Applicability of distortion product otoacoustic emissions as a new health surveillance technique for hearing screening in industry

by

Meshack Moepeng

A dissertation submitted in fulfillment of the requirements for the degree of Master of Communication Pathology (Audiology).
Department of Speech-Language Pathology and Audiology
University of Pretoria

Supervisor: Dr. Maggi Soer
Co-Supervisor: Prof. Bart Vinck

June 2016

Acknowledgements

I would like to extend my sincere gratitude to the following persons:

Dr Maggi Soer and Professor Bart Vinck for the wonderful support and guidance you gave me during the course of this research.

Dr Elsie Naudé, thank you for your excellent and expeditious work in language editing this dissertation.

My research participants, I am indebted to all of you for your willingness to take part in this study. The successful outcome of this research is due to your input.

My wife Keneilwe, thank you for the unconditional love and the support I received from you throughout the course of my studies. Even during the difficult moments you always encouraged and believed in me.

My adorable daughter Tshephang born during the course of my research, thank you for being a calm baby allowing me to study at night.

All thanks go to God for carrying me through my studies, giving me the strength and wisdom I needed to complete my research work.

Abstract

Title: Applicability of distortion product otoacoustic emissions as a new health surveillance technique for hearing screening in industry

Background: Distortion product otoacoustic emissions (DPOAEs) are a promising screening technique for the early detection of subtle noise induced cochlear function changes.

Objectives: To determine the applicability of DPOAEs as a health surveillance technique for the early detection of noise induced hearing loss (NIHL) in workers at a steel manufacturing industry.

Methods: DPOAEs were recorded in 20 participants with no history of occupational noise exposure and 20 participants exposed to noise in the steel manufacturing industry. Participants were not exposed to noise for at least 48 hours prior to testing. All participants were male with normal audiometric thresholds of ≤15 dB HL. The DPOAE presence and response amplitude levels for different frequencies were compared between the two groups. The study further evaluated the short-term test-retest repeatability of DPOAE measurements, and also compared the total test duration of performing DPOAEs to the duration of screening audiometry.

Results: The noise exposed group had statistically significantly lower DPOAE response amplitudes than the control group for all the tested frequencies; ($p<0.001$) at 2002 to 4004 Hz, and ($p=0.01$, $p=0.001$) at 6348 and 7996 Hz respectively, suggesting more cochlear damage in the noise exposed group due to early outer hair cell damage. DPOAEs showed very good reproducibility, and the average duration of performing a set

of DPOAEs was significantly shorter (461 ± 68.2 seconds) than the duration of performing audiometry (591 ± 76.9 seconds), $p<0.001$.

Conclusion: DPOAEs appeared to be a sensitive technique in detecting noise induced subtle cochlear function changes. DPOAEs could be used as a health surveillance technique for the early detection of NIHL in the steel manufacturing industry.

Key words: Distortion product otoacoustic emissions, hearing screening, health surveillance, noise exposure, noise induced hearing loss

TABLE OF CONTENTS

List of tables

List of figures

List of appendices

Abbreviations

ADC	Analogue to digital converter
ARTs	Acoustic reflex thresholds
DAC	Digital to analogue converter
daPa	Decapascal
dB	Decibels
DPOAEs	Distortion product otoacoustic emissions
ENT	Ear Nose and Throat
HL	Hearing level
HCPs	Hearing conservation programs
HPDs	Hearing protection devices
HSE	Health and Safety Executive
Hz	Hertz
LIDEN	Leading Indicator of Damaging Exposure to Noise
NIHL	Noise induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OHC	Outer hair cell
OSHA	Occupational Safety and Health Administration
PC	Personal computer
SNR	Signal to noise ratio
SPL	Sound pressure level
TEOAEs	Transient evoked otoacoustic emissions
TTS	Temporary threshold shift

1. INTRODUCTION

This chapter presents the problem statement and rationale of the current study. The chapter also puts forward the definition of terms and chapter layout.

1.1. Problem statement and rationale

Pure tone audiometry is currently the gold standard test used in detecting and monitoring noise induced hearing loss (NIHL) in different industries (including steel manufacturing factories) where the daily noise exposure rate levels are in excess of 85 dB(A) (Attias, Horovitz, El-Hatib, & Nageris, 2001; HSE, 2011). Existing NIHL can be easily measured using pure tone audiometry. In detecting subclinical and pre-clinical noise induced cochlear changes, however, the sensitivity of pure tone audiometry is questioned (Attias et al., 2001; Balatsouras, 2004; Marshall, Lapsley, & Heller, 2001) as it measures the integrity of the whole auditory pathway while NIHL in its early stages starts affecting primarily the outer hair cells (OHCs) in the cochlea (Attias et al., 2001; SCENIHR, 2008). There are some notable limitations when pure tone audiometry is used as the only hearing screening technique for occupational health surveillance. These limitations are as follows:

- Pure tone testing is subjective and requires cooperation of the employee, therefore results obtained from uncooperative individuals who could be malingering for compensation purposes may often be unreliable (HSE, 2011).
- Pure tone audiometry only detects hearing damage when permanent irreversible damage is already present; therefore it mostly fails to provide timely prevention of

OHC damage from occupational noise exposure (Edwards & Taela, 2008; HSE, 2011).

The aforementioned limitations of using pure tone audiometry as the only hearing screening technique in noise health surveillance programs demonstrate the importance of having a more sensitive test that could detect cochlear function changes at an early stage before permanent, irreversible noise induced OHC damage occurs. OHCs have the capacity for electromotility, enabling them to quickly contract, elongate, and generate energy in response to acoustic stimuli (Brownell, 1996; Gelfand, 1998). OHC motility has nonlinear properties and it is believed to be responsible for the generation of otoacoustic emissions (OAEs) (Kemp, 2002).

Several studies suggest that all forms of OAEs could be a more suitable diagnostic tool for early detection of cochlear function changes resulting from excessive noise exposure, allowing early detection of cochlear damage before it is evident through conventional audiometry (Attias et al., 2001; Silva, Sampaio, Oliveira, Tauil, & Jansen, 2012; Vinodh & Veeranna, 2010). OAE testing is a quick, objective, and sensitive hearing assessment tool used for differentiating between normal and abnormal OHC function (Hall, 2000). OAEs have proved to be very sensitive in showing adverse effects of noise damage on OHCs (Silva et al., 2012; Vinck, Van Cauwenberge, Leroy, & Corthals, 1999), therefore they may be considered a promising hearing screening health surveillance technique for the early detection of NIHL in industrial hearing conservation programs (HCPs). Researchers are therefore increasingly proposing the incorporation of OAEs as part of occupational health surveillance hearing screening procedures (HSE, 2011, HSE, 2013).

The two most common clinically used OAEs are transient evoked OAEs (TEOAEs) and distortion product OAEs (DPOAEs) (Hall, 2000; Kemp, 2002). Both TEOAEs and DPOAEs have previously been used in monitoring the effects of noise (Job et al., 2009; Silva et al., 2012; Vinck et al., 1999).

DPOAE responses are frequency specific, have good test-retest repeatability and perform better in high frequencies, therefore it appears they might be suitable for the early detection of NIHL which mostly affects the high frequencies (Balatsouras, 2004; Edwards, Van Coller, & Badenhorst, 2010). Some studies report that changes in DPOAEs correspond well to changes in pure tone audiometry hearing thresholds, therefore DPOAEs might be used as an effective objective hearing assessment tool to complement conventional pure tone audiometry in the early detection of NIHL in an occupational industrial setting (Attias et al., 2001; HSE, 2011).

The main aim of this study was to determine the applicability of DPOAEs as a health surveillance technique for the early detection of NIHL in subjects working in a steel manufacturing industry.

1.2. Definition of terms

Distortion product otoacoustic emissions (DPOAEs): low level acoustic responses elicited by simultaneously presenting two closely-spaced pure tones (often called primaries) to the cochlea (Prieve & Fitzgerald, 2002; Ziarani & Konrad, 2004).

Excessive noise exposure: being exposed to sounds with an average 8 hour noise rating levels exceeding 85 dB(A). Such exposure could eventually lead to permanent hearing damage if appropriate hearing protection devices (HPDs) are not used (OSHA, 2002).

Health surveillance: a program that involves routine health checks to detect early signs and symptoms of work-related health conditions, prompting actions to be taken to prevent the progression of these conditions and protect workers' health as a result (HSE, 2011).

Hearing conservation program (HCP): a program designed to prevent NIHL in employees exposed to noise with an average 8 hour noise rating levels exceeding 85 dB(A). The program generally includes the following components: noise exposure monitoring; audiometry; engineering controls; provision and usage of HPDs; employee education and training; and record keeping (OSHA, 2002).

Noise induced hearing loss (NIHL): a permanent hearing loss caused by prolonged exposure to excessive noise (OSHA, 2002).

Otoacoustic emissions (OAEs): low level sounds emitted by the OHCs in the cochlea and recorded in the external ear canal (Kemp, 1978).

Outer hair cells (OHCs): sensory hair cells in the organ of Corti primarily connected to the efferent neural fibres of the auditory nerve and responsible for the mechano-electric transduction and generation of OAEs (Cheng, 2000; Kemp, 2002).

Pre-clinical hearing loss: sub-clinical noise induced cochlear changes detected by DPOAE measurements that eventually develop into a hearing loss that could be measured audiometrically (Marshall et al., 2001).

Pure tone audiometry: a subjective, behavioral measurement to determine the softest sound level a person can hear (hearing threshold) for each pure tone stimulus presented at each specific frequency (HSE, 2011).

Sub-clinical cochlear changes/damage: a reduction in DPOAE response amplitude that is significantly greater than the change shown by a comparable control group, while there is no significant change in the pure tone audiometry hearing threshold (Marshall et al., 2001).

1.3. Chapter layout

Chapter 1: Introduction

This chapter presents the problem statement and rationale of the current study. The chapter also puts forward the definition of terms and chapter layout.

Chapter 2: Literature review

This chapter uses the available literature to provide the theoretical background of NIHL, the nature of HCPs, and the use of DPOAEs in the detection and monitoring of early NIHL. The chapter ends with a presentation of the research question for the current study.

Chapter 3: Methodology

This chapter presents the aim, hypothesis, and the research design of the current study, as well as the ethical considerations, procedures for selection of participants, description of participants, procedures for interpretation and recording of data and the procedure used in statistical data analysis.

Chapter 4: Results and discussion

This chapter presents the results and the discussion of the results of the current study. The chapter discusses the research findings of the current study using the current available literature to support deductions and indicate the clinical implications of these research findings.

Chapter 5: Conclusion, limitations and recommendations

This chapter presents the conclusion based on the presented research findings and clinical implications of the current study. It further outlines the limitations of the current study and provides recommendations for further research.

2. LITERATURE REVIEW

This chapter uses the available literature to provide the theoretical background with regard to NIHL, HCPs and the use of DPOAEs in detecting and monitoring early NIHL. The chapter ends with a presentation of the research question for the current study.

2.1. Noise induced hearing loss

NIHL continues to be a major concern in occupational environments involving hazardous noise levels, mostly affecting workers in industries such as mining, military, manufacturing, construction, transportation, and agricultural enterprises **(**Attias et al., 2001; Franks, Stephenson, & Merry, 1996). In these environments workers are exposed to excessive noise for extended periods, which adversely affects their hearing and ultimately causes occupational NIHL. NIHL can be defined as a permanent hearing loss caused by prolonged exposure to excessive noise (OSHA, 2002). It is typically a sensorineural type of hearing loss, often bilateral and symmetrical (Nandi & Dhatrak, 2008). On very rare occasions conductive or mixed hearing loss can develop from very high acoustic level impulse noises such as explosions or bomb blasts (acoustic trauma) which lead to mechanical damage to the ear drum, the ossicles, and the basilar membrane (SCENIHR, 2008).

Exposure to recreational noise is also known to cause NIHL (Ramma, Peterson, & Singh, 2011). NIHL can affect individuals negatively on emotional, social, and financial levels with consequent adverse effects on their quality of life. The costs of compensations and of running HCPs could economically harm the affected organizations (Attias et al.,

2001). Since NIHL is 100 percent preventable, it is important that best measures always be put in place to prevent or reduce the prevalence of NIHL in the workplace (e.g. occupational health surveillance programs). NIHL can be temporary or permanent, depending on whether an individual has a temporary threshold shift (TTS) or a permenant threshold shift. NIHL is cumulative in nature, thus the individual's hearing usually gradually deteriorates over time. The severity of NIHL is largely dependent on the type of noise (impulse/continuous), the intensity of the noise, and the duration of noise exposure (Marshall et al., 2001). Impulse noise (e.g. gunshooting/explosion) is more damaging than constant noise exposure.

A study by the U. S. National Institute for Occupational Safety and Health (NIOSH, 1972) reported that a person working in noise for 40 years, with a daily average noise exposure level of 80, 85, or 90 dB(A), has an estimated risk of developing NIHL of 3%, 16% or 29% respectively. Based on these findings NIOSH (1972) recommended an eight hour rating exposure limit of 85 dB(A). The NIOSH (1972) findings are consitent with the findings of Lutman (2000), which indicated that the risk of NIHL is negligible at 80 dB(A) average daily noise exposure level, marginal at 85 dB(A), and remarkable at levels exceeding 90 dB(A). Lutman (2000) therefore indicated that daily noise exposure levels not exceeding 85 dB(A) are considered to have minimal risk of hearing loss.

Lutman (2000) further reports that different 'Noise at Work regulations' stipulate that for workers exposed to noise levels exceeding 85 dB(A), measures should be taken to protect these individuals from the negative effects of occupational noise exposure through

identifying and marking noise hazard zones, reducing exposure times, and provision of personal HPDs (ear plugs/muffs). The aforementioned statement is supported by NIOSH (1972) and the South African National Standard (SANS 10083, 2013) both of which recommend the use of personal HPDs for every person entering a noise zone where the 8 hour rating noise level exceeds 85 dB(A) regardless of how long they will be in that area. However, the European Union Directive 2003/10/EC (European Union Parliament, 2003) stipulates that employers must make personal HPDs available to their workers for noise exposure levels equal or above 80 dB(A), even though the workers are not obliged to use the HPDs at this level . The directive further states that when workers are exposed to noise exposure levels equal or exceeding 85 dB(A) employers shall ensure that noise hazard zones are identified and appropriately marked, workers' noise exposure times are reduced, and personal HPDs are provided and worn when in these noise hazard zones.

It should be noted that there is great inter-individual variability in susceptibility to NIHL from excessive noise exposure, even when individuals are exposed to the same chronic noise level (SCENIHR, 2008), therefore individual susceptibility to noise is an important consideration in the development of NIHL. There are different factors that may lead to susceptibility to NIHL, such as age, gender, eye colour, hypertension, smoking, cholestrol levels, and genetic factors (SCENIHR, 2008). A clinician should always keep these factors in mind when performing hearing assessments (e.g. pure tone audiometry) in the case of persons exposed to noise.

Pure tone audiometry is currently viewed as the most ideal standard test used for detecting and monitoring NIHL (Attias et al., 2001). The most affected frequency is usually 4 kHz, and in the early stages of NIHL the affected frequencies are 3 kHz and above while the lower frequencies usually remain intact (Attias et al., 2001; Lutman, 2000). It is evident that existing NIHL can be easily detected and measured using pure tone audiometry. In detecting subclinical noise induced cochlear changes and pre-clinical hearing loss, however, the sensitivity of pure tone audiometry is questioned (Attias et al., 2001; Balatsouras, 2004; Marshall et al., 2001). Pure tone audiometry measures the integrity of the whole auditory pathway while NIHL in its early stages starts affecting primarily the OHCs in the cochlea (Attias et al., 2001; SCENIHR, 2008). As the OHCs are affected in the initial stages of damage due to exposure to high levels of noise, the damage could eventually extend to inner hair cells and auditory nerve endings, depending on the extent of the acoustic trauma (Attias et al., 2001).

The OHCs and inner hair cells are sensory hair cells situated in the organ of Corti on top of the basilar membrane and responsible for mechano-electric transduction. Inner hair cells are connected to the afferent nerve fibres which convey the neural signals from the organ of Corti to the central auditory system. Conversely OHCs are primarily connected to the efferent neural fibres which are responsible for transmitting neural signals from the central auditory system to the organ of Corti (Cheng, 2000). OHCs have the capacity for electromotility, enabling them to quickly contract, elongate, and generate energy in response to acoustic stimuli (Brownell, 1996; Gelfand, 1998). One of the characteristics of a healthy cochlea is that it works as a non-linear system, hence the common use of the

term ‘cochlear nonlinearity’. Cochlear nonlinearity means the growth of the cochlear response level (output) is not proportional to the stimulus level (input) and this is usually compressive; thus the input/output (I/O) function is less than 1 dB/dB (Cheng, 2000). The active cochlear nonlinearity is largely responsible for producing normal hearing sensitivity and frequency selectivity (Cheng 2000). Any damage to the OHCs (e.g. due to excessive noise exposure) will impair the active, nonlinear cochlear processes, resulting in reduced hearing sensitivity and frequency selectivity (SCENIHR, 2008).

OHC motility has nonlinear properties and is believed to be responsible for the generation of OAEs (Kemp, 2002). Research is increasingly showing that OAEs could detect the development of NIHL earlier than the conventional screening pure tone audiometry, therefore researchers are increasingly proposing the incorporation of OAEs as part of occupational health surveillance hearing screening procedures (e.g. HCPs) (HSE, 2011; HSE, 2013).

2.2. Hearing conservation programs

It is very important for employers to consider devising HCPs which focus mainly on the prevention of NIHL for all workers exposed to excessive noise within their organization. In the USA, the Occupational Health and Safety administration (OSHA) stipulates that a written HCP is required whenever an employee is exposed to noise with an 8 hour noise rating level exceeding 85 dB(A). The OSHA Occupational Noise Exposure Standard (29 CFR 1910.95) recommends that a HCP should consist of noise exposure monitoring; determining the effectiveness of a HCP through audiometric test procedures; engineering

controls; provision of HPDs; employee education and training; and record keeping. This standard requires employers to perform noise measurements to identify and monitor all employees exposed to an average 8 hour noise rating level exceeding 85 dB(A). Employees exposed to the aforementioned noise levels should undergo regular audiometric tests, including baseline audiometry, annual monitoring audiometry and other appropriate audiometric follow-ups of employees' hearing status, especially of workers whose audiograms indicate hearing loss or hearing deterioration. The employer incurs all the costs of the audiometric tests. The standard further recommends that employees should be provided with personal HPDs free of charge. Inappropriate use of personal HPDs could lead to NIHL, therefore it is essential that employees are educated regarding the effects of excessive noise exposure and that training be provided on appropriate use of HPDs.

There is an increasing body of evidence indicating that long-term noise exposure to noise levels exceeding 75 dB(A) but below 85 dBA may have a small risk of causing NIHL (Agarwal, Nagpure, & Gadge, 2016; Kumar, Kumar, & Barman, 2013; NOHSC, 2000). In Europe, the European Union Directive 2003/10/EC (European Union Parliament, 2003) introduced stringent measures to protect workers exposed to noise levels equal to or above 80 dB(A) from acquiring NIHL. This noise legislation states that employers must ensure that for workers exposed to noise exposure levels equal or above 80 dB(A), personal HPDs are made available, and that information and training regarding excessive noise exposure and its effects are provided to workers. The training is to cover: the nature of the risks from noise exposure; the exposure limit and the exposure action level values;

the correct use of HPDs; safe working practices to minimize exposure to noise; why and how to detect and report signs of hearing damage; the workers' entitlement to health surveillance; and the purpose of the health surveillance. This directive (European Union Parliament, 2003) further stipulates that when workers are exposed to noise levels equal to or exceeding 85 dB(A), it is the responsibility of the employer to ensure that workers wear personal HPDs and to establish an appropriate audiometric health surveillance program for the early detection of NIHL and for the prevention of possible noise induced hearing damage.

An effective industrial HCP should have good health surveillance techniques for hearing screening to ensure early detection of NIHL. A health surveillance program entails health screenings performed to identify signs/symptoms of work-related health conditions at an early stage (HSE, 2011). Pure tone audiometry is currently the most widely accepted test used in noise health surveillance programs for the early detection and monitoring of NIHL (HSE, 2011). However, as discussed in section 1.1., there are some limitations in using pure tone audiometry as the only hearing screening technique within a HCP, therefore there is a need to consider other hearing screening techniques (e.g. OAEs) for early detection and monitoring of NIHL.

In the UK, the Health and Safety Executive (HSE) is working towards incorporating OAEs to be part of the health surveillance programs, in order to improve the current HCPs. In February 2011 HSE held an international expert symposium to consider the use and the applicability of OAEs in occupational health surveillance. In November 2013

HSE held an OAEs workshop, and it was during this workshop where the Leading Indicator of Damaging Exposure to Noise (LIDEN) approach was introduced (HSE, 2013).

The LIDEN approach embarked on involving the international community to develop a standardized and effective approach of including OAE testing in HCPs. The LIDEN approach recommends a three stage approach where baseline testing consists of pre-test procedures (otoscopy, health and noise questionnaire, tympanometry and acoustic reflexes), pure tone audiometry, and OAE testing. At the annual monitoring stage only pre-test procedures and OAE testing are performed, while pure tone audiometry is only performed where indicated. The pre-test procedures in the context of the LIDEN approach are procedures performed before pure tone audiometry and OAE testing. These procedures comprise a noise and health questionnaire, otoscopic examination, tympanometry, and acoustic reflexes. The LIDEN approach further recommends that the last stage should be performed every three years. The last stage consists of pre-test procedures, pure tone audiometry, and OAE testing (HSE, 2013). This approach will particularly benefit workers who are exposed to occupational noise and who present with good emissions at baseline testing (HSE, 2011). The approach is aimed at early detection or indication of OHC function changes and enabling timely preventative measures before further hearing damage occurs in an employee exposed to excessive occupational noise. OAEs have a remarkable clinical potential, therefore they can be considered a potentially promising hearing screening technique for the early detection of NIHL in industrial HCPs.

2.3. Otoacoustic emissions

OAEs are low level sounds emitted by the cochlea and recorded in the external ear canal (Kemp, 1978). OAEs are a result of the pre-neural active cochlear processes, which depend on the normal functioning of OHCs (Prieve & Fitzgerald, 2002). Most of the energy generated by the OHCs is fed into the forward travelling wave, but a small amount of energy escapes back from the cochlea through the middle ear and eardrum and can be recorded in the ear canal as OAEs (Kemp, 1997). The different structures of the auditory system play a significant role in the generation of OAEs and have an influence on the OAE recordings (Hall, 2000). OAEs are a good, quick, objective and sensitive hearing assessment tool for differentiating between normal and abnormal OHC function (Hall, 2000). They have been proven to be very sensitive in showing adverse effects of noise damage on the OHCs (Silva et al., 2012; Vinck et al., 1999). Several studies indicated that OAEs could be a suitable diagnostic tool for the early detection of cochlear function changes caused by excessive noise exposure, allowing early detection of cochlear damage before it is evident through conventional audiometry (Attias et al., 2001; Silva et al., 2012; Vinodh & Veeranna, 2010). OAEs could therefore be used for the early detection of NIHL and be used as an objective tool to complement audiometric test results (Cheng, 2000; Hall, 2000).

The two most common clinically used OAEs are TEOAEs and DPOAEs (Hall, 2000; Kemp, 2002). These OAEs are mainly defined by the type of stimuli used to evoke them (Prieve & Fitzgerald, 2002). TEOAEs are evoked by brief acoustic stimuli such as clicks or tone bursts (Dietl & Weiss, 2004). DPOAEs are elicited by simultaneously presenting two closely spaced pure tones to the cochlea (Prieve & Fitzgerald, 2002; Ziarani &

Konrad, 2004). TEOAE and DPOAE response amplitudes reflect the existence and functionality of the integrity of the cochlear amplifier (Abdala & Visser-Dumont, 2001; Sininger & Cone-Wesson, 2004). Furthermore both TEOAEs and DPOAEs have previously been used in monitoring the effects of noise (Job et al., 2009; Silva et al., 2012; Vinck et al., 1999). In this study DPOAEs were used as a data collection procedure, therefore further discussion will focus mainly on DPOAEs.

2.3.1. Distortion product otoacoustic emissions

DPOAEs are low level acoustic responses elicited by simultaneously presenting two closely-spaced pure tones (often called primaries) to the cochlea (Prieve & Fitzgerald, 2002; Ziarani & Konrad, 2004). These primary tones are labelled f1 and f2 (f2 >f1) measured in Hz at corresponding stimulus intensity levels L1 and L2 (L1≥L2) measured in dB SPL (Marshal et al., 2001). DPOAEs are present in nearly 100 percent of normal hearing ears (Cheng 2000; Lonsbury-Martin, Harris, Stagner, Hawkins, & Martin, 1990). Furthermore, DPOAEs are reported to be always present when the hearing threshold is lower than 15 dB HL and absent or greatly reduced for hearing thresholds above 50 dB HL (Harris, 1990; Reavis et al., 2011). Since OAEs are pre-synaptic responses, DPOAEs are unreliable for predicting hearing thresholds but they are a good indicator of the status of cochlear functioning (Kemp, 2002).

DPOAEs are a result of the non-linear behaviour of the cochlea (Cheng, 2000; Prieve & Fitzgerald, 2002).When the two primary tones (f1 and f2) are simultaneously presented to the cochlea, due to its active nonlinear properties the intermodulation between the two

tones within the cochlea generates several distortion products which can be recorded in the ear canal, for example; f2-f1, 2f1-f2, 3f1-2f2, 2f2-f1 etc. (Grabham et al., 2013; Kemp, 2002). The 2f1-f2 distortion product is usually more robust than other distortion products in humans and animals (Marshall et al., 2001; Ziarani & Konrad, 2004). The 2f1-f2 distortion product OAE is sometimes referred to as the cubic difference tone (Cheng, 2000; Gelfand, 1998). The use of the term DPOAE in the current study will be referring to the 2f1-f2 distortion product, unless otherwise specified. The lower primary tone (f1) is generally best presented at a stimulus level (L1) of 60 to 70 dB SPL while f2 is generally best presented at stimulus level (L2) of 50 to 70 dB SPL (Kemp, 2002). The DPOAE responses are best generated when the intensity difference between the primaries is 10 dB SPL (i.e. L1-L2= 10 dB SPL). The most commonly clinically used DPOAE levels are L1=65 dB and L2=55 dB SPL (Hall, 2000).

The DPOAE responses are also influenced by the frequency ratio of the primaries, commonly denoted f2/f1. Previous studies show that DPOAEs are usually more robust when the f2/f1 ratio is in the range of 1.2 to 1.22 (Hall, 2000; Kemp, 2002; Marshall et al. 2001; Ziarani & Konrad, 2004). Typically the 2f1-f2 DPOAE response amplitude which is commonly used for assessing cochlear function in humans increases when the f2/f1 ratio is increased from 1.0 to approximately 1.20 and decreases when the f2/f1 ratio is increased above 1.20 (Moulin, 2000). It is believed that presenting the primary tones as indicated above stimulates the cochlea close to the f2 frequency region (Hall, 2000).

Several previous studies have shown that DPOAEs have good test-retest repeatability in humans and animals (Hoshino, Ueda, & Nakata, 1999; Stuart, Passmore, Culbertson, &

Jones, 2009). Test-retest reliability is an essential component of the validity of any clinical measure (McCrae, Kurtz, Yamagata, & Terracciano, 2011). In light of the high test-retest reliability of DPOAEs reported in literature some researchers are proposing the applicability of DPOAEs as a health surveillance hearing screening tool in industry (Prasher & Sulkowski, 1999; Seixas et al., 2005).

2.3.1.1. Factors influencing DPOAE measurements

There are several factors that could possibly influence DPOAE measurements, therefore it is important to outline and control for factors that could possibly influence the DPOAE response levels in any study. These factors are discussed below.

2.3.1.1.1. Age

Previous studies show conflicting results as to whether DPOAE response amplitudes reduce with age or not. A study by Engdahl (2002) with 6415 adult subjects found a decrease in TEOAEs and DPOAEs with increasing age. Similar findings were reported by Lonsbury-Martin et al. (1990) in their study of 44 normal hearing subjects. They measured 2f1-f2 DPOAEs in response to three equilevel primary tones (65, 75, and 85 dB SPL). The study revealed that DPOAE response amplitudes reduced with increasing age. A longitudinal study by Uchida et al. (2008) with 331 audiometrically normal hearing adults aged 40 to 82 years also showed that DPOAE response amplitude levels decrease with age. In contrast Hoth, Gudmundsdottir, and Plinkert (2010) concluded that the reduction of DPOAE response amplitude levels with increasing age is mainly due to age related hearing loss rather than to aging alone.

2.3.1.1.2. Ear asymmetry

There is a limited body of research concerning the influence of ear asymmetry on DPOAEs. Keogh, Kei, Driscoll, and Smyth (2001) studied 1003 children (age range = 5.2 to 7.9 years) and found statistically significantly higher DPOAE signal-to- noise ratios in their right ears than in their left ears. In contrast, a study by Balatsouras (2004) found no statistically significant difference between right and left ear DPOAE responses. The findings of the latter study are supported by a recent study by Pavlovcinová et al. (2010) reporting on 229 (12-year-old) children where no ear asymmetry effect on DPOAE responses of children was found.

2.3.1.1.3. Physiological and non-physiological noise

The DPOAE response can be significantly affected by any ambient, physiological or equipment noise (Hall, 2000; Keppler et al., 2010). External environmental noise decreases the reliability of DPOAE response amplitude levels (Keppler et al., 2010).

There are two different phenomena that could contribute to the interference of noise with DPOAE responses, namely, additive and suppressive noise. In the case of the additive noise phenomenon the DPOAE measurement would comprise of the response to the primary tones stimuli plus the additional noises which obscure the response. This problem can be resolved to some extent through averaging of the OAE response. Suppressive noise reduces the overall emission energy through certain cochlear non-linear processes, occurring as a result of the intermodulation distortion of the stimulus and the noise signals. There are only few studies that investigated the effects of noise on

DPOAE responses, but noise as a factor impacting on DPOAE responses should be controlled by the clinician or the researcher (Hall, 2000).

A clinician/researcher has to understand the clinical applications of DPOAE measurements to use them effectively, as discussed in the next section.

2.3.1.2. Clinical applications

DPOAEs can be used in various clinical applications, such as newborn hearing screening, difficult to test populations, non-organic hearing loss assessments, differential diagnosis (e.g. auditory neuropathy), ototoxicity monitoring, and noise induced cochlear damage monitoring (Hall, 2000; HSE, 2011). Since the current study focuses on the early detection of NIHL, only the clinical application of DPOAEs in monitoring NIHL is discussed**.**

2.3.1.2.1. NIHL monitoring

It has been highlighted earlier in sections 1.1 and 2.1 that pure tone audiometry is currently the gold standard test generally used for detecting and monitoring NIHL in different industries (including steel manufacturing factories) where the daily noise exposure rate levels are in excess of 85 dB(A) (Attias et al., 2001; HSE, 2011). A successful hearing screening technique within a health surveillance program should be sensitive and specific (HSE, 2011; Urkin, Bar-David, & Porter, 2015). Several studies have indicated that DPOAEs could be a more sensitive test than pure tone audiometry in the early detection of cochlear function changes caused by excessive noise exposure (Attias et al., 2001; Silva et al., 2012; Vinck et al., 1999; Vinodh & Veeranna, 2010).

Some of the characteristics that define DPOAE responses (viz. being frequency specific, having good test-retest repeatability, and performing better in high frequencies) make them particularly suitable for monitoring NIHL which mostly affects the high frequencies (Balatsouras, 2004). Since DPOAE responses are frequency specific, it is possible to separate and analyze DPOAE specific frequency components (e.g. the NIHL frequency range). Some studies have shown that changes in DPOAE response levels correspond well to changes in pure tone audiometry hearing thresholds, therefore DPOAEs could possibly be used as an effective objective hearing assessment tool to complement conventional pure tone audiometry in the early detection of NIHL in an occupational industrial setting (Attias et al., 2001; HSE, 2011).

2.4. Summary

It is apparent that several studies question the sensitivity of pure tone audiometry in detecting sub-clinical noise induced cochlear changes and pre-clinical hearing loss (Attias et al., 2001; Balatsouras, 2004; Marshall et al., 2001). Furthermore, it is also evident from several studies that DPOAEs could offer a more sensitive test than pure tone audiometry for the early detection of cochlear function changes caused by excessive noise exposure (Attias et al., 2001; Silva et al., 2012; Vinck et al., 1999; Vinodh & Veeranna, 2010). The current study was therefore conceived to address the following research question: Could DPOAEs be applied as a hearing screening health surveillance technique for the early detection of NIHL in subjects working in a noisy steel manufacturing environment?

3. METHODOLOGY

This chapter presents the aims of the study, the hypotheses, and the research design, as well as the ethical considerations, procedures for selection of participants, procedures for recording data, and procedure for statistical data analysis.

3.1. Aims of the study

3.1.1. Main aim

To determine the applicability of DPOAEs as a health surveillance technique for the early detection of NIHL.

3.1.2. Sub aims

3.1.2.1. To evaluate the DPOAE response amplitude levels in workers in the steel manufacturing industry who are exposed to noise but present with normal audiometric thresholds.

3.1.2.2. To determine the proportion of present DPOAEs in workers in the steel manufacturing industry who are exposed to noise but present with normal audiometric thresholds.

3.1.2.3. To determine the repeatability of DPOAE measurements using a single probe fit paradigm.

3.1.2. 4. To determine the test duration of the measurement of DPOAEs in comparison with standard screening audiometry.

3.2. Hypothesis

3.2.1. Null hypothesis

The null hypothesis of the current study: DPOAEs are not sensitive enough to be used as a health surveillance technique for the early detection of NIHL.

3.2.2. Alternative hypothesis

The alternative hypothesis of the current study: DPOAEs are sensitive enough to be used as a health surveillance technique for the early detection of NIHL.

3.3. Research design

The research design outlines and specifies relevant processes to be performed under given conditions to drive the research methodology and to answer the research question (Bless, Higson-Smith, & Kagee, 2006; Walsh & Wigens, 2003). A cross-sectional descriptive design was selected for the current study. The study used the DPOAE response amplitude levels and the proportion of present DPOAEs to compare participants exposed to excessive noise (hereafter referred to as the *noise exposed group*) to a non-exposed group (the *control group*). The study also compared the duration of performing DPOAE measurements to the duration of performing conventional screening pure tone audiometry. The design of this study therefore suits the definition of a cross-sectional study, where two different groups (exposed versus non-exposed) are compared within the same parameters, which are measured within a short period of time (Ho, Peterson, & Masoudi, 2008; Sim & Wright, 2000; Williams, 2007).

Cross-sectional studies fall within the category of descriptive studies (Sousa, Driessnack, & Mendes, 2007; Williams, 2007). The results of the current study provided further

information regarding the applicability of DPOAEs in the early detection of NIHL and can be used by other researchers in future, to investigate similar noise exposed target populations. One of the advantages of using this design is that different variables can be measured simultaneously within a short period of time with limited resources (Ho et al., 2008). The current study managed to measure and compare DPOAE response amplitudes for the two groups in a short period of time, with limited resources. The results were used to determine if there was any difference in DPOAE response amplitudes or in the proportion of present DPOAEs between the two groups. The results were also used to determine the within-subject short term test-retest repeatability and reliability of DPOAEs. The duration of performing pure tone audiometry was also compared to the duration of performing a set of DPOAE measurements to determine whether there is a statistically significant difference in the duration for performing the two procedures. The primary independent variables of this study were noise exposure (with two categorical levels, non-exposed versus exposed), DPOAE testing, and pure tone audiometry testing. The primary dependent variables of this study were the measured DPOAE response amplitude levels (dB SPL) in each condition, the percentage of present DPOAEs (%) in each condition and the recorded time (seconds) for each procedure.

3.4. Ethical considerations

The research proposal for this study was approved by the Faculty of Humanities, University of Pretoria Research and Ethics Committee (REF NO: 14336392), as well as the Botswana Ministry of Health Research Committee (REF NO: PPME-13/18/1 VOL IX (154)). The researcher obtained permission from Bamalete Lutheran Hospital for their

employees to participate in this study and also for the researcher to use the hospital facilities and equipment to perform all the procedures and tests involved in the research. Permission was also obtained from the Fencing Centre Ltd Company for their employees to be released from work and to participate in this study. The participants from Fencing Centre were paid BWP 50, to cover transport costs to and from the hospital. The researcher obtained informed consent from all the participants before embarking on data collection. Upon agreeing to participate in the study all participants completed a consent form (Appendix B). Participants were free to withdraw from the study at any stage of the study if they wished to do so, without any prejudice. The participants' personal and medical information was kept confidential.

3.5. Participants

3.5.1. Inclusion and exclusion criteria

Participants were included or excluded from this study based on specific criteria. These criteria were applied in order to reduce the influence of confounding factors on the results of the study.

3.5.1.1. Otological status

To take part in this study all participants had to be otologically normal. Each participant had to be in a normal state of health, and free from any signs and symptoms of ear disease. Participants had to have no history of ear infections/discharges, and also no history of exposure to potentially ototoxic drugs/agents, as these could reduce the DPOAE responses (Kei, Brazel, Crebbin, Richards, & Willeston, 2007; Reavis et al.,

2011). The questionnaire that was used to determine the otological and health status of each participant can be found in Appendix E.

3.5.1.2. Normal external ear

Participants underwent an otoscopic examination prior to DPOAE measurements to ensure that the participants' ear canals were clear of occluding wax or any foreign body and to rule out discharging ears. Any occluding wax or foreign body was removed before the DPOAE measurements as such substances could block the probe tips and interfere with the DPOAE stimuli and responses. Any participant with discharging ears or with ear infections was excluded from this study and were appropriately referred for medical management at the Ear Nose and Throat (ENT) clinic.

3.5.1.3. Middle ear function

Middle ear problems can significantly reduce DPOAE response amplitudes (Kei et al., 2007), therefore it was important to perform immittance measurements to rule out any middle ear pathology prior to performing the DPOAE measurements. The current study included only participants with type A tympanograms with a middle ear pressure of ± 50 daPa, middle ear compliance of 0.3 to 1.5 ml, and ear canal volume of 0.6 to 2 ml (Mikolai, Duffey, & Adlin, 2006). Type C tympanograms with middle ear compliance of 0.3 to 1.5 ml and middle ear pressure of -51 to -400 daPa indicated Eustachian tube dysfunction. Ipsilateral acoustic reflexes were performed at 0.5, 1, and 2 kHz. Ipsilateral acoustic reflexes are sensitive to middle ear pathologies. Acoustic reflexes were considered to be normal when they could be elicited at 80 to 100 dB HL at the

aforementioned frequencies. Participants with absent or elevated acoustic reflexes were excluded from the study, as that could be an indication of middle ear pathology (Gelfand, 2002).

OAE measurements are largely dependent on the integrity of the middle ear and the cochlea (Hall, 2000). The measurement of OAEs is negatively affected by middle ear pathology (Wang, Wang, Zhang, & Cao, 2009), therefore in the current study participants with middle ear pathology (e.g. ear drum perforation, otitis media with effusion, Eustachian tube dysfunction) were excluded from the study and appropriately referred to the ENT clinic for treatment.

3.5.1.4. Normal hearing status

All participants in this study had normal pure tone hearing thresholds (≤ 15 dB HL) in both ears at 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz. The reason for testing frequencies outside the OAE response frequency spectrum was to ensure that only subjects with completely normal hearing were included in this study (Marshall & Heller, 1996). Participants with hearing thresholds > 15 dB HL at any of the tested frequencies were excluded from this study.

3.5.1.5. Noise exposure

Participants were divided into two groups. Those who had been exposed to noise were eligible take part in this study if they had worked in a noisy steel manufacturing factory for at least one year. The researcher considered this duration of noise exposure (one year

or more) as a long-term noise exposure that could possibly reduce the DPOAE response amplitude levels. The control group participants were eligible to participate in this study only if they had no history of occupational or recreational noise exposure. In order to exclude the effects of TTS, all participants avoided excessive noise exposure for at least 48 hours prior to the measurements. TTS is reported to disappear 16 to 48 hours after noise exposure (Kirchner et al., 2012).

3.5.1.6. Age

This study included only participants aged between 18 to 55 years. There is still controversy regarding whether age alone does have an effect on DPOAEs or not, as discussed in section 2.3.1.1.1. In view of this controversy the current study controlled for age, to avoid any possible effects of age or presbyacusis. Since age related hearing loss can decrease DPOAE response amplitudes (Hoth et al., 2010), subjects older than 55 years were excluded from the study.

3.5.1.7. Present DPOAEs

Participants were included in the final analysis of the DPOAE measurements only when they displayed present average DPOAEs for at least one of the following frequencies; 2002, 3174, 4004, 6348, and 7996 Hz. This was determined by averaging the DPOAE response amplitudes that were 6 dB SPL or more above the noise floor level for any of the aforementioned test frequencies (Silva et al., 2012). A detailed description of this process can be found in section 3.6.2.1.4.

3.5.2. Informed consent

All participants signed an informed consent form (Appendix B) at the beginning of the study. Participants were free to withdraw from the study at any stage of the procedure if they wished to do so, without any prejudice. However, no participant withdrew from the study. The data collection from each participant started only after the participant had signed the consent form.

3.5.3. Materials and apparatus for sample population selection

The materials and apparatus used in the selection of participants in this study consisted of an otoscope, immittance meter, an audiometer**,** and the OAE system.

3.5.3.1. Otoscope

To rule out any outer ear pathology or other contraindications, a Riester otoscope was used for performing otoscopic examinations. The otoscope uses a rechargeable battery. Appropriate sterilized adult size reusable specula were used, based on the size of the participants' ear canals.

3.5.3.2. Immittance meter

The GSI-38 clinical immittance meter (calibrated 26/11/2014) was used to perform Y-226 Hz tympanometry, to confirm normal middle ear status of each participant and to perform ipsi-lateral acoustic reflexes at 0.5, 1, and 2 kHz.

3.5.3.3. Audiometer

A GSI 61 (2-channel) clinical audiometer (calibrated 26/11/2014) was used to determine the audiometric thresholds of the participants in both groups. TDH-50 headphones were used to deliver the stimulus from the audiometer to the participant, and the participant used a response button to respond. The audiometric tests for both groups were performed using the same audiometer in the same double walled soundproof booth at Bamalete Lutheran hospital.

3.5.3.4. OAE system

DPOAEs were recorded using the Otodynamics DP ILO 292 USB Echoport, which was connected to the OAE probe and a portable personal computer (PC). The whole system was controlled by the Otodynamics ILO version 6 software installed in HP 550 laptop PC which uses a Windows 7 operating system. The DPOAE measurements for the two groups were carried out in the same doubled walled sound-treated room at Bamalete Lutheran Hospital.

3.5.4. Procedure for selection of sample population

Before commencing the DPOAE recordings the following procedures were carried out to ensure that the participants fulfilled the inclusion/exclusion criteria of the study.

3.5.4.1. Health assessment questionnaire

After the participant had signed the consent form, a health assessment questionnaire (Appendix E) was completed to rule out any medical, otological, and audiological

conditions that may have affected the auditory system and consequently influenced the diagnostic measurements (Kei et al., 2007; Reavis et al., 2011). The questionnaire was administered by the researcher. To maintain participant confidentiality each participant was assigned a number which was used to identify the participant in all the test results records. Participants with any history of hearing disorders, tinnitus, ear operations, ear infections, use of ototoxic medications/agents, and other health conditions that could have affected the auditory system (e.g. diabetes mellitus, hypertension, tuberculosis, malaria) were excluded from the study to avoid factors that may possibly influence the DPOAE measurements. History of noise exposure was also taken from participants and where applicable types of hearing protectors used were determined for those exposed to noise. The answers from the health assessment questionnaire were documented, and helped the researcher in determining participants that could proceed to the next stage, viz. otoscopic examination. All the results of subsequent tests were accordingly recorded on the appropriate test results forms.

3.5.4.2. Otoscopic examination

An otoscopic examination was performed in both ears of each participant by the researcher, an experienced audiologist, to rule out any possible outer or middle ear pathology. The participant had to have normal landmarks, normal tympanic membranes with a light reflex, no wax, no ear discharge, and no foreign body or any noticeable pathology on the ear canal. The otoscopic findings were appropriately recorded on the results recording sheet (Appendix F). Any occluding wax was removed by the researcher before the participant could proceed with other tests. Participants with any abnormal ear

canals, ear discharges, pus, blood traces, foreign body, otitis externa, dull/retracted tympanic membranes, perforated ear drums, or any noticeable pathology of the tympanic membrane or in the ear canal were referred to the ENT clinic within the hospital for medical management. Only participants with normal otoscopic findings proceeded to immittance measurements.

3.5.4.3. Immittance testing

Tympanometry and acoustic reflexes were performed by the research audiologist for each participant with normal otoscopic findings to ensure that participants had normal middle ear function (Ramma et al., 2010). The participant was comfortably seated in a chair, given instructions, and informed that he would feel some pressure in the ear and hear a humming sound as well as some loud beeping tones. They were further advised to avoid any body movements, coughing, or yawning during the test as this could affect the test results. Tympanometry was performed, automatically followed by the acoustic reflex measurements at the selected frequencies (0.5, 1, and 2 kHz). Only participants with normal tympanograms and acoustic reflexes were included in the study. Normal tympanogram was considered to be a type A tympanogram, with a middle ear pressure of -50 to +50 daPa **(**Shanks & Shohet, 2009), middle ear compliance of 0.3 to 1.5 ml and ear canal volume of 0.6 to 2 ml (Mikolai et al., 2006). Normal acoustic reflexes were classified as those with acoustic reflex thresholds (ARTs) of 80 to 100 dB HL at 0.5, 1, and 2 kHz (Gelfand, 2002). The immittance results were recorded on the results recording sheet (Appendix F). Participants with abnormal immittance results were

referred to the ENT clinic for medical management. Participants with normal immittance test results proceeded to the audiometry phase of the study.

3.5.4.4. Pure tone audiometry (air conduction)

To ensure that the participants have normal audiometric thresholds, the research audiologist performed air conduction pure tone audiometry in both ears of each participant. The participant was comfortably seated in a double walled soundproof booth. The participant was instructed to press the response button every time he heard a beeping tone, no matter how faint the tone sounds were. TDH-50 earphones were then placed on the participant's ears, and the response button handed to the participant. The air conduction hearing thresholds were then measured at 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz following the recommended procedure (British Society of Audiology, 2011) for pure tone audiometry. The duration of the full pure tone audiometry procedure was recorded. It was then used later during analysis to compare to the duration for performing DPOAE testing. The audiometric results were printed out and recorded on the results recording sheet (Appendix F). Participants with hearing loss in either ear were appropriately managed and followed up by the researcher within the audiology clinic, and where necessary referrals to the ENT specialist for medical management were made. Participants with normal hearing thresholds ≤ 15 dB HL proceeded to DPOAE measurements.

3.5.5. Description of the sample population

The participants were assigned to each of the two groups (non-noise exposed participants and the noise exposed steel manufacturing factory workers) in the following manner.

The control group (non-noise exposed) consisted of participants with no history of occupational noise exposure. These were clinical staff members recruited from Bamalete Lutheran Hospital. Information was placed on the hospital notice boards to recruit the participants to the study. Participants were then subjected to the inclusion/ exclusion criteria outlined in section 3.5.1.

The noise exposed group participants were recruited from a steel manufacturing factory (Fencing Centre Pty Ltd) and had to have been working in a noisy plant for at least one year in order to take part in the study. The inclusion/exclusion criteria were discussed with the section manager, where after the section manager addressed the employees about the researcher's research interests and collected the names of all the employees who were willing to participate. The researcher contacted the interested participants individually and scheduled a date and time with them for the screening tests and data collection. This information was then relayed to the section manager to make the necessary arrangements to release the employees from work to enable them to participate in the study. The researcher then selected the participants based on the inclusion/exclusion criteria outlined in section 3.5.1. The researcher determined that the participants from the noise-exposed group were all men; therefore women were excluded from the control group as well to avoid any possible gender bias in the results of the study. The average noise exposure duration was 10.9 ± 6.5 years (exposure duration range was 2 to 22 years). The noise exposed participants were exposed to various types of noise, from noisy machines for drilling, grinding, and welding steel fencing material. The distribution of the noise

exposed group participants according to the duration of noise exposure is shown in Table 1.

Table 1. Distribution of participants according to noise exposure duration

Noise exposure duration (years)	Number of participants
1-5	6
6-10	4
11-15	5
16-20	3
21-25	2

3.5.5.1. Sample size

Forty male participants (excluding the four participants used in the pilot study), all volunteers aged 19 to 55 years who adhered to the study inclusion/exclusion criteria, participated in this study. Twenty participants (40 ears) were from the noise exposed group with a mean age of 36.9 ± 11.5 years (age range 22 to 54 years). The control group consisted of 20 clinical staff members (40 ears) with mean age of 34.6 ± 7.5 years (age range 19 to 55 years). The difference in age profile between the experimental and the control group was not statistically significant. The distribution of the participants from the two groups according to their age profile is shown in Table 2.

Table 2. Distribution of group participants according to age

Age (years)	No. of participants per group	
	Control	Noise exposed
19-29	5	7
30-39	12	5
40-49	2	4
50-55	1	4

3.5.5.2. Statistical power and sample size estimation

The sample size of this study was calculated using the 'Power and sample size calculation' software. Beattie and Bleech (2000) suggested that when using a 95 % confidence interval the difference between the two DPOAE response amplitudes is statistically significant if it approximately exceeds 6 dB SPL. Hall and Lutman (1999) also reported a DPOAE test-retest repeatability standard deviation of 3.1 dB SPL. These values were used for sample size calculation of this study, for a power of 95% at 5% level of significance ($p<0.05$). The calculation required a sample size of at least 16 subjects (8 subjects per group) for the study to have a chance of 95% to truly show the reduction of DPOAE response amplitudes from noise exposure if the effect is present for $p<0.05$ using the relevant descriptive statistics.

3.5.5.3. Pure tone audiometry testing: mean hearing thresholds

All participants from both groups included in this study had normal hearing thresholds of ≤15 dB HL at 0.25 to 8 kHz. The one-sample Kolmogorov-Smirnov test of normality revealed that the mean pure tone audiometry hearing thresholds for the control and the noise exposed group were normally distributed, $p>0.05$. A paired samples t-test was used to compare the right and the left ears pure tone audiometry hearing thresholds. The hearing thresholds did not differ significantly, $p>0.05$ across all the eight tested frequencies, therefore the data from right and left ears were combined for further analysis. The mean pure tone audiometry hearing thresholds for 40 ears of the control group participants versus 40 ears of the noise exposed group participants are shown in Figure 1.

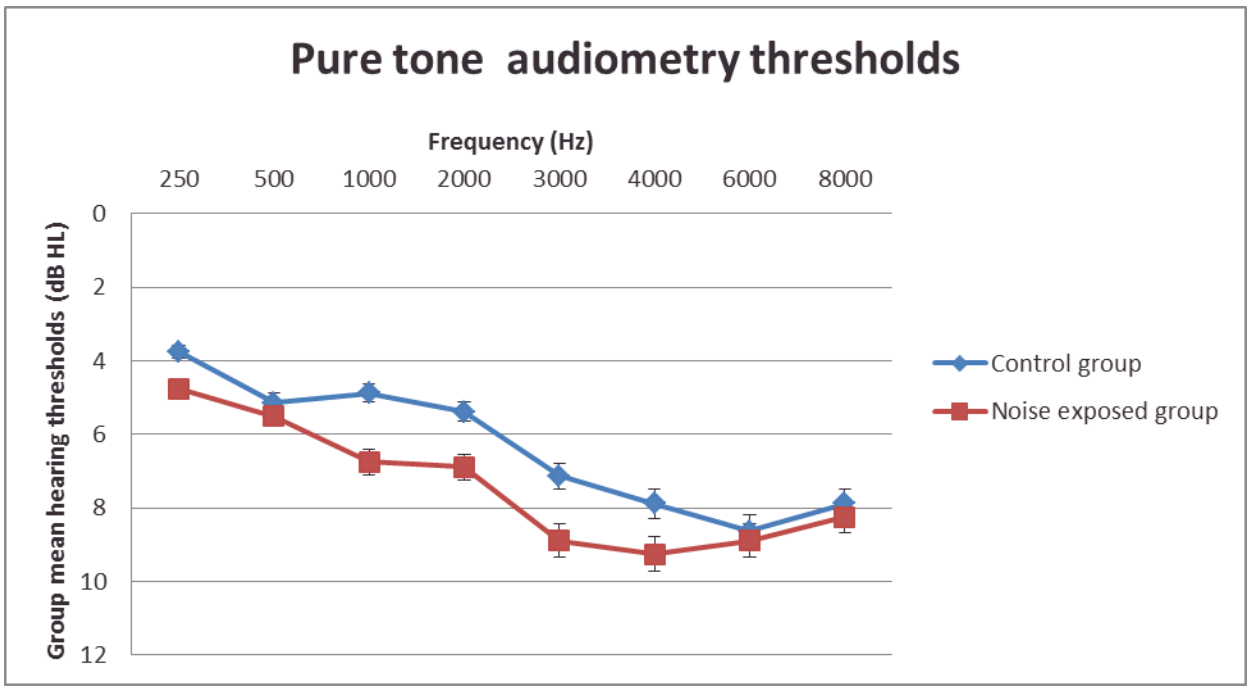


Figure 1. Mean pure tone audiometry hearing thresholds for the control and the noise exposed groups. Error bars represent a ±5% error range for each frequency.

As shown in Figure 1, the mean pure tone audiometry hearing levels for the control group ranged from 3.75 dB HL (SD=5.40 dB) at 250 Hz to a maximum level of 8.63 dB HL (SD=5.31 dB) at 6 kHz. The noise exposed group mean thresholds ranged from 4.75 dB HL (SD=5.42 dB) at 250 Hz to a maximum of 9.25 dB HL (SD= 4.74 dB) at 4 kHz. The mean hearing thresholds for the noise exposed group were higher than the mean hearing thresholds for the control group across all the tested frequencies from 250 Hz to 8 kHz, but the difference between the two groups across all the frequencies (determined using independent samples two tailed t-test) was not statistically significant, $p>0.05$.

3.5.6. Pilot study

A pilot study was carried out prior to collecting the data for the main study. Four male participants (two from each group) were used for the pilot study. Their results were excluded from the analysis of the results of the main study. These participants were selected according to the inclusion/exclusion selection criteria that were followed for the selection of all participants. The pilot study helped the researcher to estimate the duration of testing per participant to collect the data, and to allow for any adjustments to be made where necessary before commencing the main study data collection. This was to ensure that the data collection processes of the study were feasible and the researcher was well prepared before starting the main study. The average duration for data collection per participant obtained from the pilot study are shown in Table 3.

Table 3. Pilot study procedure - average duration per participant

Procedure	**Average duration per participant**
Participant information & consent form signing	6 minutes
Health assessment questionnaire	6 minutes
Otoscopy	1 minute
Immittance tests	4 minutes
Air conduction pure tone audiometry	13 minutes
DPOAE measurements	10 minutes
Total data collection duration	**40 minutes**

The pilot study indicated that the total average time of 40 minutes was required for data collection per participant. No problems were encountered during the pilot study, therefore no changes were made to the planned data gathering procedures. As the pilot study

indicated that carrying out this study would be feasible the researcher proceeded to carry out the main study.

3.6. Data collection

3.6.1. DPOAE recording setup

DPOAEs were recorded using the Otodynamics DP ILO 292 USB Echoport, connected to the OAE probe and a portable personal computer (PC). The whole system was controlled by the Otodynamics ILO version 6 software installed in HP 550 laptop PC using a Windows 7 operating system. For a typical DPOAE measurement, two tone stimuli were generated from the PC. This was then converted to an analogue signal with the digital-to-analogue converter (DAC) incorporated within the ILO 292 device. The signal was subsequently amplified and transmitted to the ear canal through two earphones coupled within the soft OAE probe. The OAE generated from the cochlea was recorded in the ear canal by a microphone coupled within the OAE probe. This low level signal was then amplified and converted to a digital signal using an analogue-to-digital converter (ADC) within the ILO-292 device. This digital signal was transmitted to the PC for synchronous averaging, storage, analysis, and display. The equipment set-up used for recording DPOAEs is illustrated in Figure 2.

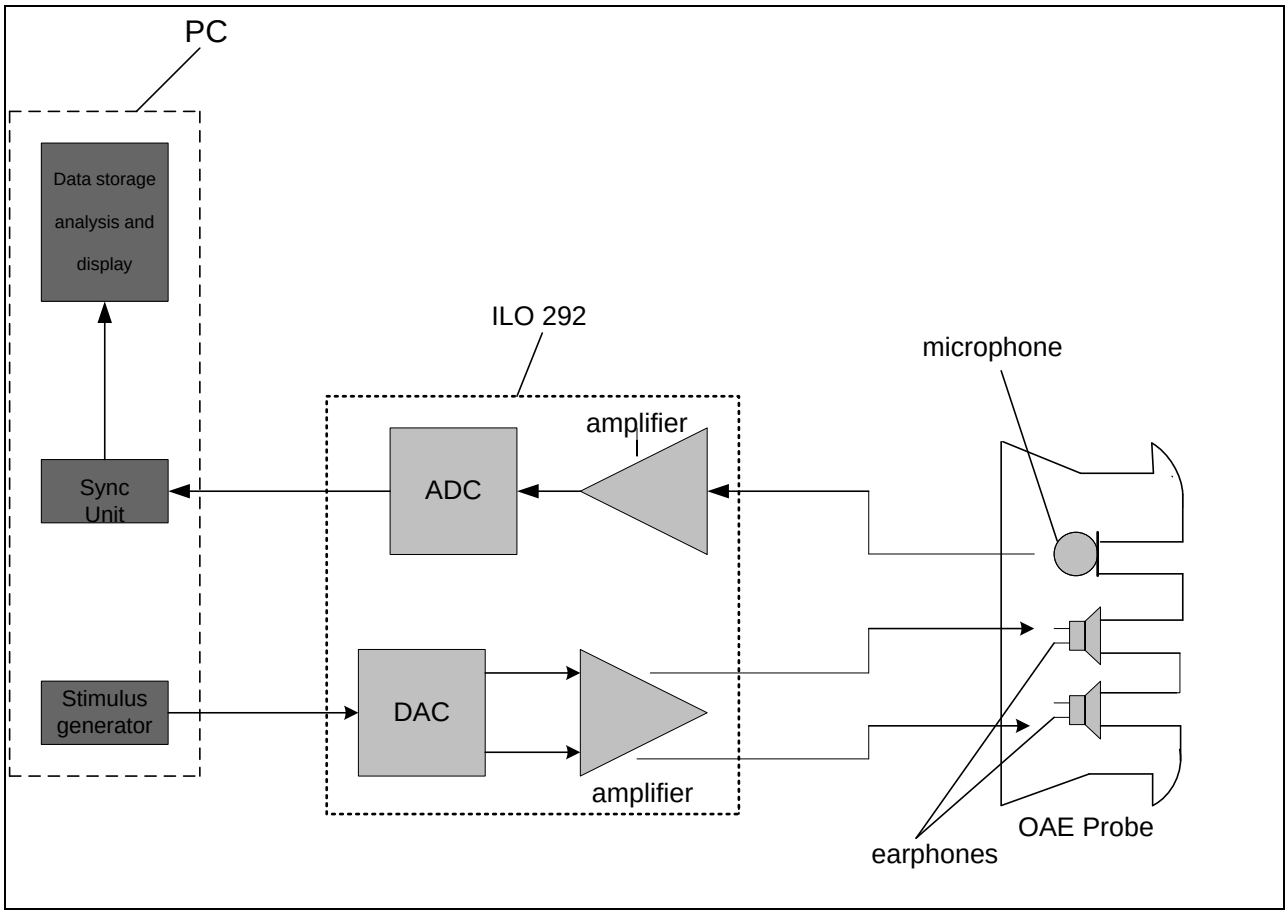


Figure 2. Schematic diagram for equipment set-up used to record DPOAEs.
The arrows indicate the direction and path followed by the acoustic signal from the stimulus generator in the PC to the earphone incorporated within the OAE probe placed in external ear canal, and the direction and path followed by the OAE response recorded in the microphone within the OAE probe to the processor (responsible for data storage, analysis and display) in the PC.

3.6.2. Procedure for recording of data

3.6.2.1. DPOAE testing

All the procedures followed to perform the DPOAE measurements are discussed below.

3.6.2.1.1. Calibration

To ensure that the DPOAE recording system was not faulty, a probe calibration was performed at the beginning of each session of recordings. This was done by inserting the probe into a 1 cc cavity placed on a non-vibrating surface. The probe has two ports, one

has two speakers for stimulus presentation and another has a microphone for detection and recording of the emissions (Bowman, Brown, & Kimberley, 2000). After securely sealing the probe in the 1 cc cavity, the calibration test was run. The calibration results were then compared to the standard values previously saved in the system software, the accepted difference was ± 2 dB SPL. Prior to DPOAE measurements, a check fit procedure was performed. A flat spectral frequency response between 0.5 and 6.0 kHz was obtained before proceeding with the recordings (Attias et al., 2001).

3.6.2.1.2. Stimulus parameters

After obtaining a satisfactory response from the check fit procedure, DPOAE measurements were recorded in both ears of each participant by the research audiologist using the ILO 292 Otodynamic analyzer in the DP test mode. The researcher maintained the default settings of the Otodynamics DPOAE test parameters. The 2f1-f2 DPOAE response amplitudes were measured in the two groups of subjects (the control versus the noise exposed group) using the stimulus parameters outlined below. Two primary tones were presented simultaneously at frequencies f1 and f2 (f2>f1) at constant stimulus levels L1=65 dB SPL and L2=55 dB SPL, such that L1-L2=10 dB SPL. The f2/f1 ratio was fixed at 1.22. These frequency ratio and stimulus levels have previously been reported to produce more robust DPOAEs (Hall, 2000; Kemp, 2002; Marshall et al., 2001; Ziarani & Konrad, 2004).

The primary tones were presented in such a way that the f2 frequencies corresponded with the audiometric frequencies at 2, 3, 4, 6, and 8 kHz, with recordings done at three points per octave (Attias et al., 2001). DPOAEs were considered to be present when the

DPOAE response amplitude was 6 dB SPL or more above the noise floor for a specific test frequency (Silva et al., 2012). A detailed description of when the DPOAEs were considered present is outlined in section 3.6.2.1.4.

3.6.2.1.3. 2f1-f2 DPOAE measurements

The DPOAE measurements for the two groups were performed by the research audiologist in a doubled walled sound-treated room at Bamalete Lutheran Hospital. The DPOAE measurements were carried out with participants comfortably sitting upright on a chair in a doubled walled sound-treated room in order to reduce the ambient noise levels, since high noise levels could interfere with the DPOAE measurement results (Keppler et al., 2010). Kemp (2002) indicates that ambient noise levels ≤ 40 dB(A) are recommended when performing OAE measurements. The precision sound level meter (Bruel & Kjaer type 2232) was used to monitor the noise levels during the DPOAE measurements. The ambient noise levels were maintained at ≤ 35 dB(A) throughout the course of the recordings. The probe calibration was performed as indicated in section 3.6.2.1.1.

The following instructions were given to each participant before starting the DPOAE measurements: *'Now I am going to put this soft tip into your ear to measure your hearing. You will hear a clicking sound in your ear. I would like you to relax as much as possible, and not to move or swallow during the test. I will start the recordings in the right ear and proceed to the left ear immediately after completing the right ear measurements. The test will take about 10 minutes. Feel free to stop me at any point if you want to. Do you have any questions?*'

The two groups of participants underwent the same DPOAE recordings, using the Echoport ILO 292 system. Appropriate sized probes were selected according to each participant's ear canal size. The probe was snugly and securely placed in the participant's ear canal, and the probe cable positioned well to prevent it from making noise when the participant moved. A good probe fit was necessary to optimize the DPOAE response, reduce the effects of noise, and reduce the possibility of losing the low frequency stimulus energy (Kemp, 2002; Prieve & Fitzgerald, 2002).

To improve the reliability of the results the current study used the single probe fit paradigm. For each participant the DPOAE recordings were repeated four times in one ear without removing the probe tip between measurements. After testing the first ear, a new probe tip was used in the second ear and DPOAE recordings were repeated four times again without removing the probe tip. This single probe fit paradigm method has been shown to produce more repeatable and reliable DPOAE responses (Keppler et al., 2010; Valero & Ratnam, 2011; Wagner, Heppelmann, Vonthein, & Zenner, 2008).

The DPOAE measurements were performed as per the stimulus parameters outlined in section 3.6.2.1.2. The DPOAEs were recorded in the 2 to 8 kHz frequency range. It is reported that DPOAEs are more stable over this frequency range (Hoshino et al., 1999). The DPOAEs were then produced at the 2f1-f2 frequency region. The 2f1-f2 DPOAE response amplitudes (in dB SPL) were recorded as a function of stimulus frequency (f2) (Grabham et al., 2013). DPOAE frequency analysis was performed at 2002, 3174, 4004, 6348 and 7996 Hz. The DPOAE response amplitudes for the four repeated recordings

were averaged, to give an average DP response amplitude value at each stimulus frequency for each ear. Similarly the DPOAE noise floor levels for the four repeated recordings were averaged, to give an average noise floor level at each specific stimulus frequency for each ear. The duration of performing DPOAE measurements for each participant was also recorded. It was used later during analysis to compare to the duration of performing audiometry. The duration for a set of DPOAE recordings consisted of the duration of giving the participant instructions, probe placement in each ear, four repeated recordings in the right ear, and four repeated recordings in the left ear. The DPOAE results and the duration of the procedure for each participant were recorded on the DPOAEs recording sheet (Appendix G). The DPOAE test data for each participant was then saved on the PC hard disc drive, and on compact discs which were labeled and stored appropriately.

3.6.2.1.4. Present 2f1-f2 DPOAEs

The 2f1-f2 DPOAEs were considered to be present only when the average DPOAE response amplitude level was at least 6 dB above the average noise floor level at a specific frequency (Silva et al., 2012). Only DPOAE responses with amplitude levels that were 6 dB or more above the noise floor levels at specific frequencies were considered for further analysis. Thus, for each frequency the difference between the average DPOAE response amplitude and the average noise floor level was calculated, and if the difference was below 6 dB SPL, the OAE was not considered to be present at that frequency, and the data at that frequency was excluded from the final data analysis. This criterion was used as the criterion for including data in the final analysis. Considering OAE data per

frequency assisted in determining patterns of the affected frequencies (e.g. whether the DPOAE response amplitude reduction is greater in the NIHL frequency region). Since each frequency was analysed separately, the absence of DPOAEs at a particular frequency did not affect the inclusion of the OAE data in subsequent frequencies with present OAEs. Wagner et al. (2008) report that signal-to-noise-ratio (SNR) has no significant influence in the test-retest repeatability of DPOAE measurements as long as the SNR is ≥ 6 dB SPL.

3.6.2.2. Avoiding experimental bias

There are various ways in which the researcher could conceivably bias the data gathering. One such an example is by performing the test differently for participants in the control group and the participants in the noise exposed group. Ways in which the researcher could influence the results are the following:

- The quality of the probe-fit which could affect the stimulus amplitude, waveform, and frequency content.
- The researcher's decisions following undesirable events which might require a test to be abandoned, such as the probe falling out, the subject sneezing or coughing excessively, or excessive environmental noise.
- The researcher's decisions regarding the exclusion of data from the final analysis.
- The researcher's decisions regarding the final analysis that was undertaken.

It was therefore imperative to specify at the outset a standard test protocol which would be rigorously adhered to throughout the course of the study. This was done to prevent the

researcher from taking biased decisions in the final analysis. The protocol for addressing the aforementioned four issues is described in the following sections.

3.6.2.2.1. Probe-fitting procedure

For each ear, the appropriate OAE probe tip size that gives a snug fit was selected by trial fitting without stimulus presentation prior to the start of the DPOAE recordings. The same probe tip was used for all the measurements in that ear and a new probe tip was used for the other ear. For each measurement the probe was inserted into the ear canal until the researcher felt that a secure fit has been achieved. After snugly fitting the probe tip, no further adjustments of the probe were made. The recording started immediately after performing the checkfit procedure.

3.6.2.2.2. Action in case of a test being abandoned

Whenever there was a need for the test to be abandoned, the participant was given five minutes silent break, and then both tests for each ear were repeated. The test was abandoned whenever the researcher judged that it was necessary due to an unusual event, such as the probe falling out or excessive noise contamination.

3.6.2.2.3. Inclusion criteria for data in the final analysis

Data of participants were included in the final analysis only when their DPOAE response amplitudes were 6 dB SPL or more above the noise floor for each test frequency. A detailed description of this process can be found in section 3.6.2.1.4. Since each

frequency was analyzed separately, the inclusion of data in the final analysis was determined per frequency, thus the absence of DPOAE at a particular frequency, did not affect the inclusion of the OAE data in subsequent frequencies with present OAEs.

3.6.2.2.4. The format of the final analysis

The final statistical analysis described in section 3.7 was strictly adhered to.

3.7. Statistical data analysis

Commercially available software, IBM SPSS version 18 was used to perform all analyses. The DPOAE responses were described and analysed using both descriptive and inferential test statistics. The normality of the data distributions for the dependent variables was tested using the one-sample Kolmogorov-Smirnov test. The mean DPOAE response amplitudes in the control versus the noise exposed groups were compared per frequency using the independent samples two tailed t-test (Field, 2009). The percentage of present DPOAEs for the control versus the noise exposed groups was compared using the chi square test or the Fisher's exact test (Field, 2009). The DPOAE response amplitude test-retest repeatability and reliability for the two groups were determined using one way repeated measures ANOVA and the intraclass correlation coefficient respectively (Field, 2009). The mean test duration of DPOAE testing versus conventional screening pure tone audiometry testing was compared using a paired samples two tailed t-test. All tests were considered statistically significant at $p<0.05$ (Field, 2009).

4. RESULTS AND DISCUSSION

In this chapter the results of the study are presented and discussed. The research findings are interpreted and discussed using the currently available literature to support the present findings and to establish the clinical implications of these research findings. The main aim of the study was divided into four sub-aims. The results pertaining to each sub-aim are presented and their subsequent clinical implications are discussed accordingly. The main aim of the study was to determine the applicability of DPOAEs as a health surveillance technique for the early detection of NIHL in workers at a steel manufacturing industry. To achieve this aim, the study compared the DPOAE response amplitude levels and the proportion of present DPOAEs for different frequencies between the control group and the noise exposed group participants presenting with normal hearing audiometric thresholds ≤15 dB HL. The study further evaluated the short term test-retest repeatability of DPOAE measurements, and also compared the total duration of performing DPOAEs to the duration of screening audiometry.

4.1. DPOAE testing: response amplitudes

The one-sample Kolmogorov-Smirnov test of normality revealed that the mean DPOAE response amplitude levels at each of the five recorded frequencies (2002, 3174, 4004, 6348 and 7996 Hz) for the control and the noise exposed group were normally distributed, $p>0.05$. A paired samples t-test was used to compare the right ear to the left ear DPOAE response amplitudes. This was done to avoid the effect of ear asymmetry on DPOAEs (Keogh et al., 2001). Since the right and the left ear responses did not differ

significantly, p>0.05 across all the five test frequencies, their data were combined for further analysis.

4.1.1. Mean DPOAE response amplitude comparisons

The mean DPOAE response amplitudes for the 40 ears of the control group and the 40 ears of the noise exposed group were statistically compared using the independent samples two tailed t-test. The mean DPOAE response amplitudes at each test frequency for the control group and the noise exposed group participants are shown in Table 4.

Table 4. Mean DPOAE response amplitudes for the control and the noise exposed groups.

DP-gram Frequency(Hz)	Mean DPOAE Amplitude ± SD (dB SPL)		P-Value
	Control	Noise exposed	
2002	13.6 ± 4.5	6.6 ± 5.9	p<0.001
3174	12.5 ± 4.5	4.4 ± 5.1	p<0.001
4004	12.5 ± 4.1	4.8 ± 4.4	p<0.001
6348	8.2 ± 6.5	1.7 ± 4.0	p=0.01
7996	1.1 ± 5.2	-2.4 ± 1.1	p=0.001

Mean DPOAE response amplitudes for the control and the noise exposed groups were compared using the independent samples t-test.

The mean DPOAE response levels for both groups decreased progressively with an increase in stimulus frequency. As shown in Table 4 the noise exposed group showed statistically significantly lower DPOAE response amplitudes compared to the control group for all the tested frequencies: at 2002 to 4004 Hz (p<0.001), at 6348 Hz (p=0.01) and at 7996 Hz (p=0.001). This occurred despite the fact that all the participants from both groups had normal audiometric thresholds (no statistical difference between the two groups), suggesting OHC damage from noise exposure in the noise exposed group, even

though that was not yet evident from the audiogram. Comparison of mean DPOAE response amplitudes for the two groups shows that the noise exposed group DPOAE response amplitudes were lower than for the control group by 7 dB SPL ($p<0.001$) at 2002 Hz. The DPOAE response amplitudes were greatly reduced by 8.1 and 7.7 dB SPL ($p<0.001$) at 3174 and 4004 Hz respectively. At 6348 and 7996 Hz the noise exposed group DPOAE response amplitudes were lower than those of the control group by 6.5 and 3.5 dB SPL ($p=0.01$, $p=0.001$) respectively, showing that the DPOAE response amplitude reduction was more evident at the 3 to 4 kHz frequency region. These DPOAE response amplitude differences at each test frequency between the two groups are illustrated in Figure 3.

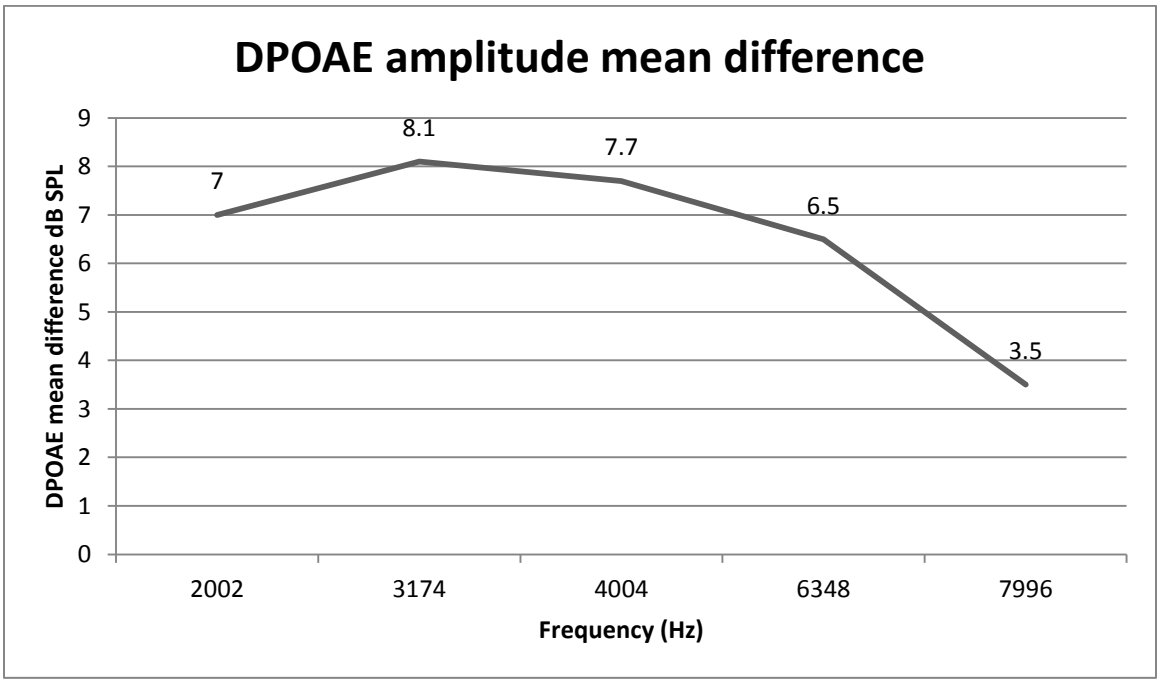


Figure 3. Mean DPOAE response amplitude difference between the control and the noise exposed groups.

As shown in Figure 3 the current study compared the DPOAE response amplitudes registered in 40 ears of the control group to those registered in 40 ears of a noise exposed group (the age difference between the groups was not statistically significant) and found a significant reduction in DPOAE response amplitudes ranging from 3.5 to 8.1 dB SPL at 2002 Hz to 7996 Hz frequency range in the noise exposed group. This was evident despite the fact that all the subjects in both groups had normal audiometric thresholds of ≤15 dB HL and that the difference in the mean pure tone audiometry hearing thresholds between the two groups was statistically insignificant. Thus for this noise exposed participant group the use of DPOAEs made it possible to detect cochlear damage before it was evident on the audiogram (Jaffer & Razi, 2004). The findings of the current study suggest that DPOAE testing could be a more sensitive test than pure tone audiometry in detecting subtle cochlear function changes due to long-term noise exposure. This is consistent with the findings reported by other studies (Atchariyasathian et al., 2008; Attias et al., 2001; Balatsouras, 2004; Job et al., 2009; Vinck et al., 1999; Vinodh & Veeranna, 2010).

As indicated earlier, the current study showed a progressive decrease in DPOAE response amplitudes for both groups as the f2 frequency increased. This decrease was more pronounced in the noise exposed group. The current study further showed when comparing the mean DPOAE response amplitudes between the two groups that the noise exposed group DPOAE response amplitudes were significantly lower at all the tested frequencies, from 2002 to 7996 Hz. The largest differences in emission levels were observed at 3174 and 4004 Hz, where the noise exposed group mean DPOAE response

amplitude levels were lower than the control group responses by 8.1 and 7.7 dB SPL respectively, with a notch shown in the mean DPOAE response amplitude difference at 3174 Hz (Figure 3). This demonstrates the capacity of DPOAEs as an instrument to provide frequency specific information. DPOAEs have already demonstrated in other studies the capacity to provide localized cochlear frequency specific information (Atchariyasathian et al., 2008).

The findings of the current study are consistent with several other studies that demonstrated that excessive noise exposure may decrease DPOAE response levels (Atchariyasathian et al., 2008; Attias et al., 2001; Guida, Morini, & Cardoso, 2009; Korres et al., 2009, Vinck et al., 1999). Balatsouras (2004) used 34 workers exposed to industrial noise and 30 non-noise exposed subjects, and found a statistically significant reduction of DPOAE response amplitudes in the noise exposed group from 1587 Hz to 6348 Hz. This is also in agreement with the findings of the study in hand.

In the current study, comparison of the mean DPOAE response amplitudes between the control group and the noise exposed group has shown that DPOAE testing could be a more sensitive test than pure tone audiometry in the early detection of NIHL. This is consistent with reports from other studies (Atchariyasathian et al., 2008; Attias et al., 2001; Balatsouras, 2004; Job et al., 2009; Vinck et al., 1999; Vinodh & Veeranna, 2010).

Vinck et al. (1999) exposed subjects to a 90 dB SPL broad band noise for one hour and found that DPOAEs were significantly reduced while pure tone audiometry hearing thresholds showed no significant threshold shifts at the time. DPOAEs did not fully recover to the pre-exposure reference levels in the 4 kHz frequency region one hour post

exposure. The authors concluded that their findings might suggest that DPOAEs could be used for the early detection of noise induced subtle OHC function changes. However, there are still different views amongst researchers regarding the applicability of DPOAEs in the early detection of occupational NIHL. Seixas et al. (2012) found no evidence to support the use of DPOAEs as a sensitive test to detect noise induced cochlear damage at an early stage. This discrepancy could possibly be due to the different experimental designs used in these studies (Vinck et al., 1999).

4.2. DPOAE testing: percentage of present DPOAEs

DPOAEs were considered to be present only when the DPOAE response amplitude level was at least 6 dB above the noise floor level at a specific frequency. Only present DPOAE responses were included in the final data analysis. Table 5 shows the number of ears with present DPOAEs for the control group and the noise exposed group participants.

Table 5. Number of ears with present DPOAEs for the control and the noise exposed groups

DP-gram Frequency(Hz)	Present DPOAE (N)	
	Control	Noise exposed
2002	40	38
3174	40	33
4004	40	26
6348	39	8
7996	32	7

After determining the number of ears with present DPOAEs for both groups as shown in Table 5, the percentage of present DPOAEs for the control and the noise exposed group was compared using the chi square test or the Fisher's exact test. Figure 4 illustrates the difference in percentage of present DPOAEs between the control group and the noise exposed group participants.

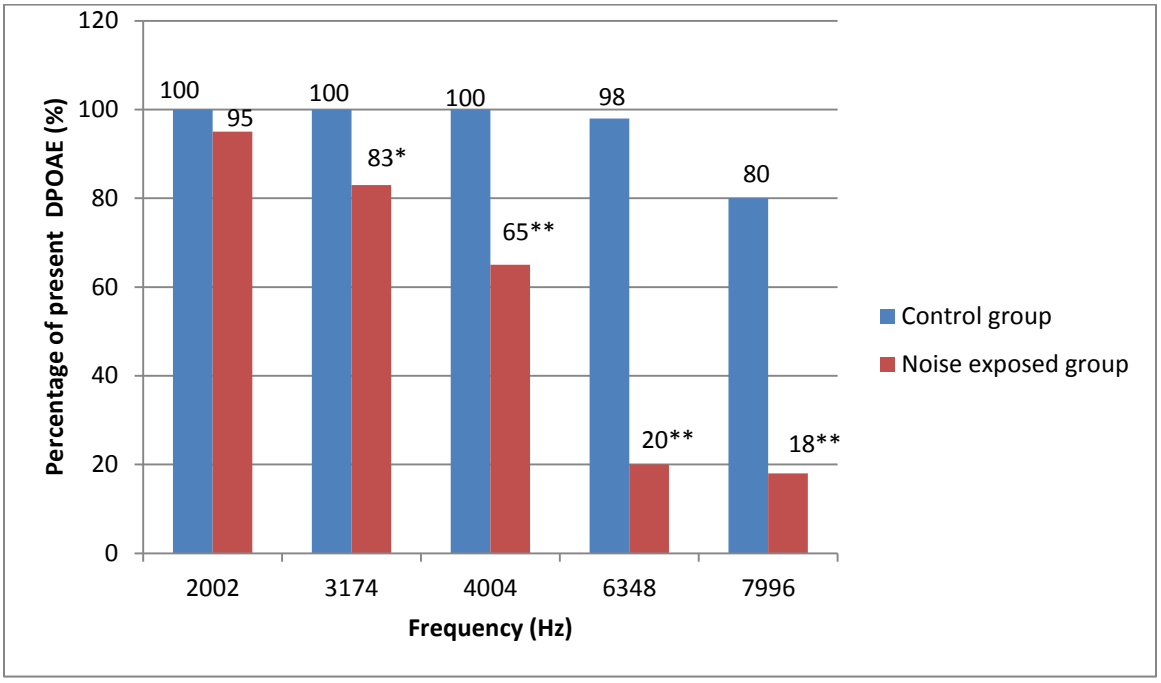


Figure 4. Percentage of present DPOAEs for the control group versus the noise exposed group. Fisher's exact test, *p<0.05, Chi square test, **p<0.001

Table 5 and Figure 4 show a high proportion of present DPOAEs for the control group, 100% for all 40 ears at 2002, 3174, and 4004 Hz, 98% (39 ears) at 6348 Hz and 80% (32 ears) at 7996 Hz. The noise exposed group, on the other hand, showed a lower percentage of present DPOAEs compared to the control group, with the proportion of present DPOAEs progressively reducing from 2002 Hz to 7996 Hz. Thirty eight ears (95%) of the noise exposed group had present DPOAEs at 2002 Hz. This progressively reduced to

83%, 65%, 20% and 18% at 3174, 4004, 6348, and 7996 Hz respectively. As shown in Figure 4, the difference in DPOAE presence between the control group and the noise exposed group was not statistically significant at 2002 Hz ($p>0.05$), but the control group had significantly more present DPOAEs than the noise exposed group, $p=0.012$ at 3174 Hz and $p<0.001$ at 4004, 6348, and 7996 Hz. These results for the proportion of present DPOAEs are consistent with the DPOAE response amplitude results discussed in section 4.1.1.

It is apparent from Figure 4 that the control group showed significantly more present DPOAEs than the noise exposed group. The difference in percentage of present DPOAEs between the two groups was found to be statistically significant from 3174 Hz to 7996 Hz. Similar findings were reported by other studies (Atchariyasathian, Chayarpham, & Saekhow, 2008; Attias et al., 2001; Balatsouras, 2004; Vinodh & Veeranna, 2010). The lower percentage of present DPOAEs observed in the noise exposed group despite the fact that all participants had normal audiometric thresholds (not statistically different between the two groups) further suggests that DPOAE testing could be a more sensitive test in detecting subtle cochlear function changes due to long-term noise exposure than pure tone audiometry. Balatsouras (2004) also reported a lower percentage of present DPOAEs from 1 kHz to 6 kHz in the noise exposed group, which is consistent with the findings of the current study.

DPOAEs are generally present in almost 100% of ears with normal pure tone audiometry hearing thresholds (Tiradentes, Coube, & Costa Filho, 2002). The control group of the study in hand showed a very high percentage of present DPOAEs, 98% to 100 % at 2002

Hz to 6348 Hz frequency range. However, only 80% of the control group had present DPOAEs at 7996 Hz. This lower percentage rate of present DPOAEs observed at 7996 Hz could possibly be ascribed to the fact that DPOAEs are generally poor at 8 kHz (Silva et al., 2012).

The findings of the current study suggest that DPOAE response amplitude reduction or absent DPOAEs could be considered early indicators of NIHL even when the audiogram is normal. The reduction in DPOAE response amplitude may be taken as a signal to take action to prevent further damage to OHCs even before the pure tone audiogram starts showing some hearing loss (Jaffer & Razi, 2004). The significantly lower DPOAE response amplitude levels across all the frequencies observed in the noise exposed group of the current study, accompanied by significantly lower percentage of present DPOAEs in the same group evident in most of the frequencies despite all participants having normal audiometric thresholds, suggests that DPOAEs could detect early noise induced OHC damage before it is evident on the audiogram.

4.3. DPOAE testing: repeatability and reliability

For each participant DPOAEs were repeated four times without removing the probe in each ear to determine the short term test-retest repeatability of DPOAE measurements. The one sample Kolmogorov-Smirnov test of normality showed that the data for the four recordings at each of the tested frequencies (2002, 3174, 4004, 6348, and 7996 Hz) for both the control and the noise exposed groups were normally distributed, $p>0.05$. One

way repeated measures ANOVA was used to test the repeatability of the four recordings for each frequency. The mean DPOAE response amplitudes for the four repeated recordings at each test frequency are shown in Table 6.

Table 6. Mean DPOAE response amplitudes for the four repeated recordings.

DP-gram Frequency (Hz)	Mean DPOAE response amplitudes (dB SPL)				P-Value	Intraclass Correlation Coefficient	95% Confidence Interval
	DPOAE Recordings						
	1st	2nd	3rd	4th			
2002	10.1	10.1	10.3	10.2	0.31	.996	.995 -.997
3174	8.7	8.8	8.9	9.0	0.86	.997	.995 -.998
4004	9.2	9.4	9.6	9.6	0.06	.993	.989 -.995
6348	6.8	7.1	7.3	7.1	0.11	.994	.991 -.996
7996	0.5	0.4	0.5	0.6	0.82	.989	.982 -.994

The mean DPOAE response amplitudes for the four repeated recordings were compared using a one way repeated measures ANOVA, followed by intraclass correlation coefficient for the five frequencies (the data for the control and the noise exposed groups at each frequency were combined).

Table 6 shows that the DPOAE response amplitude levels were not statistically different between the four recordings ($p>0.05$) for each of the five frequencies, 2002 Hz to 7996 Hz. The repeated DPOAE measurements further showed a high degree of reliability with the following intraclass correlation coefficients: .996, .997, .993, .994, and .989 at 2002, 3174, 4004, 6348, and 7996 Hz respectively (Table 6).

The current study revealed reliable test-retest repeatability of DPOAE measurements when using a single probe fit paradigm. The DPOAE response amplitudes for the four repeated measurements across all five tested frequencies from 2002 to 7996 Hz showed

no statistically significant difference and a very high degree of association (intraclass correlation coefficient > .98 across all the test frequencies). These findings are in agreement with those from other studies that demonstrated that DPOAE responses are repeatable and reliable (Jaffer & Razi, 2004; Keppler et al., 2010; Valero & Ratnam, 2011; Wagner et al., 2008). As a result of this reported good test-retest reliability of DPOAEs some researchers are proposing that DPOAEs should be applied as a health surveillance hearing screening tool in industry (Seixas et al., 2005).

4.4. Test duration: DPOAE testing versus pure tone audiometry testing

The duration of performing air conduction pure tone audiometry for each participant was compared to the duration of performing a set of DPOAE recordings (four repeated recordings in the right and the left ears). The one-sample Kolmogorov-Smirnov test of normality showed that the data for pure tone audiometry testing duration and DPOAE testing duration for both groups were normally distributed, $p>0.05$. Performing air conduction audiometry had a mean duration of 591 ± 76.9 seconds and performing a set of DPOAE recordings had a mean duration of 461 ± 68.2 seconds. The mean duration of performing a set of DPOAE measurements was found to be significantly shorter than that of performing a screening pure tone audiometry (paired t-test, $p<0.001$) per participant. This demonstrates that it is less time consuming to perform a set of DPOAE measurements than to perform air conduction pure tone audiometry. To the researcher's knowledge this is the first study to compare the duration of performing DPOAEs to audiometry in adult population. Kreisman, Bevilacqua, Day, Kreisman, & Hall (2013) used 198 preschool participants to compare the mean testing times between DPOAE

screening protocols (1,2,3,4,5 kHz and 2,3,4,5 kHz) and a pure tone testing protocol (1, 2, 4 kHz). Their study reported that the mean testing time for the 1 to 5 kHz and 2 to 5 kHz DPOAE screening protocols were 94.52 seconds and 55.19 seconds respectively, while the mean testing time for the pure tone screening protocol was 213.14 seconds. The DPOAE screening testing times for both protocols were reported to be significantly faster than the pure tone testing time. These findings are therefore consistent with the findings of the current study. Even though there is limited research on comparing DPOAE testing duration to pure tone testing duration, there are many reports suggesting that performing DPOAEs is less time consuming than conventional audiometry (Attias et al., 2001; Guida et al., 2009; Jaffer & Razi, 2004; Vinck et al., 1999; Vinodh & Veeranna, 2010). The results of the current study further suggest that DPOAEs might be used as a quick, objective hearing assessment tool to complement conventional pure tone audiometry in the early detection of NIHL in the steel manufacturing industry (Attias et al., 2001; HSE, 2011; Job et al., 2009).

4.5. Summary

The noise exposed group showed statistically significantly lower DPOAE response amplitudes compared to the control group for all the tested frequencies from 2002 Hz to 7996 Hz. The control group, on the other hand, showed a significantly higher percentage of present DPOAEs than the noise exposed group from 3174 Hz to 7996 Hz. This occurred despite the fact that all the participants from the two groups had normal pure tone hearing thresholds, with statistically insignificant difference between hearing thresholds from the two groups. These results from the DPOAE response amplitudes and

the percentage of present DPOAEs between the control and the noise exposed group suggest that DPOAE testing could be a more sensitive test than pure tone audiometry in detecting subtle cochlear function changes due to long-term noise exposure. DPOAEs also demonstrated the capacity to provide frequency specific information. DPOAE measurements were further found to be highly repeatable and reliable when recorded using the single probe fit paradigm. Comparison of the test duration for DPOAE testing to the duration of pure tone audiometry testing revealed that the mean duration of performing a set of DPOAE measurements was significantly shorter than that of performing conventional screening pure tone audiometry.

5. CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

This chapter presents the conclusion of the current study based on the results presented and discussed in the preceding chapter. It outlines the limitations of the current study and provides recommendations for further research.

5.1. Conclusion

The main aim of the current study was to determine if DPOAEs can be applied as a health surveillance technique for the early detection of NIHL. The significantly lower DPOAE response amplitudes across all the frequencies in the noise exposed group from the current study, accompanied by the lower percentage of present DPOAEs in the same group evident in most of the frequencies despite all subjects having normal audiometric thresholds, clearly suggest that DPOAEs can detect early noise induced OHC damage before it is evident on the audiogram. This is in support of the alternative hypothesis which states that DPOAEs are sensitive enough to be used as a health surveillance technique for the early detection of NIHL. The null hypothesis of the current study postulated that DPOAEs are not sensitive enough to be used as a health surveillance technique for the early detection of NIHL. Based on the findings of the current study, the null hypothesis of this study is rejected in favour of the alternative hypothesis.

The findings suggest that DPOAEs could be a more sensitive test in detecting noise induced subtle cochlear function changes due to long-term noise exposure. The study also found DPOAEs to be reliably repeatable and found that DPOAE testing may be performed in a shorter period of time than pure tone audiometry. It confirmed that

DPOAEs can be used successfully as an objective, quick, sensitive, and reliable health surveillance technique to complement pure tone audiometry in the early detection of NIHL in the steel manufacturing industry.

5.2. Limitations of the study

Due to lack of the necessary equipment the current study did not carry out a noise survey in the workplaces of the noise exposed group participants. It would have been interesting to determine the average daily noise exposure levels of the noise exposed group for easy comparison of the current study findings to other related studies. Furthermore the noise level measurements would have provided the researcher with useful information to use in future when giving feedback and discussing the outcomes of the current research with employers. This information also could have helped in substantiating the recommendations to be made to the employers on the prevention of NIHL.

The current study did not investigate the relationship between chronic noise exposure duration and DPOAE response amplitudes. It would have been interesting to determine if there is any relationship between these factors. In the current study the participants in the two groups were of the same age range, with no statistical significant difference in age profile between the experimental and the control group, but pairwise age matching of participants between the two groups was not used. Previous studies have shown that age could have an effect on DPOAE response amplitudes (Engdahl, 2002; Uchida et al., 2008), therefore lack of appropriate age matching could have influenced the results of the study. The current study used a small sample size, possibly decreasing the quality of the

study findings. Furthermore, this study used a cross-sectional study design therefore the cause-effect relationship between NIHL and DPOAEs could not be proved (Levin, 2006).

5.3. Recommendations for further study

During the course of this research, the researcher established issues that may need to be addressed in the future through research.

Even though this was not part of the objectives of the current study, an interesting observation from the study is that only 55 % of workers from the noise exposed group were provided with and used HPDs while the other 45% mainly from the welding section did not use HPDs as they were not provided with them. This suggests that some industrial workers and their employers could possibly still lack awareness regarding the devastating effects of excessive noise exposure on hearing, and highlights the need for more awareness campaigns on the prevention of NIHL in the steel manufacturing industry.

There is a need for a research survey within different industries across Botswana where this research was carried out, to evaluate the employee/employer knowledge about the effects of NIHL, benefits of NIHL prevention and the value of HCPs. The findings of the survey can then be used as a yardstick for promoting relevant and effective NIHL awareness campaigns, which would ultimately result in the establishment of HCPs in these industries. It is only after adequate education on NIHL that the value of early detection of NIHL using DPOAEs as a complementary test to pure tone audiometry in hearing screening programs within the steel manufacturing and other related industries will be realized.

There is also a need for research on the prevalence of NIHL in workers exposed to excessive noise (≥85 dB A) across different industries in Botswana. The results of this study will provide a further incentive for the establishment of HCPs and also influence policy makers to come up with a policy or legislation that will bring pressure to bear on all companies in industries involved in excessive noise exposure to have HCPs in place to protect employees from the adverse effects of harmful noise in their work environment.

One of the limitations concerning the design of the current study (a cross-sectional study) may be difficulty in establishing the cause-effect relationship between NIHL and DPOAEs (Levin, 2006), therefore a large scale longitudinal study on the same subject, with monitored noise exposure levels and age matched participants, is recommended to further substantiate the findings of the current study. The suggested longitudinal study could further explore the relationship between noise exposure duration and DPOAE response amplitudes.

6. REFERENCES

1. Abdala, C. & Visser-Dumont, L. 2001. Distortion product otoacoustic emissions: A tool for hearing assessment and scientific study. *Volta Rev.*; 103(4): 281-302.
2. Agarwal, G., Nagpure, P. S., & Gadge, S. V. 2016. Noise induced hearing loss in steel factory workers. *Int J Occup Safety Health*; 4(2): 34-43.
3. Atchariyasathian, V., Chayarpham, S. & Saekhow, S. 2008. Evaluation of noise-induced hearing loss with audiometer and distortion product otoacoustic emissions. *J Med Assoc Thai.;* 91(7): 1066-1071.
4. Attias, J., Horovitz, G., El-Hatib, N. & Nageris, B. 2001. Detection and clinical diagnosis of noise-induced hearing loss by otoacoustic emissions. *Noise Health*; 3(12): 19-31.
5. Balatsouras, D.G. 2004. The evaluation of noise-induced hearing loss with distortion product otoacoustic emissions. *Med Sci Monit.*; 10(5): 218-222.
6. Beattie, R. C. & Bleech, J. 2000. Effects of sample size on the reliability of noise floor and DPOAE. *Br J Audiol.;* 34(5): 305–309.
7. Bless, C., Higson-Smith, C. & Kagee, A. 2006. *Fundamentals of social research methods: An african perspective.*4th Ed. Cape Town. Juta & Company Ltd.
8. Bowman, D.M., Brown, D. K. & Kimberley, B.P. 2000. An examination of gender differences in DPOAE phase delay measurements in normal-hearing human adults. *Hear Res.*; 142(1): 1–11.

9. British Society of Audiology (2011). Recommended procedure: Pure-tone air-conduction and bone-conduction threshold audiometry with and without masking. United Kingdom. Reading: British Society of Audiology.
10. Brownell, W.E. 1996. Outer hair cell electromotility and otoacoustic emissions. In Berlin, C.I (Ed.) *Hair Cells and Hearing Aids*. San Diego. London, Singular Publishing Group, Inc, pp.3-27.
11. Cheng, J. 2000. Signal processing approaches on otoacoustic emissions. Thesis, Karolinska Institutet, Stockholm.
12. Dietl, H. & Weiss, S. 2004. Evoked otoacoustic emissions in normal-hearing infants and children: emerging data and issues. In Proceedings of BIOSIGNAL 2004 International EURASIP conference.
13. Edwards, A.L. & Taela, M. 2008. Feasibility of screening distortion product otoacoustic emissions to monitor cochlear functioning in noise-exposed mineworkers. *Occup Health Southern Afr*.; 14(1): 18-21.
14. Edwards, A., Van Coller, P., & Badenhorst, C. 2010. Early identification of noise induced hearing loss: a pilot study on the use of distortion product otoacoustic emissions as an adjunct to screening audiometry in the mining industry. *Occup Health Southern Afr.*; 16(4): 28-35.
15. Engdahl, B. 2002. Otoacoustic emissions in the general adult population of Nord-Trondelag, Norway: I. Distributions by age, gender, and ear side. *Int J Audiol.;* 41(1): 66-77.

16. European Union Parliament. 2003. Directive 2003/10/EC: Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Brussels: *Official Journal of the European Union.*
17. Field, A. 2009. *Discovering statistics using SPSS*. 3rd Ed. London. SAGE Publications Ltd.
18. Franks, J.R., Stephenson, M.R., & Merry, C.J. 1996. Preventing occupational hearing loss: A practical guide. *DHHS (NIOSH)*; Publication No. 96-110. Cincinnati, OH: National Institute for Occupational Safety and Health (1-800-35-NIOSH).
19. Gelfand, S. A. 1998. *Hearing: An introduction to psychological and physiological acoustic*s. 3rd Ed. New York. Base, Marcel Dekker, Inc.
20. Gelfand, S.A. 2002. The acoustic reflexes. In: Katz J, editor. *Handbook of clinical audiology*. 5th ed. Lippincott: Williams& Wilkins; pp. 205-232.
21. Grabham, N. J., Swabey, M. A., Chambers, P., Lutman, M. E., White, N. M., Chad, J. E. & Beeby, S. P. 2013. An evaluation of otoacoustic emissions as a biometric. *IEEE Transactions on Information Forensics and Security*; 8: 174-183.
22. Guida, H.L., Morini, R.G. & Cardoso, A.C.V. 2009. Audiologic and otoacoustic emission evaluation in individuals exposed to noise and plaguecides. *Int Arch Otorhinolaryngol.*; 13(3): 264-269.
23. Hall, J.W., III, 2000. *Handbook of otoacoustic emissions*. San Diego. Thompson Learning, Singular Publishing Group, Inc.
24. Hall, A.J. & Lutman, M.E. 1999. Methods for early identification of noise-induced hearing loss. *Audiol*ogy; 38 (5): 277–280.

25. Harris, F.P. 1990. Distortion-product otoacoustic emissions in humans with high-frequency sensorineural hearing loss. *J Speech Hear Res.*; 33: 594-600.
26. Ho, P.M., Peterson, P.N. & Masoudi, F.A. 2008. Evaluating the evidence: Is there a rigid hierarchy? *Circulation;* 118: 1675-1684.
27. Hoshino, M., Ueda, H. & Nakata, S. 1999. Long-term stability between click-evoked otoacoustic emissions and distortion productotoacoustic emissions in guinea pigs: A comparison. *ORL J Otorhinolaryngol Relat Spec.*; 61(4): 175-180.
28. Hoth, S., Gudmundsdottir, K. & Plinkert, P. 2010. Age dependence of otoacoustic emissions: the loss of amplitude is primarily caused by age-related hearing loss and not by aging alone. *Eur Arch Otorhinolaryngol.;* 267(5): 679-690.
29. HSE [2011]. Report of an international expert symposium on the usefulness of otoacoustic emissions (OAE) testing in occupational health surveillance, 8-9th February 2011, Bootle: Health & Safety Executive.
30. HSE [2013]. Workshop: Use of OAE testing in hearing conservation programmes as a Leading Indicator of Damaging Exposure to Noise (LIDEN); an international collaboration, November 2013, Buxton: Health & Safety Executive.
31. Jaffer, S. & Razi, M.S. 2004. Hearing loss in walkman users. *J Occup Safety Health*; 1: 31–37.
32. Job, A., Raynal, M., Kossowski, M., Studler, M., Ghernaouti, C., Baffioni-venturi, A., … Guelorget, A. 2009. Otoacoustic detection of risk of early hearing loss in ears with normal audiograms: a 3-year follow-up study. *Hear Res.*, 2009; 251(1): 10-16.

33. Kei, J., Brazel, B., Crebbin, K., Richards, A. & Willeston, N. 2007. High frequency distortion product otoacoustic emissions in children with and without middle ear dysfunction. *Int J Pediatr Otorhinolaryngol*.; 71(1): 125-133.
34. Kemp, D.T. 1978. Stimulated acoustic emissions from within the human auditory system. *J Acoust Soc Am*.; 64: 1386-1391.
35. Kemp, D.T. 1997. Understanding and using otoacoustic emissions. Herts, Otodynamics Ltd.
36. Kemp, D.T. 2002. Otoacoustic emissions, their origin in cochlear function, and use. *Br Med Bull.*; 63(1): 223-241.
37. Keogh, T., Kei, J., Driscoll, C. & Smyth, V. 2001. Distortion product otoacoustic emissions in school children: effects of ear asymmetry, handedness, and gender. *J Am Acad Audiol.*; 12(10): 506-513.
38. Keppler, H., Dhooge, I., Maes, L., D'haenens, W., Bocksteal, A., Philips, B., … Vinck, B. 2010. Transient-evoked and distortion product otoacoustic emissions: a short-term test-retest reliability study. *Int J Audiol.;* 49(2): 99–109.
39. Kirchner, D.B., Evenson, E., Dobie, R.A., Rabinowitz, P., Crawford, J., Kopke, R. & Hudson, T.W. 2012. Occupational noise-induced hearing loss. *J Occup Environ Med*.; 54(1): 106-108.
40. Korres G.S., Balatsouras, D.G., Tzagaroulakis, A., Kandiloros, D., Ferekidou, E. & Korres, S. 2009. Distortion product otoacoustic emissions in an industrial setting. *Noise Health*; 11(43): 103-110.

41. Kreisman, B. M., Bevilacqua, E., Day, K., Kreisman, N. V. & Hall, J.W., III. 2013. Preschool hearing screenings: A comparison of distortion product otoacoustic emission and pure tone protocols. *J Educ Audiol.*; 19: 49-57.
42. Kumar, P., Kumar, K., & Barman, A. 2013. Effect of short-duration noise exposure on behavioral threshold and transient evoked otoacoustic emission. *Indian J Otol.*; 19(1): 9-12.
43. Levin, K. A. 2006. Study design III: Cross-sectional studies. *Evid Based Dent.*; 7(1): 24-25.
44. Lonsbury-Martin, B. L., Harris, F. P., Stagner, B., Hawkins, M. D. & Martin, G. K. 1990. Distortion product emissions in humans: I. Basic properties in normally hearing subjects. *Ann Otol Rhinol Laryngol Suppl.*; 147: 3-14.
45. Lutman, M. E. 2000. What is the risk of noise-induced hearing loss at 80, 85, 90 dB (A) and above? *Occup. Med.;* 50: 274-275.
46. Marshall, L. & Heller, L.M. 1996. Reliability of transient-evoked otoacoustic emissions. *Ear Hear*; 17(3): 237-254.
47. Marshall, L., Lapsley, M.J.A. & Heller, L.M. 2001. Distortion-product otoacoustic emissions as a screening tool for noise-induced hearing loss. *Noise Health*; 3: 43-60.
48. McCrae, R.R., Kurtz, J.E., Yamagata, S. & Terracciano, A. 2011. Internal consistency, retest reliability, and their implications for personality scale validity. *Pers Soc Psychol Rev.*; 15(1): 28-50.
49. Mikolai, T.K, Duffey, J., & Adlin, D. 2006. A guide to tympanometry for hearing screening. Maico Diagnostics, MN 55344 Eden Prairie.

50. Moulin, A. 2000. Influence of primary frequencies ratio on distortion product otoacoustic emissions amplitude. II. Interrelations between multicomponent DPOAEs, tone-burst-evoked OAEs, and spontaneous OAEs. *J Acoust Soc Am.;* 107(3): 1471-1486.
51. Nandi, S.S. & Dhatrak, S.V. 2008. Occupational noise-induced hearing loss in India. *Indian J Occup Environ Med*.; 12(2): 53–56.
52. NOHSC. 2000. National standard for occupational noise. National Occupational Health and Safety Commission [NOHSC: 1007, 2000] 2nd edition, Australian Government, Canberra.
53. NIOSH [1972]. NIOSH criteria for a recommended standard: occupational exposure to noise. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. HSM 73-11001.
54. OSHA. 2002. Hearing conservation. Occupational Safety & Health Administration. U.S Department of Labor: Publication No. OSHA 3074.
55. OSHA [29 CFR 1910.95].Occupational Noise Exposure Standard. Occupational Safety and Health Standards, Occupational Health and Environmental Control, Occupational noise exposure. U.S Department of Labor, Washington DC: Occupational Safety & Health Administration.
56. Pavlovcinová, G., Jakubíková, J., Trnovec, T., Lancz, K., Wimmerová, S., Sovcíková, E. & Palkovicová, L. 2010. A normative study of otoacoustic emissions, ear asymmetry, and gender effect in healthy school children in Slovakia. *Int J Pediatr Otorhinolaryngol*.; 74(2): 173-177.

57. Prasher, D. & Sulkowski, W. 1999. The role of otoacoustic emissions in screening and evaluation of noise damage. *Int J Occup Med Environ Health*; 12: 183–192.

58. Prieve, B.A. & Fitzgerald, T.S. 2002. Otoacoustic emissions. In: Katz J, editor. *Handbook of clinical audiology*. 5th ed. Lippincott: Williams& Wilkins; pp. 440-466.

59. Ramma, L., Petersen, L. & Singh, S. 2011. Vuvuzelas at South African soccer matches: Risks for spectators' hearing. *Noise Health*; 13: 71-75.

60. Reavis, K.M., McMillan, G., Austin, D., Gallun, F., Fausti, S.A., Gordon, J.S., … Konrad-Martin, D. 2011. Distortion-product otoacoustic emission test performance for ototoxicity monitoring. *Ear Hear;* 32 (1): 61–74.

61. SCENIHR. 2008. Potential health risks of exposure to noise from personal music players and mobile phones including a music playing function. *Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR).*

62. Seixas, N.S., Goldman, B., Sheppard, L., Neitzel, R., Norton, S. & Kujawa, S.G. 2005. Prospective noise induced changes to hearing among construction industry apprentices. *Occup Environ Med.*; 62: 309–317.

63. Seixas, N.S., Neitzel, R., Stover, B., Sheppard, L., Feeney, P., Mills, D. & Kujawa, S. 2012. 10-Year prospective study of noise exposure and hearing damage among construction workers. *Occup Environ Med.*; 69(9): 643-650.

64. Shanks, J. & Shohet, J. 2009. Tympanometry in clinical practice. In: Katz J, editor. *Handbook of clinical audiology*. 6th ed. Philadelphia: Lippincott, Williams & Wilkins; pp. 157 – 188.

65. Silva, V.G., Sampaio, A.L., Oliveira, C.A., Tauil, P.L. & Jansen, G.M. 2012. Hair cell alteration prevalence rates in students of a school in Distrito Federal. *Braz J Otorhinolaryngol.*; 78(4): 91-97.

66. Sim, J. & Wright, C. 2000. *Research in health care: concepts, designs and methods.* Cheltenham. Nelson Thornes Ltd.

67. Sininger, Y.S. & Cone-Wesson, B. 2004. Asymmetric cochlear processing mimics hemispheric specialisation. *Science;* 305: 1581.

68. Sousa, V.D., Driessnack, M. & Mendes, I.A.C. 2007. An overview of research designs relevant to nursing: Part 1: Quantitative research designs. *Rev Latino-am Enfermagen maio-junho;* 15(3): 502-507.

69. South African National Standards. 2013. The measurement and assessment of occupational noise for hearing conservation purposes. *SANS: 10083:2013*. Pretoria: South African National Standards.

70. Stuart, A., Passmore, A.L., Culbertson, D.S. & Jones, S.M. 2009. Test-retest reliability of low-level evoked distortion-product otoacoustic emissions. *J Speech Lang Hear Res.*; 52: 671–681.

71. Tiradentes, J. B., Coube, C. Z. V. & Costa Filho, O. A. 2002. Study of the dp growth rate answers pattern of the otoacoustic emission distortion product in normal hearing people. *Rev Bras Otorrinolaringol.*; 68(1): 21-26.

72. Uchida, Y., Ando, F., Shimokata, H., Sugiura, S., Ueda, H. & Nakashima, T. 2008. The effects of aging on distortion-product otoacoustic emissions in adults with normal hearing. *Ear Hear*; 29(2): 176-184.

73. Urkin, J., Bar-David, Y. & Porter, B. 2015. Should we consider alternatives to universal well-child behavioural-developmental screening? *Front Pediatr.;* 3(21): 1-6.

74. Valero, M.D. & Ratnam, R. 2011. Reliability of distortion-product otoacoustic emissions in the common marmoset (Callithrix jacchus). *Hear Res*.; 282(1-2): 265–271.

75. Vinck, B.M., Van Cauwenberge, P.B., Leroy, L. & Corthals, P. 1999. Sensitivity of transient evoked and distortion product otoacoustic emissions to the direct effects of noise on the human cochlea. *Audiology;* 38: 44-52.

76. Vinodh, R.S. & Veeranna, N. 2010. Evaluation of acoustic shock induced early hearing loss with audiometer and distortion product otoacoustic emissions. *Indian J Med Sci.*; 64(3): 132-139.

77. Wagner, W., Heppelmann, G., Vonthein, R. & Zenner, H.P. 2008. Test-retest repeatability of distortion product otoacoustic emissions. *Ear Hear*; 29(3): 378-391.

78. Walsh, M. & Wigens, L. 2003. *Foundations in nursing and health care: introduction to research.* Cheltenham. Nelson Thornes Ltd.

79. Wang, L., Wang, Z., Zhang, D. & Cao, K. 2009. Application of intraoperative round window electrocochleography for screening the patients with auditory neuropathy. *Chin Med J*; 122(8): 941-944.

80. Williams, C. 2007. Research methods. *J Bus Econ Res*; 5(3): 65-72.

81. Ziarani, A.K. & Konrad, A. 2004. A Novel Method of Estimation of DPOAE Signals .*IEEE Trans. Biomed. Eng.*; 51(5): 864-868.

Appendix A: Participant information letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Humanities
Department of Speech-Language Pathology and Audiology

July 2014

Dear Participant,

PARTICIPATION IN RESEARCH PROJECT

I am a Masters student at the Department of Speech-Language Pathology and Audiology at the University of Pretoria. As partial completion of the degree M. Communication Pathology, it is mandatory to complete a research study.

Thank you for taking your time to consider participating in this research. The aim of this research is to investigate whether certain specialized tests could be used to detect noise induced hearing loss before more damage is done to an individual's hearing. The results of this research may help in suggesting improvements in the hearing assessment of workers exposed to noise in order to protect them from excessive noise exposure. Before participating in this study the researcher will provide you with all the information you need. If you do agree, more information is provided on the consent form, which you have to sign if you agree to participate in this study. You will be given the opportunity to ask questions, and the researcher will provide you with appropriate answers.

If you agree to participate in this study and you sign the consent form, then the researcher will ask you a few questions about your general health. If your occupation involves excessive noise exposure, you will further be asked about your job and the noise levels that you are exposed to at your work place. All your personal, medical information and the results from the tests will be strictly confidential, only you and the research team will have access to the information we get from you. Your name will not be revealed in the study. Your employer will not have any access to your results or the information you disclose in the research.

The tests will be investigating on which tests could be used for early detection of noise induced hearing loss. The tests results may bring improvements in tests used to monitor protection of hearing from noise in the steel manufacturing industries and other related industries where workers are exposed to occupational noise. The research will not in any way involve issues of compensation. The researcher will explain all the tests to you before performing them. The results of the tests will be clearly explained to you as well. Participation in this study is voluntary. You can withdraw from the study at any stage if you decide to do so or if you are unsatisfied with the answers given. The results of the study will be archived for 15 years for research purposes.

If you are willing to participate in this study, see the consent form attached to this letter, the researcher will read the relevant sections of the consent form to you. Kindly sign the consent form if you are satisfied with the contents of the form, the purpose of the study and that all your questions have been fully answered.

University of Pretoria
PRETORIA 0002
Republic of South Africa

Tel: 012 420 2355
Fax: 012 420 3517

maggi.soer@up.ac.za
www.up.ac.za

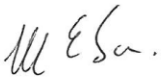
Should you require any further information, feel free to contact me or my supervisors.

Kind Regards

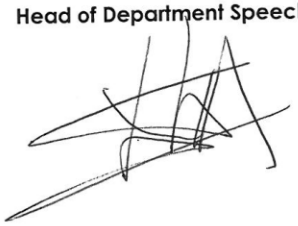
Meshack Moepeng
Researcher

Date: 16/07/2014

Dr Maggi Soer
Supervisor: Department Speech-Language Pathology and Audiology



Prof Dr Bart Vinck
Head of Department Speech-Language Pathology and Audiology



Appendix B: Informed consent form

Informed Consent Form

This form entails information given to the participants and a request for them to give consent to participate in this study. The information will be divided into two sections for the two groups of participants: Section 1 for the non-noise exposed group; section 2 for the noise exposed group.

The researcher will read relevant sections to each participant before performing the audiometric tests. The participants will be given a chance to ask questions and they will be given appropriate answers. The information to be read is as follows;

The aim of this research is to investigate whether certain specialized tests could be used to detect noise induced hearing loss before more damage is done to an individual's hearing. The results of this research may help in suggesting improvements in the hearing assessment done on workers exposed to noise, to protect them further from excessive noise exposure.

Control (non-noise exposed) group

If you agree to take part in this study I will ask you a few questions about your general health. All your personal, medical information and the results from the tests will be strictly confidential. Only you and the research team will have access to the information we get from you. Your name will not be revealed in the study. We will explain all the tests to you before performing them. The results of the tests will be clearly explained to you as well. Participation in this study is voluntary. You can withdraw from the study at any stage if you decide to do so or if you are unsatisfied with the answers given. If you agree to participate in this study you have to sign on the given space below.

Do you agree to take part in this study? Yes/No
NB: If yes proceed.

I the undersigned agree to participate in this study. I understand that I will be participating voluntarily and that I can withdraw from the study at any point. I am satisfied with the explanations given about the purpose of this study and all my questions have been fully answered.

Name: .....

Signature: .....

Date: .....

Noise exposed group

If you agree to take part in this research we will ask you a few questions about your general health, your job and the noise exposures at your work. All your personal, medical information and the results from the tests will be strictly confidential. Only you and the research team will have access to the information we get from you. Your name will not be revealed in the study. Your employer will not have any access to your results or the information you disclose in the research.

The Reliance Foundries Ltd Company has given the research team the permission to carry out this research on its employees. The tests will be investigating on which tests could be used for early detection of noise induced hearing loss. The tests results may result in improvements in tests used to monitor protection of hearing from noise in the steel manufacturing industries and other related industries where workers are exposed to occupational noise. The research will not in any way involve issues of compensation. We will explain all the tests to you before performing them. The results of the tests will be clearly explained to you as well. Participation in this study is voluntary. You can withdraw from the study at any stage if you decide to do so or if you are unsatisfied with the answers given. If you agree to participate in this study you have to sign on the given space below.

Do you agree to take part in this study? Yes/No
NB: If yes proceed.

I the undersigned agree to participate in this study. I understand that I will be participating voluntarily and that I can withdraw from the study at any point. I am satisfied with the explanations given about the purpose of this study and all my questions have been fully answered.

Name: .....

Signature: .....

Date: .....

Appendix C: Ethics clearance approval letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

21 January 2015

Dear Dr Soer

Project:	**Applicability of Distortion Product Otoacoustic Emissions as a new health surveillance technique for hearing screening in industry**
Researcher:	**M Moepeng**
Supervisor:	**Dr M Soer**
Department:	**Speech-Language Pathology and Audiology**
Reference number:	**14336392**

Thank you for your response to the Committee's letter of 3 November 2014.

The **Research Ethics Committee** notes that the outstanding permission that was submitted as requested and has therefore given **final approval** for the above application at an *ad hoc* meeting on 20 January 2015 Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

The Committee requests you to convey this approval to the researcher.

We wish you success with the project.

Sincerely

Prof Karen Harris
Acting Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail:Karen.harris@up.ac.za

Appendix D: Botswana Ministry of Health approval letter

TELEPHONE: 363 2766
FAX: 391 0647
TELEGRAMS: RABONGAKA
TELEX: 2818 CARE BD

Republic of Botswana

MINISTRY OF HEALTH
PRIVATE BAG 0038
GABORONE

REF NO: PPME-13/18/1 Vol IX (154) 15 December 2014

Health Research and Development Division

Notification of IRB Review: New application

Meshack Moepeng
P.O. Box V6
Ramotswa

Protocol Title: **APPLICABILITY OF DISTORTION PRODUCT OTOACOUSTIC EMISSIONS AS A NEW HEALTH SURVEILLANCE TECHNIQUE FOR HEARING SCREENING IN INDUSTRY**

Review Date: 12 December 2014
Expiration Date: 12 December 2015
HRDC Review Type: HRDC
Risk Determination: **Minimal risk**

Dear Mr Moepeng

Thank you for submitting a new application for the above referenced study. The study was reviewed and approved for a period of one year with effect from 2 December 2014.

Approved documents:-
- Application form
- Proposal
- Other supporting documents

This permit does not however give you authority to collect data from the selected site without prior approval from the management. Consent from the identified individuals should be obtained at all times.

The research should be conducted as outlined in the approved proposal. Any changes to the approved proposal must be submitted to the Health Research and Development Division in the Ministry of Health for consideration and approval.

1

Furthermore, you are requested to submit at least one hardcopy and an electronic copy of the report to the Health Research, Ministry of Health within 3 months of completion of the study. Copies should also be submitted to all other relevant authorities.

Continuing Review

In order to continue work on this study (including data analysis) beyond the expiry date, submit a Continuing Review Form for Approval at least three (3) months prior to the protocol's expiration date. The Continuing Review Form can be obtained from the Health Research Division Office (HRDD), Office No. 7A.7 or Ministry of Health website: www.moh.gov.bw or can be requested via e-mail from Mr. Kgomotso Motlhanka, e-mail address: kgmmotlhanka@gov.bw As a courtesy, the HRDD will send you a reminder email about eight (8) weeks before the lapse date, but failure to receive it does not affect your responsibility to submit a timely Continuing Report form.

Amendments

During the approval period, if you propose any change to the protocol such as its funding source, recruiting materials, or consent documents, you must seek HRDC approval before implementing it. Please summarize the proposed change and the rationale for it in the amendment form available from the Health Research Division Office (HRDD), Office No. 7A.7 or Ministry of Health website: www.moh.gov.bw or can be requested via e-mail from Mr. Kgomotso Motlhanka, e-mail address: kgmmotlhanka@gov.bw . In addition submit three copies of an updated version of your original protocol application showing all proposed changes in bold or "track changes".

Reporting

Other events which must be reported promptly in writing to the HRDC include:

- Suspension or termination of the protocol by you or the grantor
- Unexpected problems involving risk to subjects or others
- Adverse events, including unanticipated or anticipated but severe physical harm to subjects.

If you have any questions please do not hesitate to contact Mr. P. Khulumani at pkhulumani@gov.bw, Tel +267-3914467 or Lemphi Moremi at lamoremi@gov.bw or Tel: +267-3632754

Thank you for your cooperation and your commitment to the protection of human subjects in research.

Yours sincerely

P. Khulumani
For Permanent Secretary

Appendix E: Health assessment questionnaire

Name:…… Date of birth……..

Sex: Male/Female Subject number…….

Occupation……..

Contacts: Telephone…….. Mobile……

Date of completion: / / 2015

Answer the following questions by circling appropriate answers and giving specific details where necessary.

Do you have any difficulty with your hearing? Yes/No
If yes, please explain.

Did you have any ear operations in the past? Yes/No
If yes, explain.

Have you ever had any ringing sounds in your ear(s) (tinnitus)? Yes/No
If yes, please explain how often and how bothersome is the tinnitus.

Have you taken any ototoxic medication in the past? Yes/No
If yes, please give details.

What kind of medication was it?

Did you notice any changes in your hearing after using the medication?

Have you ever taken a chemotherapy/radiotherapy treatment? Yes/No

Is there any history of hearing loss in your family? Yes/No

If yes, please explain.

Have you ever received treatment for any of the following conditions?

Troublesome tinnitus: Yes/No
If yes, specify.

Ear disease: Yes/No
If yes, specify.

Cardiovascular disease: Yes/No
If yes, specify.

High Blood Pressure: Yes/No
If yes specify.

Diabetes mellitus: Yes/No
If yes, specify.

Renal failure: Yes/No
If yes specify.

Malaria: Yes/No
If yes specify.

Epilepsy: Yes/No
If yes specify.

Psychiatric condition: Yes/No
If yes, specify.

Tuberculosis: Yes/No

If yes, specify.

Any other medical problem: Yes/No
If yes, specify.

Have you been exposed to noise in the past 48 hours: Yes/No

If yes, please specify.

Have you been exposed to loud recreational noise in the past (e.g. loud music, gun shooting, fire crackers, motorcycles etc.)? Yes/No

If yes, please describe.

Do you work in a noisy environment: Yes/No

If yes

How long have you been working in a noisy environment?

Briefly describe the nature of your work.

What types of loud sounds are you exposed to?

How often are you exposed to this noise? (e.g. no. of days/week)

How long are you exposed to this noise? (e.g. Hrs/day)

Do you wear ear protectors at work when exposed to noise? Yes/No

If yes:

How often?
Please tick.

All the time : ☐

Sometimes: ☐

Occassionally: ☐

If No, explain why?

What type of ear protectors do you use?

Earplugs ☐

Ear muffs ☐

Earplugs and Ear muffs ☐

Custom made ear plugs ☐

Have you experienced any of the following symptoms after a work shift?

Fullness in the ear?

A temporary change in your hearing ability?

Ringing sound in your ears?

When was your last working shift?

Appendix F: Results recording sheet

Subject number: .....

Date of completion: / / 2015

The research audiologist will fill all the sections by appropriately ticking when the condition is present or filling specific details where necessary.

OTOSCOPIC FINDINGS I		
Tympanic membrane status	**Right ear**	**Left ear**
Normal		
Light Reflex Absent		
Dull		
Retracted		
Scarred		
Perforated, specify		
Tympanosclerosis		
Grommet instu		

Remarks:

OTOSCOPIC FINDINGS II		
External ear canal status	**Right ear**	**Left ear**
Normal		
Wax, specify (minimal or occluding)		
Otitis externa		
Pus		
Fungus		
Discharging, specify		
Bleeding, specify		
Foreign body, specify		
Swollen/Red		
Growth, specify		
Exostosis		
Abnormal ear canal, specify		

Remarks:

IMMITTANCE TEST RESULTS		
Tympanogram	**Right ear**	**Left ear**
Middle ear pressure (daPa)		
Middle ear compliance (ml)		
Ear canal volume (ml)		
Acoustic reflexes		
Frequency (Hz)	**Right (ART level) (dB HL)**	**Left (ART level) (dB HL)**
500		
1000		
2000		

Remarks

Pure tone audiometry (air conduction) thresholds								
Frequency (kHz)	**0.25**	**0.5**	**1**	**2**	**3**	**4**	**6**	**8**
Right ear (dB HL)								
Left ear (dB HL)								

Duration of the procedure for both ears: ……..

Remark:

Appendix G: DPOAEs recording sheet

Subject number: ..... Date of completion: / / 2015

2kHz	DPOAE amplitude					2kHz	DPOAE NF level					
Ear	1	2	3	4	Average DP level		1	2	3	4	Average NF level	DP-NF average
Rt												
Lt												
3kHz						3kHz						
Rt												
Lt												
4kHz						4kHz						
Rt												
Lt												
6kHz						6kHz						
Rt												
Lt												
8kHz						8kHz						
Rt												
Lt												

DPOAE measurements duration for both ears	
Instructions =	**8 Measurements=**
Total duration = instructions duration + $\sum$ 8 DPOAE recordings duration	

Remark:

Appendix H1: DPOAE response amplitude levels at 2 kHz

Participant	Group	Right ear amplitude level (dB SPL)				Left ear amplitude level (dB SPL)			
		1	2	3	4	1	2	3	4
1	I	16.3	15.5	15.4	15.2	8.3	9.0	8.9	9.3
2	I	9.7	10.6	10.5	10.9	21.4	21.3	21.3	21.3
3	I	3.2	4.6	6.0	5.5	8.3	8.7	7.4	7.2
4	I	14.9	15.0	14.2	14.1	10.1	11.0	11.3	11.0
5	I	11.4	12.1	12.5	12.3	12.9	12.4	12.6	12.8
6	I	15.9	16.3	17.7	16.8	19.3	19.8	19.3	18.8
7	I	9.0	7.7	7.0	8.3	13.1	13.0	12.9	13.3
8	I	12.1	10.6	11.0	11.1	15.6	15.4	14.8	13.9
9	I	17.8	18.0	18.0	17.2	17.5	17.7	18.2	17.5
10	I	17.9	18.1	18.3	18.0	18.3	18.1	18.0	17.8
11	I	10.9	11.1	10.5	11.2	9.1	9.3	9.4	7.7
12	I	9.3	9.6	8.7	9.5	5.9	6.3	6.1	4.7
13	I	12.8	13.2	12.8	13.2	11.2	11.3	11.4	11.3
14	I	15.4	15.4	15.2	15.2	15.9	15.2	16.2	15.0
15	I	8.1	8.1	8.1	8.1	12.5	11.7	11.5	10.7
16	I	14.8	15.0	14.5	14.6	12.8	12.7	12.8	12.5
17	I	24.9	25.4	25.0	25.3	20.8	20.9	21.7	21.1
18	I	15.2	16.2	16.4	16.7	10.7	11.6	13.2	12.1
19	I	16.1	15.5	15.2	15.5	16.9	17.7	17.8	17.8
20	I	8.6	9.3	8.7	9.9	17.2	15.6	15.1	16.0
21	II	1.2	4.4	3.8	3.6	5.8	5.5	5.7	6.3

22	II	12.6	12.9	14.5	13.0	16.1	16.6	16.4	16.3
23	II	2.8	3.2	2.0	4.0	1.4	-0.8	2.3	2.1
24	II	6.0	5.0	4.6	5.1	8.2	8.0	7.7	7.3
25	II	15.5	15.5	15.5	15.6	1.1	-0.8	4.0	0.0
26	II	6.3	6.3	7.0	6.6	7.4	7.0	8.7	6.8
27	II	7.4	6.9	6.9	8.0	7.5	8.4	8.4	8.8
28	II	-1.7	-6.3	-1.9	-2.5	-2.2	-3.0	-2.1	-0.7
29	II	4.5	6.6	4.6	5.6	7.0	6.6	7.1	6.2
30	II	-1.3	-4.0	-1.9	-0.9	7.6	6.5	5.9	4.6
31	II	14.3	14.3	11.9	14.0	8.1	8.9	8.6	8.6
32	II	19.2	19.3	19.3	19.4	21.0	21.7	21.9	21.8
33	II	3.0	3.8	5.0	5.7	8.1	9.3	8.7	7.3
34	II	2.3	0.3	2.0	1.7	3.7	2.5	4.4	3.9
35	II	5.9	7.2	7.2	6.8	3.5	4.7	2.7	4.9
36	II	6.7	6.8	7.1	6.1	15.6	15.8	14.9	14.6
37	II	-3.4	-1.6	-2.2	-1.4	-5.9	-7.5	-6.0	-13.0
38	II	7.4	7.9	8.8	9.4	11.2	11.4	11.6	11.2
39	II	-1.4	-1.9	-2.0	-1.9	5.1	5.8	4.7	6.3
40	II	0.7	3.8	3.1	4.1	-30.0	-30.0	-30.0	-30.0

Appendix H2: DPOAE response amplitude levels at 3 kHz

Participant	Group	Right ear amplitude level (dB SPL)				Left ear amplitude level (dB SPL)			
		1	2	3	4	1	2	3	4
1	I	4.5	4.1	5.1	5.6	9.6	10.9	10.8	10.9
2	I	9.4	10.2	10.0	9.8	13.1	12.2	12.7	12.4
3	I	8.1	8.8	8.9	8.8	8.2	7.3	6.9	7.8
4	I	12.2	11.5	11.8	12.3	12.8	13.3	14.3	14.4
5	II	11.8	11.8	11.9	11.5	10.4	12.1	12.3	11.3
6	I	17.4	16.8	17.8	17.1	14.4	13.7	12.7	13.0
7	I	11.0	11.2	11.9	11.6	10.8	8.7	6.5	8.7
8	I	14.9	14.6	15.5	14.2	17.6	17.8	18.0	18.2
9	I	18.1	18.1	18.2	17.7	14.3	13.0	14.0	14.1
10	I	25.6	25.4	25.4	25.4	24.1	24.1	25.1	25.0
11	I	8.0	9.5	8.7	9.5	8.0	7.5	8.2	7.0
12	I	5.3	5.8	5.5	6.2	6.9	6.8	7.1	6.6
13	I	13.0	13.0	13.6	13.7	5.9	6.1	7.0	6.7
14	I	10.1	9.7	9.4	10.6	13.0	14.0	14.3	14.0
15	I	9.4	10.2	9.5	9.8	14.9	14.6	14.2	14.0
16	I	15.8	16.2	17.2	17.3	17.6	17.2	17.9	17.5
17	I	14.7	15.0	14.6	14.8	10.5	10.2	11.2	10.8
18	I	8.4	8.5	9.0	8.3	8.6	10.9	9.4	10.1
19	I	14.5	13.4	13.1	12.6	13.4	14.3	14.3	14.2
20	I	13.6	11.8	12.1	13.9	15.5	15.2	15.5	18.0
21	II	1.2	2.9	1.6	2.5	3.6	1.9	3.0	2.0

22	II	0.7	0.5	-0.4	1.3	7.3	8.0	7.8	8.3
23	II	-20.3	-15.4	-15.0	- 10.5	-30.0	-10.4	-6.3	-18.0
24	II	1.4	-0.1	1.3	1.1	-2.0	0.3	0.9	0.8
25	II	10.2	9.9	9.8	11.3	9.1	9.9	9.1	8.9
26	II	-0.5	-1.1	-0.7	-1.6	-11.4	-14.9	-18.7	-10.6
27	II	7.7	8.3	8.6	8.7	4.1	6.2	6.8	7.4
28	II	3.8	4.0	3.7	4.8	0.7	0.1	1.4	1.3
29	II	4.6	5.6	5.3	4.5	-5.1	-6.1	-4.3	-3.1
30	II	0.1	0.6	-0.7	-0.3	11.4	10.9	10.3	10.7
31	II	13.8	13.2	13.5	13.5	2.0	-0.9	1.1	0.9
32	II	14.7	14.9	14.7	14.9	2.9	5.0	5.4	6.3
33	II	1.5	1.7	2.9	0.9	-3.6	1.1	-0.7	-0.9
34	II	0.8	0.1	-1.1	-1.4	3.5	3.5	5.1	4.8
35	II	7.1	8.0	7.3	6.8	6.4	7.8	8.0	8.8
36	II	-6.6	-30.0	-10.5	-5.3	4.0	3.8	3.1	2.6
37	II	-15.7	-16.5	-9.4	-11.0	-17.5	-12.8	-9.9	-25.7
38	II	11.0	10.7	10.9	10.3	13.4	13.7	13.9	14.0
39	II	-1.0	-3.0	-2.0	-1.4	6.7	5.2	7.5	6.8
40	II	-21.9	-16.5	-15.3	-11.4	-2.7	-2.1	-4.1	-3.1

Appendix H3: DPOAE response amplitude levels at 4 kHz

Participant	Group	Right ear amplitude level (dB SPL)				Left ear amplitude level (dB SPL)			
		1	2	3	4	1	2	3	4
1	I	10.2	10.2	9.4	10.4	5.5	7.4	6.7	6.6
2	I	2.6	1.3	4.1	2.6	11.7	12.6	13.1	13.6
3	I	15.5	15.1	15.5	15.7	13.8	13.9	13.7	13.6
4	I	14.3	15.3	15.6	15.5	15.0	14.9	15.2	15.2
5	I	16.3	16.4	15.9	15.0	13.8	13.5	14.4	13.4
6	I	19.6	19.9	20.2	20.2	15.8	16.5	16.8	16.2
7	I	7.7	6.9	7.2	7.6	12.6	11.7	12.3	11.7
8	I	17.2	17.0	17.6	17.5	11.5	12.1	12.0	12.6
9	I	19.0	19.6	20.1	20.0	14.4	14.9	16.0	16.1
10	I	15.0	15.5	14.9	15.2	9.0	11.3	7.8	9.2
11	I	7.6	7.3	8.7	8.6	6.2	6.8	7.3	5.3
12	I	7.8	8.1	8.2	8.5	11.8	11.7	11.5	10.4
13	I	5.7	5.0	5.9	6.7	14.1	13.8	14.9	14.4
14	I	14.8	15.2	15.6	15.5	12.6	11.9	10.3	11.9
15	I	15.5	16.4	16.2	16.4	13.9	13.6	14.2	13.7
16	I	15.4	16.9	16.9	16.7	13.4	13.7	13.7	13.6
17	I	12.2	12.7	13.3	13.1	9.3	9.4	9.6	10.2
18	I	4.1	5.7	4.4	5.7	13.5	13.8	13.4	14.1
19	I	12.0	12.2	12.2	12.0	13.0	13.0	13.1	12.7
20	I	17.3	17.7	17.5	17.6	7.1	2.2	7.5	13.8
21	II	4.0	3.6	3.4	2.0	6.8	6.1	7.0	6.2
22	II	2.9	2.6	1.3	0.9	1.5	3.0	3.5	2.5

23	II	-18.0	-15.0	-30.8	-15.6	-9.6	-14.5	-11.3	-12.8
24	II	-3.2	-3.8	-2.1	-0.6	-3.3	-1.9	-3.2	-0.8
25	II	3.5	5.1	3.8	4.5	8.7	8.1	9.9	8.8
26	II	-9.3	-7.0	-12.2	-11.0	-8.8	-12.0	-10.5	-6.5
27	II	9.4	9.0	8.2	9.7	3.1	2.5	2.5	1.7
28	II	5.6	6.6	7.5	5.5	9.0	9.4	9.2	9.4
29	II	4.4	5.9	4.2	3.7	-1.3	-9.4	-5.5	-1.7
30	II	-15.5	-4.2	-9.2	-8.4	4.6	5.5	3.7	1.9
31	II	9.9	11.3	11.1	11.6	-0.5	1.4	1.4	1.5
32	II	7.2	7.4	7.4	7.3	0.2	-0.5	2.4	2.5
33	II	-13.0	-11.2	-30.0	-11.1	-13.8	-12.0	-24.8	-13.2
34	II	4.1	4.8	4.5	5.6	4.0	4.4	4.1	4.0
35	II	3.9	5.1	4.5	6.1	-3.6	1.2	-1.5	-1.1
36	II	-30.0	-21.4	-12.4	-22.7	-8.2	-2.8	-3.1	-2.8
37	II	-1.2	-3.0	1.6	-3.1	-7.1	-5.1	-1.7	-3.2
38	II	13.2	13.0	13.8	14.1	13.9	13.2	14.3	14.3
39	II	0.1	-0.4	-0.3	-2.0	7.6	7.0	7.2	7.6
40	II	-8.3	-3.6	-4.0	-7.3	-4.7	-2.4	-3.3	-2.7

Appendix H4: DPOAE response amplitude levels at 6 kHz

Participant	Group	Right ear amplitude level (dB SPL)				Left ear amplitude level (dB SPL)			
		1	2	3	4	1	2	3	4
1	I	-0.3	-0.8	-3.2	0.3	-2.9	-3.0	0.1	-0.7
2	I	5.2	3.2	5.9	4.5	5.1	5.0	5.4	5.5
3	I	14.6	15.0	15.1	14.9	15.5	15.4	15.6	15.5
4	I	2.1	5.1	4.2	4.2	5.1	5.1	6.3	4.0
5	I	1.9	1.3	2.8	0.7	4.3	4.5	4.0	4.2
6	I	20.8	22.3	21.8	22.0	5.1	4.9	6.3	6.4
7	I	0.4	-2.1	-2.2	-3.0	0.3	2.0	-0.4	2.1
8	I	2.1	2.6	4.8	1.9	10.6	10.3	11.9	10.7
9	I	21.0	22.0	22.1	22.1	4.6	5.3	5.2	5.4
10	I	17.2	16.5	16.8	17.3	8.8	9.8	10.1	10.1
11	I	-4.2	0.3	-0.7	-2.1	6.4	6.2	6.2	3.4
12	I	7.5	9.6	9.0	9.3	9.2	9.6	9.5	8.8
13	I	-2.9	-2.9	-1.9	-2.0	6.7	7.9	7.6	8.4
14	I	2.9	-0.5	3.8	1.4	4.3	4.8	5.2	5.3
15	I	20.1	20.4	19.7	19.6	9.3	11.3	11.0	12.1
16	I	16.1	16.8	16.1	17.0	6.4	6.9	8.7	8.6
17	I	14.8	15.6	14.6	14.8	12.9	12.9	13.1	12.6
18	I	5.2	5.9	7.2	7.1	5.9	6.4	6.5	5.3
19	I	9.6	10.2	10.4	10.9	16.2	15.4	15.9	16.6
20	I	2.0	2.2	4.1	1.4	11.9	12.4	12.8	12.8
21	II	-1.7	-7.0	-6.0	-1.6	0.8	3.5	1.7	2.7
22	II	1.3	-2.0	-0.1	-2.3	-19.5	-7.3	-18.6	-16.3

23	II	-14.1	-18.3	-10.5	-12.1	-7.6	-19.9	-7.3	-9.0
24	II	-8.9	-10.4	-6.4	-4.8	-7.1	-5.2	-19.9	-8.5
25	II	-28.7	-21.1	-14.5	-13.7	-6.1	-20.8	-16.1	-8.3
26	II	-19.1	-19.2	-7.2	-16.9	-11.0	-31.7	-20.0	-20.8
27	II	-6.0	1.0	-4.6	-3.8	-21.9	-15.6	-5.2	-14.3
28	II	5.3	6.3	4.0	5.2	-20.6	-14.0	-11.0	-22.9
29	II	3.0	-0.3	2.5	1.0	3.0	2.9	0.1	2.0
30	II	7.0	7.1	6.0	6.8	4.5	3.9	2.3	2.7
31	II	-15.4	-24.5	-14.8	-12.7	-2.1	-1.6	-8.4	-12.2
32	II	-7.9	-11.2	-4.8	-6.7	-6.7	-5.1	-4.1	-4.2
33	II	-23.2	-10.7	-6.0	-10.3	-21.1	-18.9	-24.2	-18.7
34	II	-5.3	-18.8	-9.7	-30.0	-5.3	-10.1	-4.5	-6.2
35	II	-15.7	-18.0	-13.4	-7.5	-12.9	-14.2	-13.3	-8.6
36	II	-24.0	-10.4	-14.1	-17.7	-5.1	-11.8	-1.4	-1.5
37	II	-4.0	-7.4	-5.3	-4.7	-18.3	-23.9	-20.0	-8.0
38	II	-18.9	-8.4	-9.6	-10.8	-10.3	-8.8	-10.5	-23.1
39	II	-20.1	-21.8	-14.2	-30.0	-13.9	-11.1	-12.1	-10.2
40	II	-4.2	-6.5	-3.2	-5.3	-8.9	-6.1	-4.5	-6.2

Appendix H5: DPOAE response amplitude levels at 8 kHz

Participant	Group	Right ear amplitude level (dB SPL)				Left ear amplitude level (dB SPL)			
		1	2	3	4	1	2	3	4
1	I	2.0	1.6	0.8	2.3	-3.1	-3.6	-7.1	-5.2
2	I	-5.5	-8.3	-4.0	-12.9	-5.3	-0.9	-2.0	-1.1
3	I	8.9	9.0	8.8	8.5	8.8	8.7	9.3	8.8
4	I	-3.8	-5.2	-4.8	-5.8	0.2	-1.5	-0.2	-1.0
5	I	-3.6	-5.6	-4.7	-5.0	-1.6	-1.4	-1.6	-3.6
6	I	2.7	4.4	3.2	3.3	-0.5	-0.4	-1.0	-2.2
7	I	-18.1	-30.0	-30.0	-9.3	-29.9	-11.7	-13.1	-16.0
8	I	-5.7	-6.7	-8.8	-5.4	-1.0	-1.4	-1.5	-0.6
9	I	2.6	3.2	4.3	3.2	-3.4	-2.4	-1.0	0.4
10	I	-3.4	-4.3	-3.8	-3.8	1.0	2.3	2.5	2.6
11	I	-2.0	-3.7	-2.4	-3.8	1.3	1.6	2.8	0.5
12	I	-6.6	-8.6	-8.1	-6.6	-18.9	-14.3	-9.2	-16.0
13	I	-22.2	-19.1	-28.2	-19.4	-6.7	-8.1	-7.7	-3.2
14	I	-14.3	-25.2	-17.1	-13.5	1.5	1.9	3.0	2.8
15	I	14.4	14.2	13.9	13.7	4.9	5.3	7.6	7.8
16	I	8.5	9.4	9.6	8.3	1.4	1.5	1.8	0.9
17	I	4.8	4.8	4.1	4.3	3.5	4.5	4.2	4.3
18	I	2.9	2.9	2.1	3.1	-8.3	-6.2	-30.0	-30.0
19	I	6.0	6.6	6.8	6.5	6.4	6.4	7.2	8.0
20	I	-3.7	-6.9	-5.2	-7.1	-3.0	-2.8	-3.8	-1.4
21	II	-3.3	-3.3	-2.3	-3.5	-0.7	0.5	-0.9	-2.3
22	II	-18.8	-18.0	-16.5	-20.3	-15.9	-19.4	-16.0	-8.5

23	II	-16.7	-18.2	-30.0	-16.4	-20.8	-17.2	-30.8	-17.7
24	II	-24.3	-23.9	-13.5	-20.7	-32.2	-26.2	-18.9	-17.7
25	II	-21.3	-9.5	-11.4	-17.1	-29.4	-20.2	-14.2	-20.4
26	II	-19.9	-21.2	-14.7	-30.0	-17.3	-18.8	-22.6	-30.0
27	II	-14.9	-30.0	-15.6	-16.6	-21.3	-9.4	-15.3	-22.2
28	II	-3.0	-4.1	-2.8	-2.5	-3.4	-4.6	-2.0	-2.9
29	II	-0.3	-1.8	-0.8	-0.4	-2.4	-4.3	-4.1	-1.1
30	II	-5.7	-5.3	-7.0	-30.0	-9.0	-8.0	-8.8	-30.0
31	II	-20.7	-27.3	-17.6	-19.9	-13.1	-15.4	-11.7	-30.0
32	II	-20.8	-18.8	-38.2	-17.1	-20.5	-14.0	-22.9	-18.8
33	II	-16.4	-25.9	-22.7	-37.7	-40.1	-17.3	-15.1	-19.8
34	II	-18.9	-28.8	-30.0	-30.0	-27.7	-18.0	-25.5	-20.8
35	II	-17.8	-19.4	-14.6	-21.4	-23.1	-19.4	-16.9	-30.0
36	II	-12.7	-30.0	-23.1	-31.7	-21.2	-20.3	-22.7	-16.7
37	II	-14.6	-27.3	-27.4	-13.9	-2.5	-0.9	-2.4	-4.0
38	II	-13.6	-19.8	-16.5	-18.8	-19.0	-23.3	-16.6	-30.0
39	II	-20.6	-30.2	-13.4	-26.7	-18.7	-16.7	-18.0	-19.2
40	II	-14.4	-17.2	-11.0	-30.0	-30.0	-20.6	-25.1	-24.3

Group I = Non-noise exposed (control) group

Group II= Noise exposed group

Appendix I1: Right ear average DPOAE response amplitude and noise floor levels

Participant	Group	Right ear av. Amplitude level (dB SPL)					Right ear av. noise floor level (dB SPL)				
		2 kHz	3 kHz	4 kHz	6 kHz	8 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
1	I	15.6	4.8	10.1	-1.0	1.7	-8.3	-7.5	-8.0	-7.3	-11.9
2	I	10.4	9.9	2.7	4.7	-7.7	-10.4	-9.3	-8.4	-7.5	-12.8
3	I	4.8	8.7	15.5	14.9	8.8	-9.2	-9.7	-7.8	-7.1	-12.2
4	I	14.6	12.0	15.2	3.9	-4.9	-9.6	-8.8	-8.7	-8.0	-11.6
5	I	12.1	11.8	15.9	1.7	-4.7	-8.5	-9.6	-9.1	-6.5	-12.9
6	I	16.7	17.3	20.0	21.7	3.4	-10.4	-8.4	-9.4	-7.4	-13.1
7	I	8.0	11.4	7.4	-1.7	-21.9	-9.4	-9.7	-10.0	-8.5	-13.3
8	I	11.2	14.8	17.3	2.9	-6.7	-9.1	-8.4	-8.7	-7.0	-13.4
9	I	17.8	18.0	19.7	21.8	3.3	-9.7	-9.9	-9.4	-7.1	-12.3
10	I	18.1	25.5	15.2	17.0	-3.8	-9.0	-10.7	-8.3	-7.4	-13.6
11	I	10.9	8.9	8.1	-1.7	-3.0	-8.7	-9.0	-9.8	-7.8	-13.4
12	I	9.3	5.7	8.2	8.9	-7.5	-7.2	-9.3	-8.8	-5.8	-11.6
13	I	13.0	13.3	5.8	-2.4	-22.2	-8.8	-10.0	-10.0	-6.8	-12.7
14	I	15.3	10.0	15.3	1.9	-17.5	-5.0	-8.7	-8.8	-7.8	-12.8
15	I	8.1	9.7	16.1	20.0	14.1	-8.4	-9.0	-7.9	-7.8	-11.4
16	I	14.7	16.6	16.5	16.5	9.0	-10.6	-9.3	-7.5	-7.1	-12.4
17	I	25.2	14.8	12.8	15.0	4.5	-2.6	-7.8	-7.8	-7.9	-10.8
18	I	16.1	8.6	5.0	6.4	2.8	3.3	-6.0	-5.3	-8.0	-15.1
19	I	15.6	13.4	12.1	10.3	6.5	-10.1	-9.9	-8.3	-9.0	-12.6

20	I	9.1	12.9	17.5	2.4	-5.7	-9.0	-9.5	-8.8	-6.6	-12.5
21	II	3.3	2.1	3.3	-4.1	-3.1	-6.9	-8.6	-7.5	-7.3	-11.7
22	II	13.3	0.5	2.0	-0.8	-18.4	-8.1	-9.5	-8.6	-7.0	-12.5
23	II	3.0	-15.3	-19.9	-13.8	-20.3	-6.0	-7.2	-7.4	-8.1	-11.8
24	II	5.2	0.9	-2.4	-7.6	-20.6	-9.7	-9.0	-8.3	-7.2	-12.9
25	II	15.5	10.3	4.2	-19.5	-14.8	-9.0	-8.9	-7.7	-7.2	-11.8
26	II	6.6	-1.0	-9.9	-13.1	-21.5	-6.0	-9.1	-6.8	-6.6	-13.3
27	II	7.3	8.3	9.1	-3.4	-19.3	-9.4	-9.1	-8.0	-8.9	-13.6
28	II	-3.1	4.1	6.3	5.2	-3.1	-10.3	-9.7	-8.8	-8.8	-12.7
29	II	5.3	5.0	4.6	1.6	-0.8	-8.9	-10.6	-8.9	-6.8	-11.6
30	II	-2.0	-0.1	-9.3	6.7	-12.0	-9.3	-9.0	-8.8	-6.5	-12.7
31	II	13.6	13.5	11.0	-16.9	-21.4	-10.1	-9.8	-9.7	-7.5	-12.4
32	II	19.3	14.8	7.3	-7.7	-23.7	-9.7	-8.7	-9.0	-7.1	-12.4
33	II	4.4	1.8	-16.3	-12.6	-25.7	-4.4	-7.1	-7.6	-6.8	-12.7
34	II	1.6	-0.4	4.8	-16.0	-26.9	-8.2	-10.2	-13.0	-12.5	-18.1
35	II	6.8	7.3	4.9	-13.7	-18.3	-9.3	-10.5	-8.1	-7.5	-12.4
36	II	6.7	-13.1	-21.6	-16.6	-24.4	-9.2	-11.1	-10.4	-9.5	-13.2
37	II	-2.2	-13.2	-1.4	-5.4	-20.8	-9.0	-9.9	-7.6	-7.9	-13.1
38	II	8.3	10.7	13.5	-11.9	-17.2	-7.8	-7.8	-8.8	-7.1	-14.2
39	II	-1.8	-1.9	-0.7	-21.5	-22.7	-12.8	-14.5	-14.0	-12.3	-16.8
40	II	2.9	-16.3	-5.8	-4.8	-18.2	-9.9	-9.2	-9.1	-7.7	-12.5

Appendix I2: Left ear average DPOAE response amplitude and noise floor levels

Participant	Group	Left ear av. Amplitude level (dB SPL)					Left ear av. noise floor level (dB SPL)				
		2 kHz	3 kHz	4 kHz	6 kHz	8 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
1	I	8.9	10.6	6.6	-1.6	-4.8	-9.0	-9.0	-8.9	-7.7	-12.2
2	I	21.3	12.6	12.8	5.3	-2.3	-9.1	-8.5	-8.2	-6.8	-12.5
3	I	7.9	7.6	13.8	15.5	8.9	-8.0	-9.4	-6.4	-7.7	-12.9
4	I	10.9	13.7	15.1	5.1	-0.6	-8.7	-8.4	-8.6	-9.0	-12.2
5	I	12.7	11.5	13.8	4.3	-2.1	-9.1	-9.0	-8.5	-7.3	-11.3
6	I	19.3	13.5	16.3	5.7	-1.0	-9.6	-7.6	-7.0	-8.3	-14.2
7	I	13.1	8.7	12.1	1.0	-17.7	-7.3	-8.3	-8.0	-7.2	-10.8
8	I	14.9	17.9	12.1	10.9	-1.1	-5.0	-8.2	-8.4	-6.2	-11.3
9	I	17.7	13.9	15.4	5.1	-1.6	-3.8	-9.9	-8.2	-7.2	-12.3
10	I	18.1	24.6	9.3	9.7	2.1	-10.6	-12.2	-8.6	-6.2	-11.9
11	I	8.9	7.7	6.4	5.6	1.6	-5.9	-7.2	-9.0	-6.3	-12.8
12	I	5.8	6.9	11.4	9.3	-14.5	-7.8	-8.2	-8.6	-6.8	-12.2
13	I	11.3	6.4	14.3	7.5	-6.4	-8.0	-9.4	-9.0	-8.8	-14.3
14	I	15.6	13.8	11.7	4.9	2.3	-3.0	-6.2	-5.7	-6.9	-11.9
15	I	11.6	14.4	13.9	10.9	6.4	-8.0	-9.6	-8.3	-9.3	-12.2
16	I	12.7	17.6	13.6	7.7	1.4	-8.9	-9.2	-8.2	-7.3	-10.9
17	I	21.1	10.7	9.6	12.9	4.1	1.5	-4.0	-5.3	-8.5	-12.1
18	I	11.9	9.8	13.7	6.0	-18.6	-3.4	-5.0	-7.6	-8.1	-14.2
19	I	17.6	14.1	13.0	16.0	7.0	-11.0	-9.7	-8.1	-6.3	-13.7
20	I	16.0	16.1	7.7	12.5	-2.8	-8.2	-8.5	-7.2	-6.4	-13.4
21	II	5.8	2.6	6.5	2.2	-0.9	-9.5	-11.8	-8.1	-7.3	-12.9
22	II	16.4	7.9	2.6	-15.4	-15.0	-8.1	-8.5	-6.8	-7.4	-11.8

23	II	1.3	-16.2	-12.1	-11.0	-21.6	-7.1	-10.2	-8.8	-7.7	-12.2
24	II	7.8	0.0	-2.3	-10.2	-23.8	-8.3	-8.5	-7.4	-9.0	-14.1
25	II	1.1	9.3	8.9	-12.8	-21.1	-10.2	-9.3	-7.2	-7.5	-11.6
26	II	7.5	-13.9	-9.5	-20.9	-22.2	-3.2	-8.8	-6.7	-9.4	-11.6
27	II	8.3	6.1	2.5	-14.3	-17.1	-10.0	-9.2	-7.6	-8.4	-11.7
28	II	-2.0	0.9	9.3	-17.1	-3.2	-11.0	-14.1	-11.4	-11.5	-13.3
29	II	6.7	-4.7	-4.5	2.0	-3.0	-8.6	-11.8	-9.1	-8.0	-11.2
30	II	6.2	10.8	3.9	3.4	-14.0	-2.9	-6.0	-7.1	-5.9	-13.1
31	II	8.6	0.8	1.0	-6.1	-17.6	-10.0	-9.9	-8.5	-8.1	-13.1
32	II	21.6	4.9	1.2	-5.0	-19.1	-9.0	-9.6	-10.0	-8.1	-13.2
33	II	8.4	-1.0	-16.0	-20.7	-23.1	-3.3	-8.5	-7.5	-9.0	-14.1
34	II	3.6	4.2	4.1	-6.5	-23.0	-4.4	-10.9	-10.6	-12.2	-15.5
35	II	4.0	7.8	-1.3	-12.3	-22.4	-10.3	-9.9	-7.8	-8.5	-12.1
36	II	15.2	3.4	-4.2	-5.0	-20.2	-7.6	-8.2	-10.0	-6.4	-12.5
37	II	-8.1	-16.5	-4.3	-17.6	-2.5	-8.7	-11.5	-9.1	-7.9	-12.4
38	II	11.4	13.8	13.9	-13.2	-22.2	-9.2	-9.4	-7.0	-7.8	-12.4
39	II	5.5	6.6	7.4	-11.8	-18.2	-8.9	-9.7	-8.5	-7.5	-12.6
40	II	-30.0	-3.0	-3.3	-6.4	-25.0	-17.2	-16.1	-14.8	-14.5	-18.1

Group I = Non-noise exposed (control) group

Group II= Noise exposed group

Appendix J: Duration of performing pure tone audiometry and DPOAEs

Participant	Group	Pure tone audiometry duration (seconds)	DPOAE duration (seconds)
1	I	719	412.0
2	I	543	309.0
3	I	573	414.0
4	I	546	452.0
5	I	575	437.0
6	I	719	406.0
7	I	604	463.0
8	I	620	407.0
9	I	857	454.0
10	I	735	377.0
11	I	632	412.0
12	I	604	487.0
13	I	670	426.0
14	I	609	439.0
15	I	591	409.0
16	I	495	412.0
17	I	491	449.0
18	I	591	466.0
19	I	572	414.0
20	I	560	507.0
21	II	561	487.0
22	II	709	427.0

23	II	563	491.0
24	II	532	433.0
25	II	608	412.0
26	II	657	499.0
27	II	603	408.0
28	II	555	494.0
29	II	593	530.0
30	II	528	488.0
31	II	546	420.0
32	II	502	464.0
33	II	596	474.0
34	II	534	683.0
35	II	583	470.0
36	II	525	586.0
37	II	558	533.0
38	II	496	417.0
39	II	473	586.0
40	II	616	600.0

N:B DPOAE duration for each participant was calculated using the formula below;

$$\text{A set of DPOAE recording duration} = \text{instructions duration} + \sum 8 \text{ DPOAE recordings duration}$$

Group I = Non-noise exposed (control) group

Group II= Noise exposed group

Appendix K: Age of participants and duration of noise exposure

Participant	Group	Age	Noise exposure duration
1	I	36	n/a
2	I	39	n/a
3	I	31	n/a
4	I	38	n/a
5	I	27	n/a
6	I	45	n/a
7	I	29	n/a
8	I	25	n/a
9	I	34	n/a
10	I	29	n/a
11	I	34	n/a
12	I	37	n/a
13	I	33	n/a
14	I	55	n/a
15	I	34	n/a
16	I	36	n/a
17	I	35	n/a
18	I	34	n/a
19	I	19	n/a
20	I	41	n/a

21	II	39	20
22	II	54	6
23	II	53	21
24	II	27	9
25	II	22	2
26	II	53	22
27	II	36	15
28	II	24	6
29	II	30	12
30	II	30	12
31	II	39	19
32	II	49	11
33	II	42	15
34	II	24	4
35	II	27	3
36	II	47	10
37	II	25	5
38	II	42	5
39	II	23	4
40	II	51	17

Group I = Non-noise exposed (control) group

Group II= Noise exposed group

Appendix L: Pure tone audiometry hearing thresholds

Participant	Group	Right ear hearing thresholds (dB HL)								Left ear hearing thresholds (dB HL)							
		250 Hz	500 Hz	1k Hz	2k Hz	3k Hz	4k Hz	6k Hz	8k Hz	250 Hz	500 Hz	1k Hz	2k Hz	3k Hz	4k Hz	6k Hz	8k Hz
1	I	5	5	5	10	5	10	10	-5	5	0	0	0	10	15	15	10
2	I	5	10	0	10	5	10	0	5	10	-5	-5	10	10	5	0	0
3	I	0	5	0	5	0	-5	5	15	0	5	5	0	0	0	0	5
4	I	0	10	0	0	-5	5	10	15	5	15	0	-5	-5	5	10	15
5	I	0	0	0	-5	0	5	5	15	-5	5	-5	-5	0	10	5	10
6	I	5	5	5	5	10	10	15	5	-5	5	0	0	10	15	15	0
7	I	-5	0	5	0	5	5	5	0	0	5	10	5	5	10	5	5
8	I	10	5	10	0	5	0	0	10	10	5	5	0	0	5	5	10
9	I	0	0	5	0	10	5	5	15	0	-5	5	5	15	10	5	5
10	I	15	15	10	15	15	10	10	15	15	15	15	15	10	10	15	15
11	I	5	5	10	5	0	5	15	10	10	15	5	5	5	5	10	5
12	I	-5	0	10	10	5	5	10	5	5	0	-5	10	-5	5	0	0
13	I	5	10	15	15	15	15	15	10	0	0	5	5	15	15	15	15
14	I	10	5	5	15	15	15	10	5	10	10	15	5	15	5	10	10
15	I	5	10	10	5	10	15	10	5	5	10	10	10	15	15	10	10
16	I	0	5	0	5	10	10	15	10	5	0	0	5	5	15	10	5
17	I	10	15	10	10	10	10	15	15	10	10	10	10	15	10	15	15
18	I	-5	0	5	0	5	0	5	0	0	5	0	5	5	10	5	0
19	I	5	10	15	15	15	5	15	10	0	0	5	10	15	15	15	15
20	I	0	-5	0	5	5	0	0	5	5	0	0	0	5	0	5	0

21	II	5	5	5	5	5	5	5	5	5	10	5	5	15	0	5	0
22	II	5	10	10	10	15	15	5	15	10	5	5	10	15	15	0	10
23	II	10	0	5	15	15	15	10	5	10	5	10	15	15	15	10	0
24	II	0	0	10	15	10	15	10	10	0	10	10	15	15	15	10	10
25	II	10	15	5	0	5	0	15	15	0	10	0	-5	5	10	15	5
26	II	0	5	0	0	15	15	10	10	0	0	0	10	15	15	10	5
27	II	5	15	15	5	15	10	10	10	5	0	15	10	15	15	5	15
28	II	0	0	5	10	15	15	10	0	5	-5	5	10	10	5	0	0
29	II	-5	0	0	5	5	10	5	5	-5	-5	5	5	0	5	5	5
30	II	5	0	10	10	0	0	0	0	0	0	5	15	10	10	5	0
31	II	10	10	10	0	0	10	15	15	10	15	10	10	10	10	15	10
32	II	10	10	15	15	5	5	15	10	10	10	10	-5	5	10	15	10
33	II	15	10	15	15	15	15	15	10	10	15	15	10	5	15	15	15
34	II	5	-5	10	10	5	5	5	15	-5	-5	0	5	5	5	5	15
35	II	5	10	5	10	10	5	10	15	10	15	0	0	10	10	15	15
36	II	10	10	0	5	10	10	0	5	15	10	10	5	5	5	0	10
37	II	10	5	10	5	5	10	15	15	0	0	5	5	0	10	15	15
38	II	0	5	0	10	10	5	5	0	5	5	0	0	10	5	10	5
39	II	0	5	5	5	10	10	5	5	5	5	10	0	0	5	10	5
40	II	-5	5	15	0	10	5	15	10	5	5	0	5	10	10	10	5

Group I = Non-noise exposed (control) group

Group II= Noise exposed group