Using distortion product otoacoustic emissions to investigate the efficacy of personal hearing protection

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In memory of my mother,

Caroline van Zyl

- *you will be missed always*

To my wonderful husband, Evan – thank you for all your support, encouragement, and belief in me. I love you.

Dad, André and Adrian – no matter how far apart we are, you are always in my heart and in my thoughts.

Alita and the girls – thanks for putting up with all my moods during those stressful visits.

My Lady, thank you for Your unconditional love, acceptance and for sharing Your wisdom. I ask that You will continue to teach and guide me during this lifetime, and all others.

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ABSTRACT

This study aimed to investigate the effectiveness of the Quiet earplug noise protectors worn by a group of South African industrial workers exposed to excessive noise in the workplace. This was achieved by investigating the prevalence and amplitudes of distortion product otoacoustic emissions (DPOAEs), as they have been found to be sensitive to the effects of noise on the cochlea (Vinck, Van Cauwenberge, Leroy, & Corthals, 1999, p. 52). DPOAEs were recorded before and after noise exposure and were compared in order to determine whether the earplugs are providing sufficient protection against cochlear damage. DPOAEs were recorded using a test protocol where the primaries are fixed at L1 = 60dB SPL and L2 = 35dB SPL (L1 - L2 = 25dB) with an f_2/f_1 ratio of 1.18. The f_2 frequencies were selected to correspond closely to the audiometric test frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz.

The study found the prevalence of DPOAEs to be statistically stable and repeatable. This was true for DPOAEs measured successively during the same test sitting, as well as comparing prevalence determined before and after exposure to eight hours of noise. DPOAE prevalence alone was therefore not found to be a good indication of the temporary threshold shift (TTS) associated with the effects of noise on the cochlea. However, a significant finding of the study was that normal DPOAEs were recorded in only six right ears (24%) and seven left ears (28%) before noise exposure, even though all the subjects presented with hearing thresholds better than 25dB SPL. This may mean that cochlear pathology is already evident in some of the subjects tested. Further results of the study showed DPOAE amplitudes to be sensitive to the negative effects of excessive noise, as there was a significant difference between DPOAE amplitudes measured before and after the noise exposure. DPOAE amplitudes, specifically in the frequencies that are known to be affected by noise such as 4000Hz and 6000Hz, measured after the work-shift were significantly smaller than those measured before exposure to noise. Although correct usage of the earplugs could not be controlled for the duration of the noise exposure, each subject was instructed on the correct usage of the hearing protection before entering the noise zone. Bearing this limitation of the study in mind, because DPOAE amplitudes were reduced the implication is that the Quiet earplugs are not providing sufficient protection against the harmful effects of noise.

Key terms: Distortion product otoacoustic emissions; noise-induced hearing loss; hearing protection; temporary threshold shift; permanent threshold shift; industrial noise

OPSOMMING

Die studie het die effektiwieteit die van die Quiet oorprop gehoorbeskermers ondersoek, wat deur ‘n groep Suid Afrikaanse nywerheidswerkers gedra word. Dit word gedoen deur die voorkoms en amplitude van distorsie-produk otoakoestiese emissies (DPOAEs) te ondersoek omdat die voorkoms en aard daarvan beïnvloed word deur geraasblootstelling (Vinck, Van Cauwenberge, Leroy, & Corthals, 1999, p. 52). DPOAEs is gemeet voor en na geraas blootstelling en daarna vergelyk om vas te stel of die oorproppe die nodige beskerming teen kogleêre beskadiging bied. DPOAEs is gemeet deur ‘n toetsprotokol te gebruik waar die volgende instellings gebruik is: L1 = 60dB SPL en L2 = 35dB SPL (L1 - L2 = 25dB) met ‘n f_2/f_1 ratio van 1.18. Die f_2 frekwensie vergelyk die heel beste met die oudiometriese toets frekwensies van 2000Hz, 3000Hz, 4000Hz, 6000Hz en 8000Hz.

Die studie het gevind dat die voorkoms van DPOAEs oor die allegemeen betroubaar en herhaalbaar is. Dit is waar vir beide DPOAEs wat agtereenvolgend gedurende dieselfde toetssitting gemeet is, sowel as diè wat getoets is voor en nà agt ure van geraasblootstelling. Daar is bevind dat die voorkoms van DPOAE’s nie ‘n goeie aanduider is van die tydelike drempelverskuiwing wat met geraasblootstelling gepaard gaan nie. ‘n Betekenisvolle bevinding van die studie is dat alhoewel al die proefpersone met gehoordrempels beter as 25dB SPL voorgekom het, voor die geraasblootstelling is normale DPOAEs in slegs ses regte ore (24%) en sewe linker ore (28%) gekry. Dit beteken dat kogleêre beskadiging al reeds aanwysig is in sommige van die proefpersone wat getoets is. Die resultate van die studie wys egter dat die aard van die DPOAEs amplitude sensitief is vir die negatiewe effekte van geraasblootstelling aangesien daar beduidende verskille ten opsigte van die amplitude voor en na geraasblootstelling gevind is. Die amplitude van die DPOAE, veral by die frekwensies soos 4000Hz en 6000Hz wat veral sensitief is vir geraasbeskadiging, was beduidend laer na geraasblootstelling as voor die aannvang van die werksskof. Hoewel die korrekte gebruik van die oorproppe nie gekontroleer kon word nie, is die korrekte gebruik vooraf aan elke proefpersoon verduidelik. Op grond van die verlaagde amplitudes wat na geraasblootstelling gevind is, is die gevolgtrekking dat die Quiet oorpop gehoorbeskermers nie genoegsame gehoorbeskerming aan hierdie groep werkers verskaf nie.

Sleutelterme: distorsie-produk otoakoestiese emissies; geraasdoofheid; gehoorbeskerming; tydelike drempelverskuiwing; permanente drempelverskuiwing; nywerheidsgeraas

1. INTRODUCTION

It is agreed that while noise-induced hearing loss is the second most prevalent form of sensorineural hearing loss and irreversible, it is virtually 100 percent preventable. (Rabinowitz, 2000, p. 2749). Intensive noise exposure is known to directly influence the outer hair cells of the cochlea and can eventually result in irreversible hearing impairment (Dunn, 1988, p. 275). This may be attributed to damage to a "metabolically dependant and nonlinear biomechanical mechanism" which is associated with the hair cells of the cochlea (Siegel & Kim, 1982, p. 148). The outer and inner hair cells are the two types of sensory receptor cells found in the Organ of Corti (Dallos, 1997, p. 16). The Organ of Corti, together with the basilar membrane and the scala media compartment, are important structures in the cochlea. Due to active properties, the outer hair cells of the cochlea increase mechanical energy within the cochlea. This leads to vibrations of the basilar membrane which are stimulus-specific. The energy is transmitted to the inner hair cells where hearing sensitivity and frequency selectivity is enhanced (Hall, 2000, p. 48).

The damage to the sensitive cochlear structures caused by exposure to excessive noise can be incurred in two ways. Mechanical injury of the Organ of Corti occurs when direct shearing forces damage the outer hair cells and the delicate stereocilia of the cochlea. The function of the outer hair cells is to provide biomechanical feedback in order to enhance cochlear sensitivity and frequency selectivity. The stereocilia detect displacement of the basilar membrane and are the weakest link in the transduction of sound information to the cochlea. The other causative agent of cochlear damage is cellular metabolic overload that results from overstimulation. This metabolic exhaustion, if maintained, eventually leads to cell death. While there is potential for pharmacological treatment for the metabolic effects of excessive noise exposure, mechanical injury is irreversible and permanent (Prasher, 1998, p. 1240).

Noise typically causes two types of hearing loss. The threshold shifts that result from excessive noise exposure may be either temporary or permanent. A temporary threshold shift (TTS), resulting from metabolically induced fatigue, usually follows exposure to loud sounds. The localisation of the cochlear damage depends on the type of noise. In the case of multifrequency noise mostly found under industrial circumstances, damage occurs in the upper basal turn of the cochlea – the 3000Hz to 6000Hz frequency range in humans (Sataloff & Sataloff, 1987, p. 362). Traumatic noise exposure leads to swelling of the outer hair cells, alterations in the endoplasmic reticulum and the stereocilia of the outer hair cells begin to bend and fuse (Durrant, 1978, p. 118). Recovery typically occurs after a few hours or days, proportional to the length of noise exposure (Seidman, 1999, p. 30). Restoration of normal hearing thresholds after TTS may be attributed to a number of processes that include activation of stress and repair mechanisms, restoration of depleted metabolites and neurotransmitters, and a decrease in slight edema of the hair cells (Wenthold, Schneider, Kim & Dechesne, 1992, p. 29). Repeated TTS may progressively lead to permanent hearing loss, known as a permanent threshold shift (PTS) (Hooks-Horton, Geer & Stuart, 2001, p. 52). If damage due to noise has been caused, avoiding further exposure can stop progression of the debilitation (Rabinowitz, 2000, p. 2749).

There are various strategies of protecting against noise damage (Seidman, 1999, p. 35). The first approach is to reduce noise exposure. This is achieved either through engineering, as in adapting machinery design, or by making changes in the workers' schedules and shift rotations. In cases where this may not be a feasible line of defense, personal hearing protection devices are used. Both active and passive forms of hearing protection are available. Electronic noise reduction devices effectively cancel sound waves at the ear. Passive hearing protection, such as earmuffs and earplugs, reduce sound energy mechanically (Lusk, 1997, p. 397). South African National Standards (SANS: 083, 1996) has provided specifications regarding exposure to noise in the workplace. These guidelines state that if noise levels equal or exceed 85dB A, for an eight-hour rating level, the noise levels should be reduced. This can be done by adapting machinery and by issuing personal hearing protection. The eight-hour rating level is that rating level normalised to a nominal eight-hour workday. Expert advice regarding noise reduction is recommended if noise levels equal or exceed 130dB A as conventional hearing conservation programs will no longer be sufficient in such conditions.

Variables in the workplace can have an influence on the effect of noise. It has been found that vibration exposure is often associated with noise exposure in industry (Phaneuf & Hétu, 1990, p. 37). This may have an influence on the effect of the noise exposure. While the interaction between noise and chemicals is not fully understood, the ototoxic effects of some substances, such as cisplatin, aminoglycoside antibiotics and toulene have already been established. Carbon Monoxide exposure in itself does not cause damage, but it may increase susceptibility to noise-induced hearing loss (Boettcher, Gratton, Bancroft & Spongr, 1992, p. 185). There seems to be an extensive list of variables, both acoustic and nonacoustic, which determine the severity of permanent noise-induced hearing loss. A number of ancillary endogenous factors, such as eye colour, psychological stress and tobacco use, have also been recognised as having a possible influence on an individual's susceptibility to noise induced hearing loss (Hooks-Horton et al., 2001, p. 52). This may account for the wide variation in the effects of noise on individual hearing.

Noise-induced hearing loss has become a leading industrial disease, while being almost completely avoidable. The otological damage caused by excessive noise exposure initially affects the functioning of the outer hair cells in the cochlea, particularly in the area responsible for the fine-tuning of the 3000Hz to 6000Hz frequency range (Seidman, 1999, p. 32). The resulting hearing loss is characterised by a decrease in air and bone conduction thresholds in this frequency range. The high frequency

sensorineural hearing loss is marked by a sharp dip at 4000Hz that is valuable in confirming the diagnosis. (McBride & Williams, 2001, p. 46). The loss is usually symmetrical, but may be asymmetrical if caused by noise sources such as a siren or firearm (Rabinowitz, 2000, p. 2746). It has been determined that the nonlinear behaviour of the cochlea is negatively affected by excessive acoustic stimuli. Cody and Russell (1992, p. 23) found that when the cochlea is exposed to loud sounds, the outer hair cells' response to acoustic stimuli becomes linear. This is attributed to the pathophysiological changes observed during the loss of outer hair cell function that negatively affects the functioning of the cochlea amplifier (Kummer, Janssen & Arnold, 1998, 3441).

Otoacoustic emissions (OAEs) can be defined as the audiofrequency energy which originates in and is released from the cochlea, transmitted through the ossicular chain and tympanic membrane, and measured in the external auditory meatus (Kemp, Bray, Alexander & Brown, 1986, p. 71). They can occur either spontaneously or in response to acoustic stimulation (Norton & Stover, 1994, p. 448). OAEs are believed to reflect the active biomechanical movement of the basilar membrane of the cochlea. This "retrograde travelling wave" (Rutten, 1980, p. 270) is thought to be responsible for the sensitivity, frequency selectivity and wide dynamic range of the normal auditory system. Brownell (1990, p. 82) provided strong evidence linking healthy outer hair cells of the cochlea to the production of OAEs. The relationship between the outer hair cells and OAEs has been shown by evidence that OAEs are affected by ototoxic substances that cause selective damage to the outer hair cells (Norton & Stover, 1994, p. 448). It is generally agreed that the presence of OAEs indicates that the preneural cochlear receptor mechanism, together with the middle ear system, responds to sound in a normal way (Kemp, Ryan & Bray, 1990, p. 94). In other words, OAEs are seen as an inevitable by-product of the processes that are essential to hearing.

There are two broad classes of otoacoustic emissions: spontaneous otoacoustic emissions (SOAEs) and evoked otoacoustic emissions (EOAEs). SOAEs are continuous narrowband signals emitted by the human ear, in the absence of sound stimulation. They occur in approximately half of the normal hearing population. EOAEs occur either during or immediately following acoustic stimulation (Martin & Clark, 2000, p. 176). There are several types of EOAEs and they are classified according to the evoking stimulus (Norton & Stover, 1994, p. 448). The two major types we find used most in the clinical setting are transient evoked otoacoustic emissions (also known as click evoked OAEs) and distortion product otoacoustic emissions (Danhauer, 1997, p. 62). Transient-evoked otoacoustic emissions (TEOAEs) are recorded in response to a click or tone pip. This form of signal stimulates the entire cochlea, so if an emission in reduced or absent, it cannot be exactly determined where the auditory disorder lies. Distortion product otoacoustic emissions (DPOAEs) are measured in response to two tones presented to the ear. The interaction of the two tones within the normal cochlea gives rise to an audible signal at a specific additional frequency. A study by Smurzynski, Leonard, Kim, Lafreniere & Jung (1990, p. 1316) found that DPOAEs are indeed able to “test the micromechanical properties of the outer hair cells in frequency-specific regions”. Most, but not all, distortion product energy is generated in and emitted directly from the f_2 emission site of the basilar membrane (Knight & Kemp, 1999, p. 457). The primary tones can therefore be selected to test a specific frequency region. This property has important implications for the use of DPOAE when evaluating cochlear disorders that are known to affect certain frequencies, such as noise-induced hearing loss.

DPOAEs are widely believed to be a rapid, objective, reliable and repeatable measure of the physiological integrity of the outer hair cells of the cochlea. These phenomena can be recorded in almost all normal ears, and are known to be reduced or absent in ears with hearing loss (Lonsbury-Martin, McCoy, Whitehead & Martin, 1993, p. 12). They are defined as the acoustic energy that is recorded from the ear as a result of the nonlinear interaction between two simultaneously presented pure tone signals (Norton & Stover, 1994, p. 455). This interaction gives rise to the creation of a response at frequencies not included in the input signal. The evoking tones for eliciting DPOAEs are known as the primaries and are referred to as f_1 and f_2, with f_1 representing the lower frequency stimulus and f_2 the higher frequency tone; in other words $f_2 > f_1$ (Lonsbury-Martin, Whitehead & Martin, 1991, p. 969). Current studies have shown that DPOAEs recorded in the ear canal cannot be traced back to a single source along the basilar membrane (Knight & Kemp, 1999, p. 457). The first and primary source of the DPOAE energy is due to the nonlinear distortion between the two primary tones, at the place of f_2. This is also known as the generation site. The second source of the DPOAE measured in the ear canal is caused by the reflection of the coherent wave at $2f_1 - f_2$, or f_{DP}. This is also referred to as the re-emission site (Mauermann, Uppenkamp, van Hengel & Kollmeier, 1999, 3473). The cubic difference tone f_{DP}, described by the algebraic expression $2f_1 - f_2$, is the most prominent DPOAE measured in humans, as well as many animal species (Probst, Lonsbury-Martin & Martin, 1991, p. 2033).

When investigating DPOAEs, a vital prerequisite for the accurate measurement of these emissions is a normal functioning middle ear system. This is because it is essential that the acoustic energy be transmitted in a reverse direction from the cochlea in order to be recorded (Hall & Chase, 1993, p. 29). These authors stress the importance of vital factors to keep in mind when measuring DPOAEs, such as the influence of probe fit and both ambient and internal noise (p. 30). The DPOAE response is embedded in noise and if these levels are too high, the DPOAE may not be readily detected. The recording of robust DPOAEs may also be negatively affected by the presence of contralateral sound. This has been shown to lead to a reduction in DPOAE amplitudes (Moulin, Collet & Duclaux 1993, p. 193).

Due to the strong evidence that links healthy outer hair cells to the production of OAEs, the suggestion to use DPOAEs to monitor the effects of noise on hearing is meaningful. The high frequency specificity of DPOAEs is valuable when assessing hearing loss that only affects certain areas of the auditory range, such as noise induced hearing loss (Wilson, 1992, p. 91). It is known that the generation site of the DPOAE is very close to $f_{2.}$ (Mauermann et al., 1999, p. 3473). The eliciting tones of the DPOAE can therefore be selected to test a specific frequency region. Decreased hearing sensitivity at 4000Hz is generally the first sign of cochlear damage resulting from noise exposure (Phaneuf & Hétu, 1990, p. 35) so DPOAE measures should be able to provide information regarding the locus of damage, and thus the possible etiology of a hearing loss. While this property of DPOAE may be useful in complementing the pure tone audiogram (Probst et al., 1991, p. 2057), results should only be interpreted within the framework of a thorough clinical test battery.

DPOAEs are known to be adversely affected by TTS resulting from noise exposure (Subramaniam, Henderson & Spongr, 1994, p. 306). In their 1993 study (p. 1586), Engdahl and Kemp found a reduction in DPOAE amplitudes as a result of noise exposure. The DPOAE recordings were able to show the TTS associated with limited noise exposure. This was later confirmed by Vinck et al. (1999, p. 51). Probst, Harris and Hauser (1993, p. 89) are of the opinion that OAEs can be useful in monitoring the short, mid, and long-term effects of noise. A study by Kummer et al. (1998, p. 3441) showed that linearisation of the DPOAE responses, could be linked with the changes in outer hair cell function resulting from cochlear impairment.

It has been shown that DPOAEs are able to detect subtle changes in the sensory hearing mechanism. Cochlear dysfunction, resulting in abnormal DPOAE results, may be present while the patient is still within the clinical limits of audiometrically normal (Attias, Bresloff, Reshef, Horowitz &

Furman, 1998, p. 45). Their work supports the findings of Hamernik, Ahroon and Lei (1996, p. 1003), which suggest that DPOAEs are more sensitive to the effects of noise than pure tone threshold measures. This may be as a result of subclinical pathologic changes, which cause deficits in cochlear function, but are not yet detected by conventional audiometry (Lonsbury-Martin, Harris, Stagner, Hawkins & Martin, 1990, p. 15). This ability of DPOAE measures may have important implications for the early identification of outer hair cell damage, in cases of cochlear insults known to primarily influence these cells, such as ototoxicity or excessive noise exposure. This damage may eventually lead to permanent hearing loss. Lucertini, Moleti and Sisto (2002, p. 977) found that TEOAEs were useful in detecting early subclinical cochlear damage in noise-exposed populations with normal audiometric hearing thresholds. Their opinion is that this early diagnosis would be valuable in limiting further noise exposure before irreversible cochlear damage occurs. Kossowski, Mom, Guitton, Poncet, Bonfils and Avan (2001, p. 120) suggest that DPOAEs "can be useful in identifying minor cochlear impairment" resulting from auditory fatigue, in other words TTS. This argument is further supported by findings by Kiss, Tóth, Rovó, Venczel, Drexler, Jóri, & Czigner (2001, p. 140) that found significant decreases in DPOAE amplitudes following noise exposure.

Noise-induced hearing loss is seen as the most preventable of industrial diseases (Sataloff & Sataloff, 1992, p. 1). Unfortunately, although industrial workers are issued with hearing protectors, there is still a large population of workers who do not make use of them (Patel, White, Zuckerman, Murray-Johnson, Orrego, Maxfield, Meadows-Hogan, Tisdale & Thimons, 2001, p. 156). Davis and Sieber (1998, p. 721) state that even though hearing protective devices, such as earmuffs and earplugs are provided, the effectiveness of the protection is reduced if employees fail to utilise these safety devices properly. A number of factors may influence the inefficiency of the hearing protectors. These may include improper insertion and use,

or that the earplugs themselves are not sufficient protection against the noise source. From the above argument, it would seem feasible to use DPOAE testing to determine any difference in DPOAE amplitude after exposure to excessive noise, while making proper use of the earplugs. Because we know that DPOAEs are relatively stable over time (Roede, Harris, Probst & Xu, 1993, p. 280), any change in DPOAE responses may be because of the influence of noise. Conclusions could then be drawn as to whether or not the earplugs are effectively preventing TTS.

2. METHODOLOGY

The aims of the study, as well as the procedures that were followed in order to reach them, will be fully discussed in this section.

2.1 Aims of the study

2.1.1 Main aim

This study aimed to investigate the effectiveness of the Quiet earplug noise protectors worn by a group of South African industrial workers.

2.1.2 Sub aims

In order to investigate the effectiveness of the Quiet earplugs, the following specific subaims were formulated:

2.1.2.1 To determine the prevalence of DPOAEs before exposure to excessive noise for eight hours.

2.1.2.2 To measure the DPOAE amplitudes obtained before exposure to excessive noise for eight hours.

2.1.2.3 To determine the prevalence of DPOAEs after exposure to excessive noise for eight hours.

2.1.2.4 To measure the DPOAE amplitudes obtained after exposure to excessive noise for eight hours.

2.1.2.5 To compare the DPOAE prevalence and amplitude levels from before and after noise exposure, in order to determine whether a significant difference exists between them.

2.2 The research design

A research design is “a strategic framework for action that serves as a bridge between research questions and the execution or implementation of the research” (Dane, 1990, p. 29). The current study implements a quasi-experimental quantitative research design, which is descriptive in nature, in order to determine the effectiveness of the earplugs worn by a specific population of industrial workers.

The study is quasi-experimental in design because the study lacks random assignment (Dane, 1990, p. 117). In quasi-experimental designs, equivalence between subjects is required in terms of certain relevant characteristics. The control of these characteristics attempts to limit the number of plausible rival explanations of any effects that are observed (Tredoux, 1999, p. 322). It is therefore “imperative that the researcher be thoroughly aware of the specific variables the design fails to control” (Leedy & Ormond, 2001, p. 238). These variables must be taken into account when interpreting the data. It is impossible for this study to clinically control all the variables involved when investigating the use of noise protectors and exposure to noise, as the researcher is unable to monitor the subjects’ movements throughout the work shift.

The research design is quantitative in nature as the data are collected in the form of numbers, statistical types of data analysis are used, and it begins with a series of predetermined categories (Durrheim, 1999, p. 42). Quantitative research is implemented either to identify the “characteristics of an observed phenomena or to explore possible correlations among two or more phenomena” (Leedy & Ormond, 2001, p. 191). The data are measured and used to make comparisons that can be generalised. The values obtained from the various test procedures will undergo inferential statistical analysis, in order to determine comparisons, differences and variances between sample populations (McBurney, 1994, p. 412). This study will also describe a situation as it is, without changing the situation under investigation. It is therefore descriptive in nature. The descriptive information gained from a quantitative study allows for broad comparisons and generalisations to other pools of collected data within the investigated area (Durrheim, 1999, p. 42).

2.3 Sample population

This section will discuss the criteria for the selection of subjects as well as the procedures that were followed in order to do so.

2.3.1 Criteria for selection of subjects

Subjects were selected on the basis of the following criteria:

2.3.1.1 Age

According to Stover and Norton (1993, p. 2679) age alone is not thought to have a significant effect on the measurement of DPOAEs. However, it is know that there is a confounding effect of age on an individual's susceptibility to noise-induced hearing loss. It was therefore decided that subjects must be younger than 60 years of age, in order to be selected to participate in the study (Mills, Dubno & Boettcher, 1998, p. 121).

2.3.1.2 Normal external ear structure

No abnormalities of the ear canal or tympanic membrane may be present as this may have an influence on the recording of distortion product otoacoustic emissions (Lonsbury-Martin et al., 1993, p. 15). A normal external ear structure was indicated by the absence of any soft tissue or bony growth, foreign bodies or infection in the external auditory meatus (Ginsberg & White, 1994, p. 11). The colour of the membrane, which should be pearly grey, and the presence of a conical light reflex were used to judge the integrity of the tympanic membrane (Martin & Clark, 2000, p. 234). There must also not be a significant amount of cerumen in the ear canal as this may block the tympanometer or DPOAE probe tips.

2.3.1.3 Normal middle ear function

It is been established that DPOAEs are reduced or eliminated by compromise of the middle-ear conduction pathway. Normal middle ear function is a prerequisite for measuring DPOAE and it is therefore important to include immittance measurements when investigating DPOAEs (Osterhammel, Nielsen & Rasmussen, 1993, p. 115). In this study, normal middle ear functioning was defined as a Type A tympanogram, indicating a middle ear pressure within the range of –50 to +50 daPa (Martin & Clark, 2000, p. 156). In addition, normal values for static compliance ranged from $0.30ml^3$ to $1.60ml^3$ and the volume of the adult external ear canal varied between $0.65ml^3$ and $1.75ml^3$ (Hall & Chandler, 1994, p. 284, 285).

An ipsilateral stapedius reflex at 1000Hz was also elicited. The acoustic reflex threshold is thought to be a characteristic of a relatively stable auditory system. Measuring the acoustic reflex forms part of the basic audiometric test battery and it is “standard routine clinical practice to specify the acoustic reflex” of an ear being tested (Northern & Gabbard, 1994, p. 302). The acoustic reflex should therefore always be included when interpreting findings. This measure is also used to confirm the presence or absence of any middle ear pathology. The ipsilateral acoustic reflex threshold was seen as normal if the level at which it is elicited falls between 70dB HL and 100dB HL.

2.3.1.4 Normal hearing thresholds

In order for subjects to be selected to participate in the study they had to present with hearing thresholds falling between 0dB HL and 25dB HL, across the test frequencies of 250Hz to 8000Hz. According to Clark (1981, p. 496), "most hearing classification systems begin designating hearing loss at 25dB HL". The classification system of hearing loss modified from Lloyd and Kaplan (1978), found in Silman and Silverman (1991, p. 51), was chosen for this study. This classification views hearing thresholds below 26dB as falling within normal limits. In addition, the presence of an air-bone gap contra-indicated the selection criteria, and the subject was not selected for the study.

2.3.1.5 Informed consent

Informed consent to participate in the study was obtained and guidelines specified by McBurney (1994, p. 375) were followed. If the subject complied with the selection criteria, the study was explained. If the subject agreed to participate in the study, he was asked to sign the informed consent section, found at the bottom of the record sheet. A copy of the record sheet can be seen in Appendix A. Once informed consent had been confirmed, the researcher proceeded with the collection of test data.

2.3.2 *Description of apparatus and materials for selection of sample population*

The following apparatus and materials were used to select the sample population:

2.3.2.1 Otoscope

A Welch Allyn Otoscope was used to perform the otoscopic examination. Two size C Alkaline batteries of 1.5 volts each were used to power the otoscope. Plastic speculae were used.

2.3.2.2 Immittance meter

An Interacoustics Impedance Audiometer AT235 was used to obtain immittance measurements. It was calibrated on 18 February 2002, so as to comply with the IEC 1027 “Instruments for the measurement of aural acoustic impedance / admittance” standards, as well as the IEC 601 – 1 “Safety of medical electric equipment” specifications. A UPS400 external switch mode power supply was used to connect the AT235 to the electrical supply. The test was performed using a probe tone frequency of 226Hz (Hall & Mueller, 1997, p. 189). Interacoustics plastic eartips were fitted over the probe tip during testing. Hibitane was used to disinfect both the immittance probe tips and the otoscope speculae after use.

2.3.2.3 Audiometer

An Interacoustics Impedance Audiometer AT235 was used to determine the pure tone air conduction hearing thresholds. It was calibrated on 18 February 2002, in accordance with the IEC 1027 “Instruments for the measurement of aural acoustic impedance / admittance” standards, as well as the IEC 601 – 1 “Safety of medical electric equipment” specifications. A UPS400 external switch mode power supply was used to connect the AT235 to the electrical supply. Telephonics TDH-39P earphones and a patient response button were used for the audiometry testing. They are connected to the AT235 via the corresponding connection points at the back of the AT235. Audiometric testing took place in the soundproof booth of the occupational clinic.

2.3.2.4 Record sheet

A copy of the record sheet can be found in Appendix A. This was used to record the findings of the otoscopic examination and the immittance testing. An audiogram form is also found on this form in order to record the hearing test.

2.3.3 Procedure for selection of sample population

The following procedures were used to obtain information pertaining to the selection of the sample population.

2.3.3.1 First contact and introduction

The researcher is currently performing diagnostic audiological testing for a number of industries. The service is co-ordinated by the occupational health sisters based at each of the industries. One of the occupational health clinics was telephoned. The purpose and test procedure of the study was discussed. The occupational sister then discussed the implications of testing the workers with the Human Resources manager and General Health manager. The researcher met with these managers to discuss the study. Permission to test employees at the factory was then granted.

2.3.3.2 Pilot study

A pilot study was conducted in order to determine how the process of data collection would occur. Two subjects, who complied with the selection criteria, participated but the collected data was not used in the main study. The pilot study was conducted one week prior to the start of the main study, in order to allow for any necessary changes in test procedure to be made.

The otoscopic examination was conducted first, followed by the immittance, acoustic reflex and pure tone testing. The results of these investigations were noted on the record sheet, as seen in Appendix A. The questionnaire (see Appendix B) was then completed to ensure that subjects were able to answer the questions. The subjects were then instructed on the proper insertion and use of the earplugs. DPOAE testing was performed, and repeated until a set of consistent, repeatable DPOAEs were recorded for each ear. The subject then worked one eight-hour shift, using his earplugs appropriately. As the subject finished his work shift, he underwent a second set of DPOAEs testing. These results also had to be repeatable and consistent. The subject was finally asked the few post-exposure questions of the questionnaire regarding the nonacoustic variables related to changes in DPOAE amplitudes and TTS (see Appendix B).

No significant problems were experienced during the pilot study. The only cause for concern was that there might be some difficulty ensuring that there were four possible subjects to test each day, as some line managers were reluctant to release their workers. This is in spite of the Human Resources manager instructing them to do so. It was therefore proposed that the researcher would continue to visit the factory and conduct testing until sufficient data for the current study had been collected from 25 right ears and 25 left ears. This amount was provided by the statistician as the fewest number of subjects from which to obtain statistically valuable information. The data collection took eight weeks, with testing occurring on average three days per week.

The pilot study resulted in the following procedure breakdown:

Otoscopic examination:	2 minutes per subject
Immittance (including reflex):	5 minutes per subject
Questionnaire:	4 minutes per subject
Pure tone air conduction thresholds:	10 minutes per subject
DPOAE:	10 minutes per subject
Retest:	10 minutes per subject

Total testing time: 41 minutes per subject

The following procedures were followed in order to determine whether the subjects complied with the selection criteria of the study:

2.3.3.3 Otoscopic examination

A disinfected speculum was fitted to the otoscope and the otoscope was switched on. The helix of the ear is pulled backwards and upward in order to straighten out the external auditory meatus slightly. The speculum was placed in the opening of the external auditory meatus and the condition of the ear canal observed. The criteria for a normal otoscopic examination were met if a light reflex was clearly visible, and if there was little or no cerumen, or any other obstruction, present in the ear canal. The results of the otoscopic examination were recorded on the record sheet. A check mark was made in the corresponding space, according to the condition of the external auditory meatus and tympanic membrane. The decision as to whether or not the subject passed or failed the otoscopic examination was then indicated on the record sheet (Appendix A).

2.3.3.4 Immittance

The subject was seated in a comfortable chair. The subject was told that no participation during testing is necessary, but that coughing, talking and swallowing would affect the results. The subject was warned that he may experience a slight pressure sensation in the ear, and that one or more tones may be heard during the test. An appropriate ear tip was selected and fitted to the probe. Once an airtight seal at the opening of the external auditory meatus had been obtained, the tympanometry test and acoustic reflex test was performed automatically. Once the tympanogram had been completed, the green indication light on the probe switched off and the

tympanogram was displayed on the liquid crystal display screen of the AT32 Impedance Audiometer (Interacoustics Impedance Audiometer AT356 Operation Manual, p. 14). The tympanogram shape, the middle ear pressure, the compliance and the ear canal volume were noted in tabular form, on the record sheet (see Appendix A). The subject would have complied with the criteria for normal middle ear functioning if the middle ear pressure fell between –50daPa and +50daPa (Martin & Clark, 2000, p. 156); the ear canal volume fell between 0.30 ml^3 and 1.60 ml^3; and the static compliance values were between 0.65 ml^3 and 1.75 ml^3 (Hall & Chandler, 1994, p. 284, 285). The decision as to whether or not the subject passed this selection criterion was then indicated on the record sheet. If the stapedial reflex was elicited at a level regarded as normal, in other words between 70dB HL and 100dB HL (Northern & Gabbard, 1994, p. 302), the appropriate pass block was checked. Similarly, if the acoustic reflex was absent or reduced, the fail block was marked. Immittance was then repeated for the opposite ear.

2.3.3.5 Determination of hearing thresholds

The hearing thresholds for each subject were determined as follows:

2.3.3.5.1 Patient instructions

The subject was seated in a soundproof booth in a quiet room of the occupational clinic. It was explained that the subject would hear tones of different frequencies or pitches. The subject was required to push the response button every time he heard a tone, no matter how soft or faint it became. The response button was handed to the subject. The Telephonics TDH-39P earphones were then placed over the subject’s ears, with the red earphone over the right ear and the blue earphone over the left ear.

2.3.3.5.2 Audiometric testing procedure

The test ear was selected by pressing the red "Right" button or blue "Left" button. The better ear, as judged subjectively by the subject, was tested first. The test frequency was selected using the "Frequency Decr / Incr" buttons. The frequencies were tested in the following order: 1000Hz, 2000Hz, 3000Hz, 4000Hz, 6000Hz, 8000Hz, 1000Hz (to confirm the threshold), 500Hz and 250Hz (Martin & Clark, 2000, p. 83). The tone was presented by pressing the "Present tone" button. The tone was initially presented at 30dB SPL. The subject acknowledged the tone by pressing the patient response button. Once the button had been pressed a rectangular block on the audiometry screen lit up. If no response was given, the intensity was increased in 20dB steps. The intensity was increased or decreased by pressing the "Intensity Decr / Incr" buttons. Once a response had been given, the intensity was decreased in 10dB steps until the subject stopped responding. The intensity was then increased in 5dB steps until the subject again indicated that he had heard the tone. The threshold was then confirmed by decreasing the intensity by 10dB and increasing it in 5dB steps (Martin & Clark, 2000, p. 84). The confirmed threshold was then noted down on the record sheet (Appendix A). Air conduction thresholds for the frequencies of 500Hz, 1000Hz, 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz were recorded. The other ear was then selected and the test procedure repeated for the untested ear. Thresholds for the right ear were indicated with a circle at the appropriate intensity level on the audiogram, while air conduction thresholds for the left ear were marked by a cross. Only subjects with hearing thresholds below 26dB HL were selected for the study.

2.3.4 Description of the sample population

Subjects who complied with the selection criteria were selected to participate in the study. In total there were 27 subjects, resulting in 25 right ears and 25 left ears. The relevant characteristics of the sample population can be found in Table 1.

TABLE 1. DESCRIPTION OF SAMPLE POPULATION

Subject No.	Age	Ear Rt / Lt	Ear Canal Volume (ml)	Middle ear Compliance (ml)	Middle ear Pressure (daPa)	Acoustic Reflex: 1000Hz (dB)	Air conduction threshold					
							1000Hz	2000Hz	3000Hz	4000Hz	6000Hz	8000Hz
1	27	Rt	1.12	0.76	-18	85	15	15	10	5	10	0
		Lt	0.97	0.69	-25	85	10	5	10	5	5	5
2	26	Rt	1.09	0.78	2	85	5	10	5	10	10	0
		Lt	1.02	1.10	-2	85	10	5	10	10	10	10
3	30	Rt	1.22	1.07	-17	95	15	10	10	15	10	10
		Lt	1.07	0.72	-49	95	5	15	15	10	5	0
4	31	Rt	1.40	1.13	-8	85	20	15	5	15	15	20
		Lt	1.45	1.24	1	85	15	10	0	10	15	10
5	39	Rt	1.58	0.63	11	90	20	20	25	25	10	0
		Lt	1.67	0.62	13	85	10	25	20	15	20	5
6	35	Rt	1.31	1.20	6	85	20	25	15	30	15	10
		Lt	1.09	1.21	0	85	20	15	20	25	20	5
7	33	Lt	1.27	1.19	3	80	5	15	15	25	25	5
8	43	Rt	1.22	1.15	-19	95	20	25	25	20	25	25
		Lt	1.71	0.86	9	95	25	25	25	25	25	25

TABLE 1. DESCRIPTION OF SAMPLE POPULATION cont.

Subject No.	Age	Ear Rt / Lt	Ear Canal Volume (ml)	Middle ear Compliance (ml)	Middle ear Pressure (daPa)	Acoustic Reflex: 1000Hz (dB)	Air conduction threshold					
							1000Hz	2000Hz	3000Hz	4000Hz	6000Hz	8000Hz
9	49	Rt	1.63	1.22	-11	95	20	20	25	25	25	25
10	42	Rt	1.52	1.30	-4	90	20	15	25	25	25	15
		Lt	1.46	1.21	6	85	15	15	20	20	25	0
11	41	Rt	1.52	2.43	14	90	5	15	20	25	25	25
		Lt	2.27	2.97	44	90	15	15	20	25	25	20
12	41	Rt	0.85	2.07	3	85	15	5	15	15	15	15
		Lt	0.99	2.25	6	85	15	10	15	15	25	5
13	33	Rt	1.68	1.07	14	100	25	15	25	25	10	0
14	34	Rt	1.54	0.87	7	85	15	15	15	15	15	0
		Lt	1.35	0.95	3	80	5	10	5	10	25	5
15	38	Rt	1.24	0.97	4	80	10	15	5	10	15	15
		Lt	1.54	0.24	-23	80	5	15	15	15	20	5
16	24	Rt	1.69	0.48	-4	80	5	5	5	15	25	0
		Lt	0.98	1.18	-8	85	10	5	10	5	25	0
17	27	Rt	1.34	0.97	-4	90	25	20	5	20	25	15
		Lt	1.20	0.50	-4	85	15	25	15	15	25	10

TABLE 1. DESCRIPTION OF SAMPLE POPULATION cont.

Subject No.	Age	Ear Rt / Lt	Ear Canal Volume (ml)	Middle ear Compliance (ml)	Middle ear Pressure (daPa)	Acoustic Reflex: 1000Hz (dB)	Air conduction threshold					
							1000Hz	2000Hz	3000Hz	4000Hz	6000Hz	8000Hz
18	44	Rt	1.29	0.62	-3	80	10	0	25	25	15	0
		Lt	1.03	0.43	-28	80	10	15	25	25	25	10
19	38	Rt	1.26	0.57	-17	80	15	25	20	25	15	5
		Lt	1.52	2.43	14	80	15	15	15	25	10	0
20	45	Rt	1.17	0.66	-16	90	25	20	25	20	10	0
		Lt	1.28	0.50	-4	85	15	15	20	15	25	0
21	46	Rt	2.37	1.32	19	95	20	5	15	20	25	10
		Lt	2.67	1.21	17	95	20	10	10	15	25	15
22	32	Rt	2.13	1.46	26	85	15	20	25	25	25	25
		Lt	1.80	0.93	6	95	10	25	15	20	25	25
23	28	Rt	1.50	1.03	-24	95	25	25	20	25	25	15
		Lt	1.58	1.05	-22	80	15	15	20	20	25	15
24	26	Rt	0.74	0.82	0	95	25	15	20	20	25	0
		Lt	1.22	1.10	11	95	20	20	20	25	25	5
25	49	Rt	0.89	0.55	-10	90	20	25	25	25	25	20
		Lt	0.82	0.71	-17	90	20	25	25	25	25	15

TABLE 1. DESCRIPTION OF SAMPLE POPULATION cont.

Subject No.	Age	Ear Rt / Lt	Ear Canal Volume (ml)	Middle ear Compliance (ml)	Middle ear Pressure (daPa)	Acoustic Reflex: 1000Hz (dB)	Air conduction threshold					
							1000Hz	2000Hz	3000Hz	4000Hz	6000Hz	8000Hz
26	40	Rt	1.14	0.31	-14	80	10	5	10	5	15	0
		Lt	1.04	0.30	-4	80	5	15	25	15	10	0
27	48	Rt	1.83	0.85	13	85	15	15	25	20	20	10
		Lt	1.20	1.52	1	90	20	20	15	15	20	10

2.4 Collection of test data

2.4.1 Description of apparatus and materials for collection of test data

The following apparatus and materials were used in order to gather the test data:

2.4.1.1 Questionnaire

A questionnaire was used in order to obtain information regarding the subject that is relevant to the study. The questionnaire was constructed according to guidelines suggested by Bless and Higson-Smith (1995, p.115). Firstly a section on personal information is found, as this provides identifying information such as name, age, etc. Then questions detailing the subjects' subjective experience of their hearing ability, noise exposure and medical history are found. The final section of the questionnaire contains the information required after the work shift has been completed. The noise exposure questions and those related to medical history were formulated specifically in order to determine the subject's exposure to variables that are known to affect either DPOAE responses or susceptibility to TTS. There are a number of nonacoustic factors that are known to influence DPOAE responses or sensitivity to TTS. Individuals who smoke may have increased susceptibility to noise (Henderson, Subramaniam & Boettcher, 1993, p. 154) and information regarding the number of cigarettes smoked during the shift should be noted. These authors also discuss the influence of ototoxic medications (such as aminoglycoside antibiotics and cisplatin), carbon monoxide, and solvents (such as toulene), on the effect of noise exposure (p. 155, 156). The time elapsed since the subject's last exposure to noise may also have an influence on the DPOAE responses measured. A copy of the questionnaire can be seen in Appendix B.

2.4.1.2 Quiet Earplugs

The factory safety officer issues the employees at the industry with a pair of Quiet earplugs whenever necessary. These are the earplugs that are supplied to the industrial workers, and therefore the earplugs that feature in this study. While a comprehensive explanation as to why these earplugs are used by this particular factory is not available, one of the reasons is that they are disposable and cost effective. The earplugs are bullet or bell shaped and are orange in colour, with an orange connecting cord. The earplugs meet the SANS 1451-2 Hearing protectors Part 2: Ear-plugs (1988) requirement. The real ear attenuation values can be seen in Table 2.

TABLE 2. REAL EAR ATTENUATION VALUES OF THE QUIET EARPLUG

Frequency (Hz)	Measured Attenuation (dB)	Standard Deviation (dB)	Minimum Attenuation (dB) (SANS 1451)
125	21.2	3.7	18
250	22.8	5.2	16
500	20.8	6.4	19
1000	23.0	4.8	23
2000	31.8	4.3	26
4000	41.0	3.4	30
8000	37.5	7.4	30

This table shows how the Quiet Earplugs provide sufficient attenuation of sound pressure levels, in accordance with the specifications provided by the SANS.

2.4.1.3 **DPOAE**

The Bio-logic Scout Sport Ver. 3.04 DPOAE System, together with Entymotic Bio-logic OAE probe tips, were used on the ER-10C probe microphone measurement system to obtain DPOAE readings. The microphone measurement system consists of two independent transducers that deliver the primary tones, and a measurement microphone that is used for ear-canal calibrations and response measurements. The AuDX handheld unit was connected to an Intel Pentium III (182MHz with 128 MB RAM) desktop computer. The Microsoft Windows 98 operating system was being used in order to run the Scout Ver. 3.04 software.

*2.4.2 **Procedure for the collection of test data***

The following procedures were carried out in order to gather the test data:

2.4.2.1 Completion of questionnaire for control of nonacoustic influences known to affect DPOAE responses or sensitivity to TTS

While English was not the first language of most of the participating subjects, most of them could understand English. The subjects are all well known to the occupational sister at the clinic, and she was able to inform the researcher if any subjects would not be able to understand the questions asked during the interview. In these cases she was able to act as a translator. If the researcher at any time during the interview was not certain that the subject clearly understood the question, the occupational sister was asked to assist. She did this by asking the question in the subject’s first language, and translating the response into English in order for the researcher to note the answer. Facial expressions, hesitations and inappropriate answers were seen as indications that the subject was confused by the questions.

The questions regarding the various aspects were asked and the responses noted down on the questionnaire. When the DPOAE testing was repeated after the 8-hour work shift had been concluded, the "Post-exposure" section of the questionnaire was completed. This includes information regarding the use of the hearing protectors or any medication during the shift, as well as the number of cigarettes smoked. It is important to keep these aspects in mind when analysing the test data.

2.4.2.2 **Correct implementation of hearing protectors**

This study aimed to investigate the effectiveness of the hearing protectors worn by this population of industrial workers. It was therefore important that they used the earplugs correctly. An explanation of how to insert the earplugs properly was given to each individual subject. A demonstration was then carried out. Finally, the subject was asked to insert his own earplugs, in order for the researcher to be certain that he could do so correctly. The subject was also made aware of the purpose of the study, and the consequent importance of the correct usage of the hearing protectors throughout the shift. The occupational sister continued to act as an interpreter as necessary.

2.4.2.3 **DPOAE testing**

The DPOAE responses were obtained as follows:

2.4.2.3.1 **Test environment**

Environmental noise can have a negative impact on the recording of DPOAEs. While a soundproof booth is not vital to a successful recording, efforts should be made to keep ambient noise levels as low as possible (Danhauer, 1997, p. 66). The testing took place in a quiet room at the occupational clinic. No actual measurements of environmental noise were taken to determine whether the testing before and after noise exposure took place under the same conditions. However, subjectively the room was quiet and no sounds from the rest of the clinic were audible. The patient was instructed to remain as quiet and still as possible during the testing as internal noise may also mask DPOAEs (Hall & Chase, 1993, p. 30).

2.4.2.3.2 **System setup**

DPOAEs were recorded by presenting the eliciting primaries simultaneously to the ear. A sensitive microphone, used to measure the response, is housed in the probe. The probe also contains the two transducers that deliver the stimulus tones (Osterhammel & Rasmussen, 1992, p. 38). The test protocol, named “1.18 ratio”, was created and saved in the Scout software program. The protocol was chosen to correspond with that found by Delb, Hoppe, Liebel and Iro (1999, p. 73) to elicit the largest difference in DPOAE amplitudes between pre- and post-noise exposure measurements. Delb et al. (1999, p. 68) conducted a study using various DPOAE stimuli combinations. This was done to find a stimulus combination that would be optimal for the detection of a TTS caused by noise exposure. Four different f_2/f_1 ratios, with two variations of primary intensities, were investigated. The results showed that f_2/f_1 ratios of 1.22 and 1.20, with stimulus intensities of L1 = 65dB and L1 - L2 = 25dB, were not suitable for detecting differences between noise-exposed and unexposed subjects. In addition, the diagnostic test parameters of f_2/f_1 = 1.20, L1 = 65dB and L1 – L2 = 10dB (Hall & Mueller, 1997, p. 247) also failed to show any difference between test populations. It was found that the stimulus parameters of f_2/f_1 = 1.18, L1 = 65dB and L1 – L2 = 25dB were best able to detect acute acoustic trauma using DPOAEs. The detection of any changes in DPOAEs before and after noise exposure forms a major part of the current study, and thus provided the motivation for implementing the test protocol determined by Delb et al. (1999, p. 67). The exact test parameters can be seen in Table 3.

TABLE 3. **PARAMETERS DETERMINING COLLECTION OF DPOAE TEST DATA**

Protocol Name:		1.18 ratio	
Checkfit trials:	10	Calibration trials:	10
# Checkfit successes to pass:	1	# Calibration successes to pass:	1
# Checkfit failures until refit:	5	# Calibration failures until refit:	5
Checkfit / Calibration Artifact rejection:	400		

Sample Size:	2048	Min # samples:	50

Frequencies and levels:		Stopping Criteria:	
Start frequency:	8000Hz	Min. DP Amplitude:	-10.0dB
End frequency:	2000Hz	Noise Floor:	-17dB
f_2/f_1 ratio:	1.18	DP-NF:	6dB
Points per octave:	8	Point time limit:	10 sec

L1 (dB)	L2 (dB)	f_1 (Hz)	F_2 (Hz)	GM (Hz)
60.1	34.1	6771	7989	7355
59.8	34.5	4803	5670	5218
60.0	34.7	3374	3983	3666
55.9	34.9	2390	2811	2592
59.4	34.5	1687	1991	1833

Advanced parameters:			
High Pass Frequency:	300Hz	High Pass Frequency type:	Auto
Noise side bands:	2		

Key	#	:	Number	Min.	:	Minimum
	Hz	:	Hertz	GM	:	Geometric mean
	dB	:	Decibels	L	:	Intensity Level
	DP	:	Distortion product	f	:	Frequency
	NF	:	Noise floor			

Ten calibration trials were performed, with an artefact rejection of 400 and five failures until a refit is requested. The primaries were fixed at L1 - L2 = 25dB, where L1 = 60dB SPL and L2 = 35dB SPL. An f_2/f_1 ratio of 1.18 was used, where the f_2 frequency corresponded most closely to the audiometric frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz (Delb et al., 1999, p. 73). The frequency range of 2000Hz to 8000Hz was tested, as it has been shown that reliability of DPOAEs in the low frequency range can be influenced by background noise (Zhao & Stephens, 1999, p. 175). The test frequency selection is in keeping with the suggestion of Lee and Kim (1999, p. 22) that "if the purpose of DPOAE measurement is to monitor cochlea functioning regarding ototoxicity or noise exposure, then the test frequencies of interest would be above 2KHz". The DPOAE test was automatically stopped if the noise floor rose above –17dB SPL. A DPOAE response was considered present if the amplitude was greater than the prescribed amplitude of -10dB SPL and the difference between the DPOAE amplitude and the noise floor was greater than 6dB SPL. The Scout software will not allow a selection of 5dB SPL as suggested by Hall (2000, p. 140). However, Probst and Hauser (1990, p. 238) used a difference of 6dB SPL between DPOAE noise floor and amplitude as indication of emission presence. Eight points per octave were measured for each of the five pairs of frequencies. The sample size was 2048, with a minimum number of 50 samples required for a response to be measured. This meant that the minimum amount of averaging time was four seconds in duration (Scout OAE User's and Service Manual, 2000, p. 133). A larger sample size is desirable as it results in an increased signal-to-noise ratio, particularly for the higher frequencies (Beattie & Ireland, 2000, p. 100). According to Zhao and Stephens (1999, p. 178), an improved signal-to-noise will in turn provide clearer and more reliable DPOAE responses. The sample size of 2048 creates a 25Hz wide frequency band on either side of the DP frequency. The Scout program averages this band to determine the noise measurement. Two noise side bands, in other words 50Hz on either side, were averaged per test frequency. A ten-second time limit was set for detecting an emission response at each frequency.

2.4.2.3.3 **Test Procedure**

The subject was informed of the necessary instructions and information for the duration of the testing. The subject was told that an ear tip would be inserted into the ear canal. A "chirping" sound would then be heard for a few seconds, followed by a series of pulsing tones. The subject was made aware that he should not respond to the sounds in any way. He should not talk and move as little as possible. If the subject remains quiet and still for the duration of the test, it will be fastest and most accurate, and will last no more than a minute. The test was repeated twice, at both test sittings, to ensure repeatability of the emissions. The first sitting (resulting in Test 1a and Test 1b of each ear) took place before the subject had entered the noise zone. The second sitting (resulting in Test 2a and Test 2b) was eight hours later, as the subject came off his daily work shift. There was a time lapse of approximately ten minutes between leaving the noise zone and the DPOAE testing.

Once an appropriate eartip had been securely placed in the subject's ear, the test was performed. The corresponding test ear was selected by clicking on the appropriate icon in the Scout software. The "Patient Information" field opened. The subject's last name was entered and the test number noted in the comment field. Once it had been ensured that the correct test ear was selected, the OK command button was pressed. The test then began automatically. A check fit and calibration procedure took place automatically. If a problem was encountered, the eartip was removed and re-inserted. The test was restarted and the DPOAEs were measured. The ear canal pressure is averaged to reduce the noise floor and spectrally analysed for the primaries' levels and the distortion product (Sininger, 1993, p. 251). Fast Fourier transforms (FFT) analysis is then used to determine the DPOAE at the pre-selected frequency (Probst et al., 1991,

p. 2033). The high pass frequency (HPF) filter was set to automatic. This setting begins filtering the response at half the value of f_2, which means the HPF is different for each frequency tested. This results in a reduction of "artifacts by reducing frequency measurements below the area of interest" for the particular DP frequency (Scout OAE User's and Service Manual, p. 135).

Once the test had been completed the researcher saved the data by pressing the Y key. The test was repeated for the same ear, until two sets of repeatable DPOAE data were recorded. This was to ensure that the DPOAEs had been reliably recorded. DPOAEs were seen as repeatable if they fell within 3dB and 5dB of each other. (Hall & Mueller, 1997, p. 255). The toolbar icon for the other ear was then selected and the procedure repeated.

2.4.2.3.4 **Recording of DPOAE test data**

The DPOAE responses were recorded with DPOAE amplitude (in dB SPL) as a function of stimulus frequency. This is commonly known as a DPOAEgram (Hall, 2000, p. 116, 118). The f_2 values are represented on the horizontal axis and the amplitude of the DPOAEs for the different frequencies is plotted on the vertical axis. In order to perform this interpretation of DPOAE results, constant level primary tones, in this case L1 = 60 and L2 = 35dB, were measured as a function of regular increments in stimulus frequency. To produce DPOAEgrams, emissions are generally evoked with primaries with geometric mean frequencies between 500Hz and 8000Hz, at four to twelve points per octave, depending on the desired frequency resolution (Lonsbury-Martin et al., 1993, p. 12). This study measured eight points per octave. The DPOAE amplitudes are obtained by averaging sound in the frequency region of the $2f_1$-f_2 distortion product, for multiple stimulus presentations. The number of stimulus presentations is determined by the criteria detailed in the setup procedure.

The Scout program measures and averages the DPOAEs and displays the response. After the test, the DPOAEgram remained on the screen. Spectral information regarding the particular emission was displayed by selecting one of the data points on the DPOAEgram. This spectral information was displayed as a table of numeric values in the test box above the DPOAEgram. Values for f_1, f_2, the geometric mean of f_1 and f_2, L1, L2, the DP amplitude in dB SPL, the noise floor (NF) in dB SPL and the difference between the DP and NF (DP-NF) were found. An example of the DPOAEgram can be seen in Appendix C.

For this study, the prevalence and amplitudes of each DPOAE at each frequency, for each of the four tests were used as data. Using guidelines provided by Hall (2000, p. 140), the prevalence of an emission was judged by the following criteria:

- The emission amplitude must be greater than or equal to –10.0dB
- The DP amplitude less the noise floor (in dB) must be greater than 6.0dB (in other words, the DP amplitude must be 6.0dB greater than the noise floor)
- The DPOAEs must be repeatable and must therefore fall within 3dB and 5dB of each other.

2.5 Analysis of test data

The following section discusses the materials and procedures related to the analysis of the test data.

2.5.1 Description of apparatus and materials for the processing of test data

The test data was transferred from the Scout Ver. 3.04 software to a Microsoft Excel spreadsheet. In order for the test data to undergo statistical analysis, the

SAS application (1985) as well as the BMDP Statistical Software application (1993) was used.

2.5.2 Procedure for analysis of test data

Statistical analysis is a tool for making numerical data more meaningful. This is so that a researcher can see the nature of the data and better understand their inter-relationships (Leedy & Ormond, 2001, p. 235). In order for statistical techniques to be employed, the data must first be organized into a form that will allow manipulation of the data. The DPOAE responses were therefore transferred to an Excel spreadsheet, from the Scout display screen. For each of the four test results, it was indicated whether or not a valid DPOAE was recorded. Using the information recorded on the spreadsheet, statistical analysis was conducted. Prevalence was indicated numerically as a *1* for present and a *2* for absent. Right ears were similarly represented by a *1* and left ears by a *2*. The DPOAE amplitude of each emission was also entered into the spreadsheet. Amplitudes were recorded in dB SPL.

The data displayed in the Excel spreadsheet was then analysed by using two statistical software applications. These were the SAS application (1985) and the BMDP application (1993).

The Chi-square goodness-of-fit test was used to analyse the prevalence of DPOAE responses. According to Leedy and Ormond (2001, p. 278) the Chi-square test is used to determine how closely the observed probabilities match. A significant relationship between the sets of data exists if the probability is less than 0.05. In order to determine whether significant ($p < 0.05$) or highly significant ($p < 0.01$) differences exist between the DPOAE amplitudes recorded before and after the noise exposure, the Wilcoxon matched-pair signed rank test was used. This test determines whether two related samples differ from each other (Leedy & Ormond, 2001, p. 278). Delb et al. (1999, p. 70) made use of this statistical procedure in their study.

3. RESULTS AND DISCUSSION

The main aim of this study was to determine the efficiency of the Quiet earplugs worn by a group of industrial workers exposed to excessive noise in the workplace. DPOAE measures were used as they are known to be sensitive to the effects of noise on the cochlea (Vinck et al., 1999, p. 52). The DPOAEs obtained before and after noise exposure were therefore compared to determine whether the Quiet earplugs provided sufficient protection against cochlea damage. The raw data that were collected can be seen in Appendix D.

3.1 DPOAE prevalence

The results and clinical implications of the findings regarding DPOAE prevalence will be discussed in this section.

3.1.1 The prevalence of DPOAEs before exposure to excessive noise for eight hours

DPOAEs from 25 right ears and 25 left ears, which all presented with normal hearing, were recorded in this study. Normal hearing was seen as thresholds better than 25dB HL (Lloyd & Kaplan (1978) in Silman & Silverman, 1991, p. 51). A DPOAE was seen as present if the amplitude was greater than or equal to –10dB (Hall, 2000, p.140) and the difference between the DPOAE amplitude and the noise floor was 6dB or more (Probst & Hauser, 1990, p. 238). Test 1a and Test 1b are the DPOAE results obtained from 25 right ears and 25 left ears, before the subjects entered the noise zone. Two tests were performed in order to determine and ensure the reliability of the test procedure. The reliability of the test procedure can be examined by comparing DPOAE prevalence found in the tests performed before noise exposure. These results can be found in Figure 1. The number of responses seen as present or absent for each ear and at each of the five test frequencies, for both Test 1a and Test 1b, are given. The DPOAEs were elicited using a test protocol where f_2/f_1 = 1.18, L1 = 60dB SPL and L2 = 35dB SPL.

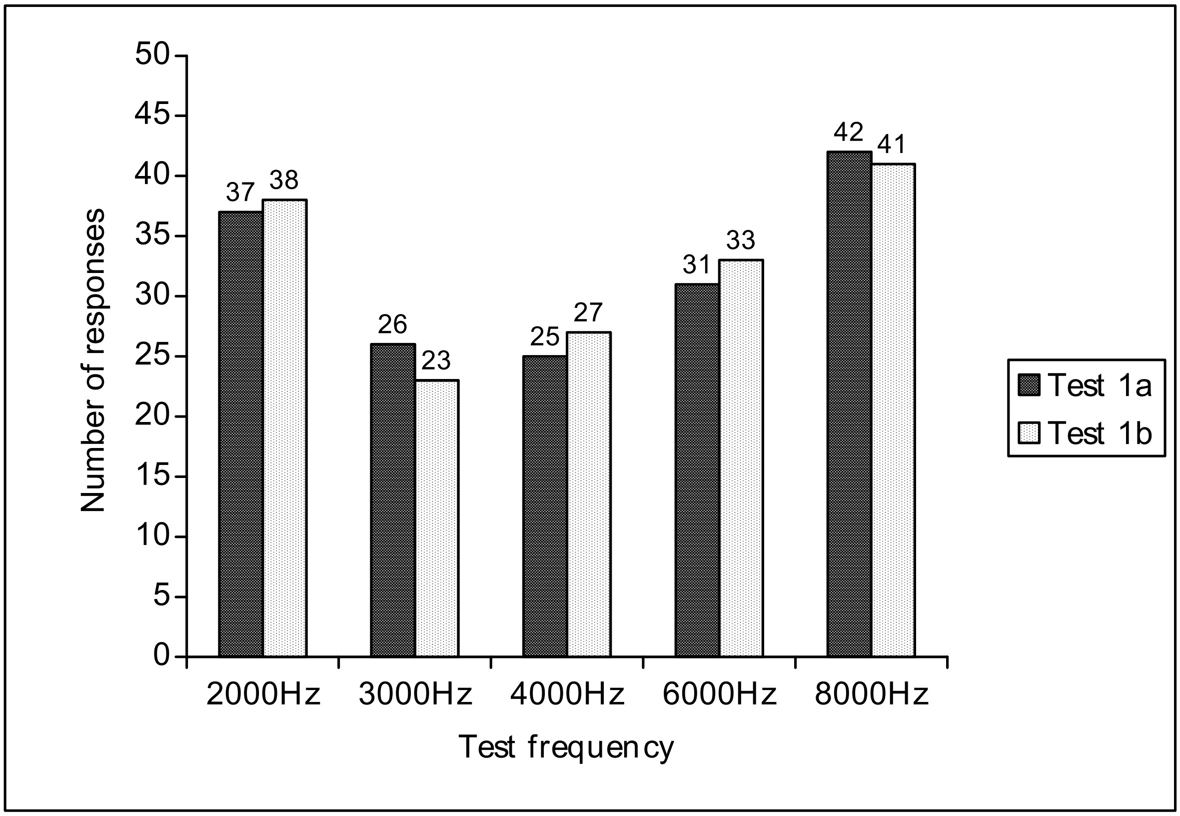

Figure 1. Repeatability of DPOAE prevalence in Test 1a and Test 1b.

The repeatability of DPOAEs between Test 1a and Test 1b was good. The greatest difference in prevalence between tests was found at 3000Hz, where three more DPOAEs were measured in Test 1a than Test 1b. Repeatability was greatest at the lowest and highest frequencies of 2000Hz and 8000Hz 8000Hz as prevalence in Test 1a and Test 1b differed by only one emission. A Chi-Square test (Durrheim, 1999, p. 119) was conducted during statistical analysis. This is in order to determine the probability of a relationship or the association between two sets of data. There has been little research published regarding the effects of ear differences, and there are no reported findings showing a distinct influence on the measurement of DPOAEs (Hall, 2000, p. 181). In support of this, Hooks-Horton et al. (2001, p. 56) found no ear effect, when specifically investigating

TTS. The current study found no clear indication of significant differences between DPOAEs measured in right and left ears. It was therefore decided that it would not influence the study findings if the results from the right and left ears were combined, when looking at relationships between Test 1a and Test 1b. This would then also allow for a greater sample size, which is generally preferred in research (Leedy & Ormond 2001, p. 221). The prevalence of emissions in Test 1a, for all 50 ears and at the test frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz, and 8000Hz, was compared to that of Test 1b. A Chi-Square test was done to determine if there is a relation between the two tests. A p-value of less than 0.05 indicates a significant relationship between the prevalence of DPOAEs in Test 1a and Test 1b. The relationship probability was found to be <0.0001 for all sets of DPOAE responses obtained at each of the five test frequencies. This means that there is a highly significant relationship between the DPOAE prevalence found in Test 1a and Test 1b. It can therefore be said that the DPOAEs recorded before noise exposure were consistent and repeatable. This confirms findings by a number of studies, such as that of Franklin, McCoy, Martin and Lonsbury-Martin (1992, p. 428), which showed the consistency of DPOAEs for daily and weekly test intervals. It also confirms the high reliability of the test procedure.

The highest number of DPOAE responses were measured at the test frequency of 8000Hz for both Test 1a and Test 1b. The fewest DPOAEs were measured at 4000Hz for Test 1a and at 3000Hz for Test 1b. DPOAE responses were recorded across all test frequencies in only six right ears (24%) and five (20%) left ears for Test 1a. Test 1b resulted in recorded DPOAEs at the five test frequencies in only four (16%) right ears and seven (28%) left ears. This is in spite of all the subjects presenting with normal hearing. Most researchers believe that distortion product otoacoustic emissions are present in essentially all normal ears (Roede et al., 1993, p. 280). Hall (2000, p. 15) states that in cases of hearing thresholds of 15dB HL or better and no cochlear pathology, DPOAEs can be recorded in more than 99% of the ears tested. Others, such as Furst and Lapid, (1988, p.

222) disagree and feel that DPOAEs vary greatly and are therefore not detectable in every healthy human cochlea. Although all subjects presented with hearing thresholds better than 25dB HL, this study found DPOAEs to be present in 88% of the ears tested, for at least one of the five test frequencies, and in only 26% for all tested frequencies.

Cochlear dysfunction, resulting in abnormal DPOAE results, may be present while the patient is still within the clinical audiometry limits of normal. This may be as a result of subclinical pathologic changes, which cause deficits in cochlear function, but are not yet detected by conventional audiometry (Lonsbury-Martin et al., 1990, p. 15). This idea is shared by Hall and Mueller (1997, p. 278), who feel that in some cases it is possible to find abnormal evoked otoacoustic emissions and normal audiometric thresholds. This study has therefore confirmed this by showing that robust DPOAEs are not present in all ears with normal hearing when using a test protocol of $f_2/f_1 = 1.18$, L1 = 60dB SPL and L2 = 35dB SPL. Because abnormal or absent DPOAEs in the presence of normal hearing may be evident of early cochlear pathology (Lucertini et al., 2002, p. 977), the low level of DPOAE prevalence found may be an indication that the subjects present with existing cochlear damage. This may be because their protection devices are not providing effective protection against the harmful effects of noise in the workplace, or that they are not wearing their earplugs properly.

3.1.2 The prevalence of DPOAEs after exposure to excessive noise for eight hours

Subaim 2.1.2.3 was to determine the prevalence of DPOAEs after the subject had been exposed to eight hours of impulse industrial noise. The level of noise subjects were exposed to varied from 84dB SPL to 96dB SPL. The subject's Quiet earplugs remained correctly in situ for the duration of his workshift. Twenty-five right and left ears were tested. The DPOAEs are elicited using a test protocol where $f_2/f_1 = 1.18$, L1 = 60dB SPL and L2 = 35dB SPL. Two sets of DPOAEs were elicited within ten minutes of the workshift being completed, and were labelled Test 2a and Test 2b. This was done in order to ensure the reliability of the test procedure and to compare DPOAE results obtained before and after noise exposure. The prevalence of DPOAEs after noise exposure can be seen in Figure 2.

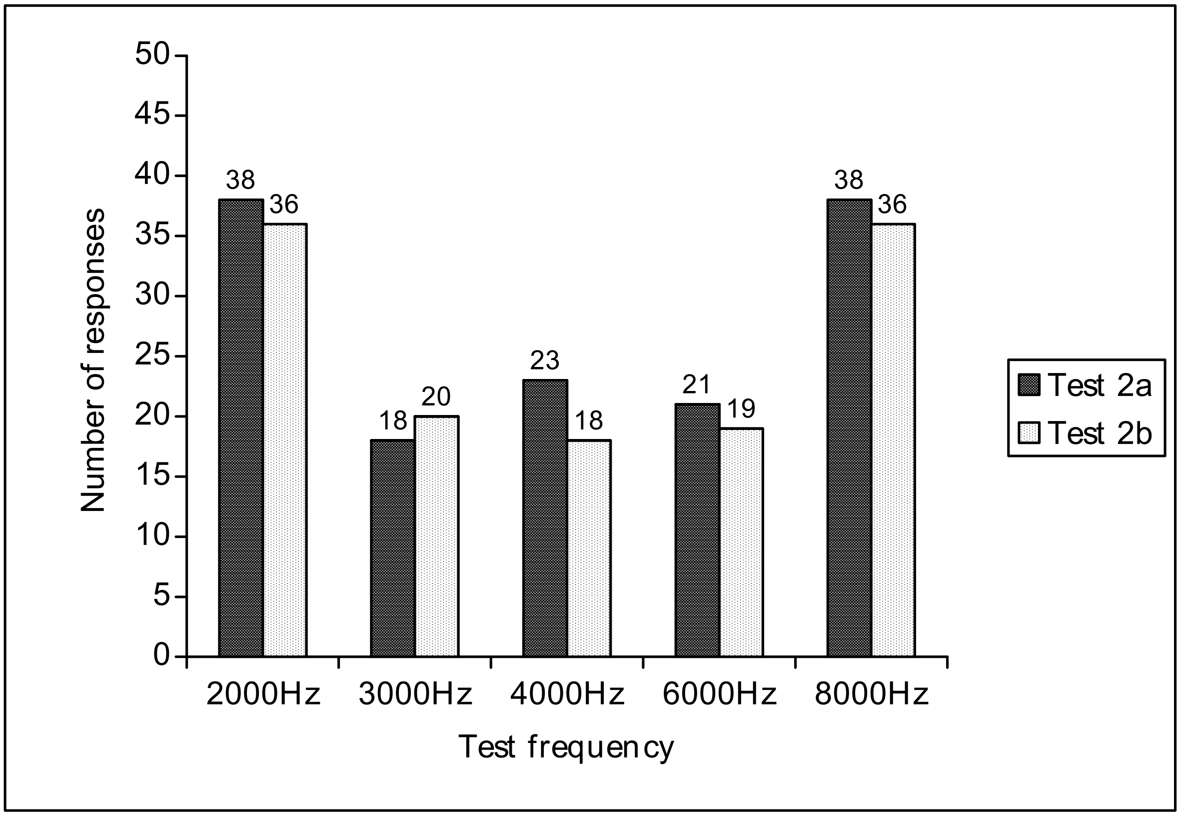

Figure 2. Repeatability of DPOAE prevalence in Test 2a and Test 2b.

As was found from results found prior to noise exposure, the repeatability of responses was good. Although DPOAE prevalence dropped slightly by 4% at most test frequencies, and by 10% at 4000Hz, in Test 2b, the difference between Test 2a and Test 2b was not found to be statistically significant. A Chi-Square test (Durrheim, 1999, p. 119) was conducted to obtain statistical data. The prevalence of emissions in Test 2a, for all 50 ears and at the test frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz, and 8000Hz, was compared to that of Test 2b. The relationship probability was found to be <0.0001 for all sets of DPOAE responses. Because the relationship probability must be less than 0.05 in order to be significant, the results show that there is a highly significant relationship between the prevalence of DPOAE in Test 2a and Test 2b. There is therefore a high level of test re-test reliability between Test 2a and Test 2b.

There were more DPOAEs recorded at 2000Hz and 8000Hz of Test 2a than at any of the other test frequencies. Thirty-eight (76%) emissions were found. Similarly, Test 2b also had the highest number of measureable DPOAEs at these frequencies. However, the prevalence was slightly lower, with 36 (72%) DPOAEs being recorded. The middle frequency range tested showed more variability in results when looking at the lowest prevalence of DPOAEs. Test 2a had the fewest DPOAE responses at 3000Hz, while this was found at 4000Hz for Test 2b. Test 2a had slightly higher prevalence values at 4000Hz and 6000Hz, than did Test 2b. Test 2b resulted in two more (4%) DPOAEs at 3000Hz than did Test 2a. Valid DPOAE responses for all frequencies were only recorded in six right ears (24%) for Test 2a and in three ears (12%) for Test 2b. DPOAEs were present across the test frequency range in only three (12%) of the left ears for Test 2a and only a single case (4%) for Test 2b. DPOAEs were therefore present in more right ears after noise exposure, than left ears. This differs from results obtained prior to exposure to noise where robust DPOAEs were elicited from seven (28%) left ears and only six (24%) right ears. It can be seen that the DPOAE prevalence decreased in left ears after noise exposure, but remained stable for the right ears tested. DPOAEs across all test frequencies were therefore found in only 9 (18%) of ears tested. Eighty percent, or 40 test ears, were found to have at least one DPOAE at any test frequency.

It has therefore been shown that DPOAE prevalence obtained after exposure to eight hours of noise while wearing the Quiet earplugs, i.e. DPOAEs recorded in Test 2a and Test 2b, are consistent and repeatable. This was also found to be true for DPOAE measures obtained in Test 1a and Test 1b, before noise exposure. This is in keeping with results from a study by Zhao and Stephens

(1999, p. 175) that found no significant differences in test-retest variability of DPOAEs. The test procedure can be seen as reliable and repeatable.

3.1.3 Relationship between DPOAE prevalence and smoking

There are nonpathologic factors that are known to influence susceptibility to hearing damage due to noise. Most of these are controlled by the selection criteria and the specific workplace. One of these variables, that of smoking (Henderson et al., 1993, p. 154), cannot be easily controlled. This is attributed to not being able to prevent the subjects from smoking for the duration of the study. While the influence of smoking of DPOAE prevalence is not a specific aim of this study, the relationship is investigated in order to ensure that the validity of the study is not be affected by the confounding variable of smoking (McBurney, 1994, p. 120). Henderson et al. (1993, p. 154) found that individual's who smoke are more susceptible to noise damage. This study compared the DPOAE prevalence at each test frequency for Test 1b (obtained before noise exposure) with that found in Test 2b (obtained after noise exposure). The results of the Chi-square test (Durrheim, 1999, p. 119) can be seen in Table 4. Test 1b is the second DPOAE test performed before exposure to noise and Test 2b is the second DPOAE test performed after noise exposure.

TABLE 4. RELATIONSHIP BETWEEN SMOKING AND DPOAE PREVALENCE.

	P-value	
Test frequency	**Test 1b**	**Test 2b**
2000Hz	**0.9259**	**0.6369**
3000Hz	**0.3126**	**0.2237**
4000Hz	**0.0994**	**0.3625**
6000Hz	**0.4503**	**0.7024**
8000Hz	**0.4691**	**0.7906**

During statistical analysis, there were some warnings that the cell size (indicating the amount of usable data) was too small. However, this is not significant as no relationships showing an influence of smoking on DPOAE prevalence were found. Because all of the p-values were greater than 0.05, there is no association between smoking and DPOAE prevalence. This is true for DPOAEs measured before as well as after the noise exposure. This study shows that smoking does not have a significant influence on DPOAE prevalence. This also shows that smoking would not have influenced the reliability of the test procedure.

3.1.4 Comparison of DPOAE prevalence before and after eight hours of noise exposure

Chi-Square analysis (Durrheim, 1999, p. 119) was done to compare DPOAE prevalence of DPOAE measured in all 50 test ears during Test 1b and Test 2b. Test 1b is the data obtained from the second test before subjects entered noise zone. Test 2b is the data obtained from the second test directly after the subjects had been removed from the excessive noise. The goal was to determine whether a significant difference exists between the data collected before and after the excessive noise exposure lasting eight hours. Test 1b and Test 2b were used for statistical analysis as it was shown that the results obtained at each test sitting were highly reliable and consistent. The results of the Chi-Square analysis show that for all test frequencies a significant relationship between prevalence in Test 1b and Test 2b was found. The probability was found to be $p < 0.0001$ for 2000Hz, 3000Hz, 4000Hz and 6000Hz. At 8000Hz, a probability value of 0.042 was found. This means that although a significant relationship between the prevalence of DPOAEs in Test 1b and that of Test 2b exists, a tendency to show a difference in prevalence may have been starting. In other words, there may have been a tendency towards a decrease in test – retest reliability. A larger sample population may have resulted in a greater probability value. The high repeatability of emissions is in strong agreement with findings by Roede et al. (1993, p. 280) that showed DPOAEs to be relatively stable over time.

The level of noise that the subjects in this study were exposed to varied from 84dB to 96dB. According to the guidelines stipulated by the South African National Standards (SANS: 1996), noise levels that equal or exceed 85dB SPL, for an eight hour rating level, are potentially harmful and should be reduced. This is usually achieved by implementing the use of hearing protection like earplugs. The results of this study show that the eight hours of noise exposure had no significant difference on the prevalence of DPOAEs. This is because a similar number of DPOAEs were elicited before and after the excessive noise exposure. Because no differences were found in DPOAE prevalence before and after noise exposure, may therefore be proposed that the Quiet earplugs were affording sufficient protection from the noise. However, the generalisation of these results is questionable as the prevalence of DPOAEs found before exposure to noise is not consistent with normative findings. Normal DPOAEs were not found in all the subjects, regardless of normal hearing thresholds. This together with the fact that the subjects had already been working in a noise zone for many years prior to the current study, proposes that existing outer hair cell damage resulting from excessive noise in the workplace is probably evident. This may be either due to ineffective hearing protection, or the incorrect use of such devices. Results may be been more conclusive if a 100% DPOAE prevalence was recorded prior to noise exposure. However, the high level of consistency of DPOAE prevalence recorded does show the reliability of the two test sittings and the test procedure as a whole.

3.2 DPOAE amplitudes

The results and clinical implications of the findings regarding DPOAE amplitude will be discussed in this section.

3.2.1 DPOAE amplitudes obtained before exposure to excessive noise for eight hours

The mean DPOAE amplitude values and the standard deviation (SD) for each test frequency for Test 1a and Test 1b can be found in Table 5. The frequencies of f_1 and f_2 were chosen so that the f_2 frequency relates to the audiometric test frequencies of 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz (Nieschalk, Hustert & Stoll, 1998, p. 87). DPOAEs were recorded at each of these five test frequencies. All values are given in dB SPL and have been rounded off to the nearest one hundredth. The p-value, indicating the relationship probability between DPOAE prevalence in Test 1a and Test 1b, is also given. The p-value is less than 0.05 therefore the relationship between the results of the two tests is significant.

TABLE 5. MEAN VALUES AND STANDARD DEVIATIONS OF DPOAE AMPLITUDES MEASURED BEFORE NOISE EXPOSURE.

	Test 1a				Test 1b				
Frequency	Mean (dB SPL)		Standard deviation (dB SPL)		Mean (dB SPL)		Standard deviation (dB SPL)		p-value
	Right	Left	Right	Left	Right	Left	Right	Left	
2000Hz	-5.49	-6.50	±6.82	±4.69	-6.05	-8.06	±6.48	±6.19	<0.0001
3000Hz	-9.37	-10.58	±6.83	±6.59	-10.90	-10.42	±7.70	±8.57	<0.0001
4000Hz	-10.37	-10.39	±6.67	±5.78	-10.37	-8.55	±7.86	±7.08	<0.0001
6000Hz	-9.23	-8.97	±7.25	±7.44	-7.70	-8.64	±8.88	±7.18	<0.0001
8000Hz	-2.27	-3.56	±6.19	±6.97	-4.02	-2.16	±7.76	±6.21	<0.0001

3.2.1.1 Results obtained from Test 1a

The results obtained from Test 1a will be discussed first. The mean DPOAE amplitudes recorded during Test 1a, for the right ear, ranged from a maximum of

–2.27dB SPL (SD = 6.19dB SPL) at 8000Hz to a minimum of –10.37dB SPL (SD = 6.67dB SPL) at 4000Hz. The highest mean DPOAE amplitude for Test 1a in the left ear was –3.56dB SPL (SD = 6.97dB SPL) at 8000Hz. The lowest mean amplitude of –10.58dB SPL (SD = 6.59dB SPL) was found at 3000Hz. The largest mean DPOAE amplitudes were therefore found at 8000Hz bilaterally, while the lowest were found at 4000Hz and 3000Hz for the right and left ear respectively. These are the test frequencies which indicate damage caused by exposure to excessive noise. The sample population had been previously working in noise for many years. The fact that DPOAE amplitudes are reduced, even though hearing levels are normal, implies that there may be early outer hair cell damage already.

The standard deviation found across the test frequencies varied from 6.19dB SPL to 7.25dB SPL in the right ear and from 4.69dB SPL to 7.44dB SPL in the left ear. The standard deviation is the standard variability in most statistical operations and is appropriate when investigating data that are normally distributed (Leedy & Ormond, 2001, p. 269). It is a measure of the variability from the mean calculated from the data, and is represented in the same units as the data (McBurney, 1994, p. 419). In the current study, all data collected are expressed as decibels sensation level (dB SPL).

3.2.1.2 Results of Test 1b

Test 1b revealed mean DPOAE amplitudes in the right ear ranging from –4.02dB SPL (SD = 7.76dB SPL) to –10.90dB SPL (SD = 7.70dB SPL), at 8000Hz and 3000Hz respectively. In the left ear the highest mean amplitude was found at 8000Hz, with a value of –2.16dB SPL (SD = 6.21dB SPL). The lowest was again found at 3000Hz, with a mean amplitude of –10.42dB SPL (SD = 8.57dB SPL). The standard deviations at each test frequency ranged from 6.48dB SPL to 8.88dB SPL in the right ear and 6.19dB SPL to 8.57dB SPL in the left ear. This means that the DPOAE amplitudes measured varied between approximately 6dB and 9dB from the calculated mean DPOAE amplitudes, at each test frequency.

3.2.1.3 Comparison of Test 1a and Test 1b

The difference between the mean DPOAE amplitudes obtained in Test 1a and Test 1b can be seen in Figure 3.

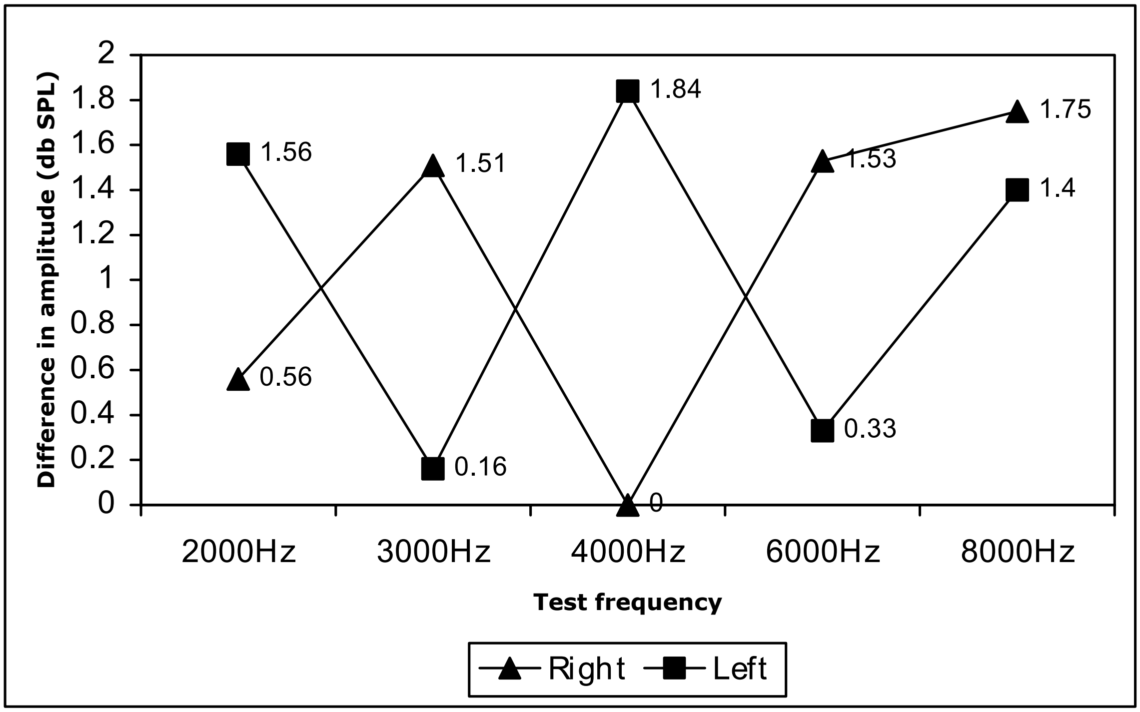

Figure 3. Difference between mean DPOAE amplitudes recorded in Test 1a and Test 1b.

The mean DPOAE amplitudes from Test 1a and Test 1b were similar, with both having the largest mean at 8000Hz and the smallest at 3000Hz. The DPOAE amplitudes were also highly repeatable between Test 1a and Test 1b, for both the right and left ears tested. This is shown by the largest difference between the mean DPOAE amplitudes of the two tests that was not greater than 1.84dB SPL, that was found at 4000Hz in the left ear. As discussed above, emissions can be seen as repeatable if they fall within 3dB to 5dB of each other. The standard deviation values were greater for Test 1b than for Test 1a. A maximum variability of 8.57dB SPL was found at 3000Hz in the left ear for Test 1b, while Test 1a had a maximum of 7.44dB SPL, also in the left ear, at 6000Hz.

3.2.1.4 Comparison with other study findings

The amplitudes of DPOAEs (n = 50) were determined before the subjects entered a noise zone. Two tests were conducted, allowing data to be collected for Test 1a and Test 1b. The test parameters used when eliciting the DPOAE are known to influence the emission response. The amplitude of the measured emission as well as the difference between the DPOAE amplitude and that of the noise floor determines the presence of a DPOAE. Harris and Glattke (1992, p. 74) state that the amplitude of the DPOAE is highly dependent on the relationship of the levels and frequencies of the primaries. The optimal ratio between the primary frequencies, which results in the greatest magnitude DPOAE has also been widely discussed. The value of approximately 1.22, determined by an extensive study by Harris, Lonsbury-Martin, Stagner, Coats & Martin (1989, p. 226), was found to generate the largest DPOAE amplitudes. Nielsen, Popelka, Rasmussen and Osterhammel (1993, p. 159) later determined that a single f_2/f_1 ratio between 1.2 and 1.25 used, for any test frequency, will result in emissions of clinical value. Hall Baer, Chase & Schwaber (1994, p. 31) however suggest that the optimal f_2/f_1 ratio may vary significantly from one subject to the next. The function of the stimulus intensity level and the frequency range that is being assessed may also influence the maximum DPOAE level. Stover, Gorga, Neely and Montoya (1996, p. 966) showed that DPOAEs of maximum amplitude are measured when using intensity levels of L1 = 65dB SPL and L2 = 55dB SPL. Higher primary levels may miss slight hearing loss and lower primary levels may predict hearing loss that is not actually present.

The decisions regarding the multiple stimulus variations, in terms of relationship ratio and intensity, are influenced by the objective of the DPOAE measurement

(Hall et al., 1994, p. 33). In this study, one of the aims was to determine any changes in DPOAE amplitude after excessive noise exposure. A test protocol where an f_2/f_1 ratio of 1.18 and primary intensity levels of L1 = 60dB SPL and L2 = 35dB SPL was therefore used in this study. These test parameters are as determined by the study by Delb et al. (1999, p. 73) to be most sensitive in detecting changes in DPOAE amplitude before and after exposure to noise. As discussed earlier, the study by Delb at al showed the more commonly implemented diagnostic test parameters of f_2/f_1 = 1.2, L1 = 65dB and L2 = 55dB (Hall & Mueller, 1997, p. 247) to be less sensitive to the acute effects of noise. The amplitudes and standard deviations found in this study therefore differ from the normative data (obtained from populations of normally hearing, non noise-exposed subjects) provided by Hornsby, Kelly and Hall (1996, p. 40) as well as Hall and Mueller (1997, p. 260). The comparison can be seen in Table 6. Due to the fact that four sets of data were recorded for each test frequency (e.g. right ear, Test 1a; right ear, Test 1b; etc.) the range of mean amplitudes and standard deviations are indicated. All values are given in dB SPL.

TABLE 6. COMPARISON OF STUDY DATA AND NORMATIVE DATA.

Mean amplitudes (dB SPL):	2000Hz	3000Hz	4000Hz	6000Hz
Current study before noise exposure	-5.49 to -8.06	-9.37 to -10.90	-8.55 to -10.39	-7.70 to -9.23
Current study after noise exposure	-6.08 to -8.62	-10.42 to -13.40	-10.00 to -13.06	-9.29 to -12.51
Normative data (Hall & Mueller, 1997)	6.85	6.1	6.1	1.22
Normative data (Hornsby et al., 1996)	7.39	7.46	7.35	2.37
Standard deviations:	2000Hz	3000Hz	4000Hz	6000Hz
Current study before noise exposure	±4.69 to ±6.82	±6.59 to ±8.57	±5.78 to ±7.86	±7.18 to ±8.88
Current study after noise exposure	±6.18 to ±6.85	±6.60 to ±7.88	±5.51 to ±7.02	±6.99 to ±7.46
Normative data (Hall & Mueller, 1997)	±6.4	±5.18	±5.68	±8.51
Normative data (Hornsby et al., 1996)	±6.94	±5.03	±6.0	±8.15

Hall and Mueller’s (1997, p. 260) normative data show mean DPOAE amplitudes of 6.85dB SPL at 2000Hz, 6.1dB SPL at 3000Hz and 4000Hz SPL, and an amplitude of 1.22dB SPL at 6000Hz. The DPOAEs recorded by Hornsby et al. (1996, p. 40) had mean amplitudes approximately 1dB SPL larger than those found by Hall and Mueller. This is true for all test frequencies. The DPOAEs elicited in the current study, before noise exposure, were considerably smaller than those in both normative studies. For example, mean amplitudes ranged from –5.49dB SPL at 2000Hz to –10.39dB SPL at 4000Hz. The largest mean DPOAE amplitude measured at 6000Hz was –7.70dB SPL, almost 9dB smaller than that given by Hall and Mueller (1997, p. 260) and more than 10dB smaller than the norm provided by Hornsby et al. (1996, p. 40). Both normative studies have standard deviations within 0.5dB SPL of each other. The standard deviations obtained for the study, before noise exposure, and the normative data are similar at most of the frequencies tested. The test protocol implemented in the current study was not chosen for diagnostic purposes and therefore differs significantly from that used in the normative studies. Those protocols were specifically chosen to elicit diagnostic DPOAEs (Hall & Mueller, 1997, p. 247). The diagnostic protocol implements an f_2/f_1 ratio of 1.2 and L1 – L2 = 10dB, where L1 = 65dB and L2 = 55dB. Hornsby et al. (1996, p. 40) varied this protocol slightly by using an f_2/f_1 ratio of 1.22. The test populations also differ significantly: the normative studies used subjects with normal hearing and no history of noise exposure, while subjects used in the current study have a history of prolonged noise exposure in the workplace. A final consideration when comparing normative data to that of the current study is that the DPOAEs were recorded in a quiet environment, as opposed to the diagnostic DPOAEs measured for the normative studies from within a soundproof booth.

When comparing DPOAEs amplitudes measured in the current study prior to noise exposure and those of Delb et al. (1999, p. 69), the differences in amplitudes are not as large. The same test protocols were used, so the influence of collection parameters will no longer have an effect on the elicited responses. The 1999 study found mean DPOAE amplitudes that ranged from approximately –2dB SPL to –8dB SPL across 2000Hz to 4000Hz. The mean amplitude at 6000Hz was slightly larger and found closer to 0dB. The current study had mean amplitudes smaller than those found by Delb et al. An example of this is the largest DPOAE mean amplitude at 6000Hz found in this study is –7.70dB, compared to the 0dB at 6000Hz in the earlier study.

The above discussion may support the likelihood that the test parameters could be a contributing factor to the reasons why valid DPOAE responses across all frequencies are only recorded in a maximum of thirteen (26%) of all the ears tested (six right ears and seven left ears). However, it is far more likely that the cause of DPOAEs not being reliably recorded in all the subjects, regardless of normal hearing thresholds, is that cochlear damage is already evident. Other than the possibility of undiagnosed cochlea damage, there are a number of other nonpathologic and pathologic factors that can influence the measurement of DPOAEs (Hall, 2000, p. 100). The sample selection criteria eliminated a number of these factors, such as cerumen, stenosis or otitis externa. However, considerations such as probe tip insertion may have been harder to control. In 1994 (p. 146) Siegel and Hirohata found that standing waves present in the ear canal could result in errors of -/+20dB or more in the estimate of the DPOAE level. The various standing waves resulted from different positions of the probe in the ear canal. While every effort was made to ensure correct probe tip insertion, the findings of this study show that variations in the method of measurement may contribute to the variability of DPOAE amplitudes.

3.2.2 DPOAE amplitudes obtained after exposure to excessive noise for eight hours

Table 7 shows the mean amplitude values and the standard deviation for each test frequency from Test 2a and Test 2b. Test 2a and Test 2b were obtained from recording DPOAEs in subjects after they had been exposed to noise. All values given are expressed in dB SPL and have been rounded off to the nearest one hundredth. The p-value indicating the relationship probability between DPOAE prevalence in Test 2a and Test 2b is also shown. The p-values at all test frequencies are <0.0001 so the relationship between results found in Test 2a and Test 2b are therefore significant.

TABLE 7. MEAN VALUES AND STANDARD DEVIATIONS OF DPOAE AMPLITUDES MEASURED AFTER EIGHT HOURS OF NOISE EXPOSURE.

	Test 2a				Test 2b				
Frequency	Mean (dB SPL)		Standard Deviation (dB SPL)		Mean (dB SPL)		Standard Deviation (dB SPL)		p-value
	Right	Left	Right	Left	Right	Left	Right	Left	
2000Hz	-6.08	-8.20	±6.85	±6.18	-6.59	-8.62	±6.76	±6.19	<0.0001
3000Hz	-11.42	-13.17	±7.88	±6.60	-10.42	-13.40	±7.82	±6.74	<0.0001
4000Hz	-13.06	-10.00	±6.73	±5.51	-12.21	-11.16	±7.02	±5.67	<0.0001
6000Hz	-10.28	-12.04	±7.46	±7.39	-9.29	-12.51	±6.99	±7.33	<0.0001
8000Hz	-3.10	-3.54	±6.93	±5.38	-3.05	-5.04	±7.28	±6.58	<0.0001

3.2.2.1 Results obtained from Test 2a

The results found in Test 2a will be discussed first. The mean DPOAE amplitudes for the right ear ranged from a maximum of –3.10dB SPL (SD = 6.93db SPL) at 8000Hz to a minimum value of –13.06dB SPL (SD = 6.73db SPL) at 4000Hz. The left ear also had the largest mean DPOAE amplitude of –3.54dB SPL (SD = 5.38dB SPL) at 8000Hz. The smallest mean DPOAE amplitude in the left ear was found at 3000Hz, and was –13.17dB SPL (SD = 6.60db SPL). The standard deviation values found in the right ear were larger than those for the left ear. Those for the right ear ranged from 6.73dB SPL at 4000Hz to 7.88dB SPL at 3000Hz. The left ear had the smallest standard deviation of 5.51dB SPL at 4000Hz and this ranged to 7.39dB SPL at 6000Hz

3.2.2.2 Results obtained from Test 2b

Test 2b showed similar results, with the highest mean DPOAE amplitudes for both ears found at 8000Hz. The maximum mean amplitude of –3.05dB SPL found in the right ear was 2.01dB SPL bigger than that of –5.04dB SPL found in the left ear. The minimum mean DPOAE amplitude in the right ear was found at 4000Hz, and at 3000Hz in the left ear. The lowest mean amplitudes were –12.21dB SPL (SD = 7.02dB SPL) and –13.40dB SPL (SD = 6.74dB SPL) found in the right and left ears respectively. For the second test the range of standard deviation varied from 6.76dB SPL to 7.82dB SPL in the right ear and from 5.67dB SPL to 7.33dB SPL in the left ear.

3.2.2.3 Comparison of Test 2a and Test 2b

The difference between the mean DPOAE amplitudes obtained in Test 2a and Test 2b can be seen in Figure 4.

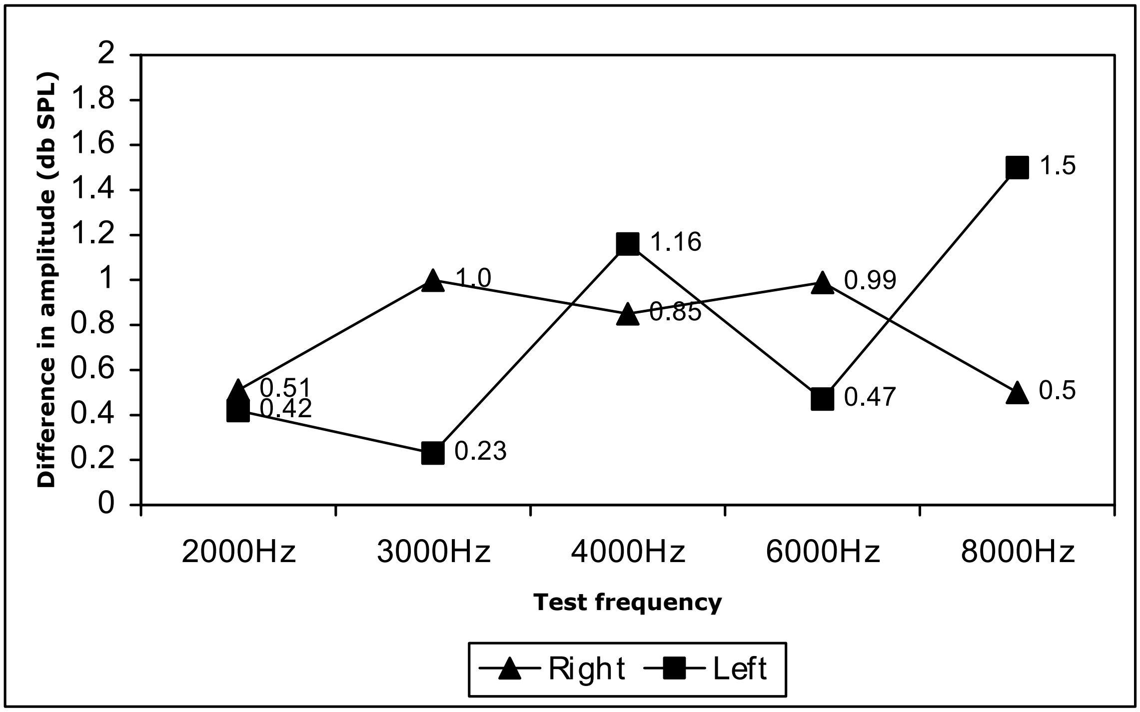

Figure 4. Difference between mean DPOAE amplitudes recorded in Test 1a and Test 1b.

The DPOAE amplitudes were highly repeatable between Test 2a and Test 2b, for both the right and left ears tested. This is shown by the largest difference between the mean DPOAE amplitudes of the two tests that was not greater than 1,5dB SPL, found at 8000Hz in the left ear. Emissions are seen as repeatable if they fall within 3dB to 5dB of each other. The standard deviations also did not vary greatly between Test 2a and Test 2b. A maximum variability of 7.88dB SPL was found at 3000Hz in the right ear for Test 2a, while Test 2b had a maximum of 7.82dB SPL, also in the right ear, at the same test frequency of 3000Hz.

3.2.2.4 Comparison with other study findings

Comparison with the normative data obtained from Hall and Mueller (1997, p. 270) and Hornsby et al. (1996, p. 40), as seen in Table 6, shows differences in the values for mean DPOAE amplitudes recorded. The mean DPOAE amplitudes measured after exposure to excessive noise are less than those shown by the normative studies. In particular, the mean amplitudes found at 3000Hz differed by up to 19.50dB SPL from the norms of 6.1dB SPL given by Hall and Mueller (1997, p. 240) and by up to 20.86dB SPL from the norm of 7.46dB SPL given by Hornsby et al. (1996, p. 40). Similarly, at 4000Hz the mean DPOAE amplitudes differed by up to 19.16dB SPL (from 6.1 dB SPL) and 20.41dB SPL (from 7.35dB SPL) for the values provided by Hall and Mueller, and Hornsby et al. respectively. The mean DPOAE amplitudes recorded during the current study, after eight hours of noise exposure can therefore be seen to be significantly smaller than those determined by normative studies. Although DPOAE amplitudes may be affected by the particular test parameters used to elicit the emissions, as previously discussed, a difference of up to 20dB SPL between the study data and normative data and cannot be blamed on test protocol, or variations of probe fit alone. This again proposes that existing cochlear pathology may be the cause of the significant differences between normative data and the study results.

3.2.3 Comparison of the nature of DPOAEs recorded before and after eight hours of noise exposure

The comparison of DPOAE amplitudes aimed to determine the efficacy of the Quiet earplugs worn by a specific group of industrial workers. The efficacy of the earplugs was determined by comparing DPOAEs measured before and after exposure to excessive noise. Studies have shown that the effect of the time-of-day on DPOAEs is less than 1dB and does not seem to significantly influence test results (Cacace, McClelland, Weiner & McFarland, 1996, p. 1147). Notable difference in DPOAE amplitudes can therefore not be attributed to circadian-linked cochlea activity. Thus, if a significant difference between DPOAE amplitudes from before and after the noise exposure is found, it may indicate a lack of effective protection against the noise. The mean DPOAE amplitude at each test frequency of 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz was determined from measurements from all 50 test ears, for each of the tests conducted. Gross analysis of the DPOAEs obtained before and after noise exposure shows similar results in terms of at which frequency the maximum and minimum amplitudes were found. In all tests and both ears, the maximum DPOAE amplitudes were found at 8000Hz. Most of the smallest amplitudes were found at 4000Hz in the right ear, except for 3000Hz for Test 1b. The left ear was found to have all minimum amplitudes at 3000Hz.

For statistical analysis, the mean amplitudes and the standard deviations obtained from each test were combined to form three sets of data. This is shown in Table 8. The p-value, obtained by using the Wilcoxon matched-pair-signed rank (Delb et al., 1999, p. 70), that describes the relationship between the compared data is also shown. The Wilcoxon matched-pair-signed rank test is used in order to compare two means that have been paired together (Leedy & Ormond, 2001, p. 278). If the p-value is less than 0.05, the indication is that a statistically significant difference exists between the two sets of data. If the p-value is positive it means that the value from the first set of data (which are the results from testing before noise exposure) is greater than the second set of data (the results from testing after the noise exposure). P-values that indicate a statistically significant difference between results obtained before and after noise exposure have been printed in bold and underlined. All values, except for the p-value, are given in dB SPL.

TABLE 8. MEAN AMPLITUDES, STANDARD DEVIATIONS AND P-VALUES OBTAINED BY COMPARING TEST DATA.

	A (Test 1a, b and Test 2a, b)			**B** (Test 1a & 2a)			**C** (Test 1b & 2b)		
	Mean	Standard deviation	p-value	Mean	Standard deviation	p-value	Mean	Standard deviation	p-value
2000Hz	0.85	±3.17	<u>**0.0349**</u>	1.44	±3.61	<u>**0.0349**</u>	0.55	±3.90	0.2796
3000Hz	1.78	±6.27	0.1677	2.32	±5.94	<u>**0.0077**</u>	1.24	±7.98	0.8200
4000Hz	1.69	±4.15	<u>**0.0019**</u>	1.15	±4.42	<u>**0.0333**</u>	2.23	±5.74	<u>**0.0035**</u>
6000Hz	2.38	±6.03	<u>**0.0073**</u>	2.03	±6.53	<u>**0.0462**</u>	2.73	±7.27	<u>**0.0125**</u>
8000Hz	0.68	±5.74	0.5243	0.40	±5.59	0.6500	0.95	±7.68	0.6055

The three sets of results have been renamed, according to the different data calculations, in order to make comparisons between them slightly simpler. The comparison between the mean amplitudes obtained from the combined results of Test 1a and 1b and Test 2a and 2b (in other words, amplitudes at each test frequency from all four tests) is indicated by *A*. The mean DPOAE amplitudes, standard deviations and p-values obtained by comparing Test 1a with Test 2a is represented by a *B*. Finally, those findings from comparing DPOAEs from Test 1b and Test 2b are discussed using a *C*. This data analysis therefore compared DPOAE amplitudes obtained from both tests of Test 1 and Test 2, in three different combinations. This was done to determine if there were any differences between results in Test 1 (before noise exposure) and Test 2 (after noise exposure).

While the other results have been looked at in terms of which test they fall in, e.g. Test 1a, Test 2a etc., these results will be more effectively discussed by looking at results over specific test frequencies. It is generally accepted that excessive noise affects high frequencies from approximately 3000Hz to 6000Hz. (Seidman, 1999, p. 32). Therefore, because this study used DPOAEs to investigate any possible effects of noise on the ear, the frequencies tested will provide more information than the particular test conducted.

Looking at the test frequency of 2000Hz, it can be seen that a significant difference in amplitudes is found between measurements in *A* and *B*. The fact that the p-values are positive means that there has been a significant decrease in DPOAE amplitudes after exposure to excessive noise for eight hours. At 3000Hz, only one significant difference DPOAE amplitudes is found, when comparing Test 1a and Test 2a. However, when looking at the test frequencies of 4000Hz and 6000Hz, a clear indication of a difference in DPOAE amplitude can be found. This is true for combinations *A*, *B* and *C* of the test data obtained prior and after noise exposure. These are the test frequencies known to be affected most by noise. These results show that the DPOAE amplitudes measured after the eight hour work-shift, during which the subject was instructed to have made correct use of his Quiet earplugs, are significantly smaller than those measured before the shift. Therefore, it can be concluded that the noise in the workplace has had a negative influence on the cochlea, which may be resulting in a TTS at these frequencies. The DPOAE recording was thus able to show the TTS associated with limited noise exposure. This supports findings by Engdahl and Kemp (1993, p. 1586) who found a reduction in DPOAE amplitudes, as a result of noise exposure. The results from the current study also support those found by Hooks-Horton et al. (2001, p. 56) that noise exposure has a significant effect on DPOAE amplitudes. They found that DPOAE levels decreased by six to seven decibels after ten minutes of 2000Hz narrow-band noise. The fact that no significant differences in DPOAE amplitude are found at 8000Hz in this study is in keeping with the physiological effect that noise has on the human cochlea. Noise does not initially influence hearing at this frequency, although it is later affected in the advanced stages of noise-induced hearing loss (Touma, 1992, p. 200).

According to the real ear attenuation values of the Quiet earplugs (see Table 2), the earplugs should provide attenuation of 31.8dB at 2000Hz, 41.0dB at 4000Hz and 37.5dB at 8000Hz. These values are in keeping with SANS 1451 (1988). The results of the current study show that the cochlea has been influenced by excessive noise. This is indicated by significantly increased DPOAE amplitudes at those frequencies know to be most affected by noise (4000Hz and 6000Hz). If the Quiet earplugs are providing the protection as indicated by the attenuation values, and the subjects are using the earplugs correctly, the DPOAE amplitudes measured before and after noise exposure should not be significantly different. In addition, due to the fact that there was a low level of DPOAE prevalence before the subjects were exposed to noise, there is a strong possibility that they already present with the very early stages of noise-induced hearing loss – a further indication that the earplugs are not providing sufficient protection against noise.

3.3 Limitations of the study

A major limitation of the study is the particular test protocol that was used. The test parameters were selected specifically to detect changes in DPOAE amplitudes following noise exposure (Delb et al., 1999, p. 73) and are therefore not ideal for investigating the nature of DPOAEs, including prevalence. In addition, the sample population demonstrated DPOAE prevalence of only 26% before noise exposure, despite normal hearing thresholds. There has also been no investigation of the findings from using this test protocol in a group of non-noise exposed subjects. The results from the current study can therefore not be verified by comparison to other similar studies.

Another limitation of the study is the lack of a purely experimental research design. The fact that the subjects were not monitored for the full eight hours of noise exposure means that the possibility of incorrect usage of the Quiet earplugs cannot be ruled out. Although care was taken to ensure that the subjects were correctly instructed, human error will always be a confounding variable when implementing a research design that is not purely experimental in nature. Davis and Sieber (1998, p. 721) warn that care must be taken when interpreting data regarding hearing protector usage. This is because “hearing protection incorrectly worn or worn only part-time reduces the effectiveness of the hearing protection”. Bearing this in mind, the results of this study are in agreement with Sallustio, Portalatini, Soleo, Cassano, Pesola, Lasorsa, Quaranta & Salonna (1998, p. 108) in finding that DPOAEs can be useful in monitoring the effects of noise. These authors suggest that this procedure should however be used in conjunction with the pure tone audiogram. It must be noted that the current study shows DPOAE amplitudes to be useful in investigating the harmful effects of noise, and not DPOAE prevalence.

A third limitation is that there is a large variability found in individual susceptibility to cochlea damage resulting from noise exposure (Sallustio et al., 1998, p. 95). Some of the variables known to affect susceptibility to noise-induced hearing loss, such as age and exposure to certain solvents have been controlled for, by completion of the questionnaire (Appendix A). However, factors such as differences in acoustic reflex functioning and the role of the efferent system (Henderson et al., 1993, p. 165) have not been taken into account.

A final limitation is one of sample size. A small sample, resulting in less test data, may affect the degree of precision with which conclusions are drawn about the population being studied (Leedy & Ormond, 2001, p. 221).

To conclude the discussion of the results found in this study, it cannot be said that the Quiet earplugs, as they are currently being used by the subjects, offer complete protection from the noise the subjects are exposed to in the workplace. This is indicated by the significant decrease in DPOAE amplitudes after exposure to excessive noise for eight hours, as well as the below normal DPOAE prevalence before noise exposure.

4. CONCLUSIONS AND RECOMMEDATIONS

The main aim of this study was to determine the effectiveness of the Quiet earplugs worn by a group of South African industrial workers. This was done by investigating the DPOAEs measured before and after eight hours of excessive noise exposure in the workplace.

The study found the prevalence of DPOAEs to be statistically stable and repeatable. This was true for DPOAEs measured during the same test sitting (i.e. Test 1a and Test 1b or Test 2a and Test 2b), as well as comparing DPOAE prevalence determined before and after the noise exposure. This can be seen when looking at the prevalence of normal DPOAEs measured before and after the workshift. Thirteen (26%) subjects had normal DPOAEs across all tested frequencies before they started working in noise. This figure dropped to nine (18%) when testing was conducted after the workshift. However, Chi-square analysis (Durrheim, 1999, p. 119) found the prevalence relationships between the various tests to be highly significant, with all p-values at <0.0001. In addition, smoking was not found to have a significant influence on the test re-test reliability of DPOAE prevalence. The high level of consistency when measuring DPOAE prevalence showed the reliability of the test procedure. However, if consistent prevalence of emissions may be used as an indicator of the efficiency of the Quiet earplugs used by the subjects, it would have to be deduced that the earplugs were affording effective protection against the noise.

The current study has shown that there was however a significant difference between DPOAE amplitudes measured before and after the noise exposure, specifically in the frequencies that are known to be affected by noise (4000Hz and 6000Hz). It is thought that DPOAEs are more sensitive to subtle changes of hearing sensitivity in cases of cochlear insults known to primarily influence the outer hair cells, such as excessive noise exposure (Vinck et al., 1999, p. 52). In this study, this has shown to be the case:

DPOAE amplitudes were significantly smaller when measured after the work-shift. DPOAEs have the potential to detect TTS associated with noise damage to the cochlea (Vinck et al., 1999, p. 44). The reduction in DPOAE amplitudes implies that the Quiet earplugs are not providing sufficient protection against the harmful effects of noise. It must however be kept in mind that factors, such as the inconsistent use of the earplugs themselves, may have contributed to the decreased DPOAE amplitudes. The findings of the current study support those by authors such as Kossowski et al. (2001, p. 120) by showing that DPOAEs are sensitive to “minor cochlea impairment due to mild auditory fatigue”. In other words, DPOAEs can be used to identify the effects of noise exposure on the inner ear.

For this study, data collection was dependent on the co-operation of both the management of the particular industrial plant and the individual subjects. For every subject participating in the study, one less employee was at work on the production line, which may ultimately result in decreased productivity. The managers were therefore reluctant to release more than one or two employees at a time, from their working positions. This may always be a factor when investigating subjects in a workplace, and may consequently have a negative effect on the collection of sufficient data. The researcher is of the opinion that a larger sample size may be more representative of the efficiency of the earplugs worn in the workplace. If the study were to take place over an extended period of time a larger test sample could be gathered. Different industries could also be approached. Data from the various earplugs and earphones used could be collected and their effectiveness compared. While most industries maintain a high level of occupational health policies, it may require further education and motivation to make employee safety more important than company profitability.

In addition, the researcher recommends that a sample of volunteers be correctly fitted with the earplugs before entering a simulation of the noise environment in the workplace. The usage of the earplugs can then be monitored for the full period of noise exposure. This would result in data with a high level of internal validity, regarding attenuation and protection from noise. The fact that the subjects used in the current study have all been working in a noise zone for many years will have had a negative effect on the reliability of the results, as they may already have cochlea damage. A study using subjects with no history of noise exposure would be valuable in providing data that has not been compromised by possible existing cochlea pathology.

A final recommendation is to interview the subjects more thoroughly regarding opinions and attitudes towards the hearing protection they are provided with. This information may provide insight into reasons why employees are neglecting to wear their hearing protection appropriately. Improvement in personal opinion, environmental factors and proper education about noise-induced hearing loss may result in increases in correct hearing protection usage. This would ultimately lead to a decrease in the high prevalence of permanent, chronic, irreversible noise-induced hearing loss in industrial workers.

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RECORD SHEET

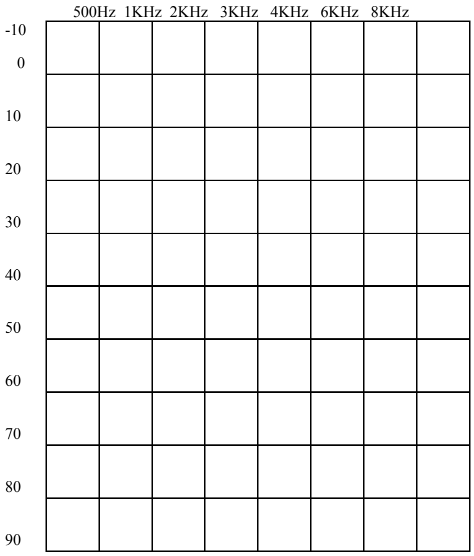
NAME: SUBJ. #:

OTOSCOPIC EXAMINATION				
	RIGHT		LEFT	
Tympanic membrane clearly visible				
Light reflex visible				
Tympanic membrane occluded by wax				
Other abnormality				
	pass	fail	pass	fail

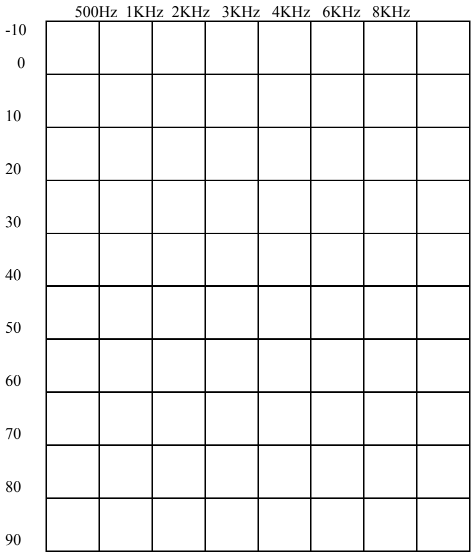
TYMPANOMETRY										
	RIGHT					LEFT				
Type	A	As	Ad	B	C	A	As	Ad	B	C
Ear canal volume (in ml^3)										
Compliance (in ml^3)										
Pressure (in daPa)										
Acoustic reflex threshold (in dB)										
	pass		fail			pass		fail		

PURE TONE AUDIOMETRY

Right Ear



Left Ear



I, ________________________, understand the process and the purpose of this study, and hereby agree to participate.

Signed: Date:

QUESTIONNAIRE

PERSONAL INFORMATION: Subject No: ☐

Name: ______________________ Birthdate: ______________________

Age: ______________________ Date: ______________________

INFORMATION ABOUT YOUR HEARING:

Is there a history of hearing loss in your family? ______________________

If yes, what was the cause of the hearing loss? ______________________

NOISE EXPOSURE:

Do you work in noise? ______________________

If yes, when was your last shift? ______________________

How long have you worked in noise? ______________________

Describe the type of noise you are exposed to (for example gunshots, machinery, loud music)? ______________________

How many hours per day is your work shift? ______________________

How many shifts per week do you work? ______________________

Do you wear hearing protectors? ______________________

If no, why not? ______________________

If yes, which kind? ______________________

Have you been shown how to use the hearing protectors correctly? ____________

MEDICAL HISTORY:

Are you currently taking any medication? If so please provide the details regarding the type of medication, the dosage and the length of time you have been using it.

Have you taken any aspirin in the past 24 hours? ________________

Do you smoke? ____________________ How many a day? ________________

Are you exposed to any chemicals during your work shift? ________________

If yes, name them? ____

POST-SHIFT:

Did you wear your hearing protectors all the time? ______________________________

If not, why not? ____

Are you experiencing tinnitus (buzzing / ringing) in the ears? ________________

How many cigarettes did you smoke today? ______________________________

Did you take any medication? ____

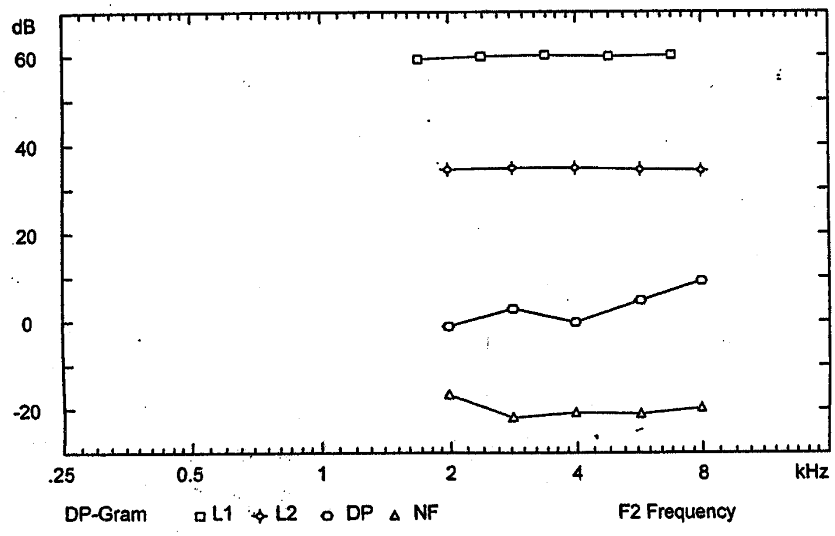
Any other relevant information? ____

APPENDIX C

BIO-LOGIC OTOACOUSTIC EMISSIONS (OAE) REPORT - Page 1 of 1

Patient: Example 1,
Birthdate:
Comment: Test 1

Ear: Right
ID:



Example - Right 17-Jul-02 - 1.18 ratio

L1(dB)	L2(dB)	F1(Hz)	F2(Hz)	GM(Hz)	DP(dB)	NF(dB)	DP-NF(dB)
60.1	34.1	6771	7989	7355	9.0	-19.9	28.9
59.8	34.5	4803	5670	5218	4.8	-21.3	26.1
60.0	34.7	3374	3983	3666	-0.3	-20.9	20.6
59.9	34.9	2390	2811	2592	2.6	-22.0	24.6
59.4	34.5	1687	1991	1833	-1.2	-16.9	15.7

APPENDIX D

Raw Test Data

Subject	Ear	Test	2000Hz		3000Hz		4000Hz		6000Hz		8000Hz	
			Prevalence	DPOAE amplitude	Prevalence	DPOAE amplitude	Prevalence	DPOAE amplitude	Prevalence	DPOAE amplitude	Prevalence	DPOAE amplitude
1	1	1a	1	3.4	1	0.5	1	-0.1	1	5.7	1	11.9
1	1	1b	1	1.4	1	0.4	1	1.2	1	5.1	1	12.0
1	1	2a	1	0.8	2	-20.3	1	-6.8	1	0.1	1	7.9
1	1	2b	1	-0.1	2	-22.0	1	-4.0	1	3.1	1	8.9
1	2	1a	2	-12.0	1	-1.0	1	2.7	1	0.5	1	-1.2
1	2	1b	2	-21.6	1	-4.2	1	3.0	1	-2.5	1	-4.8
1	2	2a	1	-10.0	1	-2.5	1	1.0	2	-15.1	1	2.2
1	2	2b	2	-11.0	1	-2.9	1	1.5	2	-13.2	1	4.1
2	1	1a	1	-4.1	1	-3.3	1	-6.4	2	-19.1	1	1.7
2	1	1b	1	-3.8	1	-6.1	1	-5.3	2	-14.4	1	-0.5
2	1	2a	1	-4.9	1	0.1	1	-8.4	2	-13.2	1	0.6
2	1	2b	1	-8.2	1	-1.1	1	-7.9	2	-11.2	1	1.2
2	2	1a	2	-8.5	2	-10.6	2	-10.7	1	-4.3	1	4.3
2	2	1b	2	-11.6	2	11.1	1	-8.1	1	-6.3	1	0.9
2	2	2a	1	-1.2	2	-11.4	1	-4.2	1	-7.1	1	0.5
2	2	2b	1	-8.0	2	-17.3	2	-12.3	1	-8.3	1	-3.2
3	1	1a	1	-4.3	1	-8.9	1	0.6	1	-2.8	1	-2.7
3	1	1b	1	-4.3	2	-11.4	1	1.7	1	-7.1	2	-11.8
3	1	2a	1	-5.4	2	-16.6	1	-3.4	2	-22.0	1	-3.5
3	1	2b	1	-5.0	2	-13.4	1	-2.6	2	-19.2	1	-3.3
3	2	1a	1	-9.5	2	-12.1	1	-7.3	1	-7.1	1	-12.9
3	2	1b	2	-13.3	2	-19.2	1	-8.1	1	-8.9	1	-1.3
3	2	2a	2	-22.0	2	-12.3	2	-11.1	2	-11.2	2	-9.2
3	2	2b	2	-21.6	2	-13.2	2	-10.9	2	-11.1	1	-9.6
4	1	1a	1	2.8	2	-11.1	1	-6.2	1	-9.7	1	2.8
4	1	1b	1	-3.1	2	-12.9	1	-6.4	1	-9.2	1	-3.0
4	1	2a	1	0.2	1	-9.8	1	-7.5	1	-3.6	1	-1.8
4	1	2b	1	0.7	1	-9.8	1	-9.0	1	-3.0	1	-4.3
4	2	1a	1	-2.6	1	-8.6	2	-15.0	2	-11.4	1	3.6
4	2	1b	1	-1.8	1	-9.5	1	-9.8	1	-9.2	1	6.9
4	2	2a	1	-1.3	2	-1.7	2	-13.9	2	-12.8	2	-5.8
4	2	2b	1	-1.3	1	-7.0	2	-14.8	2	-14.7	2	-5.9
5	1	1a	2	-16.5	2	-18.3	2	-15.0	2	-11.8	1	-1.6
5	1	1b	1	-8.9	2	-21.2	2	-18.0	1	-6.6	1	2.7
5	1	2a	2	-16.0	2	-19.2	2	-15.9	1	-1.3	2	-9.5
5	1	2b	2	-14.8	2	-16.9	2	-15.7	1	-0.9	2	-8.6
5	2	1a	2	-11.1	2	-12.6	1	-7.4	1	-6.4	1	2.4
5	2	1b	2	-15.5	2	-10.9	1	-5.6	1	-4.7	1	5.8
5	2	2a	2	-18.2	2	-22.0	1	-5.7	1	-5.6	1	-8.8

APPENDIX D

5	2	2b	2	-17.6	2	-19.9	1	-6.2	1	-6.4	1	-8.4
6	1	1a	1	-2.1	2	-15.9	2	-12.1	1	-9.3	1	-1.1
6	1	1b	1	-3.8	2	-17.3	2	-13.8	2	15.6	2	-14.8
6	1	2a	1	-6.8	1	-4.0	1	-8.6	1	-9.9	1	0.9
6	1	2b	1	-2.6	1	-5.7	1	-3.3	2	-15.3	1	0.3
6	2	1a	1	-6.8	1	-4.0	1	-8.6	1	-9.9	1	0.9
6	2	1b	1	-2.6	1	-5.7	1	-3.3	1	-15.3	1	0.3
6	2	2a	1	-3.4	1	-8.0	1	-2.5	1	-8.6	1	6.3
6	2	2b	1	-3.8	2	-16.8	2	-18.9	1	-9.0	2	-22.0
7	2	1a	1	0.6	1	-5.8	2	-12.0	1	-8.5	1	-1.0
7	2	1b	1	-0.9	1	-3.7	1	-10.0	1	-7.9	1	0.1
7	2	2a	1	-3.6	2	-12.8	2	-17.2	2	-22.0	1	1.7
7	2	2b	1	-3.2	1	-7.4	1	-9.7	2	-22.0	1	0.9
8	1	1a	2	-8.6	2	-21.6	2	-17.4	2	-22.0	1	-8.5
8	1	1b	1	-8.2	2	-22.0	2	-22.0	2	-22.0	2	-14.2
8	1	2a	1	-7.6	2	-22.0	2	-21.8	2	-10.4	2	-10.1
8	1	2b	1	-9.1	2	-21.5	2	-22.0	2	-11.0	2	-9.8
8	2	1a	2	-11.3	2	-17.7	2	-22.0	2	-22.0	2	-19.2
8	2	1b	2	-13.2	2	-22.0	2	-22.0	2	-19.0	2	-21.9
8	2	2a	2	-14.6	2	-15.3	2	-12.2	2	-12.2	2	-12.0
8	2	2b	2	-16.1	2	-15.6	2	-14.1	2	-13.8	2	-13.2
9	2	1a	2	-8.5	1	-8.7	1	-8.4	2	-18.2	2	-14.7
9	2	1b	2	-14.9	1	-10.0	1	-2.3	2	-11.5	1	-2.9
9	2	2a	2	-12.1	1	-9.7	1	-6.5	2	-16.7	1	-4.2
9	2	2b	2	-13.4	1	-9.1	1	-7.8	2	-13.5	1	-3.8
10	1	1a	1	-7.3	1	-9.0	2	-13.7	2	-15.1	1	1.2
10	1	1b	1	-10.0	2	-12.5	2	-15.5	2	-16.5	1	-3.8
10	1	2a	1	-6.3	2	-13.7	2	-20.6	2	-15.9	1	-1.6
10	1	2b	1	-7.3	2	-11.8	2	-21.0	2	-16.3	1	0.8
10	2	1a	2	-13.9	2	-22.0	2	-22.0	2	-12.4	2	-6.8
10	2	1b	2	-16.5	2	-20.0	2	-21.3	1	-1.7	1	0.1
10	2	2a	2	-7.4	2	-20.0	2	-12.5	2	-11.0	2	-8.6
10	2	2b	2	-11.3	2	-20.0	2	-12.8	2	-12.3	2	-7.6
11	1	1a	1	0.3	1	-6.9	2	-19.7	2	-22.0	2	-11.1
11	1	1b	1	-10.0	1	-9.9	2	-17.2	1	-6.6	2	-16.9
11	1	2a	1	-5.6	1	-7.8	2	-18.8	2	-21.8	2	-13.7
11	1	2b	1	-4.8	1	-8.4	2	-19.0	2	-22.0	2	-12.0
11	2	1a	1	-5.0	2	-21.5	1	-4.8	1	-1.8	1	3.8
11	2	1b	1	-8.0	2	-22.0	1	-5.4	1	1.3	1	-1.2
11	2	2a	1	-7.6	2	-21.6	1	-5.2	1	0.7	1	-1.7
11	2	2b	1	-6.2	2	-21.9	1	-4.9	1	-0.9	1	-1.7
12	1	1a	1	3.9	1	3.7	1	-5.7	1	-9.0	1	2.7
12	1	1b	1	5.9	1	5.0	1	-5.4	1	-7.3	1	3.5
12	1	2a	1	5.0	1	3.5	1	-8.8	1	-7.3	1	1.2
12	1	2b	1	6.9	1	2.8	2	-12.2	1	-8.4	1	0.3

APPENDIX D

12	2	1a	1	1.6	1	-1.7	1	-4.2	1	-5.7	1	-0.4
12	2	1b	1	1.7	1	-1.0	1	-6.3	1	-3.5	1	0.5
12	2	2a	1	-3.1	1	-2.1	1	-5.2	1	-6.8	1	-4.5
12	2	2b	1	-1.8	1	-2.8	1	-0.6	2	-13.6	2	-4.7
13	1	1a	2	-19.0	1	-6.8	2	-21.4	1	-7.5	1	4.1
13	1	1b	2	-22.0	1	-5.8	2	-22.0	1	0.0	1	1.7
13	1	2a	2	-20.1	1	-7.6	2	-22.0	1	-1.6	1	2.3
13	1	2b	2	-20.2	1	-6.1	2	-14.1	1	-2.4	1	3.0
14	1	1a	1	-7.0	2	-11.2	1	-6.8	2	-13.2	1	-9.7
14	1	1b	1	-8.4	2	-19.4	1	-3.5	2	-15.6	1	-8.4
14	1	2a	1	-1.9	2	-19.7	1	-9.4	2	-12.6	1	-6.3
14	1	2b	1	-2.5	2	-18.9	1	-9.6	2	-13.4	1	0.7
15	1	1a	2	-18.4	2	-19.2	2	-11.0	1	-4.9	1	-3.0
15	1	1b	2	-19.2	2	-18.7	2	-10.1	1	-5.2	1	-3.2
15	1	2a	2	-20.5	2	-15.2	1	-9.5	1	-6.1	2	-10.0
15	1	2b	2	-22.0	2	-17.5	2	-12.9	1	-4.3	2	-9.7
15	2	1a	2	-14.8	1	-0.3	2	-13.9	1	-5.1	1	-3.8
15	2	1b	2	-13.5	1	0.5	2	-13.5	1	-4.9	1	-1.8
15	2	2a	2	-22.0	2	-16.6	2	-13.3	1	-6.3	1	-4.5
15	2	2b	2	-20.5	2	-21.0	2	-12.8	1	-2.2	1	2.9
16	1	1a	2	-11.7	2	-13.6	2	-13.2	2	-16.7	2	-8.3
16	1	1b	2	-10.3	2	-16.7	2	-13.7	2	-17.8	2	-14.5
16	1	2a	1	-9.9	2	-11.2	2	-17.1	2	-11.8	1	1.1
16	1	2b	2	-10.2	2	-14.3	2	-15.0	2	-12.2	1	-0.8
16	2	1a	1	-7.8	2	-21.8	1	-9.9	2	-13.2	1	0.4
16	2	1b	1	-4.1	2	-22.0	2	10.9	2	-14.1	1	3.6
16	2	2a	1	-6.0	2	-17.0	2	-11.5	2	-14.1	1	2.0
16	2	2b	1	-5.5	2	-18.2	2	-11.1	2	-13.9	1	2.0
17	1	1a	1	2.8	1	-0.3	1	-9.0	1	-9.1	2	-11.3
17	1	1b	1	2.3	1	-0.1	1	-8.3	1	-9.3	2	-14.4
17	1	2a	1	3.4	1	-1.9	2	-17.1	2	-17.4	2	-16.6
17	1	2b	1	-10.0	1	3.8	2	-22.0	2	-16.5	2	-11.6
17	2	1a	1	1.7	1	-9.8	1	-9.2	2	-15.9	1	2.8
17	2	1b	1	2.1	1	-7.6	1	-9.9	2	-17.6	1	0.8
17	2	2a	1	2.8	1	-6.5	2	-10.8	2	-22.0	2	-13.9
17	2	2b	1	1.2	1	-0.1	2	-11.6	2	-18.8	2	-16.6
18	1	1a	1	-3.7	2	-19.4	2	-14.1	1	-5.9	1	7.1
18	1	1b	1	-3.3	2	-22.0	2	-17.3	1	-4.9	1	8.0
18	1	2a	1	-6.7	2	-13.3	2	-14.5	1	-5.3	1	6.4
18	1	2b	1	-4.1	2	-14.5	2	-17.5	1	-5.4	1	6.7
18	2	1a	1	-7.9	2	-22.0	2	-14.9	2	-19.5	1	-6.6
18	2	1b	1	-9.9	2	-22.0	2	-15.0	2	-18.0	1	-4.3
18	2	2a	1	-8.4	2	-22.0	2	-15.2	2	-20.5	1	-5.6
18	2	2b	1	-9.2	2	-22.0	2	-14.8	2	-21.8	1	-6.3
19	1	1a	1	-8.2	1	-9.0	2	-11.9	2	-12.6	1	-9.4

19	1	1b	1	-8.3	1	-10.0	2	-22.0	2	-22.0	1	-1.1
19	1	2a	1	-8.3	2	-22.0	2	-21.2	2	-20.8	1	-1.3
19	1	2b	2	-12.5	2	-16.7	2	-22.0	2	-15.0	2	-11.3
19	2	1a	1	-4.8	2	-12.7	2	-15.8	2	-18.4	1	-3.9
19	2	1b	1	-10.0	2	-16.2	2	-11.2	2	-21.2	1	0.8
19	2	2a	1	-9.9	2	-18.0	2	-17.8	2	-18.1	1	-1.4
19	2	2b	1	-9.7	2	-11.7	2	-22.0	2	-20.8	1	-5.3
20	1	1a	1	-9.6	2	-15.4	2	-21.0	1	-2.0	1	-2.0
20	1	1b	1	-5.6	2	-16.9	2	-18.2	1	0.4	1	-4.0
20	1	2a	1	-8.7	2	-17.7	2	-16.5	1	-3.3	1	-5.8
20	1	2b	1	-6.5	2	-22.0	2	-17.3	1	-2.7	1	-3.9
20	2	1a	1	-4.0	2	-11.2	2	-10.3	1	2.4	2	-15.5
20	2	1b	1	-7.3	2	-12.4	2	-12.4	1	-3.0	2	-10.4
20	2	2a	1	-6.7	2	-11.6	1	-8.5	1	-3.3	1	-5.7
20	2	2b	1	-10.0	2	-12.6	2	-11.2	1	-3.9	1	-3.7
21	1	1a	1	-9.2	1	-2.2	2	-11.1	1	0.4	1	-4.5
21	1	1b	1	-9.0	1	-1.7	2	-10.7	1	-2.3	1	-3.3
21	1	2a	1	-8.5	1	1.1	1	-9.7	1	-7.7	1	-2.5
21	1	2b	1	-8.7	1	0.5	2	-10.1	1	-4.6	1	-3.5
21	2	1a	1	-2.8	1	-2.8	1	-9.0	2	-13.7	1	-6.8
21	2	1b	1	-1.9	1	-3.2	1	-8.5	2	-14.3	1	-7.2
21	2	2a	1	-3.4	1	-7.3	2	-10.5	2	-21.8	1	-5.3
21	2	2b	1	-1.4	1	-8.0	2	-10.5	2	-21.9	1	-6.7
22	1	1a	1	-1.5	1	-5.4	1	-4.9	2	-18.5	1	-6.9
22	1	1b	1	0.5	1	-5.0	1	-1.4	2	-20.5	1	-5.0
22	1	2a	1	-0.5	1	-6.9	1	-8.7	2	-12.7	1	0.9
22	1	2b	1	-0.8	1	-9.9	1	-4.9	2	-12.9	1	1.4
22	2	1a	1	-3.6	1	-9.9	1	-9.4	1	-3.8	1	-6.4
22	2	1b	1	-6.8	1	-2.4	1	-10.0	1	-4.2	1	-4.6
22	2	2a	1	-3.1	2	-22.0	2	-12.2	2	-12.1	1	-0.7
22	2	2b	1	-0.7	2	-20.2	2	-11.2	2	-11.0	1	-9.8
23	1	1a	1	-2.1	1	-6.5	1	-5.7	1	-6.4	1	-0.6
23	1	1b	1	-1.4	1	-8.6	1	-4.7	1	-2.8	1	0.1
23	1	2a	1	1.4	1	-10.0	1	-7.4	1	-7.1	1	4.0
23	1	2b	1	-0.8	1	-8.5	1	-4.7	1	-6.5	1	4.3
23	2	1a	1	0.0	2	-10.1	1	-9.2	1	-5.3	1	2.5
23	2	1b	1	0.3	2	-11.4	1	-5.8	1	-5.9	1	1.9
23	2	2a	1	-4.4	2	-17.6	1	-9.4	2	-11.1	1	-2.0
23	2	2b	1	-3.2	2	-15.4	1	-10.0	2	-14.7	1	-1.8
24	1	1a	1	6.9	1	0.0	1	2.8	1	3.7	1	8.1
24	1	1b	1	4.5	1	0.2	1	4.1	1	2.8	1	8.9
24	1	2a	1	5.2	1	-0.1	1	3.8	1	2.8	1	8.7
24	1	2b	1	4.8	1	0.2	1	3.1	1	3.5	1	8.4
24	2	1a	1	-7.7	1	-3.9	1	-0.4	1	7.5	1	4.2
24	2	1b	1	-10.0	1	-4.6	1	-4.4	1	6.9	1	3.1

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24	2	2a	1	-8.7	1	-4.2	1	-2.3	1	7.2	1	4.0
24	2	2b	1	-9.8	1	-4.1	1	-3.2	1	6.8	1	3.7
25	1	1a	1	-7.9	2	-12.2	2	-16.6	1	-10.0	1	-7.0
25	1	1b	1	-8.2	2	-15.1	2	-14.8	1	-9.8	1	-7.2
25	1	2a	1	-9.8	2	-21.0	2	-22.0	2	-20.2	1	-9.6
25	1	2b	1	-10.0	2	-14.1	2	-19.5	2	-19.0	1	-6.7
25	2	1a	1	-7.0	2	-13.7	2	-16.5	1	-8.6	1	-8.5
25	2	1b	1	-7.9	2	-14.6	2	-15.1	1	-7.9	1	-8.2
25	2	2a	1	-10.0	2	-20.0	2	-22.0	2	-20.5	1	-5.1
25	2	2b	1	-7.7	2	-11.1	2	-22.0	2	-22.0	1	-2.3
26	1	1a	1	-8.4	1	-8.6	1	-3.6	1	-8.4	1	-4.7
26	1	1b	2	-10.1	2	-12.4	1	-2.5	2	-10.8	1	-6.5
26	1	2a	2	-12.2	2	-17.6	2	-19.2	2	-22.0	2	-14.9
26	1	2b	1	-9.1	1	-2.2	1	-8.2	2	-11.0	2	-22.0
26	2	1a	1	-4.8	1	-8.2	1	-6.5	1	-4.3	1	4.2
26	2	1b	1	-5.0	1	-9.2	1	-3.0	1	-3.4	1	1.8
26	2	2a	2	-10.6	2	-13.6	1	-5.7	2	-10.9	1	4.9
26	2	2b	2	-12.7	2	-22.0	2	-11.4	2	-10.5	1	4.8
27	1	1a	1	-7.7	2	-13.6	2	-16.0	1	-6.0	1	-4.0
27	1	1b	1	-8.0	2	-12.5	2	-13.5	1	-5.8	1	-4.9
27	1	2a	1	-8.2	2	-12.7	2	-15.4	1	-5.9	1	-4.2
27	1	2b	1	-7.9	2	-12.4	2	-13.8	1	-5.7	1	-4.7
27	2	1a	2	-12.1	2	-11.7	2	-15.1	2	-19.2	2	-10.4
27	2	1b	1	-9.3	2	-18.4	2	-16.6	2	-19.3	2	-12.0
27	2	2a	2	-10.2	2	-13.4	2	-15.6	2	-19.1	2	-11.1
27	2	2b	2	-11.0	2	-14.6	2	-15.8	2	-19.3	2	-11.8