national and international jurisdictions. New Zealand is included for reference.

Nation or Authority	Government/ Jurisdiction	Criterion Level (dB)	Exchange Rate (dB)	Ceiling Levels
ISO		NA	3	NA
EU	European Union	80 *a	3	135 dBC (Lower action level)
		85 *b		137 dBC (Upper action level)
		87 *c		140 dBC (With protection)
Argentina		85 (HC)	3	115 dBA max
		90 (NC)		135 dBA peak
Australia	Federal - NOHSC	85	3	140 dBC peak
	Western Australia	85	3	140 dBC peak
	ACT	85	3	140 dB peak
	South Australia	85	3	140 dBC peak
	New South Wales	85	3	140 dBC peak
	Northern Territory	85	3	140 dB peak
	Queensland	85	3	140 dBC peak
	Tasmania	85	3	140 dBC peak
	Victoria	85	3	140 dBC peak
Austria	Ministry of Work and Employment	85 (HC)		110 dBA max
Canada	Federal Labour Operations	87	3	120 dBA max
	Alberta	85	5	115 dBA slow
				140 dB peak
				10,000 impacts at 120 dB
				1000 impacts at 130 dB
				100 impacts at 140 dB
	British Columbia	85	3	135 dBA peak
	Manitoba	85 (HC)	3	
		90 (NC)		
	New Brunswick	85	5	140 dB peak
				100 impacts max
	Newfoundland	85	3	140 dBC peak

Northwest Territories (also covers Nunavut)	85	5	140 dB peak 140 impacts max
Nova Scotia	85	5	140 dB peak 100 impacts max
Ontario	90	5	140 dB peak 100 impacts max
Prince Edward Island	85	3	140 dB peak
Quebec	90	5	140 dB peak 100 impacts max
Saskatchewan	80 (HPDs) 85 (HC) 90 (NC)	3	
Yukon Territories	85	3	103 dB max 140 dB peak
Chile	85	5	115 dBA max 140 dB peak
China	70-90 depending on industry	3	115 dBA max
Denmark	85 (HC) +5 to measured Leq if impulsive noise exposure	3	115 dBA peak 115 dBC peak
Finland	85 (HC & NC)	3	140 dBC peak
France	85 (HC) 90 (NC)	3	135 dBC peak
Germany	85 (HC) 90 (NC)	3	140 dBC peak
Hungary	85 90 (NC)	3	125 dBA max 140 dBC peak
India	90		115 dBA max 140 dBA peak
Ireland	85 (HC) 90 (NC)	3	140 dB peak
Israel	85	5	115 dBA max 140 dBC peak
Italy	85 (HC)	3	140 dBC peak

	90 (NC)		
Japan	90 85 (HC) 85 (NC)	3	
Netherlands	85 80 (HC) 90 (NC)	3	140 dBA peak
New Zealand	85 (HC)	3	140 dB peak
Norway	85 (HC), (general industry) 70 (sensitive communications) 55 (critical communications) 83 (offshore, 12-hr exposure) 90 (on board vessels)	3	110 dBA fast max or 120 dBA fast max 130 dBC peak
Poland	85 (non-impulsive noise)	3	130 dB (100 impulses/day) 120 dB (1000 impulses/day) 110 dB (10000 impulses/day)
Singapore	85 (HC) 90 (NC) (if more than 50 people exposed)	3	140 dBA peak
South Africa	85 (HC) 85 (NC)		135 dBA peak
Spain	85 80 (HC) 90 (NC)	3	140 dBC peak
Sweden	85 (HC) 85 (NC)	3	115 dBA fast max 140 dBC peak

Switzerland		85 or 87	3	125 dBA max 140 dBC peak
Thailand		80 (AL) 90		
UK		85 1st AL 90 2nd AL		140 dBA peak
USA	American Conference of Governmental Industrial Hygienists	85	3	140 dBC peak
	American National Standards Institute	NA	3 or 5	NA
	California Occupational Safety and Health Administration	85 (HC)	5	115 dBA max
		90 (NC)		140 dB peak
	Federal Railroad Administration	90	5	115 dBA max
	Mine Safety and Health Administration	85 (HC)	5	115 dBA max
		90 (NC)	Dual HPDs above 105 dBA	
	National Institute for Occupational Safety and Health	85	3	140 dB peak
	Occupational Safety and Health Administration	90 (NC) 85 (HC)	5	115 dBA max 140 dB peak (advisory)
	Occupational Safety and Health Administration	90	5	115 dBA max 140 dB peak (advisory)
	Washington Industrial Safety and Health Administration	85 90 (NC)	5	115 dBA max 140 dBC peak
	US Coast Guard	82 (NC)* 77 (HC)*	5	115 dBA max 140 dB peak
		*note: these are 24-hour average levels, (Leff 24) HPDs for exposure >85 dBA HC program for routine exposure >85 dBA		
	US Military	85	3 USAF 3 USAR 4 USN	140 dBA peak
Uruguay		90	3	110 dBA max

Key:

HC = Hearing conservation

NC = Noise control

AL = Action level

HPD = Hearing protection devices

*a (Lower Action Level, daily training, information, provision of hearing protection devices)

*b (Upper Action Level, daily noise control and hearing protection use)

*c (Exposure Limit WITH protection, daily and/or weekly: noise control, hearing protector use)