Chapter 2
Noise-induced Hearing Loss

2.1 Definition

Noise-induced hearing loss (NIHL) is defined as an impairment of hearing, resulting from exposure to excessive noise that manifests over a number of years and results in bilateral and symmetrical impairment of hearing. The cumulative permanent loss of hearing is always of the sensori-neural type, which develops over months or years of hazardous noise exposure (McBride; 2004; RMA, 2003; ASHA 1996).

Pure-tone hearing thresholds are irreversibly shifted due to damage to the hearing mechanism in the inner ear, in the form of selective destruction of the cochlear outer hair cells (OHCs). The damage is caused by exposure to either consistent or impulse noise at levels of above 80 dBA that leads not only to a reduced ability to hear sounds but also to a reduction in the intelligibility of speech (Celik, 1998; Edwards, 2002; Attais, Horovitz, El-Hatib & Nageris, 2001).

2.2 Effects of Noise Exposure

Exposure to noise has anatomical, non-auditory and auditory effects. Each of these effects of noise is discussed since they impact on the health and safety of a worker to varying degrees and eventually on their quality of life.

2.2.1 Anatomical effects

The ear consists of three main parts: the outer ear, the middle ear and the inner ear. NIHL does not affect the outer ear. The middle ear is only affected when the ear is exposed to a combination of noise and severe changes in air pressure, which can be caused by, for example, descending into deep levels of an underground mine. The changes in air pressure result in barotrauma, which can have symptoms of a feeling of the ear being blocked, ear pain, hearing loss, dizziness, tinnitus, and even haemorrhaging from the ear (Donoghue, 2004; Franz and Schutte, 2005; Klingmann, Praetorius, Baumann, Plinkert, 2007). A severe blast or explosion can also affect the middle ear when the impact of the energy from the blast damages the eardrum. These symptoms are therefore not strictly NIHL but can be related to the conditions in an occupational environment such as in deep-level mining found in the South African mining industry (Franz & Schutte 2005).

The inner ear, on the other hand, is most affected by exposure to high levels of noise which causes both mechanical and metabolic changes at this site of lesion for NIHL. These anatomical and physiological effects of over-stimulation of the inner ear are the result of the high energy transfer causing mechanical damage to the delicate parts of the OHCs in the cochlea (Avan & Bonfils, 2005; Balatsouras, Tsimpiris, Korres, Karapantzos, Papadimitriou & Danielidis, 2005; Chan Wong & McPherson, 2004; Chen & Zhao, 2007). In addition, the high energy transfer also causes metabolic stress within the endolymphatic fluids of the cochlea, resulting in swelling and degeneration of the eighth nerve terminals attached to the inner hair cells (Chen & Zhao, 2007).

2.2.2 Non-auditory effects

Exposure to noise also affects workers in non-auditory ways. The following list highlights some of the non-auditory effects.

Firstly, one of the most predominant non-auditory effects of NIHL is the presence of tinnitus (Axelsson, Borchgrevink, Hamernik, Hellstrom, Henderson & Salvi, 1996; Edwards, 2002). Tinnitus can in many cases be debilitating for a worker and can influence sleep, mood, concentration, personality and in some cases speech recognition. The prevalence of tinnitus has been reported in between 30 and 65% of cases with a history of noise exposure, around twice the prevalence in the general population (Monley, West, Guzeleva, Dinh & Tzvetkova, 2003; Tyler, 2000). The relevance to this study is that the prevalence of tinnitus in the South African mining population has been reported to be 25 to 30% (Edwards, 2002).

Secondly, non-auditory effects of noise exposure are known to include symptoms related to the autonamic nervous system, such as heightened skin temperatures, increased pulse rate, increased blood pressure and a narrowing of blood vessels, abnormal secretion of hormones and tensing of muscles (Morris, 2006; Palmer, Coggon, Syddall, Pannett & Griffin, 2001).

Thirdly, the reduced ability to hear and communicate as a result of NIHL not only results in a reduced quality of life but the increased effort to hear has a 'domino effect' of increased fatigue, frustration, stress, anger, embarrassment, isolation, negative self-image and reduced autonomy (Palmer et al., 2001).

Fourthly, symptoms related to higher brain functioning have been documented and include interference in thought processing and task execution. These symptoms result from greater concentration and listening effort needed when working in noise and can in turn lead to irritability, nervousness, aggression, depression and disturbances in sleep patterns that result in decreased appetite (Morris, 2006).

Finally, the occupational impacts of NIHL and exposure to noise also include a non-auditory effect of noise exposure. Excessive noise exposure is reported to reduce job performance and can cause high rates of absenteeism (Morris, 2006). Results of a retrospective study that explored the association between the risks of occupational noise exposure, the degree of NIHL, and work-related accidents between 1983 and 1998 in Quebec showed that a hearing loss of 20 dB results in a significant increase in accident risk when controlling for age and occupational noise exposure. In the Quebec study, 12.2 % of accidents were found to be attributable to a combination of noise exposure of greater than 90 dBA and NIHL (Picard, Banville, Barbarosie & Manolache, 2008). NIHL results in increased safety risks because noise distracts the worker's attention and drowns out the sound of a malfunctioning machine, alarm signals or warning shouts. The decrease in communication in conditions of high levels of noise can also cause annoyance, disputes and stress (Dineen, 2001).

2.2.3 Auditory effects

The auditory effects of noise exposure are NIHL. More specifically, those auditory effects include: hearing threshold shift and speech perception deterioration.

2.2.3.1 Hearing threshold shift

NIHL develops gradually, but most rapidly in the first 10 years of exposure to noise (ANSI, 1996; Daniel, 2007). The audiological effects on the audiogram are first seen in the higher frequencies (3000 – 6000 Hz) and there is usually a greater loss at these high frequencies than at lower frequencies (500 – 2000 Hz) (ACOEM, 2002; ANSI S3.44, 1996). Given stable noise exposure conditions, losses at 3000, 4000, and 6000 Hz have been shown to reach a maximal point in 10 to 15 years, with the greatest loss usually occurring at 4000 Hz. (Miller, Dolan, Raphael, & Altschuler, 1998; Monley et al., 2003; Palmer et al., 2001).

The NIHL audiogram configuration has a characteristic “ski-slope” appearance with a “notch” at 4000 Hz. This “notch” deepens with additional years of exposure, but reaches a plateau after about 15 to 20 years of exposure (Gates, Schmid, Kujawa, Nam & D’Augostino, 2000; Edwards, 2002). The high frequency hearing loss usually averages 50 to 70 dB HL since NIHL seldom produces a profound hearing loss and the low frequency hearing threshold limits are approximately 40 dB (Daniel, 2007; Valoski, 1994).

Most scientific evidence indicates that previously noise-exposed ears are not more sensitive to future noise exposure and that hearing loss due to noise does not progress, in excess of what would be expected from the addition of age-related threshold shifts, once the exposure to noise is discontinued (ACOEM, 2002; Celik, 1998; Monley et al., 2003). However, contradictory reports are that the frequencies adjacent to the traditional notch at 4000Hz are more susceptible to hearing loss as the worker ages (Gates et al., 2000).

2.2.3.2 Speech perception

Another auditory effect of noise exposure is that the hearing ability is characterised by poor speech perception ability (Picard, Banville, Barbarosie & Manoloche, 1999). The function of the OHCs is frequency selectivity and the selection of important stimuli, which assist the listener to exclude background sounds (Tlumak & Kilney, 2001). NIHL results in sounds being heard in an abnormal way and the hearing loss results in reduced hearing thresholds and reduced supra-threshold functioning and speech processing (Vermaas, Edwards, & Soer, 2007; Green & Huerta, 2003).

The quality of life experienced by a person depends on the ability to communicate, which is dependent on the ability to understand spoken communication, which in turn is dependent on the ability to hear speech sounds in a way that allows the listener to understand human communication (Ringdahl, Eriksson-Mangold, & Andersson, 1998). People with high-frequency hearing loss, such as prevails in NIHL, are usually able to understand speech well in a quiet environment but experience significant difficulty in the presence of background noise or when a number of speakers are taking part in a conversation (Vermaas et al., 2007).

The degree of hearing loss and the audiogram configuration have a direct influence on the perception and processing of speech. The ability to discriminate the phonetic properties of speech requires that hearing across all frequencies of speech must be intact or the person will experience a significant degree of hearing handicap (Vermaas et al., 2007).

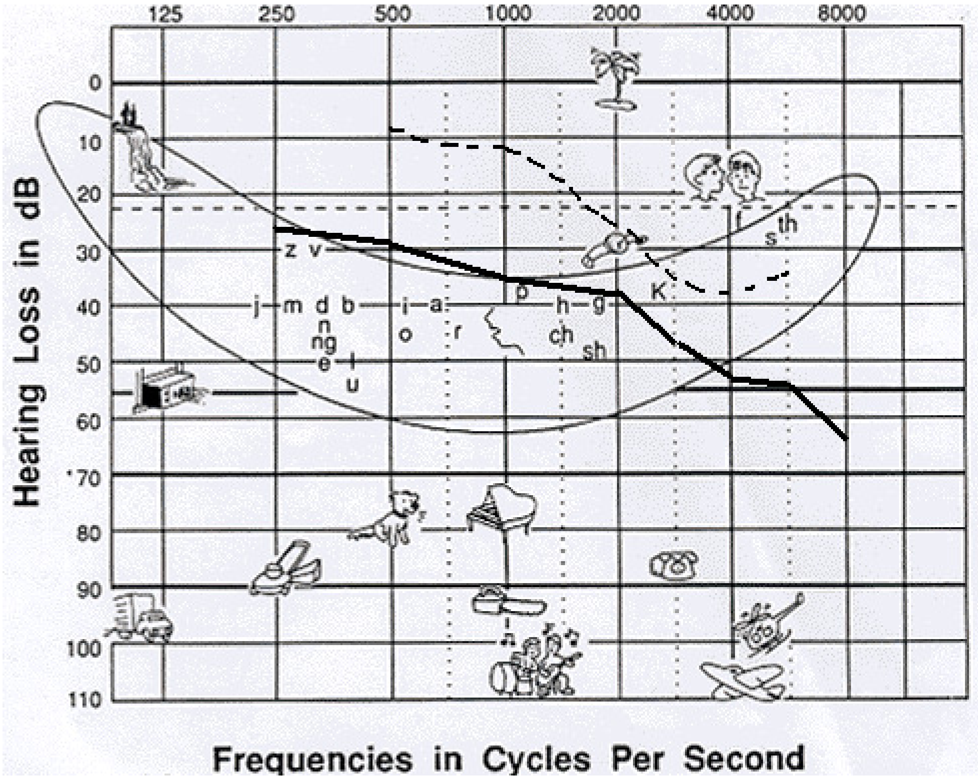
Vermaas et al., (2007) found that when the Percentage Loss of Hearing (PLH) of the gold miners' audiograms was calculated and then related to the measured hearing handicap, categories of hearing handicap could be assigned to the PLH as indicated in Table 1.

Table 2 Percentage loss of hearing related to the hearing handicap reported in South African gold miners.

PLH	Hearing handicap
<4%	None
4-10%	40-50%
10-40%	50-60%
>40%	>60%

Table 2 highlights the fact that the vast majority of miners whose PLH is between 4% and 10% are experiencing a 50% degree of handicap. This statistic supports the need to prevent NIHL and for this reason to investigate novel, accurate and objective methods of measurement.

In relation to the audiogram, the speech sounds are typically found in the low- to mid-frequency range, while some of the sounds that are essential for speech understanding, such as “s”, “k”, “f” and “th” (in English), are found in the high frequencies at the low intensities of 20 to 30 dB. The relevance of this to the current study is related to speech perception abilities of NIHL victims and in particular to these abilities in the gold miners whose records were used in this study. The audiogram in Figure 1 below indicates, by means of pictures and letters, the frequency and intensity levels of typical environmental and speech sounds in relation to the audiogram (AAA, 2008). The predicted hearing levels after 20 years of working in noise levels of 95 dBA (ANSI S3.44, 1996) have been superimposed on the audiogram in Figure 1 as the dotted line. The NIHL found in a previous study on South African gold miners (Soer, Pottas, & Edwards, 2002) has also been superimposed on the audiogram as the solid line. The hearing levels indicate that a gold miner would experience difficulty in hearing speech sounds without amplification and would not be able to discriminate speech sounds in unfavourable environments since the “f”, “s” and “th” sounds will not be heard. This would be the case for the English language, and similar speech recognition difficulties in the other languages spoken in the South African mining industry, such as Zulu or Xhosa, can be expected.



Dashed lines = predicted noise-induced hearing loss estimated to occur after 20 years of noise exposure. (Source: ANSI S3.44, 1996); solid line = reported South African miner's hearing loss (Source: Edwards. 2002).

Figure 1 Audiogram indicating the position of environmental sounds as depicted in a frequency and intensity matrix.

2.2.3.3 Speech recognition threshold

Speech audiometry is a vital part of the basic test battery of the audiologist because it represents the day-to-day nature of communication and assesses the uniquely human capacity to interpret complex sound patterns such as speech (Bonaretti, 2007). The speech recognition threshold (SRT) is most commonly used to measure the hearing threshold for speech and the selection of material for SRT is crucial for ensuring valid results (ASHA, 1988;

Ramkissoon, Proctor, Lansing, & Bilger, 2002). The technique for establishing SRT uses standardised spondee words (two-syllable words) which are:

- easily understandable;
- equally intelligible;
- multi-syllabic; and
- balanced, with stress being equal on both syllables.

The SRT can be defined as the lowest level at which the individual is able to correctly identify 50% of spondee words (Picard et al., 1999). The standardised tests used in accepted practice have been developed on the basis of the five principles of familiarity, phonetic dissimilarity, a representative sample of the language's speech sounds, homogeneity, and audibility of the test material to be considered (Ramkissoon et al., 2002). The test technique is a recognition task that requires the client to recognise a sound and associate it with a previously learnt word or sentences presented to the client through a calibrated system (Bonaretti, 2007; ASHA, 1998).

The reliability of the pure-tone thresholds obtained on behavioural audiometry tests is traditionally assessed or cross-checked as a measure of validity by audiologists, using the inter-relationship among tests (Martin, Champlin, & Chambers, 1998; Picard et al., 1999; Turner, 2003) and more specifically using the difference between the SRT and the pure-tone average (PTA). In listeners with normal hearing the SRT is usually eight to nine dB HL above the minimal detection level of speech, and a strong relationship exists between the PTAs for 500 Hz, 1000 Hz and 2000 Hz and the necessary intensity for speech sound comprehension. SRT results predictably have a 5 dB – 10 dB difference from the PTA while differences of 12 dB and above will render the reliability of the behavioural audiometry questionable (Martin et al., 1998; Quinn, Ryan, & Testing, 2004).

Multilingual and multicultural populations, such as is found in the South African mining population, present a unique challenge for valid and reliable service delivery, especially with regard to speech audiometry (Roets, 2006). When using SRT as a cross-check method in a clinical environment, it is essential that the audiologist is sensitive to the many factors which can confound the results. The confounding factors can be categorised into effects of the environment, effects of the stimuli, and effects of the listener (Turner, 2003; de Koker, 2003).

With regard to the effects of the environment, South African audiologists aspire to high standards of practice and these factors are well controlled by most audiologists (SANS, 2003). However, complex issues must be taken into account with the regard to stimuli effects of SRT testing by the audiologist servicing a multilingual and multicultural population. These complex issues are of particular relevance to the occupational audiologist in South Africa.

The stimuli effects will be influenced by the acoustics of the test items used to measure the SRT. These acoustics are, in turn, influenced by the language used for testing and the fluency with which the tester can execute the tests, as well as the way in which the stimuli reach the listener's ear (Ramikissoon & Khan, 2003). As discussed in Chapter One, South Africa is a multilingual and multicultural country and factors such as variance in linguistic background, dialect, vocabulary, and accent exist (Penn, 2002; Swanepoel, 2006). These diversities impact on the audiological service delivery since most audiological consultations are cross-cultural. This is because health professionals in South Africa are mainly English- or Afrikaans speaking (only 1% of trained audiologists speak a vernacular language) and have limited knowledge of the other nine official languages (Penn, 2002). Adjustments to standard clinical practice are reported to be the way that most audiologists cope with the many challenges faced in multilingual practice. South African audiologists report that they use some or all of the following adjustments to their mode of practice when testing multilingual clients (Roets, 2006; Ramikissoon & Khan, 2003):

- they do not use different test types for speech audiometry;
- they do not use pre-recorded test materials;
- tests are not conducted in the test subject's first language; and
- the test set size is reduced to exclude unfamiliar words.

These practices of course lead to reduced measurement accuracy and therefore reduced reliability and validity of the results (Ramikissoon & Khan, 2003).

In the mining context, the mother tongue of most clients is one of the South African vernacular languages or a language of one of the neighbouring southern African countries. To facilitate communication in the mining context the pidgin language known as “Fanagalo”, with most of its lexicon from Zulu, Xhosa, as well as adaptations of modern terms originating from English, Dutch and Afrikaans, is often spoken and used in the testing of SRT (Fromkin, Rodman, & Hymans, 2003; Gordon, 2005).

In the current study, SRT was established by means of conversational speech, using the descending method (Picard et al. 1999,). Conversational speech was used to establish SRT because no standardised word list were available in all the languages spoken by miners in South Africa, namely Sesotho, Setswana, IsiZulu, isiXhosa (Bonaretti, 2007). The vernacular-speaking testers used the language most familiar to the client, or Fanagalo where the tester was not fluent in the listener’s mother tongue, and the non-vernacular-speaking tester used Fanagalo.

With regard to the listener effects, these will be influenced by the mother tongue of the listener, his hearing levels, and the functioning of the auditory neurological pathway (Quinn et al., 2004). The listener must be willing to co-operate throughout the testing procedure, with no need to feign any degree of hearing loss. The configuration of the hearing thresholds of the listener impacts on the relationship between SRT and PTA in that, for normal hearing and flat configuration hearing losses, the relationship is predictable, as discussed previously. However, in other configurations, the SRT-PTA relationship may be misleading, e.g. in high-frequency hearing losses. This is especially true for the ski-slope or sloping configuration (where 1000 Hz and 2000 Hz may have moderate to severe loss), such as is found in the NIHL of miners. In such cases, the traditionally used PTA for 500 Hz ,1000 Hz and 2000 Hz usually results in a difference between the two measures of greater than 10 dB (Picard et al., 1999). Lack of agreement between SRT and PTA is often associated with patient factors which are unrelated to hearing, such as pseudohypacusis, poor attention span and fatigue (Picard et al., 1999). In South African clinical practice an agreement of 5-6 dB has been reported in multilingual populations, with depressed SRT scores because of a lack of familiarity with the English spondees used as test stimuli (Ramikissoon & Khan, 2003). Digits have been suggested as possible alternatives to spondees for multilingual populations and good correlations are reported in South African multilingual populations (Bonaretti, 2007).

The listener effect is of particular relevance to NIHL in the South African mining context, since SRT as part of a diagnostic occupational evaluation is usually established for the purposes of compensation for NIHL. The potential financial gain from this compensation increases the possibility of pseudohypacusis and the lack of cooperation from the listener. The South African legislation governing NIHL compensation states that, in instances where the audiologist is unable to obtain a reliable audiogram, the results for SRT may be submitted and considered in decisions regarding medico-legal compensation (COIDA, 1993). No standards for the methods used to determine an SRT are stipulated in the compensation legislation, thereby placing extra responsibility on the audiologist's training and experience to provide accurate results. The rationale for the current study is enhanced by the abovementioned factors, since the use of an objective test such as that which uses DPOAE, instead of the currently accepted SRT, appears to be a fairer and more reliable method (Miller, Crane, Fox & Linstrom, 1998). The results of the current study may provide information to substantiate any suggested changes in policy or legislation.

2.3 Factors contributing to the risk of NIHL

2.3.1 Individual susceptibility to noise-induced hearing loss

The preceding discussion outlines the general characteristics of NIHL. Those characteristics and symptoms of NIHL however, are dependant on the unique susceptibility of a person to NIHL. Individual susceptibility can vary between individuals, even when individual chronic exposure to the same intensity level of noise may be the same, and as a consequence some persons will develop significant hearing loss, while others will develop little or no hearing loss at all (Dineen, 2001; Le Page & Murray, 1998; Sliwinska-Kowalska, Dudarewicz, Kotylo, Zamyslowska-Szmytke, Pawlaczyk-Luszczynska & Gajda-Szadkowska, 2006). Some of the factors known to contribute to individual susceptibility to NIHL are genetic influences such as ethnic group (Daniel, 2007; de Koker, Clark, Franz, & Mackay, 2003); eye colour (Barrenas & Hellström, 1996); and tooth loss (Daniel, 2007). Other factors such as age (ISO 1999:1990, 1990); gender (Daniel, 2007; Ecob, Sutton, Rudnicka, Smith, Power, Strachan, et al., 2008) and life style factors such as smoking (Ecob et al., 2008), alcohol (Upile, Sipaul, Jerjes, Singh, Nouraei, El Maaytah, et al., 2007) and exercise (Daniel, 2007) have also been noted. Health factors such as tuberculosis, diabetes, hypertension and cardiovascular disease also have been reported to increase the susceptibility to the development of NIHL (Daniel, 2007). The synergistic effects of exposure to noise, ototoxins, exercise and hand-arm vibration also increase the worker's susceptibility to developing NIHL (Campbell, 2004, Duggal & Sarkar, 2007; Engdahl & Kemp, 1996; Fausti, Helt, Gordon, Reavis, Philips & Konard, 2007; Fitzpatrick & Eviatar, 1980). Finally, the level and type of noise that the worker is exposed to appears to be the single most important factor that influences the susceptibility to the development of NIHL. Some of the influencing factors mentioned above are discussed in more detail in the following sections.

2.3.2 Age

Presbycusis, or age-related hearing loss, has a gradual onset and develops as part of the body's progressive deterioration of physiological functions associated with the degeneration of sensory organs and aging. The interaction between aging and noise exposure is complex (Rosenhall, 2003). The most commonly accepted assumption is that the combined effects of age and noise exposure are additive in nature (Dobie, 2001; Henderson & Saunders, 1998; Miller et al., 1998; Miller, Ren, Dengerik, & Nuttal, 1996). The ISO 1999:1990 (1990) favours this additive model of the interaction between aging and noise exposure and provides hearing threshold levels expected for different ages in an unscreened population. The expected hearing threshold levels for males at the 0.1 fractile are summarised in Table 3.

Table 3 Predicted hearing threshold levels (dB) of males for advancing ages in an unscreened population.

Frequency	Age			
	30 years	**40 years**	**50 years**	**60 years**
500 Hz	15	19	21	26
1000 Hz	10	15	16	21
2000 Hz	13	19	28	43
3000 Hz	20	41	51	62
4000 Hz	38	50	54	68
6000 Hz	32	62	62	80

(Source: ISO 1999:1990, 1990)

The expected hearing threshold levels for a person who is exposed to noise and who is aging are summarised in the next section, where the effects of gender are also depicted (ISO 1999:1990, 1990).

However, other studies have contended that the additive model overestimates the interaction between aging and noise exposure (Mills, Dubno & Boettcher,1998) and suggest that other factors such as smoking, serum cholesterol, blood pressure and use of analgesics play as important a role in the development of NIHL especially when the noise exposure level is below 98 dBA and when there were more than two of these so-called confounders contributing to the development of hearing loss (Toppila, Pyykkö & Starck, 2001). Elderly workers are reported to have considerably higher hearing loss and are therefore more susceptible to NIHL development than younger workers and this confirms the findings in animal studies (Toppila et al, 2001; Miller et al, 1998).

The suggestions by studies that the development of NIHL before old age reduces the effects of ageing at noise-associated frequencies, but accelerates the deterioration of hearing in adjacent frequencies (Gates et al., 2000; Edwards, 2002) is of particular relevance to the South African mining industry because miners typically leave the industry by the time they are effected by the onset of presbycusis and the impact of their working career continues to impact on the quality of life during old age.

2.3.3 Gender

The ANSI SE.44-1996 standard shows that gender differences exist in NIHL development. Table 4 indicates the expected hearing threshold levels (at a 0.1% fractile level) for males and females, for progressively longer years of exposure to increasingly higher noise levels. The table shows that for the noise exposure level of 85 dBA very little difference is found between the two genders. This is also the case for the frequencies 500 Hz and 1000 Hz when the noise exposure levels increase. However, as the noise exposure levels increase, the differences in the development of NIHL become more evident in the higher frequencies. The differences are, however, only 1 dB in all instances, and this means that the difference between male and female hearing threshold levels would not be noticeable in most workforces since the standard clinical practice uses steps of 5dB in audiometric testing.

However, more recent information indicates that hearing thresholds for males have been reported to decline twice as fast as those for females (Ecob et al., 2008), and males are reported to cope less well with the effects of NIHL (Hallberg, 1999). Males are reported to account for 94% of all NIHL claims made, but this is probably due to the predominance of males employed in high risk situations, such as in manufacturing and construction (Morris, 2006). The records used in the current study were all from male miners.

Table 4 Expected hearing threshold levels (in decibels HL) for males and females when exposed to different levels of noise for progressively longer periods of time.

		Frequency											
		500 Hz		1000 Hz		2000 Hz		3000 Hz		4000 Hz		6000 Hz	
Gender		**M**	*F*	**M**	*F*	**M**	*F*	**M**	*F*	**M**	*F*	**M**	*F*
Exposure													
85 dBA	10 yrs	**8**	*8*	**8**	*8*	**11**	*10*	**15**	*14*	**17**	*16*	**16**	*15*
	20 yrs	**8**	*8*	**8**	*8*	**11**	*10*	**16**	*15*	**18**	*17*	**17**	*16*
	30 yrs	**8**	*8*	**8**	*8*	**11**	*11*	**16**	*16*	**18**	*18*	**17**	*16*
	40 yrs	**8**	*8*	**8**	*8*	**11**	*11*	**17**	*16*	**19**	*18*	**17**	*17*
90 dBA	10 yrs	**8**	*8*	**8**	*8*	**15**	*14*	**22**	*22*	**25**	*24*	**23**	*22*
	20 yrs	**8**	*8*	**8**	*8*	**16**	*16*	**25**	*24*	**27**	*26*	**24**	*24*
	30 yrs	**8**	*8*	**8**	*8*	**17**	*17*	**26**	*26*	**28**	*28*	**25**	*25*
	40 yrs	**8**	*8*	**8**	*8*	**18**	*18*	**28**	*27*	**29**	*29*	**26**	*25*
95 dBA	10 yrs	**8**	*8*	**11**	*11*	**21**	*21*	**33**	*33*	**35**	*35*	**32**	*32*
	20 yrs	**9**	*9*	**12**	*12*	**25**	*25*	**38**	*38*	**39**	*39*	**35**	*35*
	30 yrs	**9**	*9*	**13**	*13*	**28**	*27*	**41**	*41*	**42**	*41*	**37**	*37*
	40 yrs	**9**	*9*	**13**	*13*	**29**	*29*	**44**	*43*	**43**	*43*	**38**	*38*
100 dBA	10 yrs	**15**	*12*	**19**	*19*	**31**	*30*	**48**	*48*	**49**	*49*	**45**	*45*
	20 yrs	**17**	*15*	**22**	*22*	**38**	*37*	**56**	*56*	**56**	*55*	**50**	*50*
	30 yrs	**18**	*17*	**24**	*24*	**42**	*41*	**61**	*61*	**59**	*59*	**53**	*53*
	40 yrs	**18**	*19*	**25**	*25*	**45**	*44*	**65**	*64*	**62**	*62*	**55**	*55*

(Source ANSI SE.44-1996)

2.3.4 Health

The health of a noise-exposed worker will impact on their immune system, which can, in turn, increase the rate of development of NIHL. Research has found increased susceptibility to NIHL when there is co-existence of diseases such as diabetes and cardiovascular disease (Daniel, 2007). The effects of the drugs used in the treatment of these and other diseases such as HIV/AIDS and tuberculosis (TB) can also increase the susceptibility to NIHL (Campbell, 2004; de Jager & van Altena, 2002; Duggal & Sarkar, 2007).

2.3.4.1 HIV/AIDS

Sudden onset sensori-neural hearing loss in HIV-positive patients was described as far back as 1989 (Timon & Walsh, 1989). Recent research has provided in-depth information about the prevalence and type of hearing loss associated with the HIV/AIDS disease. A 23% prevalence rate of hearing loss was found in a South African study of HIV-infected subjects and this prevalence increased with the deterioration of the patients' immunological status. Both conductive and sensori-neural types of hearing loss were encountered and the degree of loss ranged from mild to profound. The configuration of the loss related to HIV/AIDS is not frequency specific (Khoza & Ross, 2002). Other characteristics of the sensori-neural hearing loss associated with HIV/AIDS are that individuals with HIV/AIDS present alterations in the Long Latency Auditory Evoked Potentials (higher-latencies and lower amplitudes of N1, P2 and P300 waves), suggesting a disorder in the cortical regions of the auditory pathway (da Silva, Pinto & Matas, 2007). Yet another reported audiological characteristic of the HIV-positive patient is that of a vestibular disorder as a result of direct viral damage, even in the early phase of infection (Teggi, Ceserani, Luce, Lazzarin, & Bussi, 2008).The ototoxic effect of the drug regimen used in antiretroviral treatment for HIV/AIDS and the concomitant illnesses such as tuberculosis is another audiological effect of HIV/AIDS (Khoza, 2007).

The relevance of the effect on hearing of HIV/AIDS for this study is that South Africa currently harbours one of the fastest-growing HIV epidemics in the world. More specifically, South African gold miners have a 24% prevalence of HIV infection (Corbett, Churchyard, Clayton, Williams, Mulder, Hayes, & De Cock, 2000).

A further contributing factor to the problems of HIV/AIDS-infected miners is the notion that a synergistic relationship exists between certain antiretroviral treatment used to fight HIV/AIDS and noise exposure. Antiretroviral drug-treated mice have been shown to exhibit greater noise-induced decreases in DPOAE than those experiencing noise exposure alone. This drug/noise interaction is thought to be the result of the known harmful effects of HIV treatment on the body at the cellular mitochondrial level (Bektas, Martin, Stagner & Lonsbury-Martin, 2008).

The risk of hearing loss in miners such as those in this study is therefore very high and prevention requires innovative and novel methods of measuring and diagnosis. Many miners are on anti-retroviral treatment as part of the company's employee wellness programmes and the synergistic effect of noise and antiretroviral treatment has not been investigated. DPOAEs offer the occupational audiologist a powerful tool for measurement and diagnosis and, although this study was not able to control for immunological status, the results provide information for a population that is exposed to this health effect.

2.3.4.2 Tuberculosis

HIV infection and silicosis (which is very prevalent in the mining industry) are powerful risk factors for TB and are associated with an increased risk of death among South African gold miners. Drillers and winch operators are reported to have the highest TB prevalences and the highest dust and silica exposures. These occupations are also among the most noise-exposed. TB prevalence in South African gold miners ranges from 19.4% to 35.2%, depending on the method of diagnosis (Churchyard, Ehrlich, teWaterNaude, Pemba, Dekker, Vermeijs, White, Myers., 2004). The high prevalence of TB is related to hearing loss in that the population for which this study took place is known to be severely affected by compromised health conditions. More importantly, the treatment of TB with aminoglycosides is also known to cause hearing loss and result in ototoxicity. Hearing loss of 15 decibels (dB) at two or more frequencies, or at least 20 dB hearing loss at least one frequency, is reported to occur in 18% of patients treated with aminoglycosides (amikacin, kanamycin and/or streptomycin) and in 15.6% of those treated with kanamycin (de Jager & van Altena, 2002). As discussed in the section on HIV/AIDS above, although this study does not control for TB infection, the information from the study will enhance the knowledge of the characteristics of hearing loss in a population affected by health issues.

2.3.4.3 Smoking

Smokers have been found to be 1.69 times more likely to have hearing loss than non-smokers and the mean hearing thresholds of smokers are reported to be consistently poorer than their non-smoker counterparts (Cruickshanks, Klein, Klein, Wiley, Nondahl & Tweed, 1998; D'Onofrio, Becker, & Woolard, 2006; Ecob et al., 2008; Negley, Kathamna, Crumpton, & Lawson, 2007; Nomura, Nakao, & Morimoto, 2005). Smoking is reported to be associated with increased odds of having high-frequency hearing loss when exposed to occupational noise, while these synergistic interactions with smoking associated with low-frequency hearing loss could not be found (Mizoue, Miyamoto & Shimizu, 2003). Many miners are known to smoke but statistics on the prevalence of smoking are limited (Ross & Murray, 2004). Miners are therefore at risk of the development of NIHL through lifestyle factors.

2.3.4.4 Alcohol

Alcohol use has also been reported to influence the development of hearing loss, especially in the low frequencies (Bauch & Robinette, 1978; Brachtesende, 2006; Popelka, Cruickshanks, Wiley, Tweed, Klein, Klein, et al., 2000; Upile et al., 2007). As with smoking, alcohol abuse in the single-sex hostels is a widely known phenomenon. The impact of this lifestyle factor on the development of NIHL has not been described and the population for this study is indirectly affected by it.

2.3.4.5 Exercise

Dynamic physical exercise has been shown to accelerate the development of the temporary threshold shift and of hearing loss (C. Chen, Dai, Sun, Lin, & Juang, 2007; Cristell, Hutchinson, & Alessio, 1998; Engdahl & Kemp, 1996; Franks & Morata, 1996; Sliwinska-Kowalska, Prasher, Rodrigues, Zamyslowska-Szmytke, Campo, Henderson, et al., 2007). Mining is an arduous occupation that involves hard physical labour and a great deal of exercise while simultaneously being exposed to high levels of noise.

2.3.5 Toxins

Ototoxins are substances that may result in damage to the cochlea and/or the auditory pathways. Hearing damage is more likely if exposure is to a combination of substances or to a combination of substances and noise (Chung, Ahn, Kim, Lee, Kang, Lee, et al., 2007; Fuente & McPherson, 2006). Ototoxins are divided into two general classes: medication and workplace chemicals (Morris, 2006).

Medications for the treatment of TB and cancer were recognised as potentially ototoxic many years ago and guidelines recommending their use and protection from the damage caused are well documented (ASHA, 1994; Brummett & Fox, 1989; Campbell, 2004; WHO, 2006). Conversely, the protection from damage to OHCs from otoprotective agents is also widely reported (Chung et al., 2007; Le Prell, Hughes, & Miller, 2007; Minami, Yamashita, Ogawa, Schacht, & Miller, 2007; Shibata, Yagi, Kanda, Kawamoto, Kuriyama, et al., 2007; Zheng & Ariizumi, 2007).

Potential workplace ototoxins include: butanol, carbon disulphide, ethyl benzene, heptane, nhexane, perchloroethylene, solvent mixtures and fuels, styrene, toluene, trichloroethylene, white spirit (Stoddard solvent), xylene, arsenic, lead, manganese, mercury, organic tin, carbon monoxide, hydrogen cyanide, organophosphates and paraquat (NIOSH, 2002). An international workshop of world specialists in noise, chemicals, and ototoxicity held in Poland in 2006 concluded that there is increasing evidence that organic solvents are toxic to the auditory organ in industrial workers. There was no consensus among the specialists on the lowest occupational exposure limits for solvents in relation to their effect on the auditory organ, other than the fact that existing limit-values were inadequate. The synergistic effect in the case of the combined exposure to noise and solvents significantly increased the odds ratio of developing hearing loss. Also organic solvents have detrimental effects on both peripheral and central parts of the auditory pathway (Fuente & McPherson, 2006; Sliwinska-Kowalska et al., 2007). The European Parliament directive on noise exposure control requires that: the employer shall give particular attention, when carrying out the risk assessment to any effects on workers' health and safety resulting from interactions between noise and work-related ototoxic substances (EU, 2003). The recommendations from experts are for improved monitoring, classification and awareness of the effects of workplace toxins (Sliwinska-Kowalska et al., 2007).

2.3.6 Noise exposure levels

The individual susceptibility to the development of NIHL discussed above forms the basis of legislation to prevent NIHL (ANSI S3.44, 1996; SANS, 2003). Such legislation determines acceptable levels of noise exposure for an occupational environment. The most widely accepted factors that influence individual susceptibility to the development of NIHL are:

- the type of noise (impulse or continuous);
- the intensity of the noise; and
- the number of years of exposure to the noise.

The extent of hearing loss increases with the time of exposure and also increases as the intensity of sound levels to which an employee is exposed increases.

Procedures for estimating the risk of hearing loss due to noise exposure were developed by the International Standards Organisation (ISO) in 1971 and are entitled "ISO 1999: Assessment of Occupational Noise Exposure for Hearing Conservation Purposes". In 1990, the ISO 1999 standard was updated. The ISO standard used broadband, steady noise exposures for eight-hour work shifts during a working lifetime of up to 40 years, when estimating the probability that a worker would develop NIHL. In 1996, the American National Standards Institute published ANSI S3.44-1996, an adaptation of the ISO 1999:1990(E), with the same name. The standard presents, in statistical terms, the relationship between noise exposures and changes in hearing threshold levels for a noise-exposed population. The ANSI SE.44-1996 predicts:

- the hearing threshold levels (HTL) associated with age without any influence of noise exposure (HTLA);

- the permanent shift of the HTL estimated to be caused solely by exposure to noise, in the absence of other causes noise-induced permanent threshold shift (NIPTS); and
- the HTL resulting from the combination of the components associated with noise and age (HTLAN).

In 1972, the US-based National Institute for Occupational Safety and Health (NIOSH) also assessed the risk of developing NIHL as a function of levels and durations (e.g. 40-year working lifetime) of occupational noise exposure. The findings were that for a 40-year lifetime exposure in the workplace with average daily noise levels of 80, 85, or 90 dBA, the risk of developing NIHL was estimated to be 3%, 16%, or 29%, respectively. On the basis of the findings, NIOSH recommended an eight-hour time weighted average (TWA) exposure limit of 85 dBA. A re-evaluation of the risk of US workers developing NIHL in 1997 was unable to identify data that was not influenced by the extensive use in the US of hearing protection, and as a result the data from the 1972 study was used and referred to as the "1997-NIOSH model" (Prince, Stayner, Smith, & Gilbert, 1997). The difference between the 1992 and the 1997 studies was that the 1997 risk assessment considered the possibility of nonlinear effects of noise, whereas the 1972 model was based solely on a linear assumption for the effects of noise. The risk assessment theory had changed by 1997 to include the updated knowledge of hearing handicap, especially in the frequencies important for speech discrimination, and the recognition that the 4000-Hz audiometric frequency is both sensitive to noise and important for hearing and understanding speech in noisy listening conditions. As a result, the definition of hearing disability was also modified in the 1997 model to include the frequencies 1000, 2000, 3000, and 4000 Hz (ASHA, 1996; Prince et al., 1997). A comparison of the ISO (1990) prediction of the risk of developing NIHL and the NIOSH (Prince et al., 1997) prediction is shown in Table 5. In the table it can be seen that the risk varies when the frequencies used to calculate the NIHL differ. The three possible formulae used to calculate the extent of the estimated risk of developing NIHL by both the ISO and the NIOSH predictions are:

- the average of 500 Hz, 1000 Hz and 2000 Hz;
- the average of 1000 Hz , 2000 Hz and 3000 Hz; and
- the average of 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz.

The various models for estimating the excess risk of material hearing impairment have differing risk percentages, as seen in Table 5. These disparities have been explained as being due to differences in the statistical methodology or in the underlying data used. Nevertheless, all models confirm a risk of hearing impairment at 85 dBA. This predicted risk informs the recommended exposure levels for industry.

Table 5 Comparison of the risk of hearing impairment at age 60 after a 40-year exposure to occupational noise.

Average exposure level (dBA)	**Average of 500Hz, 1000Hz, 2000Hz**		**Average of 1000Hz, 2000Hz, 3000Hz**		**Average of 1000Hz, 2000Hz, 3000Hz, 4000Hz**	
	ISO	***NIOSH***	***ISO***	***NIOSH***	***ISO***	***NIOSH***
	1990	**1997**	**1990**	**1997**	**1990**	**1997**
90	3%	23%	14%	32%	17%	25%
85	1%	10%	4%	14%	6%	8%
80	0%	4%	0%	5%	1%	1%

The US recommended exposure level (REL) of 85 dBA as an eight-hour time weighted average (TWA8h) is based on the information from the 1972 and 1997 data and the ASHA task force positions on preservation of speech discrimination. Other international RELs vary slightly in the aspects that are specified by the legislation. The New Zealand (NZDOL, 2002) National Occupational Health and Safety Committee (NOHSC) standard specifies a REL of a continuous exposure level of 85 dBA TWA8h but includes a maximum peak exposure level of 140 dBC. The European Physical Agents (Noise) Directive

2003/10/EC (2003) (EU, 2003) requires the provision of worker information and training, noise assessment, personal hearing protectors and audiometric health surveillance at an exposure level of 80 dBA Leq_{8h}; the EU Directive further identifies an 87 dBA continuous exposure limit and 137 dBC peak exposure limit. The South African legislated REL, or occupational exposure level (OEL) as it is referred to in the legislation, is 85 dB(A) and the risk rating of the mean TWA8h is shown in Table 6 (COIDA, 1993; DME, 1996).

Table 6 South African classification of risk rating for noise exposure levels.

Mean TWA (dB)	Exposure rating factor and characterisation of risk
≤82	0: Insignificant risk
83-85	1: Potential risk
86-90	2: Moderate risk
91-95	3: Significant risk
96-105	4: Unacceptable risk
≥106	5: Extreme risk

(Source: COIDA, 1993)

The differences in the estimated risks and the prescribed exposure limits highlight the need for awareness on the part of the occupational audiologist of the various points of view within the field of occupational audiology. They also indicate a need for further investigation into the method that will result in the least incidences of NIHL. The differences between the various legislations of 5 dB do not appear to be significant; however, when one considers that the accepted method for calculating a safe exposure to be a 3 dB increment requires that the exposure time be halved then the difference of 5 dB would require that the safe exposure time be almost quartered (ACGIH, 1997).

2.4 Prevalence of NIHL

In the US, NIHL is reported to be the most common and preventable work-related injury with a greater prevalence amongst miners. Another NIOSH study indicated that, at the age of 50 years, 90% of coal miners and 49% of all miners had hearing loss. In contrast, only 10% of the non-noise-exposed population had a hearing impairment at age 50 (Joy & Middendorf, 2007; McBride, 2004).

An estimated 30 to 50 million workers in Europe are exposed to hazardous levels of noise and therefore are at risk for NIHL (Prasher, Morata, Campo, Fetcher, & Johnson, 2002; Starck, 2006). The Health and Safety Executive (HSE) of Great Britain reports that over 1.1m workers are at risk from high levels of noise in Britain and that about 300 new cases qualify for industrial injuries compensation each year. The HSE-supported study by the Medical Research Council in 1997-98 found that 509,000 people were affected by NIHL as a result of occupational exposure. At the time, the Association of British Insurers indicated that approximately 500,000 workers had been compensated for NIHL since 1963 (Palmer et al., 2001).

An estimated one million employees in Australia may be potentially exposed to hazardous levels of noise at work (in the absence of hearing protection). The number of deafness compensation claims in Australia was reported to be 4510 in 2001/2, representing 19% of all disease-related claims made (Miller, 2005). The three Australian industry sectors with the highest number of claims for NIHL are manufacturing, construction, and transport. However, when examining the incidence rate of claims (per 100,000 employees), the industry with the highest number of claims was the mining sector (Miller, 2005).

It is interesting that South African statistics on prevalence of NIHL are derived primarily from compensation data. This means that only once workers are compensable (10% PLH shift from the baseline assessment) are they documented as having NIHL. This means that any degree of hearing loss that is not compensable (although known to negatively influence a worker's quality of life and to result in the auditory and non-auditory effects discussed above) is not reported in public data.

With this in mind, the prevalence of NIHL in South Africa, as reported by the Rand Mutual Association (RMA) (an agency for the Compensation Commissioner) confirms the US information that NIHL is very prevalent in the mining industry. The RMA reports that within the mining industry in South Africa NIHL is responsible for 45% of compensation benefits paid for occupational diseases or injury (Begley, 2006). Table seven summarise the prevalence of occupational diseases in the non-mining that have been certified by the Compensation Commissioner in recent years. In table eight, NIHL is then contrasted with the prevalence of the other compensable occupational diseases to indicate the extent of the problem.

Table 7 Extract from report on occupational diseases certified by the Compensation Commissioner in the non-mining sector in South Africa, 2001 – 2006.

Occupational disease reported	Year					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
Noise-induced hearing loss (NIHL)	1465	1952	2549	2724	1823	1276
Post traumatic stress syndrome	970	1624	1325	1297	859	816
Tuberculosis (TB) in health care workers	211	500	384	384	323	293
Dermatitis	217	203	203	227	203	156
Pneumoconiosis	193	182	302	189	109	134
Repetitive strain injuries		168	214	165	103	74

Table 8 Occupational diseases certified for the mining sector of South Africa, 2005 – 2005.

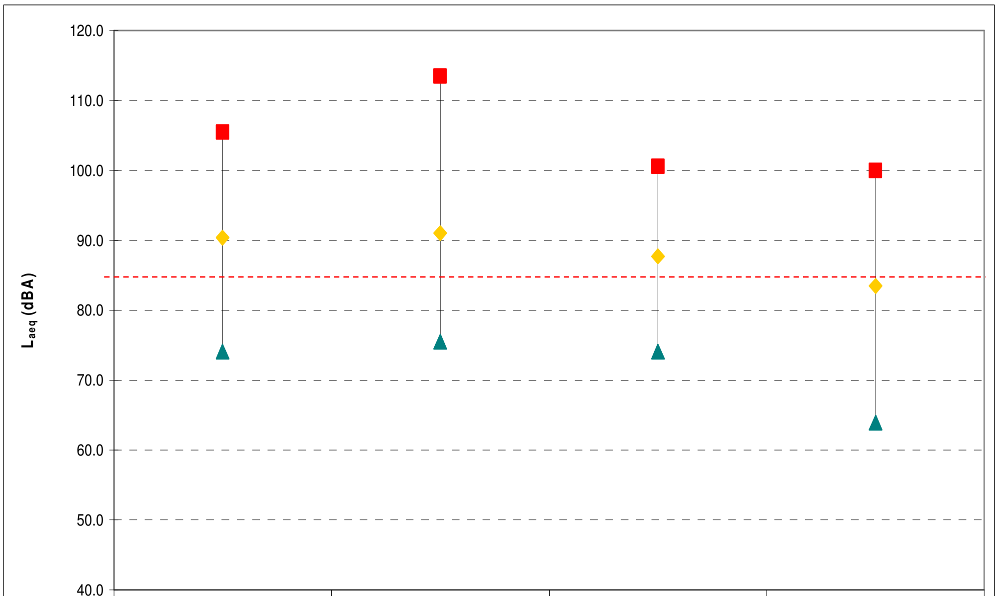
Disease	2005	2006
Pulmonary Tuberculosis	3039	2204
Silico-tuberculosis	272	363
Silicosis	207	452
COPD	225	52
NIHL	1769	1691

2.5 NIHL risk in the South African mining context

2.5.1 Noise exposure levels in different mining commodities

The discussion thus far has aimed at highlighting the general characteristics of NIHL and the prevalence of this occupational injury. The specific NIHL context of the current study is in mining, which is therefore discussed in more depth to contextualise the study further. Although NIHL can be prevented by implementing controls at the source in the workplace, prevention in the mining environment is particularly challenging because noise is generated by mining itself (Hermanus, 2007). South Africa is a mineral-rich country and as such has many miners at risk for NIHL.

A study conducted in the South African mining industry shows that currently 70% of South African miners are exposed to noise levels exceeding the legislated Occupational Exposure Level (OEL) of 85 dBA. The highest numbers of overexposures are reported to occur in underground gold mining (Dekker, Franz, & Ndlovu, 2007). Figure 2 below indicates the range of noise levels found in gold, platinum and coal mines in South Africa. Gold miners are exposed to an average of 90.4 dBA in an eight-hour working shift.



	Gold	Platinum	Coal - U/G	Coal - O/Cast
Max	105.5	113.5	100.6	100.0
Min	74.1	75.5	74.1	63.9
Average	90.4	91.0	87.7	83.5

(Source: Dekker et al., 2007)

Figure 2 Summary of Time Weighted Average (L_{aeq}) exposures for all mining commodities.

2.5.1.1 Longitudinal noise exposure levels in South African mining

The results from the abovementioned study, when compared to a similar study to identify noise exposure levels in different occupations by Franz in 1997, indicate that although miners are still exposed to noise levels above the recommended OEL for NIHL prevention, the exposure levels have been reduced for the high risk occupations (Franz, Janse van Rensburg, Marx, Murray-Smith, & Hodgson, 1997). The reductions in noise exposure can be attributed to the efforts by the industry to reduce the noise exposure at the source, and extracts from the two studies on the noise exposure levels in the South African mining industry of the high risk occupations' exposure levels (Table 9) indicates that the reductions have been in the range of 6 to 13 dB (Franz, et al., 1997; Dekker et al.,2007).

Table 9 Comparison of reported average noise exposure in gold mines in South Africa.

Occupation	Average noise exposure	
	1997 study (dBA)	2007 study (dBA)
Driller	111.4	105.5
Winch Operator	98.3	92.1
Loco Driver	95	95.3
Shiftboss	104.9	89.7
Miner	103.2	90.4
Stoper	102.3	91.2
Team Leader	104.9	93.2

Some of the impact of these noise exposure levels on the miners can be seen in the hearing threshold levels as measured at annual medical surveillance screening and from diagnostic audiology measures discussed in the following section.

2.6 Research on the auditory function of South African miners

A review of the research conducted on the characteristics of the auditory functioning of mineworkers in South Africa revealed that we already know a great deal about the effects of the occupational noise that miners are exposed to but that significant gaps in the knowledge still exist.

2.6.1 Middle ear function

A study conducted to determine the clinical value of immittance testing for the identification of middle ear pathology in South African miners reported that more than half the population was positively identified for potential middle ear pathology (Habig, 2005). Smokers were found to have a higher prevalence of abnormal middle ear functioning.

2.6.2 Screening audiometry results

A valuable database was developed by the Mine Health and Safety Council in response to the new legislation on hearing conservation namely, Instruction 171 (Government Gazette No. 2284 of 16 November 2001).which contains screening audiometry results from all commodities in the mining industry (Begley 2006). The baseline screening audiometry results indicate that the average PLH was 2.34% in the coal industry, 4.57% in the gold mining industry and 9.46% in the platinum mining industry (Begley, 2006). The calculation of PLH procedure means that a PLH of up to 2% is normal hearing when categorised according to the standard classifications of degrees of hearing loss (Clark 1981). The screening audiometry results therefore indicate that the hearing levels of miners on average are in the category of mild to moderate hearing loss.

2.6.3 Diagnostic audiology results

Studies on diagnostic audiograms in the South African mining industry found variability in the configuration of the audiograms in that the traditionally expected 4000 Hz notch, does not appear to be evident especially in the miners who have worked for periods of longer than 10 years (Edwards, 2002; Vermaas et al., 2007). This finding is confirmed by Gates et al.,(2000) that the frequencies adjacent to the 4000Hz notch are also affected by noise exposure. The reported hearing threshold levels for gold miners are greater than those expected by ANSI SE.44-1996 (ANSI S3.44, 1996). This is shown in Table 10 which compares the hearing thresholds found in the South African gold mining industry (Soer et al., 2002) with the expected hearing thresholds predicted by the ANSI prediction tables at a 95 dBA exposure level (assumed to be an average exposure level for miners).

Table 10 Comparison of estimated and actual hearing threshold levels for gold miners for the 95 dBA exposure level.

Years of exposure	Source	Frequency					
		500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
10 yrs	SA gold miners	28	30	34	42	47	51
	ANSI predicted	8	11	21	33	35	32
20 yrs	SA gold miners	29	34	38	48	52	54
	ANSI predicted	9	12	25	38	39	35
30 yrs	SA gold miners	31	37	44	54	58	60
	ANSI predicted	9	13	28	41	42	37
40 yrs	SA gold miners	32	38	48	58	61	63
	ANSI predicted	9	13	29	44	43	38

The information in Table 10 is not specific to an occupation but are the averages of hearing threshold levels for the mining population. However, Table 11 summarises the results found in the occupations in gold mining in South Africa (Soer et al., 2002; Vermaas et al., 2007) and shows the mean hearing threshold levels for different occupation types in the gold mining industry, highlighting the specific audiogram configurations found for different occupations.

Table 11 Mean hearing threshold levels for occupation types in the South African mining industry.

Occupation	Frequency							
	250Hz	500Hz	1000Hz	2000Hz	3000Hz	4000Hz	6000Hz	8000Hz
Boilermaker	22	23	26	37	51	54	54	53
Driller	29	31	39	45	53	57	61	61
Winch Operator	26	29	34	41	50	50	61	58
Loco Driver	30	33	39	46	51	57	59	59
Shiftboss	23	24	28	35	50	56	55	55
Miner	24	27	31	36	46	49	52	49
Stoper	26	29	33	36	44	49	53	55
Machine Operator	32	38	47	53	59	62	65	64
Team Leader	29	30	36	43	46	50	51	53

(Source: Edwards, 2002)

2.6.4 Otoacoustic emission

A review of the available research on the use of OAEs in the mining population in South Africa indicated the existence of some limitations that the current study could address thereby adding to the body of knowledge.

Firstly, the use of DPOAEs to measure temporary threshold shift on mine workers showed that despite wearing HPDs, up to 30% of the gold miners had a deterioration in cochlea functioning after working an eight hour shift. (Edwards & Taela, 2007).

Secondly, the MHSC funded a study to evaluate the use of both DPOAEs as well as TEOAEs and found that otoacoustic emission testing in South African mineworkers is far more sensitive than conventional audiometry offering a more prospective means of identifying NIHL-susceptible individuals and pre-symptomatic inner ear damage in noise-exposed workers (de Koker, Clark, Franz & Mackay, 2003). This study evaluated both screening and diagnostic testing for the two types of OAEs on subjects with hearing within normal limits, using stimulus protocols that only included the mid to higher frequencies namely 1,8 KHz to 7,3 KHz. The study also used the conventional criteria for evaluating the presence of an otoacoustic emission, namely 6dBSPL difference between the noise-floor and the emission level (Hall & Meuller, 1997). Therefore the results were based on a pass/fail evaluation and did not investigate the fine structure of the emissions nor the characteristics of the DPOAE responses. Similarly, the stimulus parameters in the MHSC study were based on default frequency settings from the manufacturers. Therefore, questions relating to the influence of the stimulus protocols on the results of measurements in this population remain unanswered. This limitation was also to be addressed by the current study's objectives. One of the researchers performed a more in depth analysis of the results and investigated the fine structure of the emissions. This study used geometric means of f_1 an f_2 stimulus frequencies and only three stimulus frequencies as part of a screening protocol. The averaged mean levels of the DPOAEs were reported as ranging from 8 to 17.9 dB (Clark, 2004). The screening nature of this information does not answer the question about the full range of the audiogram frequencies which would in turn provide information about the potential of using DPOAEs as a basis for compensation for NIHL. The current study aimed to begin that investigation.

2.6.5. Auditory Steady State Response (ASSR)

Another study conducted in the South African mining industry had a similar rationale as the current study, namely that psuedohypacusis negatively influences the clinical practices and compensation claims in this population. The study aimed to evaluate the use of ASSR as a method of testing for NIHL diagnosis (De Koker, 2003). The findings demonstrated the accuracy of the single-frequency ASSR method using the 40 Hz response. ASSR testing is also an objective test of the auditory system as is the DPOAE test that uses automated testing and analysis algorithms. However, the testing time was reported to be 60 minutes which was considerably longer than experienced in clinical use of DPOAE. The ASSR also estimates audiogram thresholds as the current study aimed to do. The ASSR was shown to estimate thresholds to within 10 dB of corresponding pure-tone results across the entire range of severity (normal hearing to profound hearing loss), and independent of the age of the individual. The use of sedation, as routinely used in evoked potential audiometry, was investigated was found to have no significant effect on the results and therefore was not essential for testing.

2.7 Research needs in NIHL in South Africa

The discussion on NIHL in South African mines highlights the various attempts to provide the clinician with methods and practices that will improve the accuracy and ease with which diagnosis of the degree of hearing loss can be performed.

The review highlights the need for more indepth information about the expected results in a population with pre-existing cochlea dysfunction and the way in which the long term exposure to noise in the mining environment influences the electrophysiological results found in the population. Similarly, research on the prediction of audiogram thresholds from DPOAEs has not been reported in the South African noise-exposed mining population, and the results of the current study would add to the body of knowledge in this population and facilitate an informed clinical decision on the use of different test procedures with difficult-to-test populations. The ease with which a DPOAE test can be conducted is a further motivation for improved knowledge about this test in the mining population.

2.8 Summary

This chapter has outlined the characteristics of NIHL and its development in general as well as specifically for the South African mining industry, where the current study has its context. The discussion has highlighted the research performed in the South African mining industry regarding the characteristics of the auditory functioning of this population. The research has focused primarily on aspects other than the measurement of cochlea functioning as measured with DPOAEs or has not proceeded to an indepth analysis of the test stimuli influences and characteristics of DPOAEs found in the gold mining population strengthening the rationale for the study and identifying the gaps in current knowledge. NIHL is a compensable occupational disease and the discussion in the next chapter of issues related to and practices for compensating NIHL, both internationally and in a South African context, will further develop the background to this study.