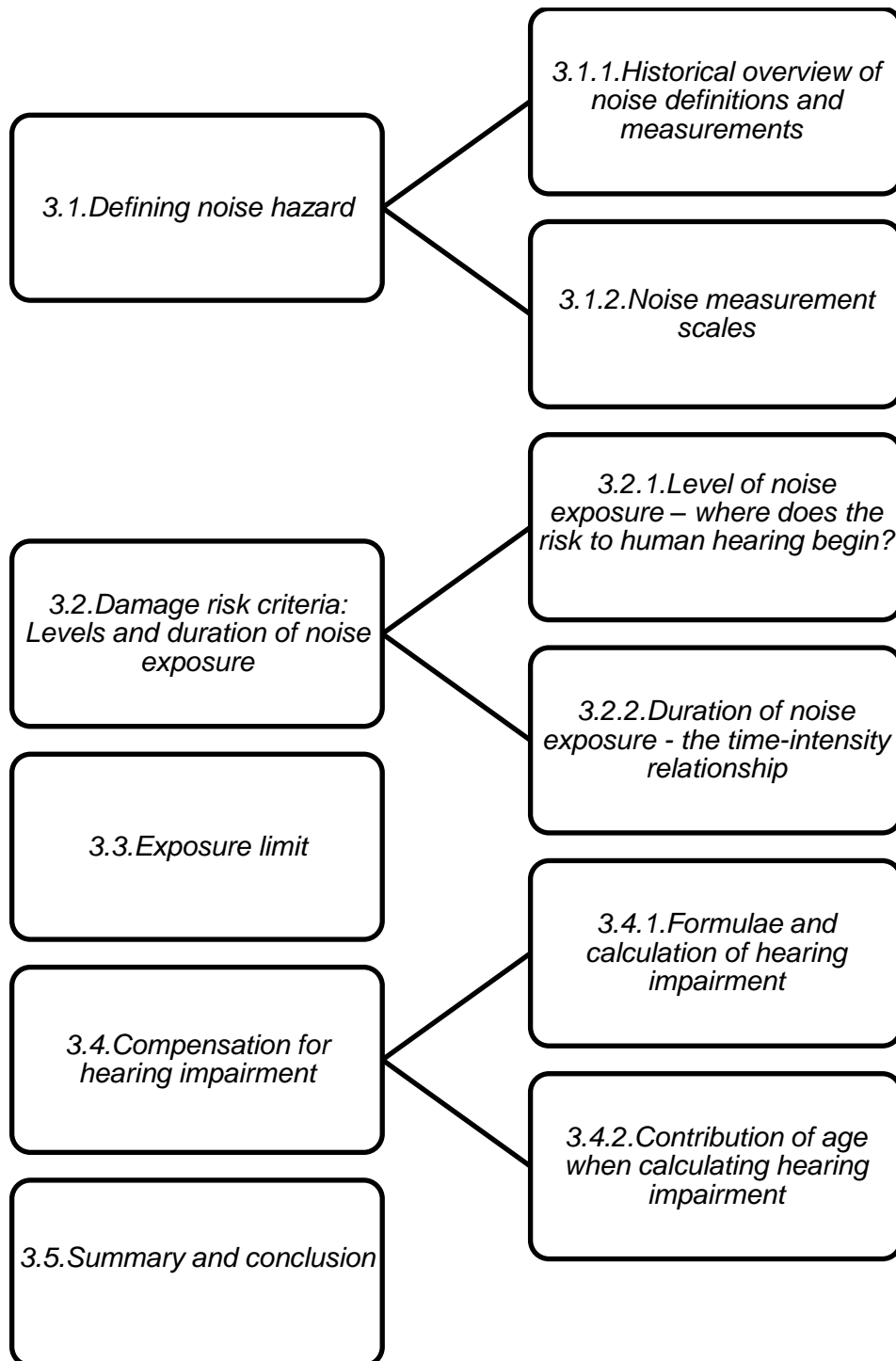
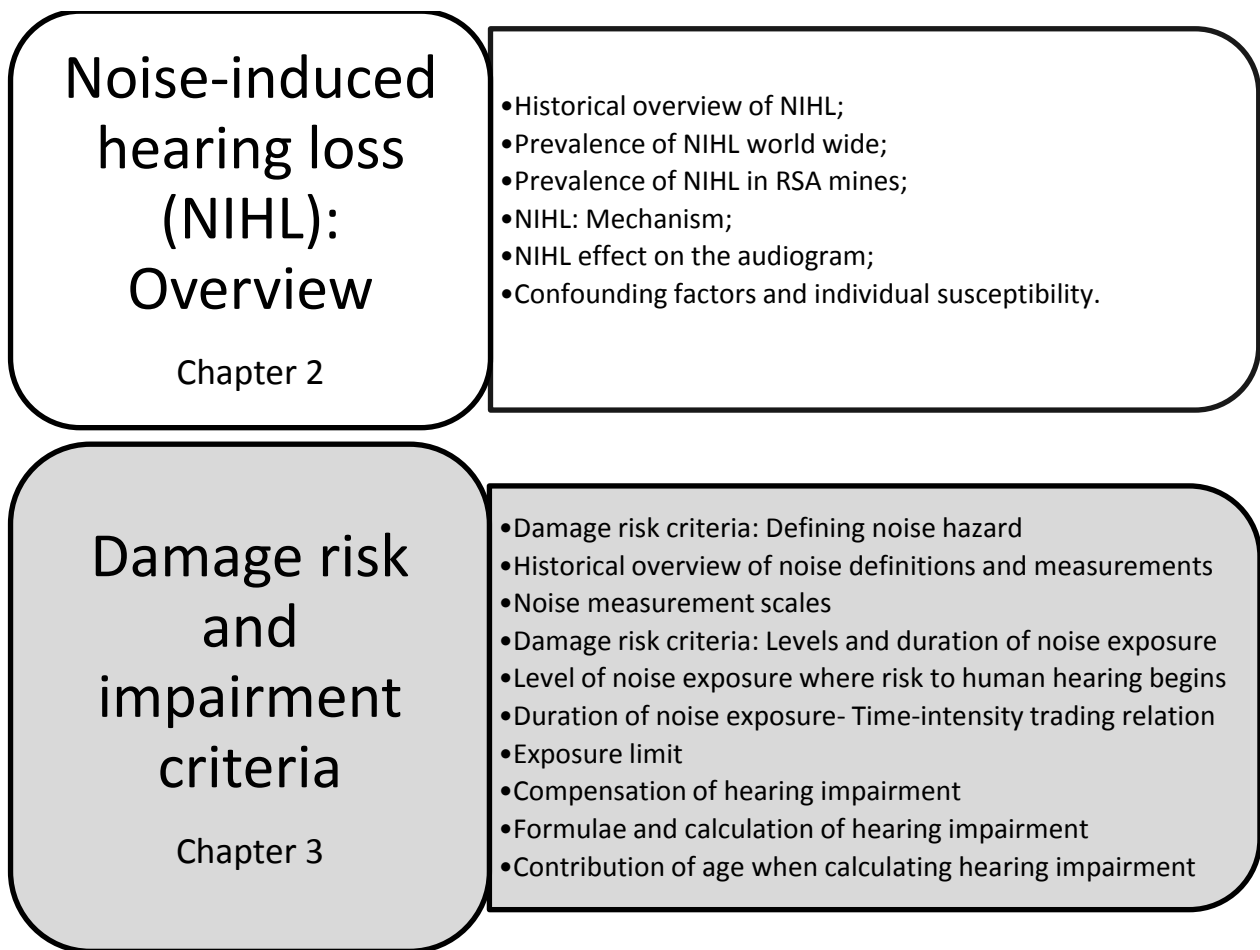


**3. Damage risk and impairment criteria**



Scheme of the literature review followed in Chapter 2 and 3:



### 3.1. Defining noise hazard

Attempts at limiting human exposure to noise have been based on damage risk criteria (NIOSH13, 1972). Prevention of a disease such as NIHL requires that the contributory hazard be carefully defined and descriptions of how it should be measured be provided. Proposing damage risk criteria for any biological hazard is a very difficult and complex problem (Glorig, 1980). Several disciplines are involved when defining risk criteria for noise. Assumptions must be made regarding the anatomical and physiological nature of the damage to the cochlea; the physical characteristics of the noise, measurements of noise and hearing, and administrative matters specific to the country must be taken into consideration. The purpose of such criteria would be to define maximum permissible levels of noise stated

<sup>13</sup> National Institute of Occupational Safety and Health (NIOSH) is not a regulatory agency, but one of its roles is to make recommendations to the Occupational Safety and Health Administration (OSHA) of the regarding areas—such as occupational noise exposure—that OSHA regulates for workplaces in the USA (Dobie, 2008).

durations, which if not exceeded, would result in an acceptably small effect on hearing levels over a working lifetime of exposure (Botsford, 1967; Fletcher & Munsen, 1933; Dear, 1987; US Department of Labor, 1983; NIOSH, 1998; NOHSC, 2000; NIOSH, 1972; SANS10083:2004, 2004).

### **3.1.1. Historical overview of noise definitions and measurements**

After initial reports of noise-related hearing loss had emerged the contributory relationship between noise and hearing became evident (Glorig, 1980). However, prior to 1950, reliable data on the amount of noise that posed a hazard to hearing were not available. Before World War II, due to lack of uniformity in instrumentation and hearing and noise units and scales, studies from around the globe often yielded varying results (Johnson, Papadopoulos, Watka, & Takala, 2006). Initially the hazard of a noise source was defined as the integrated effect of the components of the noise on the ear (Free, 1930). Without consensus about the harmful elements of a specific noise source establishing criteria for damage risk was hampered. Early measurements of noise were very rudimentary and often subjective. One example of an early measurement included the use of a tuning fork and a watch (Galt, 1930). The tuning fork was struck and the time required for the tone to decay to a level equal to that of the noise, as judged by the ear, was plotted and used to define the “deafening produced by the noise” (Galt, 1930). By 1950 researchers were in agreement that noise measurements needed to yield information about the frequencies present in the noise, the amplitudes of each and the effects of these frequencies on the ear (Free, 1930; Galt, 1930, Fletcher & Munsen, 1933; Fletcher, 1938, Rosenblith, 1953 cited in NIOSH, 1972).

At present it is accepted that the effects of sound on a person depend on three physical characteristics of the sound: amplitude, frequency, and duration (NIOSH, 1998). Early reports of sound measurements describe obtaining an audiogram of a range of ordinary noises (Galt, 1929). The first report of a portable sound level metre was given in 1933 (Osbon & Oplinger, 1933). Yet, even after measurements of sound were possible the hazard of noise to hearing remained difficult to measure (Free, 1930; Galt, 1929; Marvin, 1932; Fletcher & Munsen, 1933; Fletcher, 1938). Similar to the “tuning fork” measurement (Galt, 1929) other measurements made by

early noise metres were fraught by a lack of consensus on the definitions of underlying concepts and on which scales to use. Abbot (a research physicist at the University of Michigan, 1934) gave an unadorned account of the problem: “The principal difficulty is that larger numbers often do not represent louder sounds. The decibel seems mysterious at best, considering that 50 dB at 1000 cycles is louder than 60 dB at 100 cycles because the ear is more sensitive to the higher frequency, and 50 dB at 100 cycles is louder than 60 dB at 1000 cycles because the loudness of low-pitched sounds increases more rapidly than higher pitched ones... The fundamental difficulty seems to be that there are at least eight scales in general use for expressing the magnitude of a sound and that five of them are decibels scales” (Abbot, 1935). It was only after 1950 that noise measurements were adapted to take into account that the human ear is more sensitive to some sounds than others (NIOSH, 1972).

### **3.1.2. Noise measurement scales**

Early noise measurements were based on overall sound pressure level (Kryter, 1950). Since then those noise measurements have been replaced by measurements that are more indicative of the response of the hearing mechanism (NIOSH, 1972). Data on minimum audible field sensitivity indicated that the ear is most sensitive to acoustic stimuli in the frequency range of 2000 to 4 kHz, and less sensitive to frequencies both below and above this range (Sivian & White, 1933, Fletcher & Munsen, 1933, Harding & Bohne, 2009). This knowledge led to the implementation of a weighted scale for the measurement of noise hazard. The first standard for sound level metres was published by the American Standards Association in 1936 (American Standards Association, 1936). This standard shows two frequency weighting curves, “A” and “B”, which were modelled on the ear’s response to different levels of sound. The most common weighting today is “A-weighting”, dB A, which is similar to Curve A of the 1936 standard (NIOSH, 1972). The A-weighting network<sup>14</sup> gives essentially full weight to frequencies between 700 and 9000Hz (within 3 dB) and considerably less weight to frequencies outside of this range (Dobie, 2001). Use of A-weighting has been accepted as a rating of noise in a

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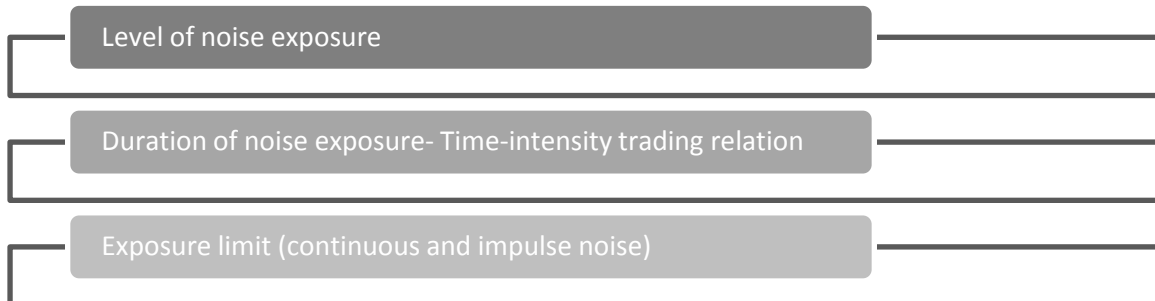
<sup>14</sup> Decibels measured using the A-weighting network of the sound level metre are referred to as dB A.

reasonably similar manner as would the human ear (NIOSH, 1972). Since the publishing of the first guidelines document for noise measurement in the United States of America (USA) the use of the A-weighted sound level for the measurement of noise hazard has become the most widely used (NIOSH, 1972). Results from several studies have confirmed the efficacy of using A-weighted sound levels in rating hazardous exposures to noise (Botsford, 1967; Passchier-Vermeer, 1968 in Passchier-Vermeer & Passchier, 2000, NIOSH, 1972). As a result, the A-weighted scale has been incorporated in many occupational noise standards internationally, including South Africa (DME, 2003; EU, 2003; NIOSH, 1998), and is commonly used in measuring noise to evaluate its effect on humans (NIOSH, 1998). Another weighting system that is sometimes used for the measurement of impulse sounds is the C-weighting system. Use of C-weighting defines the frequency response of the instrument and eliminates very low frequency impulses and sounds that are harmless (Johnson, et al., 2006).

In an effort to assess the excess risk of hearing impairment, as a function of levels and durations of occupational noise exposure, many field studies were conducted between 1950 and 1970 on hearing loss in noisy workplaces in Europe and the United States (Dobie, 2007). After that period such studies became difficult to control as a result of hearing conservation programmes that were widely implemented in most industrialised countries (Dobie, 2007). As the use of hearing protection in most industrialised countries since the early 1980s would confound determination of dose-response relationships for occupational NIHL, current risk assessment is based on a re-analysis of data from previous surveys (NIOSH, 1998). International risk criteria will be discussed in the following section.

### 3.2. Damage risk criteria: Levels and duration of noise exposure

Figure 3.1 demonstrates the aspects taken into account when defining damage risk criteria for occupational exposure to noise:



**Figure 3-1 Aspects considered in damage risk criteria for occupational noise exposure**

In the following sections aspects included in figure 3.1 will be discussed in relation to defining the damage risk along with international and other standards where damage risk criteria are considered.

#### 3.2.1. Level of noise exposure – where does the risk to human hearing begin?

The damage to hearing caused by occupational noise was evident early on as described in section 3.1. Defining the level of the noise where risk to human hearing begins depended on results from noise and hearing surveys before the 1980s when widespread hearing conservation programmes were implemented (Dobie, 2008). Not many large scale studies were done and many of the standards defining damage risk used data from the same studies. Defining the level of noise where damage risk begins and the development of the most widely accepted noise exposure standards are tantamount. In the following paragraphs the most widely accepted noise exposure standards (ISO 1990:1999; ANSI S3.44; NIOSH (1972/1998); EPA (1973)) and subsequent studies or surveys that led to assumptions about the level where damage to hearing begins will be discussed.

In the 1960s, the *International Organization for Standardization* (ISO<sup>15</sup>) began an effort to summarise the available NIHL data into a comprehensive document (standard number ISO 1990:1999) estimating risk of hearing loss from specified levels and durations of noise exposure. Data for the ISO 1990 (1971) document were derived from a study conducted by Baughn (1971) on a population of automobile factory workers (N=6735) (Baughn, 1971). The data from this study were a source of controversy and reservations with regard to its reliability (Dear, 1987; Prince, Stayner, Smith, & Gilbert, 1998; Dobie, 2007). It was criticised for instance for inaccurate noise measurements, incorrect calibration of equipment and non-exclusion of temporary threshold shift due to recent noise exposure (Dear, 1987; Dobie, 2007). The ISO 1999 was subsequently revised and is now known as the ISO 1990:1999<sup>16</sup> (ISO, 1990). The current edition of ISO 1990:1999 (ISO, 1990) is based on Johnson's (1978) synthesis of data from Great Britain and Passchier-Vermeer's (1974) summary of several European and American field studies.

ISO 1990:1999 remains in force as published in 1990 and has been republished with very minor changes by the American National Standard Institute (ANSI) as ANSI S3.44 (ANSI, 1996; Dobie, 2007). Dobie (2007) in his reassessment of the data sets used in the NIOSH (1998) study, the ISO 1990:1999 and EPA (1973) data concludes that the ISO 1990:1999 model remains the best available summary of the permanent effects of noise exposure on hearing thresholds (Dobie, 2007). Estimates from the ISO 1990:1999 (ISO, 1990) yield excess risk values of less than 1% for 80 dB A<sup>17</sup>, 3% for 85 dB A, and 8-11% for 90 dB A (for the average of 0,5 kHz, 1 kHz, and 2 kHz).

Other risk criteria documents, widely used, differ in their findings. One such document was that of NIOSH (NIOSH, 1972) (see footnote 13) and was based on a

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<sup>15</sup> ISO (International Organization for Standardization) is the world's largest developer and publisher of International Standards. ISO is a network of the national standards institutes of 163 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system (ISO, <http://www.iso.org/iso/about.htm>, 2010).

<sup>16</sup> The ISO 1990:1999 is currently under revision (ISO, <http://www.iso.org/iso/about.htm>, 2010). The previous review process for ISO 1990:1999 took at least 10 years to complete.

<sup>17</sup> The A-weighting network gives essentially full weight to frequencies between 700 and 9000Hz (within 3 dB) and considerably less weight to frequencies outside of this range (Dobie, 2001). Use of A-weighting has been accepted as a rating of noise in a reasonably similar manner as would the human ear (NIOSH, 1972).

large scale study conducted to assess the excess risk of material hearing impairment as a function of levels and durations (e.g., 40-year working lifetime) of occupational noise exposure. The data used for the NIOSH risk assessment was collected by Lempert and Henderson in 13 noise and hearing surveys (collectively known as The Occupational Noise and Hearing Survey (ONHS)) between 1968 to 1971 (NIOSH, 1998). It was concluded that for a 40-year lifetime exposure in the workplace to average daily noise levels of 80, 85, or 90 dB A, the excess risk of material hearing impairment was estimated to be 3%, 16%, or 29%, respectively (PTA 0,5 kHz, 1 kHz and 2 kHz). On the basis of this risk assessment, NIOSH recommended an 8-hour time-weighted average (TWA<sup>18</sup>) exposure limit of 85 dB A. Some of the aspects of these analyses were controversial, however. Both ISO 1990:1999 and NIOSH (1998) predict increased risk as the exposure level rises. However, ISO 1990:1999 predicts a higher risk for frequency combinations that include higher frequencies, with more NIHL expected. The NIOSH (1972) definition of hearing impairment did not include high frequencies even though the 4 kHz audiometric frequency was recognised as being sensitive to noise (Dobie, 2007). Subsequently Prince and colleagues (Prince, et al., 1998) re-evaluated the NIOSH data using different hearing impairment definitions as this will influence the magnitude of excess risk estimates. The re-evaluated data were used to compile the NIOSH 1998 revised criteria document (NIOSH, 1998). Including these modifications (for a hearing impairment definition of 25 dB average hearing threshold level at 1000, 2000, 3000 and 4 kHz) the excess risk was estimated as 8% for workers exposed to an average daily dose of 85 dB A over a 40-year working lifetime, 1% at 80 dB A and 25% at 90 dB A (Prince, et al., 1998). Prince and colleagues concluded that a serious limitation of these studies were the limited amount of data for risks below 85 dB A. Extrapolation was used to estimate risks below 85 dB A, but quantification of the risk is uncertain (Prince, et al., 1998).

Results from a study by Stephenson et al. (Stephenson, Nixon, & Johnson, 1980) found no temporary threshold shifts occurring for broad band noise exposures less than 80 dB A after 24 hour noise exposures. These data are in line with the

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<sup>18</sup> TWA= Time-Weighted Average= the A-weighted level that, if continuously present for eight hours, would pose a risk to hearing equivalent to the varying exposure measured by the dosimetre (Dobie, 2001).



Occupational Safety and Health Administration (OSHA)<sup>19</sup> recommendation that TWA exposures be less than 80 to 81 dB A for durations longer than 16 hours (NIOSH, 1998). Very narrow-band sounds such as pure tones are more hazardous than broad-spectrum sounds of the same A-weighted sound level (Dobie, 2001). The ISO 1990:1999 and the ANSI S3.44 suggest that 5 dB might be added for such sounds to obtain estimates of equivalent hazard.

In 1973 the Environmental Protection Agency published a document in which a 75 dB A exposure limit was recommended (EPA, 1973). An 8-hour level of 75 dB A was recommended as the level to protect *"public health and welfare with an adequate margin of safety"*. As previously mentioned this criteria document included the data by Baughn (1973), which had probably been contaminated by temporary threshold shifts, and therefore may not be entirely valid to estimate permanent noise effects. All the other models described confirm an excess risk of material hearing impairment at 85 dB A for an 8-hour exposure time.

Risk estimates from some of these documents are summarised in table 1.1 (NIOSH, 1998). These estimates are based on a 40-year working lifetime exposure for an 8-hour working day to occupational noise and show the percentage risk estimates for the different criteria documents as discussed.

**Table 3-1 Comparison of models for estimating the excess risk of material hearing impairment at age 60 after a 40-year working lifetime exposure to occupational noise (8-hour TWA), by definition of material hearing impairment**

Average exposure level dB A	0,5-1-2-kHz Definition (% hearing impairment)					1-2-3 kHz Definition (% hearing impairment)			1-2-3-4-kHz Definition (%hearing impairment)	
	1971-ISO	1972-NIOSH	1973-EPA	1990-ISO	1997-NIOSH	1972-NIOSH	1990-ISO	1997-NIOSH	1990-ISO	1997-NIOSH
<b>90</b>	21	21	22	3	23	29	14	32	17	25
<b>85</b>	10	10	12	1	10	16	4	14	6	8
<b>80</b>	0	2	5	0	4	3	0	5	1	1

(Source: NIOSH, Criteria for a Recommended Standard, Occupational Noise Exposure. Revised Criteria, 1998)

<sup>19</sup> OSHA is the main USA federal agency charged with the enforcement of safety and health legislation (US Department of Labor, 1983).

From table 3-1 it is clear that the excess risk estimates derived from the 1971-ISO, 1972-NIOSH, 1973-EPA, and 1997-NIOSH models are reasonably similar except for the estimates derived from the ISO 1990 model that are considerably lower than those derived from the other models. These inconsistencies may be due to differences in the statistical methodology or in the underlying data, as discussed. Nonetheless, these models confirm an excess risk of material impairment at 85 dB A.

As limited survey studies on noise exposure and hearing are available before the implementation of widespread hearing conservation programmes and these criteria documents incorporated data from available studies, noise standards around the globe have been influenced by these documents. As an example, in the United States, the formal Washington Industrial Safety and Health Act (WISHA) sets the maximum permissible exposure limit for an eight-hour working day at 85 dB A (Kurmis & Apps, 2007). This sentiment is largely reflected by the legislature of the majority of North American states and most other first world countries including Australia and South Africa. In South Africa, for example, according to the regulations for noise-induced hearing loss of the Occupational Health and Safety Act (1993), a “noise-rating limit”, referring to the value of the 8-hour rating level, is set at 85 dB A and above (OHSA, No. R. 307., 2003). This is also the recommendation of the South African Bureau of Standards (SABS 20) through the South African National Standards, SANS 10083:2007 (SANS10083:2007, 2007). A 2003 directive of the European Parliament and the Council of the European Union, stipulates an amendment to regulatory conditions within member states that took effect in 2006, to further reduce the “lower [acceptable] exposure action values” to 80 dB A (EU, 2003).

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<sup>20</sup> The South African Bureau of Standards (SABS) is a statutory body that was established in terms of the Standards Act, 1945 (Act No. 24 of 1945) and continues to operate in terms of the latest edition of the Standards Act, 2008 (Act No. 29 of 2008) as the national institution for the promotion and maintenance of standardisation and quality in connection with commodities and the rendering of services ([www.sabs.co.za](http://www.sabs.co.za)).

### 3.2.2. Duration of noise exposure - the time-intensity relationship

As described in section 3.2.1 most of the damage risk criteria assume risk to human hearing, for eight-hour daily exposures, begins at about 85 dB A. For shorter daily exposures, higher sound levels can be tolerated without appreciable risk (Dobie, 2001), but the appropriate trading relationship between time and intensity is not universally agreed upon. A trading relationship exists between exposure time and noise level, the product of the two being a measure of the total acoustical energy received (Ishii & Talbott, 1998). A functional definition of exchange rate (time-intensity trading relation) is the increase or decrease in the permissible noise level criteria as the time of permissible employee exposure at that level is halved or doubled, respectively (Sataloff & Sataloff, 1987). For example, an exchange rate of 5 dB A causes the permissible exposure time to be reduced from eight to four hours when the exposure level increases from 85 to 90 dB A. The most commonly used exchange rates incorporate either 3 dB or 5 dB per doubling or halving exposure duration (NIOSH, 1998). The principle behind the 3 dB exchange rate is that equal amounts of sound energy will produce equal amounts of hearing impairment (equal risk) regardless of how the sound energy is distributed in time (NIOSH, 1998; Kryter, 2009; Dobie, 2001). The following mathematical equation in figure 3.2 demonstrates how the doubling of sound energy yields an increase of 3 dB (NIOSH, 1998).

X= The exchange rate whereby energy is doubled

$$10 \text{ Log}_{10}(A/B) + X = 10 \text{ Log}_{10}(2 A/B)$$

$$X = 10 \text{ Log}_{10}(2A/B) - 10 \text{ Log}_{10}(A/B)$$

$$= 10 \text{ Log}_{10}(2)$$

$$= 10(0.301)$$

$$= 3.01 \text{ dB}$$

**Figure 3-2 Mathematical relationship demonstrating the equal energy rule**

This equation would not yield a doubling or halving in intensity per 5 dB increment. The equal energy or 3 dB A rule was first proposed in 1955 by Eldred et al. (Eldred,

Gannon, & von Gierke, 1955) and adopted by the ISO 1990:1999, NIOSH (NIOSH, 1998), the EPA guidelines (EPA, 1973), and the RSA standards document SANS 10083:2007 (SANS10083:2007, 2007). Not all standards support the 3 dB A rule however, OSHA (see footnote 6, page 9, chapter 3) for example abides by the 5 dB A rule instead of the 3 dB A suggested by the equal energy hypothesis (US Department of Labor, 1983). A reason proposed for the 5 dB exchange rate relates to the assumption that shorter noise exposures tend to be intermittent throughout the day and interrupted exposures cause less hearing loss than continuous exposure of equal duration (Dobie, 2001).

NIOSH (1972) initially supported the 5 dB A exchange rate but changed its opinion in the 1998 standard after research had indicated the credibility of the 3 dB A exchange rate. NIOSH (1998) incorporated data from field studies by Passchier-Vermeer (Passchier-Vermeer, 1974). The prediction models for hearing loss as a function of continuous-noise exposure level portrayed by this data corresponded well to the 3 dB A rule (equal-energy hypothesis) and also fit the data on hearing loss from varying or intermittent noise exposures.

Other authors, however, have been strong opponents of the 3 dB A rule (Dear, 2006; Sulkowski, 1980). These authors reveal shortcomings in the data of Passchier-Vermeer (1974), leading to questions about reliability and adequacy. These shortcomings include: insufficient noise measurements, inadequate histories of exposure duration, otological examinations and histories performed by inexperienced persons, audiometry conducted in rooms with high background noise, incorrect calibration of instruments, non-exclusion of TTS due to recent noise exposure, non-typical continuous or steady state noise exposure and questionable statistical techniques and interpretation of results (Dear, 2006; Sulkowski, 1980). Sulkowski's final conclusion states that there is "no general agreement about trading relation between level and exposure time, but it seems that the 5 dB doubling rate is more appropriate than 3 dB time/ intensity trade-off value" (Sulkowski, 1980, p. 206).

While not all researchers have supported the 3 dB A rule an overwhelming general consensus favoured its use at a special meeting in 1982 at Southampton, England (Johnson, et al., 2006). Many leading investigators of noise-induced hearing loss reviewed the available literature with respect to the use of equal energy (Johnson, et

al., 2006). The consensus reached at this meeting formed the basis of the ISO 1990 (1990). Later revised and named ISO 1990:1999, this revised document lent additional support to the equal-energy hypothesis. This group endorsed the use of equal energy as the most practical and reasonable method of measuring both intermittent and impact/impulse noise between 80 dB A and 140 dB A.

### **3.3. Exposure limit**

Based on the equal energy principle that ISO 1990:1999 prescribes a unified measurement method for all types of noise, also impulsive noise, is recommended (ISO, 1990). Most noise standards are based on the notion that the risk of NIHL from all types of existing noise in industrial environments can be predicted on an energy basis as long as the peak levels do not exceed 140 dB C (SANS10083:2007, 2007; ISO, 1990; NIOSH, 1998). ISO 1990:1999 allows adding a 5 dB penalty to the measured noise if a noise is “impulsive”, based on the presumption that impulsive sounds might pose a higher risk of hearing loss. The penalty is based on the results by Passchier-Vermeer (1968), showing that the hearing levels of workers exposed to widely fluctuating noises developed significantly larger losses (approximately 5 dB higher at 4 kHz) than workers exposed to continuous levels.

This approach is not yet universally accepted, however, since accurate measurement of impulse noise exposure is obscured by the multidimensional portrayal of the noise, number of impulses, temporal spacing, etc. (Dobie, 2001; (Johnson, et al., 2006). The available longitudinal studies in industrial environments of impulsive character suggest that the penalty may not be necessary for all impulsive sounds (De Toro, Ordoñez, Reuter, & Hammershøi, 2011). A recent research study investigated the TTS resulting in a Distortion Product Otoacoustic Emission (DPOAE) shift in 16 normal hearing subjects after exposure to impulse noise of different intensities (De Toro, Ordoñez, Reuter, & Hammershøi, 2011). The results from this study suggest that the risk of NIHL from impulsive exposures with peak levels below 117 dB C may be reasonably predicted according to the equal energy principle, but that the 5 dB penalty may be more suitable for noises with peak levels above 120 dB C. Although this study was done on a small sample, results indicated that the degree of hearing loss of workers exposed to low-level impulses

(113–120 dB C) could be predicted according to the standard; whereas the group exposed to higher peak levels (115–143 dB C) showed a significantly higher hearing loss.

In many industrial operations, impulsive noise occurs with a background of continuous noise. In answer to the question whether the effect of the combined exposure is additive or synergistic, NIOSH criteria (1998) concludes that “ (i)f the effects are additive, the 85 dB A limit with the 3 dB exchange rate should be sufficiently protective, if the effects are synergistic, the same should still be protective to a smaller extent”. NIOSH therefore recommends that the 85 dB A as an 8-Hour TWA be applicable to all noise exposures, whether from continuous-type noise, impulsive noise or a combination of both.

The WHO document and recommendations for a noise standard (Johnson, et al., 2006) summarise some features of legislation in various countries (1997). Table 3-2 below is the summarised results for a few countries with the RSA standard SANS 10083: 2007 (2007) added for reference.

**Table 3-2 Some features of legislation in various countries (1997). Source: Johnson, et al., 2006**

Country (Jurisdiction)	8-hour average A-weighted sound pressure level (dB)	Exchange rate (dB)	8h-average A weighted limit for engineering or administrative controls (dB)	8h-average A-weighted limit for monitoring hearing (dB)	Upper limit for peak sound pressure level (dB)
Australia (varies by state)	85	3	85	85	140 un-weighted peak
Canada (Federal)	87	3	87	84	140 C peak
(ON, PQ, NB)	90	5	90	85 (b)	
(Alta, NS, NF)	85	5	85		
(BC)	90	3	90		
United Kingdom	85	3	90	85	140 C peak
USA (e)	90 (TWA)	5	90	85	140 C peak or 115 A Slow
USA (Army and Air Force)	85	3		85	140 C peak
RSA: SANS 10083: 2007 (2007)	85 for 8-hour normalised exposure level limit	3	85	On hiring, and at regular intervals thereafter	140 C peak

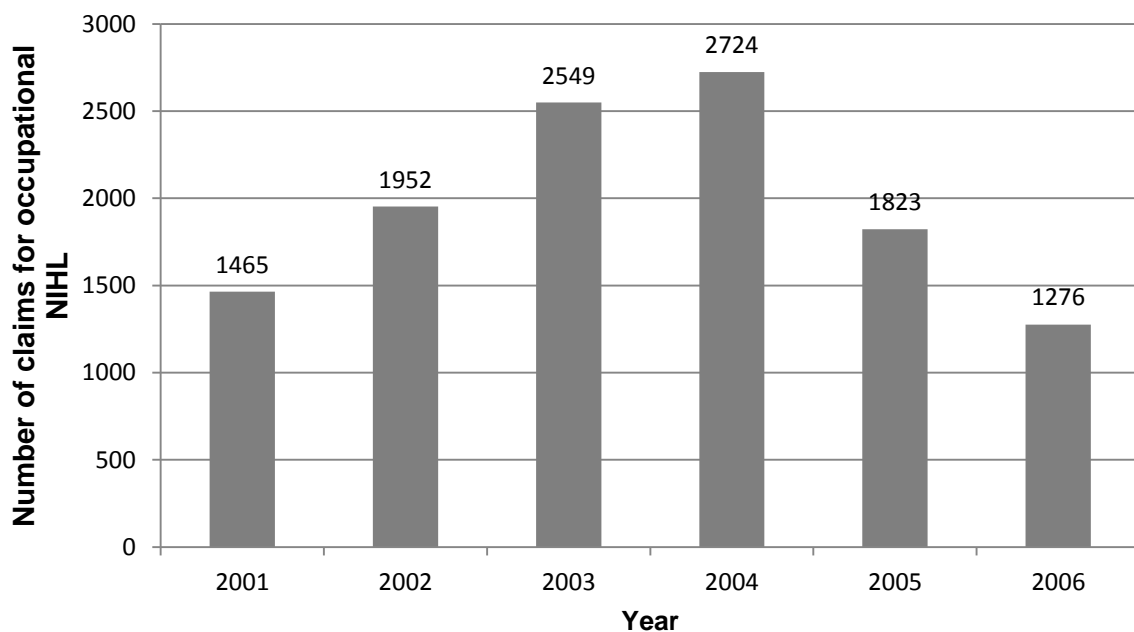
### 3.4. Compensation for hearing impairment

Since the development of noise criteria documents and because NIHL has been recognised as a preventable occupational morbidity occupational NIHL has become compensable under laws in developed and developing countries including South Africa (Nelson, et al., 2005a). Compensation for occupational injury was documented as early as 2050BC on the Nippur tablet No. 3191 from ancient Sumeria. This tablet outlines a law providing monetary compensation for specific injury to workers' body parts. Ancient Greek, Roman, Arab, and Chinese law provided sets of compensation lists, with precise payments for the loss of a body part (Guyton, 1999). According to these schedules the value of an ear was based on its surface area. The first workers'

compensation payment for occupational hearing loss in the United States of America was made in 1948 (Sataloff & Sataloff, 2006).

In South Africa compensation for occupational hearing loss was first introduced in 1941 as the Workmen’s Compensation Act 1941 (No 30 of 1941) (COIDA, 1994). This law was subsequently replaced by The Compensation for Occupational Injuries and Diseases Act, 130 (COIDA) that was signed into South African law effective from 1 March 1994, to provide compulsory compensation for all employees under contract of employment (with a few exceptions) for death or personal injury suffered in the course of their employment. In 2001 a circular instruction in respect of the determination of permanent disablement resulting from hearing loss caused by exposure to excessive noise and trauma, known as Instruction 171, was published as part of COIDA (COIDA, Compensation for Occupational Injuries and Diseases Act, No. 130 of 1993. Circular Instruction No. 171, 2001).

Compensation for occupational NIHL paid by the RSA compensation fund is summarised in figure 3-3.



**Figure 3-3 Claims submitted to the Compensation Fund during 2001-2006 (Source: RSA Compensation Fund, 2006).**



Figure 3-3 shows that between 1276 and 2724 claims were submitted annually for compensation due to permanent hearing loss caused by industry noise in South Africa. NIHL was the occupational disease during this period for which the most claims were submitted, followed by post-traumatic stress disorder (with a maximum of 1624 claims in 2004) and then tuberculosis (with a maximum of 500 claims in 2002). The rise in claims to the compensation fund between 2002 and 2004 might be explained by baseline testing that became obligatory in 2001 (COIDA, 2001). It might thus be a reflection of the backlog in hearing loss claims (Barnes, 2008). It has been stated however that the number of compensable cases will rise again in future when the threshold for compensable hearing loss is breached (Hermanus, 2007).

#### **3.4.1. Formulae and calculation of hearing impairment**

In order to determine whether a person should be compensated for occupational NIHL and the amount of financial allowance under compensation laws determination and quantification of hearing loss on an accurate percentage scale is necessary. This is, however, a variable and difficult practice. The measurement of hearing involves a complex analysis of the hearing level for a variety of pure tones and speech (Dobie, 2001). The results of these measurements must then be related to an individual's ability to communicate effectively in a variety of listening situations (Stander & Sataloff, 2006). Widespread variation exists in formulas for calculating hearing loss handicaps to arrive at disability (Dobie, 2008; Stander & Sataloff, 2006).

Authors Stander and Sataloff (2006) summarise the differences in the United States of America between the different states' compensation agencies with regard to formulas used to calculate hearing impairment caused by NIHL (summarised in Table 3-3).

**Table 3-3 Summary of US states federal compensation agencies with regard to the formulas used to calculate hearing impairment caused by NIHL (Source: Stander & Sataloff, 2006)**

Summary of state formulae used	Summary of formulae's salient points
1. Two states use the 1949 American Medical Association (AMA) formula.	A weighted chart which used four frequencies: 512, 1024, 2048, and 4096 Hz. The 512- and 4096-Hz frequencies were valued at 15% each, the 1024-Hz frequency at 30%, and the 2048-Hz frequency at 40%. The ratio of hearing loss of the poorer ear to the better hearing ear was one to five.
2. Eighteen states use the 1959 formula adopted by the American Association of Ophthalmology and Otolaryngology (AAOO)(currently (2012) the AAO).	Three frequencies, weighted equally. 500, 1000, and 2 kHz, with a low fence of 25 dB. Hearing loss less than the low fence was considered satisfactory.
3. Two states use the 1979 version of the AAOO formula (currently the AAO (2012) formula).	Under the AAO current formula (2012), the percentage of hearing loss is calculated by taking the average, in decibels, of the hearing threshold levels in each ear for the frequencies of 500, 1000, 2000, and 3000 cps, or Hz. With a low fence of 25 dB and a high fence of 92 dB.
4. One state uses the CHABA recommendation, differing as to audiometric frequencies used, and the low-fence provision.	An average of 1000, 2000, and 3 kHz with low fence of 35 dB, and a better ear correction based on four to one.
5. Twenty-seven states, by far the majority, depend entirely on medical evidence, without specifying any particular formula or set of criteria.	

From table 3-3 it is clear that the formulae mostly used are those of the AAO 1979 formula (then the AAOO). The AMA changed its formula in 1979 to the AAO formula (Dobie, 2001). The first AMA endorsed approach (in 1947) to hearing impairment calculation was based on pure tone thresholds at 0,5 kHz, 1, 2 and 4 kHz with unequal weighting, 40% for 2 kHz, 30% for 1 kHz and 15% each for 0,5 and 4 kHz (Stander & Sataloff, 2006). This calculation was changed because it was too complex and also because otologists felt that the percentage hearing impairment overestimated the true handicap (Dobie, 2001). In 1959 the AAOO (currently the AAO (2012)) recommended a new rule that was then adopted by the AMA (1961).

Monaural impairment for each ear was based on PTA 512, beginning at 25 dB HL growing linearly at 1,5% per dB up to a maximum of 100% at about 92 dB HL. Better ear to worse ear weighting was 5:1 (Dobie, 2001). Because of the lack of consideration to any high frequencies in this calculation the American Academy of Otolaryngology (AAO) - Head and Neck Surgery (then the AAOO) - was concerned that the formula did not reflect a realistic degree of speech understanding in noise and recommended in 1979 adding 3 kHz to the calculation. The AMA accepted this recommendation in that year and still recommends this formula (Dobie, 2001). As can be seen from table 3-3 this calculation is the most widely used in the United States of America and is seen as an “acceptable compromise between accuracy and simplicity” (Dobie, 2001, p. 108).

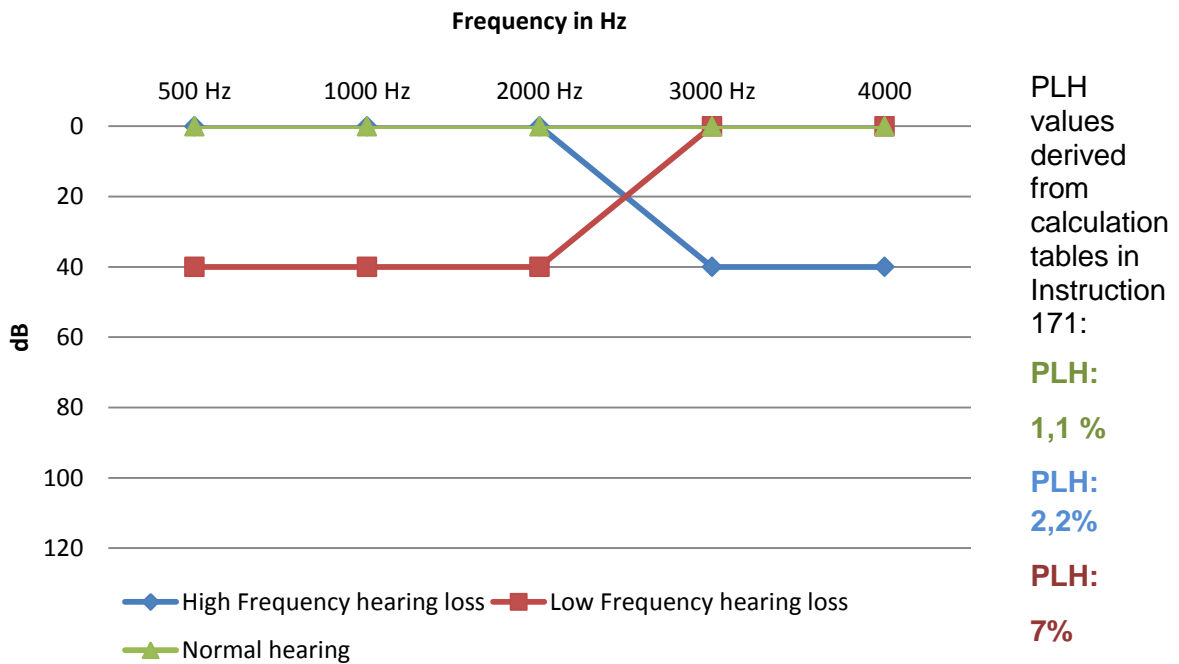
In South Africa the percentage hearing impairment is referred to as percentage loss of hearing (PLH) and is calculated using the weighted calculation tables supplied by Instruction 171 (COIDA, 2001). After a thorough review of published literature and reports it was concluded that no published data is available on the evidence supporting the development of the PLH calculation tables. Internal reports from the South African goldmines suggest that it might be based on the Australian method of determining PLH (Edwards, 2010). The PLH calculations used in Australia was developed by Macrae (1988) for the National Acoustical Laboratories (NAL). These tables were designed to give more weight to frequencies that produced the highest degree of hearing handicap when impaired. This method is very similar to the South African PLH method, but for the inclusion of 1.5 kHz. Weighting is based on the estimated contribution of the different audiometric frequencies to the hearing handicap. Based on estimations awarding the maximum potential contribution to the handicap to 1 kHz and the lowest contribution to 3 and 4 kHz, PLH weighting is calculated (Greville, 2010; Macrae, 1988). Another aspect of these tables to take into consideration is that hearing of 0 dB across the frequencies also has a PLH value, even though there is no hearing loss. Figure 3-4 from COIDA’s Instruction 171 shows the calculation table for 0.5 kHz. Decibel HL values from the better ear (based on pure tone average (PTA)) and the worse ear interlink to give a value that is added to the values derived from similar tables for 1, 2, 3 and 4 kHz, the sum of which calculates the PLH.

Contribution to PLH by hearing losses at 0,5 kHz

HTL in worse ear (dB)	4 Contribution to PLH by hearing loss at 0,5 kHz in better ear and given hearing loss at 0,5 kHz in worse ear																
	Hearing threshold level in better ear (dB)																
	≤15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	≥95
≤15	0,2																
20	0,4	0,6															
25	0,6	1,0	1,4														
30	1,0	1,4	2,0	2,8													
35	1,3	1,8	2,5	3,4	4,5												
40	1,7	2,2	3,0	3,9	5,1	6,4											
45	2,0	2,6	3,4	4,3	5,5	6,8	8,1										
50	2,3	2,9	3,7	4,7	5,8	7,1	8,4	9,7									
55	2,5	3,2	4,0	5,0	6,1	7,3	8,6	9,9	11,2								
60	2,7	3,4	4,2	5,2	6,3	7,5	8,8	10,0	11,3	12,6							
65	2,8	3,5	4,4	5,4	6,5	7,7	8,9	10,2	11,5	12,7	14,0						
70	2,9	3,7	4,5	5,5	6,6	7,8	9,1	10,3	11,6	12,9	14,2	15,5					
75	3,0	3,8	4,7	5,7	6,8	8,0	9,2	10,5	11,8	13,1	14,5	15,7	16,9				
80	3,1	3,9	4,8	5,8	6,9	8,1	9,3	10,6	12,0	13,3	14,7	16,0	17,2	18,2			
85	3,2	4,0	4,9	5,9	7,0	8,2	9,4	10,7	12,1	13,5	14,9	16,2	17,4	18,4	19,1		
90	3,4	4,1	5,0	6,0	7,1	8,3	9,5	10,8	12,2	13,6	15,0	16,3	17,6	18,5	19,2	19,7	
≥95	3,4	4,2	5,1	6,1	7,1	8,3	9,5	10,8	12,2	13,6	15,0	16,4	17,6	18,6	19,3	19,7	20,0

**Figure 3-4 Instruction 171, PLH calculation table for 0,5 kHz (Source: COIDA, 2001, complete document included as Appendix C)**

Based on calculations from these tables a low frequency hearing loss (0,5, 1 and 2 kHz) has a greater PLH value than a hearing loss in the high frequencies (3, 4 kHz). The following graph demonstrates the weighting of these calculation tables as well as the PLH value for 0 dB HL.



**Figure 3-5 Audiogram (left and right ears identical) with 0 dB HL, high frequency hearing loss, and low frequency hearing loss and associated PLH values**

Figure 3-5 demonstrates that a low frequency hearing loss of 40 dB HL has a PLH of 7% compared to the same degree of hearing loss in the high frequencies, revealing a PLH of 2,2%. Even with the absence of any hearing loss a PLH value of 1,1% is present. According to Instruction 171 compensation is paid out when a shift of 10% in PLH is present from any given audiogram and the baseline audiogram (done upon job engagement). Although NIHL is typically a high frequency hearing loss it seems that the low and mid frequencies are weighted more using the PLH calculation tables. This might be contributed to the fact that these frequencies are important for speech recognition in a quiet environment (Dobie, 2001) and compensation paid to people with occupational NIHL is focused on compensating for disability.

As part of hearing loss programmes the use of other diagnostic tests to identify NIHL have been recommended (Helleman & Dreschler, 2012; Helleman, Jansen, & Dreschler, 2010; Shupak, et al., 2007; Guida, De Sousa, & Cardoso, 2012; Attias, Bresloff, Reshef, Horowitz, & Furman, 1998). Because of the tests sensitivity to outer hair cell functioning (where noise damage first occur, see Chapter 2) these authors

were specifically referring to Otoacoustic Emission testing (OAEs). OAEs and particularly the frequency specific distortion product OAEs (DPOAEs) have been described as an effective early indicator of cochlear damage because of noise exposure (Attias, et al., 1998). Results of recent studies have however also indicated that DPOAEs could be used on individual results but is not reliable on group results and thus OAEs have a limited applicability for monitoring the hearing status of an entire population (Helleman & Dreschler, 2012). It has also been shown that DPOAE results, although frequency specific, were not significantly correlated with pure tone audiometry and thus should not be used as an objective measure of pure-tone thresholds in early NIHL (Shupak, et al., 2007). For this study however, pure tone results have been used in analyses and it is beyond the scope of this study to investigate the utility value of OAEs as part of the hearing conservation test battery.

#### **3.4.2. Contribution of age when calculating hearing impairment**

As discussed in chapter 2, hearing loss accompanies the aging process. It has been stated in literature that the effect of aging should be taken into consideration when hearing impairment is calculated (Dobie, 2001). Compensation of hearing loss is paid out to an individual who has acquired hearing loss because of the occupational noise he was exposed to. In the legal setting the company can be held liable for the damage caused to the hearing as a result of exposure to the occupational noise. It is therefore understandable that the effect of aging or another cause of hearing loss should be considered in the compensation process. Estimating hearing impairment regardless of the cause of the hearing loss or the audiometric configuration is a controversy often ignored or not made explicit (Dobie, 2001). In 1955 the AMA stated that an allowance should be made for the hearing loss with advancing age when hearing impairment is calculated (AMA, 1955). In 1971 Davis reasoned that hearing impairment should be calculated regardless of the cause of the impairment but that the relative contribution of different causes of hearing loss (such as noise or age) should be taken into consideration (Davis, 1971). This is referred to as allocation and can be defined as the process of determining the relative contributions of each cause to the individual's hearing loss (Dobie, 2001, p. 282).

As compensation in South Africa is based on a shift in PLH from the baseline audiogram it seems straightforward if a single harmful event caused a large change in hearing as measured by the shift from baseline. In contrast age-related hearing loss and NIHL typically proceed simultaneously and show a decline in the high frequencies (Agrawal, et al., 2010). It might be argued that the baselining (bracketing) done in South Africa through the estimation of a shift in the PLH value is a way of apportioning pre-existing hearing loss to a previous employer(s), but not sensitive in identifying NIHL. “Age correction” (subtracting a certain decibel value based on a person’s age from the audiometric thresholds prior to estimating hearing impairment) has been proposed as a way to deal with this issue. In 1955 the AMA stated that the hearing impairment calculation/ formula should account for the hearing loss expected with advancing age (AMA, 1955). However, very few states in the United States of America (six of the 52 states) include correction for age in their hearing impairment calculations (Stander & Sataloff, 2006). Age correction has been criticised because the compensable hearing impairment might be “downgraded” below compensation level (Dobie, 2001). The AMA (2000) criticised age correction as fundamentally unfair because of the implication that all of the impairment is to be blamed on age-related hearing loss. Davis (1971) suggested that estimation of hearing impairment and allocation of relative contributions of NIHL and age-related hearing loss should be different processes. ‘Hearing handicap’ should be calculated first, without taking into account the contribution of age to the hearing loss. Thereafter, using predictive data for presbycusis in non- noise-exposed populations the relative contribution of noise exposure to the hearing impairment can be estimated. Predictive data can be found in international standards such as the ISO 1990:1999 and ANSI S344 (1996). This approach has been used in studies to determine the burden and contribution of NIHL (Dobie, 1992; Dobie, 2005; Dobie, 1992; Agrawal, et al., 2010; Flamme, et al., 2011).

### **3.5. Summary and conclusion**

In this chapter measurements of noise and the characteristics of noise constituting a hazard to hearing were discussed by giving a historical overview of noise definitions

and measurements and describing the development of damage risk criteria. The research and surveys leading to the definitions of the level of noise exposure where risk to human hearing begins as well as the duration of noise exposure damaging to hearing were highlighted. Issues and controversies about the compensation of hearing impairment as well as formulae and calculations used for hearing impairment were deliberated. Finally the contribution of age when calculating hearing impairment was considered.