

# **The Hearing Abilities and Middle Ear Functioning of the Recreational Scuba Diver**

by

**Izabelle Pieterse**

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In partial fulfilment of the requirements for the  
degree M Communication Pathology at the  
Department of Communication Pathology  
Faculty of Humanities  
University of Pretoria

## ACKNOWLEDGEMENTS

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## ABSTRACT

<b>Title</b>	The hearing abilities and middle ear functioning of the recreational scuba diver
<b>Name</b>	Izabelle Pieterse
<b>Promoter</b>	Mrs. Nellie Venter
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<b>Department</b>	Communication Pathology
<b>Degree</b>	M Communication Pathology

Scuba diving as a recreational activity has increased in popularity over the past few years. It is believed that repeated exposure to the hyperbaric environment may have a long term effect on the auditory system. The research literature has given a lot of attention to acute injury but is very limited relating to the long term implications of scuba diving. Previous research studies did not perform a full audiometric test battery. A comprehensive audiological assessment is critical to determine in which part of the ear a pathology may occur during recreational diving.

This study endeavoured to assess and describe the hearing abilities and middle ear functioning of the recreational scuba diver and investigate the possibility that diving, on a recreational level, may have an influence on the auditory system. In order to achieve the aims of this study, a descriptive, correlation research design was selected.

The results of the current study indicate that scuba diving on a recreational level does not have a significant effect on the hearing and middle ear functioning of the individual, with the exclusion of static compliance. It appears that the inevitable compression and decompression that the middle ears are exposed to

during scuba diving might have a more permanent effect on the elasticity of the tympanic membrane.

Finally this study aims to increase the awareness of possible risks concerning the auditory system relating to scuba diving and in so doing, attribute to the prevention, diagnosing and intervention of diving related ear injuries.

**Key terms:** barotrauma, hearing acuity, hyperbaric environment, immittance measurements, middle ear functioning, recreational scuba diving, static compliance

## OPSOMMING

<b>Titel</b>	Die gehoorvermoëns en middelloorfunksionering van die buitemuurse scuba duiker
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<b>Promotor</b>	Mev. Nellie Venter
<b>Mede Promotor</b>	Dr. Lidia Pottas
<b>Departement</b>	Kommunikasiepatologie
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Hierdie studie stel dit ten doel om die gehoorvermoëns en middelloorfunksionering van die buitemuurse scuba duiker te evalueer en te beskryf. Dit ondersoek ook die moontlikheid dat duik as 'n buitemuurse aktiwiteit 'n invloed kan hê op die ouditiewe sisteem. 'n Beskrywende, korrelasie navorsingsontwerp is gebruik om die doelwitte van hierdie studie te bereik.

Die resultate van die huidige studie dui aan dat scuba duik as 'n buitemuurse aktiwiteit nie 'n noemenswaardige invloed op die gehoor en middelloorfunksionering van die individu het nie, met uitsondering van middelloor beweeglikheid. Dit wil voorkom dat die onvermydelike kompressie en dekompressie waaraan die middelloor blootgestel word gedurende scuba duik, 'n

meer permanente invloed mag hê op die elasticiteit van die timpaniese membraan.

Ten slotte is dit die oogmerk van hierdie studie om bewustheid te skep aangaande die moontlike risiko's en die invloed van duik op die auditiewe sisteem. Sodoende word 'n bydrae gelewer tot die voorkoming, diagnosering en intervensie van duikverwante oorbeterings.

**Sleuteltermes:** barotrauma, gehoorsensitiwiteit, hiperbariese omgewing, immittansie metings, middelloorfunksionering, buitemuurse scuba duik, middelloorbeweeglikheid

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Committee of the University of Pretoria

## LIST OF ABBREVIATIONS

The text of this study utilizes various discipline specific abbreviations. These abbreviations and their meanings are depicted in the following list.

<b>ABG</b>	Air Bone Gap
<b>ARCR</b>	Acoustic Reflex Contralateral
<b>ARDIF</b>	Difference between Ipsilateral and Contralateral Acoustic Reflexes
<b>ARIR</b>	Acoustic Reflex Ipsilateral
<b>bar/ata</b>	Barometric Pressure / Atmosphere Absolute
<b>daPa</b>	decaPascals
<b>dB</b>	Decibel
<b>DB1</b>	Threshold in decibel where 100% speech discrimination was measured
<b>DB2</b>	Second Measured Threshold with Speech Discrimination Testing
<b>DB3</b>	Third Measured Threshold with Speech Discrimination Testing
<b>ECV</b>	Ear Canal Volume
<b>GLM</b>	General Linear Model
<b>GRAD</b>	Gradient (tympanogram)
<b>Hz</b>	Hertz
<b>MEP</b>	Middle Ear Pressure
<b>ml</b>	milliliter
<b>NR</b>	No Response (Acoustic Reflexes)
<b>Pr</b>	Pearson Correlation Coefficient

<b>Pp</b>	P-value ( $< 0.05$ ) for Pearson Correlation Coefficient
<b>PTA</b>	Pure Tone Air Conduction
<b>PTB</b>	Pure Tone Bone Conduction
<b>RSD</b>	Recreational Scuba Diver
<b>RSDp</b>	Recreational Scuba Diver participant
<b>SC</b>	Static Compliance
<b>SD1-PTA</b>	Threshold where 100% Speech Discrimination was obtained minus the Pure Tone Average
<b>SD1</b>	100% Speech Discrimination
<b>SD2</b>	Second Percentage obtained during Speech Discrimination testing
<b>SD3</b>	Third Percentage obtained during Speech Discrimination testing
<b>Sr</b>	Spearman Correlation Coefficient
<b>Sp</b>	P-value ( $<0.05$ ) for Spearman Correlation Coefficient
<b>TW</b>	Tympanogram Width

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<b>ECV</b>	Ear Canal Volume
<b>GLM</b>	General Linear Model
<b>GRAD</b>	Gradient (tympanogram)
<b>Hz</b>	Hertz
<b>MEP</b>	Middle Ear Pressure
<b>ml</b>	milliliter
<b>NR</b>	No Response (Acoustic Reflexes)
<b>Pr</b>	Pearson Correlation Coefficient

<b>Pp</b>	P-value ( $< 0.05$ ) for Pearson Correlation Coefficient
<b>PTA</b>	Pure Tone Air Conduction
<b>PTB</b>	Pure Tone Bone Conduction
<b>RSD</b>	Recreational Scuba Diver
<b>RSDp</b>	Recreational Scuba Diver participant
<b>SC</b>	Static Compliance
<b>SD1-PTA</b>	Threshold where 100% Speech Discrimination was obtained minus the Pure Tone Average
<b>SD1</b>	100% Speech Discrimination
<b>SD2</b>	Second Percentage obtained during Speech Discrimination testing
<b>SD3</b>	Third Percentage obtained during Speech Discrimination testing
<b>Sr</b>	Spearman Correlation Coefficient
<b>Sp</b>	P-value ( $<0.05$ ) for Spearman Correlation Coefficient
<b>TW</b>	Tympanogram Width

# CHAPTER ONE

## INTRODUCTION , BACKGROUND, RATIONALE AND ORIENTATION TO THE STUDY

### AIM OF CHAPTER ONE:

*In this section the background to scuba diving and its effects on the ear will be discussed followed by the rationale behind the current study. An emphasis will be placed on the importance of a more complete audiological test battery to describe the hearing system of divers. An orientation to and description of terminology used in this study will be included. This section will conclude with the motivation for further research in the field of diving medicine with a specific focus on the possible long term effects of diving on the hearing system.*

**With that first underwater breath, the door opens to a new world. Not  
a world apart, but different nonetheless**

(Professional Association of Diving Instructors (PADI)

Open Water Diver Manual, 1999, p. 1)

### 1.1 Introduction

The self-contained underwater breathing apparatus (scuba) was developed in 1943 by Jacques Cousteau and Emile Gagnon in France (Becker & Parell, 2001). According to the research literature there appears to be a marked increase in scuba diving since the mid 1960's. Recreational scuba diving is still today one of the fastest growing leisure sports. Despite the popularity of this sport it is important to remember that the subaqua environment is inherently dangerous and scuba diving has often been described as a high-risk sport (Taylor, O'Toole & Ryan, 2002). Divers are exposed to a hyperbaric environment that has a definite effect on the body with very specific requirements and challenges.

Modern recreational scuba divers are increasingly performing multi-day repetitive diving which implies more exposure to the environmental conditions of diving that may influence the auditory system.

The rest of this chapter will be dedicated to the rationale of the current study. Attention will be given to the effect that scuba diving may have on divers' ears, the shortcomings in the available research literature and the need for further research in the field of diving related injuries. Chapter one will conclude with a description of terminology used as well as an outline of the chapters to follow, to serve as an orientation to the study.

## **1.2 Rationale of the study**

With the increasing popularity of scuba diving, came an awareness of possible injury, especially concerning the ears (Wilson, 1972). Johnston and Berger (1971), state that the sense organ most often adversely involved in diving, is the ear. Interestingly Aristotle described tympanic membrane rupture in divers more than 300 years before Christ and it is clear that the effect of diving on the ears has been a longstanding area of interest (Molvaer & Albreksten, 1990). Diving-specific acute injuries have been well described in the literature although chronic disabilities and the long term effects of diving on a divers' health, have received significantly less attention (Taylor, O'Toole & Ryan, 2003).

It is believed that repeated exposure to the hyperbaric environment and the breathing of compressed gas for prolonged periods may cause impaired physical and psychological health (Taylor, O'Toole & Ryan, 2003). Exactly how it can affect the body, especially relating to the auditory system, is still an area of great uncertainty.

Of all the diving-related injuries, middle-ear barotrauma as an acute diving related injury is by far the most common and most frequent (Becker & Parell,

2001; Coles, 1976; Draper, 1999; Eichel & Landes, 1970; Green, Rothrock & Green, 1993; Harrill, 1995; Kay, 2000; Koriwchak & Werkhaven, 1995; Leek & Reiss, 1973; Mawle & Jackson, 2002; Roydhouse, 1974; Roydhouse, 1985; Taylor, O'Toole & Ryan, 2002; Taylor, O'Toole & Ryan, 2003). In a study done by Koriwchak & Werkhaven (1995), the overall incidence of mild barotraumas was 40% and the incidence of severe barotraumas 27%. As indicated in the research literature there appears to be an average incidence of barotraumas among scuba divers of between 30% and 60%. It is indicated that barotraumas are not associated with the age, sex, experience, medication or the otolaryngologic history of the diver but rather related to poor underwater visibility, equalizing problems and hearing loss after surfacing (Koriwchak & Werkhaven, 1995).

The research literature has given a lot of attention to acute injury relating to scuba diving. It is however important to also consider the possible long term or chronic implications that scuba diving might have on the individual and more specifically on hearing. Taylor, O'Toole and Ryan (2002), placed an emphasis on the fact that research relating to the chronic implications of scuba diving are limited. Taylor, O'Toole and Ryan (2003), indicated that further research and diver education are needed to better document injury rates and minimize serious diving related injuries and permanent disabilities. Although uncommon, chronic disability directly attributable to diving is an area that needs to be investigated in more depth. The onus lies on audiologists to comprehensively evaluate the hearing acuity of current divers and to compare it to the hearing acuity of non-divers. This could lead to a more accurate determination of the prevalence and cause of hearing problems among divers (Taylor, O'Toole & Ryan, 2003).

The question whether scuba diving has a harmful effect on hearing has been a controversial issue. Some studies support the idea that hearing loss is more prevalent amongst scuba divers than amongst age-matched non-divers.

Opposed to these there are studies that state that the influence that diving has on the hearing abilities of the scuba diver, is negligible.

There are several reports of a high rate of hearing impairment amongst divers (Haraguchi, Ohgaki, Okubo, Noguchi, Sugimoto & Komatsukazi, 1999). Some authors found that there are significant differences in hearing sensitivity between divers and non-divers. Sensori-neural hearing loss, caused by conditions associated with diving, is considered to be an occupational hazard to professional scuba divers (Edmonds & Freeman, 1985). Coles (1976), mentioned the insidious development of high frequency sensori-neural hearing loss, which may be associated with diving. More emphasis is placed on the continuing suspicion that career divers develop a degree of high frequency hearing loss that is disproportionately greater in both degree and frequency than could readily be attributed to noise exposure.

Most of the research done concerning the hearing of scuba divers is done on professional divers. This is illustrated in research by Edmonds (1985), Edmonds & Freeman (1985), Molvaer & Lehmann (1985), Molvaer & Albreksten (1990), Skogstad et al. (2000) and several more. The risks involved in recreational diving have not been investigated to the same extent as that of the professional diver. However the recreational diver is exposed to the same environmental conditions and therefore similar risks occur amongst this group. This is evident in the medical statement that recreational divers have to abide by, before starting a scuba diving course and during their diving careers. Further research is also required to evaluate more clearly the risks associated with some traditionally contraindicated medical conditions (Taylor, O'Toole & Ryan, 2002).

It is evident in studies concerning diving and hearing function, that there is an increased awareness and interest in this field. Further controversy exists, concerning cause-effect and prevention of diving related injury. Coles (1976),



indicated the need for further research and careful clinical investigation, in the field of diving medicine. More recent publications still place an emphasis on the need for further investigation into the area of ear trauma in scuba divers and are also indicated in research done by Mawle and Jackson (2002).

### **1.3 Problem statement**

It is clear and authors agree that scuba diving represents a medical risk for the individual and that the ear is the area most affected by the diving environment. What is however most evident in the available research literature is that controversy exists concerning the long term implications of diving and more specifically it's effect on hearing. The audiometric test batteries used in previous research studies only included pure tone air conduction testing or tympanometry. In none of the studies have they performed a full audiometric test battery. A comprehensive audiological assessment is critical to determine in which part of the ear a pathology may occur during recreational diving.

A comprehensive audiological test battery could include; pure tone audiometry (air and bone conduction), speech audiometry (speech reception threshold testing and speech discrimination or word recognition testing) and immittance measurements (tympanometry and ipsi and contra acoustic reflex testing), to include both the behavioral evaluation of peripheral hearing functions as well as the physiologic evaluation of the auditory system (Katz, 2002).

With the increased interest in scuba diving, especially on a recreational level, the importance of future research into the possible risks for the individual cannot be emphasized enough. The research literature also supports the idea of further research on the long term medical effects of diving. This study endeavours to assess and describe the hearing abilities and middle ear functioning of the recreational scuba diver and investigate the possibility that diving, on a

recreational level may have an influence on the middle ear functioning and hearing abilities of the scuba diver and leads to the research question:

**Does scuba diving on a recreational level have an effect on the hearing and middle ear functioning of the individual?**

## **1.4 Division of chapters**

### **Chapter One**

#### **Introduction, Background, Rationale and Orientation to the Study**

This chapter provides a background to scuba diving and its effects on the ears that leads to the rationale behind the current study. Chapter one explains the research problem and places an emphasis on the audiologist's role in research implementing a more comprehensive audiological test battery. This chapter also provides expected findings and contributions of the current research endeavour.

### **Chapter two**

#### **Theoretical Perspectives to Scuba Diving, its Chronic Implications and the Research questions of the Study**

Chapter two provides a theoretical framework for the empirical research. It provides a critical evaluation and interpretation of relevant research literature. The emphasis in this chapter is placed on the importance of a comprehensive audiological test battery to evaluate the auditory system of scuba divers as well as a description of the test battery. This chapter concludes with the research questions.

### **Chapter three**

#### **Research Methodology**

Chapter three describes the operational framework implemented to conduct the empirical research and includes the scientific process implemented to ensure clinical validity. This chapter deals with the aims, research design, selection

criteria and material and equipment used for the purposes of the study. Chapter three concludes with a discussion of the procedure related to data collection, documentation and analysis.

## **Chapter four**

### **Results and discussions**

In this chapter the collected and processed data are presented, interpreted, compared and discussed. The data will be compared to the relevant literature as discussed in Chapters one and two. A summary of the data for all 90 ears is given, where after a discussion of the statistical and practical significance of the measurements will follow. Correlations between the different tests performed will be made. Chapter four concludes with a summary of the findings and the significance of these findings.

## **Chapter five**

### **Conclusion of the study**

Chapter five summarizes the results obtained through statistical analysis. Significant results and their contribution to the current research literature are highlighted. A conclusion regarding the current study will be formulated. A critical evaluation of the study highlighting the limitations of the study and subsequent recommendations for future research is provided.

### **1.5 Description of terminology**

This section aims to provide definitions for the terminology used throughout the research endeavour. The purpose of this is to give the reader a clear understanding of what is meant by the basic terminology used in this study. As stated by Leedy (1993), the responsible author makes ensures that what is published has a sound basis, is properly documented, intelligible and readable. The definitions of terminology frequently used in this study are presented in Table 1.1 (Available on the following page).

**Table 1.1: Definitions of frequently used terminology**

Terminology	Definition
Barotrauma	Barotrauma refers to trauma caused by pressure changes (Paaske, Staunstrup, Malling & Knudsen, 1991). For the purposes of the current study barotrauma refers specifically to trauma of the auditory system.
Demographical characteristic	A statistical term selected for the purposes of this study to refer to characteristics that define the selected population. In the current study demographical characteristics refers to age, gender or participant group.
Demographic group	Demographic groups refer to combinations of the different demographical characteristics.
Hearing acuity	Hearing acuity refers to the asperity or sharpness of an individual's hearing ability.
Hyperbaric environment	A hyperbaric environment refers to an environment that implicates high levels of ambient pressure changes (Shreeves, 1999).
Recreational scuba diving	Scuba diving on a recreational basis should be differentiated from scuba diving for professional, career or technical purposes. In recreational scuba diving, divers are allowed to dive to depths of 30 metres and perform diving for recreational purposes (Shreeves, 1999).
Scuba	Self-contained under water breathing apparatus (Shreeves, 1999).
Statistically significant	Data is considered statistically significant if the calculated P-value is 0.05 or less

## **1.6 Expected findings and contribution of research**

This study aimed to investigate the hearing abilities of the recreational scuba diver, the possible long term implication of diving and to determine possible risks for the individual. The researcher expected to find normal middle ear functioning in all the participants with a possible increase in the compliance of the middle ears of the scuba divers. The researcher further expected a decrease in the middle ear pressures of the diver groups as stated in a study done by Green et al. (1993). Another possible phenomenon may be higher pure tone threshold, especially in the high frequencies of the scuba diver. This could implicate a higher speech discrimination threshold correlating with increased or deviant high frequency pure tone thresholds. The increased thresholds are expected to be sensori-neural in nature. Findings such as these would support research done by Campbell (2002), Coles (1976), Haraguchi et al. (1999) and several more.

Previous studies done in this field, as illustrated in research by Edmonds (1985), Edmonds & Freeman (1985), Molvear & Albreksten (1990), Skogstad et al. (2000) and several more, included pure tone testing and impedance measurements. None of these studies included a full audiological test battery, nor was it done on the recreational diver. As mentioned earlier, a comprehensive assessment is critical to determine to which part of the ear the most damage can occur during scuba diving.

With reference to the research literature, it is evident that the subject of hearing loss in scuba divers is a controversial one. It is, however, a very important area for further research. Every day more and more people are starting to participate in recreational scuba diving, which means more and more people might be at risk for hearing problems. This is of notable importance to the audiologist, ear, nose and throat specialist and the general practitioner, but even more so to the individual who is currently diving or considering scuba diving as a recreational activity. This study aims to increase the awareness of possible risks concerning

the conditions of the individual's ear and hearing in scuba diving and in so doing, attribute to the prevention, diagnosing and intervention of diving related ear injuries.

## **1.7 Summary**

This chapter aimed to provide relevant background information to explicate the focus of the current research endeavour and to provide insight on the importance of the rationale underlying the study. Emphasis was placed on the acute and chronic medical risks involved in scuba diving, especially relating to the ears and hearing. The importance of a comprehensive audiological test battery in the evaluation of scuba diver's hearing acuity was highlighted. A description of terminology frequently used in the study as well as a discussion of the division of chapters was provided.

## CHAPTER TWO

### THEORETICAL PERSPECTIVES, RESEARCH QUESTIONS AND RATIONALE OF THE STUDY

#### **AIM OF CHAPTER TWO:**

This chapter aims to provide a theoretical framework for the empirical research. It further provides a critical evaluation and interpretation of the available and relevant research literature and its shortcomings. The emphasis is placed on the importance of a comprehensive audiological test battery to describe the possible long term effects of scuba diving. This section will conclude with the research questions.

**Research is never a solo flight – an individual excursion. It begins by researchers communicating their thoughts, their plans, their methods and their objectives for other to read, to discuss and to act upon.**

(Leedy, 1993, p. 149)

#### **2.1 Introduction**

The first section of this chapter explores the hyperbaric environment that scuba divers are exposed to and the influence that it has on the auditory system. It further focuses on the medical contraindications to diving and the medical standards that divers have to adhere to.

The second section of chapter two provides a discussion of relevant literature related to the acute and chronic medical implications of scuba diving. The shortcomings in the already limited research literature are critically evaluated.

The third section of this chapter places the emphasis on the need for a comprehensive audiological test battery in the evaluation of hearing function and provides a description of such a test battery. This chapter concludes with a motivation for the proposed research question in chapter one of this study.

## **2.2 The hyperbaric environment**

Modern recreational scuba divers are increasingly performing multi-day repetitive diving. This is possible with the availability of diving computers and implies more exposure to the environmental conditions of diving that may influence the auditory system.

During ascent and descent while scuba diving, equalization of pressure must take place between ambient water pressure and the external auditory canal, middle ear and the paranasal sinuses. If a diver is not able to equalize it can result in pain or even rupture of the occluded space. The inner ear is filled with fluid and can therefore not be compressed. The round and oval windows as well as the interfaces between the middle and inner ear are however subject to pressure changes.

One of the important laws of physics to consider the effect of pressure on the ears is Boyle's Law. This law states that for any gas at constant temperature, the volume will vary inversely with the absolute pressure, while the density will vary directly with the absolute pressure. The non-compressible middle ear cavity makes ears susceptible to damage from ambient pressure changes and middle ear pressure is governed by Boyle's Law (Harrill, 1995).

The volume change has a number of implications for the scuba diver. It indicates that any space filled with air would be affected and its volume will change with ambient pressure changes. As the depth increases the volume would decrease and therefore the pressure in the specific space will increase. If



the air is not released the pressure will build up and could lead to barotraumas. An important point to remember is that the greatest volume change occurs between zero and ten meters (South African Underwater Union Manual (SAUU), 1992). This is the depth that every diver, partaking in recreational or professional diving, is inevitably exposed to. Divers will have to dive to depths of approximately 45 meters to equal the total volume change produced during the first 10 meters of descend (Harrill, 1995). This is a clear indication of why most diving injuries occur during shallow dives. It has been reported that middle and/or inner ear barotrauma can occur in as little as approximately 2 to 3 meters of water (Harrill, 1995). Table 2.1, indicates the relationship between depth, pressure, volume and density as referred to in Boyle's Law.

**Table 2.1: The relationship between depth, pressure, volume and density**

Depth	Pressure	Volume	Density
0 m	1 bar / ata	X 1	X 1
10m	2 bar / ata	$\frac{1}{2}$	X 2
20m	3 bar / ata	$\frac{1}{3}$	X 3
30m	4 bar / ata	$\frac{1}{4}$	X 4
40m	5 bar / ata	$\frac{1}{5}$	X 5

The relationship between depth, pressure, volume and density indicates that as the depth increases, pressure and density will increase and volume will decrease. As mentioned earlier, it is of notable importance that during the first ten metres of descent, the pressure and density doubles and the volume is halved. As the depth increases beyond the first ten metres this relationship becomes less extreme. At a depth of forty metres the pressure and density will increase five times and the volume would be one fifth of what it was at zero metres.

During descent, water pressure increases and the air in your body air spaces is compressed. The ears and the sinuses are the two air spaces that are noticeably affected by the increasing pressure. As the volume decreases the pressure pushes the body tissue in. This is known as a squeeze on the air space. Equalization methods are used to deal with this pressure change.

During ascent the air expands and normally doesn't pose any problems with the ears. It is however possible that the expanding air cannot escape from an air space during ascent. In this case the diver will experience discomfort because the pressure inside the air space exceeds the surrounding water pressure. This is known as a reversed block or squeeze.

It is believed that repeated exposure to the hyperbaric environment and the breathing of compressed gas for prolonged periods may cause impaired physical and psychological health (Taylor, O'Toole & Ryan, 2003). Exactly how it can affect the body, especially relating to the ears and hearing, still requires further research.

### **2.3 Medical standards**

Before undertaking a scuba diving course, divers have to complete a medical examination or questionnaire in order to screen for medical contraindications to diving. In the South African Underwater Union manual and workbook, a set of guidelines concerning medical standards are discussed (SAUU, 1992). The guidelines are applicable to new diving recruits as well as qualified divers developing any condition that could be a health risk. It is stressed that if any such condition should occur, the diver should discuss it with the appropriate medical referee (SAUU, 1992).

There are several factors concerning the ears that would disqualify a diver from diving. Amongst these are the following: perforated eardrums, surgery to the ear, chronic or acute otitis media, Meniere's disease, equalizing problems,

vestibular dysfunction and unilateral deafness. Acute perforation of recent onset is allowed after re-evaluation. The comments made in the medical guidelines, are that hearing impairment as a result of diving is relatively common. No specific reason or motivation was given for this. Further it was mentioned that damage to the middle ear as a result of tympanic membrane perforation might be severe. Acute vertigo as a result of water in the middle ear during diving may give rise to serious problems that could put the diver at serious risk (SAUU, 1992).

With reference to an article written by Sanders (2002), in The Undersea Journal, the Recreational Scuba Training Council (RSTC) Medical Statement represented dive medical opinions as from 1989. This medical statement informs of some potential risks involved in scuba diving and of the conduct required of the diver during the scuba training program. The statement has recently been revised by the RSTC. The revision represents a unique collaboration between many notable dive medical professionals and the dive training organizations that make up the RSTC (Sanders, 2002).

The revised medical statement categorizes medical conditions by their potential risk level to the diver in the section; "Guidelines for Recreational Scuba Diver's Physical Examination". On former editions of the statement, medical conditions were divided into two categories: 1) relative contraindication to diving or, 2) absolute contraindication to diving. Medical conditions are now grouped as 1) severe risk, 2) relative risk and 3) temporary medical condition. The severe risk category would include individuals with conditions believed to be at a substantially elevated risk of decompression sickness, pulmonary or otic barotraumas or altered consciousness with subsequent drowning, compared to the general population. Individuals with conditions that may put them at a moderate increase in risk, which could be acceptable based on individual assessment, would fall in the category of relative risk. The third category of

temporary medical conditions would include those with temporary medical problems that are responsive to treatment and that would be allowed to dive after the condition has been resolved.

The final analysis and decision concerning a prospective diver's medical suitability rests with the examining physician. The responsibility however lies with the diver to provide accurate information concerning his/her medical history. A medical history checklist is given to the individual to find out whether he/she should be examined by a medical doctor before participating in recreational scuba diver training. The medical conditions concerning the ears that are included in this checklist are as follows: 1) frequent colds, sinusitis or bronchitis, 2) frequent problems with motion sickness, 3) history of ear or sinus surgery, 4) history of ear disease, hearing loss or problems with balance and 5) history of problems with equalizing ears during airplane or mountain travel.

According to the 1989 edition of guidelines for recreational scuba diver's physical examination as used by the medical practitioner; relative and absolute contraindications are included. Relative contraindications refer to medical conditions that may or may not have an influence on a diver's medical suitability for scuba diving and indicates that the individual is at relative risk. An absolute contraindication refers to conditions that will exclude the prospective diver from participating in scuba diving. Table 2.2 (available on the following page) contains a list of these contraindications with reference to otolaryngological symptoms or problems.

**Table 2.2: Contraindications with reference to otolaryngological symptoms or problems**

Relative Contraindications	Absolute Contraindications
Recurrent otitis externa	Monomeric tympanic membrane
Significant obstruction of external auditory canal	Open tympanic membrane perforation
History of significant cold injury to pinna	Tube myringotomy
Eustachian tube dysfunction	History of stapedectomy
Recurrent otitis media or sinusitis	History of ossicular chain surgery
History of tympanic membrane perforation	History of inner ear surgery
History of tympanoplasty	History of round window rupture
History of mastoidectomy	Facial nerve paralysis secondary to barotraumas
Significant conductive or sensori-neural hearing impairment	History of vestibular decompression sickness
-	Inner ear disease other than presbycusis

Several diving institutions are currently still using the 1989 medical statement. As discussed above, the revised version of the statement and more specifically the revised guidelines for recreational scuba diver's physical examination, categorize risk conditions as severe, relative and temporary risk conditions. With reference to the conditions that involve the ears the revised statement includes only relative and severe risk conditions. These match the relative and absolute contraindications as listed in Table 2.2 and there are no additions to that list (Sanders, 2002).

Traditionally there have been good theoretical reasons why certain medical conditions have been contraindicated in diving (Taylor, O'Toole & Ryan, 2002). The subaqua environment is inherently dangerous and conditions that might

reduce the physical or mental capacity of the diver may increase the risk significantly. Such conditions, specifically concerning the ears would include seasonal allergies, asthma and obstructive airway diseases, pneumothorax, equalization difficulties, chronic sinusitis, middle and inner ear disease or surgery and ocular surgery (Taylor, O'Toole & Ryan, 2002).

Taylor, O'Toole & Ryan (2002) raise the concern that after the initial medical screening, no further screenings are required and yet divers may develop diseases during their diving careers that subsequently place them at increased risk. Another concern which is mentioned is that they found that divers continued to dive, despite medical contraindications and suggested that screening examinations should be undertaken at regular intervals. It was suggested that regular screening would also assist in the determination of the prevalence of chronic disease among scuba divers (Taylor, O'Toole & Ryan, 2002).

## **2.4 The effect of diving on the ears**

Johnston & Berger (1971) state that the sense organ most often adversely involved in diving, is the ear. In a study to investigate disorders of the ear, nose and sinuses in scuba diving, done by Roydhouse (1985), 64% of all diving disorders either involve the outer, middle or inner ears. In this study the outer ear disorders included external otitis, exostoses, wax in ear, outer ear squeeze. The middle-ear problems were Eustachian tube dysfunction, tympanic membrane ruptures and middle-ear barotrauma. Inner ear problems included tinnitus, vertigo and sensori-neural deafness. Despite the apparent high incidence of injury to the auditory system during scuba diving, the research literature describing the influence of diving related to the ears and hearing is very limited.

In the study by Taylor, et al. (2002), a group of 346 divers reported medical conditions other than relative and absolute contraindications to diving. These

medical conditions were divided into divers who had a past history of the disease or condition and those presently still suffering from the condition. Table 2.3 provides an exposition of diseases and conditions relating to the auditory system.

**Table 2.3: Medical conditions other than relative and absolute contraindications to diving**

Disease system/state	Past history	Presently suffering
-	Total % of divers	Total % of divers
Equalizing problems in ears or sinuses	26.0	14.5
Chronic otitis media	3.5	0.3
Ear drum rupture	6.1	0
Inner ear surgery	1.5	0
Round or oval window rupture	0.6	0
Tinnitus	12.1	11.7
Hearing loss	3.8	8.4
Excessive wax	15.3	2.9

In this particular study 26% of the participants mentioned problems with equalizing in the ears and sinuses. 14.5% of this group found that they were still experiencing problems with equalizing. This is an alarming percentage of divers, especially considering that as mentioned earlier, equalizing problems are one of the most common causes of injury to the ears (Brylske, 1991). Another condition that was indicated both as a past and current problem was tinnitus. 12.1% of the participants experienced tinnitus in the past and 11.7% were still experiencing at the point of the study. Tinnitus could be indicative of a number of influences but also leads to the possibility of damage to the auditory system.

To determine the possible cause of the high prevalence of tinnitus in scuba divers further investigation is needed.

Even the internet today pays a lot of attention to diving health and tries to assist with the education of divers concerning the health risks involved. An example of this is; Doctor Grossan's Ear, Nose and Throat Consultant Pages. This is a diving health website that deals with several health problems that could occur during diving or that are related to diving (Grossan, 2003). He discusses complications concerning the ears, such as problems with equalizing during descent, serous otitis, myringitis, external otitis, otitis media and perilymph fistula.

#### **2.4.1 The middle ear**

As discussed in chapter one middle ear barotrauma is by far the most common diving-related injury, (Becker & Parell, 2001; Coles, 1976; Draper, 1999; Eichel & Landes, 1970; Green, Rothrock & Green, 1993; Harrill, 1995; Kay, 2000; Koriwchak & Werkhaven, 1995; Leek & Reiss, 1973; Mawle & Jackson, 2002; Roydhouse, 1974; Roydhouse, 1985; Taylor, O'Toole & Ryan, 2002; Taylor, O'Toole & Ryan, 2003). Consistently through studies performed on scuba divers there appears to be an average incidence of barotraumas among scuba divers of between 30% and 60%.

Divers experience continuous alterations in ambient pressure while ascending and descending (Green et al., 1993). The pathophysiological response to the middle ears which is observed with alterations in ambient pressure shows a decrease in middle ear pressure and otoscopic evidence of middle ear barotrauma, in proportion to diving frequency. Both are readily reversed upon cessation of diving. Tympanic membrane compliance remains normal (Green et al., 1993). Paaske, Staunstrup, Malling and Knudsen (1991) describe changes in compliance as the first but reversible change of the elastic elements of the



tympanic membrane. Later irreversible changes may occur when barotrauma to the middle ear is frequent.

A study done by Mawle and Jackson (2002), investigated ear barotrauma and ear infection in a group of 142 divers. These divers included scuba diving instructors, technical and recreational scuba divers. 64% of divers reported symptoms of barotraumas. These included pain (47,9%), temporary hearing impairment with tinnitus (27,5%) and vertigo (9,9%). The prevalence of middle ear infection was present in 37,3% of the group and were significantly more prevalent in the left ear than the right ear. The fact that the left ear was more affected could be related to the ergonomic design of the diving equipment or laterality and perception but it is unlikely that the anatomical differences between ears were involved. Mawle and Jackson (2002), also refer to previous studies that found that the left ear has been more prominent in hearing loss due to diving. Greater barotraumas symptoms were recorded in divers that consistently wore a hood during diving than those divers who only wore a hood during cold conditions. Mawle and Jackson (2002), place emphasis on diver separation and report that there was a significant relationship between barotraumas symptoms and diver separation. 27% of divers reported incidents involving separation from buddies while diving. This is a significant cause for concern as diver separation is acknowledged as one of the greatest risks of fatality in diving in novice divers.

A study done by Green, Rothrock, Hummel and Green (1993), investigated the incidence of middle ear barotraumas associated with repetitive recreational scuba diving and through tympanometry revealed a significant decrease in middle ear pressures but no middle ear effusions or otologic dysfunction, with repetitive scuba diving. These authors mentioned the possibility that middle ear barotraumas may represent a more benign disorder than has previously been assumed.

#### **2.4.2 The inner ear**

When considering damage to the inner ear and the possibility of hearing impairment during diving, it is interesting that most authors refer to sensori-neural problems caused by round window or oval window rupture; perilymphatic fistula; intralabyrinth damage; inner ear barotrauma and decompression sickness (Eichel & Landes, 1970; Grossan, 2003; Roydhouse, 1985).

A perilymph fistula, also referred to as perilymphatic fistula or labyrinthine fistula is an abnormal opening in the fluid filled inner ear (Hain, 2005; Logan, 2001). It is an abnormal communication between the fluid filled perilymphatic space of the inner ear and the air filled middle ear cavity, usually through the round or oval windows, (Hain, 2005; Harrill, 1995; Logan, 2001). Fistula types that could be related to diving include the oval and the round window type (Hain, 2005).

The most common causes of perilymph fistulas are stapes prosthesis surgery, head trauma, acoustic trauma, barotraumas or bony erosion due to infection or neoplasm (Hain, 2005; Logan, 2001). According to Logan (2001), it may also be idiopathic or spontaneous. Other causes of a perilymph fistula include collagen changes during pregnancy, forceful coughing, sneezing or straining (Hain, 2005). Perilymph fistulas seem to have a higher prevalence in females than in males (Logan, 2001). Perilymph fistula is however a very rare condition compared to most other causes of dizziness and hearing loss (Hain, 2005).

The symptoms of a perilymph fistula may include sensori-neural hearing loss that may be sudden or fluctuating, aural fullness and tinnitus that can be roaring in nature (Hain, 2005; Logan, 2001). Vestibular symptoms may include vertigo, dizziness, disequilibrium, nausea, vomiting, motion intolerance or unsteadiness which increases with activity, disorganization of memory and concentration and/or perceptual disorganization in complex surroundings (Hain, 2005; Logan,

2001). Some patients experience symptoms more severely when coughing, sneezing, nose blowing or with exertion and activity (Hain, 2005).

The research focuses mainly on trauma to the inner ear, causing sudden hearing impairment and not the effect on hearing abilities and the possibility of progressive hearing loss. It is, however, recommended that hearing should be tested, where barotrauma occurs, to ensure that the cochlea has not been damaged (Hawke, Keene & Alberti, 1990).

As mentioned before, the research literature has concentrated on acute injury relating to diving. It is however important to also consider the possible long term or chronic implications that diving might have on the individual.

## **2.5 Long term or chronic implications of diving**

Taylor, O'Toole & Ryan (2002) performed a cross-sectional, postal survey to determine whether experienced, recreational scuba divers continued to dive, despite medical contraindications. 346 divers completed and returned the questionnaires. 12,1% of the divers reported hearing difficulties and 23,4% reported past or present tinnitus. These authors further mentioned the fact that few other studies have examined the prevalence of chronic diseases and the long term implications of diving. They found a greater than expected prevalence of tinnitus and hearing difficulties and their findings suggested that it is conceivable that the repeated, even subclinical, aural barotraumas often experienced over a long diving career, might have an etiological role in these conditions. Their findings further suggest that research is needed into the possible association between scuba diving and chronic middle and inner ear disease.

The above mentioned authors performed another study on experienced and professional divers, in which they aimed to investigate the injury experiences of individual divers over long diving careers (Taylor, O'Toole & Ryan, 2003). They

stated that scuba diving-specific injuries have been well described but that the longterm experiences have been rarely investigated. Chronic disabilities have been less well reported and are usually related to the immediate consequences of acute injury. 709 experienced divers were enrolled in an international, cross sectional, descriptive postal survey. Of this group, 52.1% of divers experienced an ear “squeeze” at more than one occasion. Tympanic membrane rupture and round/oval window rupture were experienced by 5.4% and 1.1% respectively. 2% of divers had tympanic membrane rupture on more than one occasion. 2.3% of divers reported permanent disabilities, which largely consisted of hearing loss, tinnitus and balance disorders. The majority of experienced divers suffered diving related injuries and these injuries were mainly barotraumas of various forms.

## **2.6 The effect of diving on hearing**

The question whether diving has a harmful effect on hearing is a controversial issue. Some studies support the idea that hearing loss is more prevalent amongst scuba divers than amongst age-matched non-divers. Opposed to these, there are studies that state that the influence diving has on the hearing abilities of the scuba diver, is negligible.

There are several reports of a high rate of hearing impairment amongst divers (Haraguchi, Ohgaki, Okubo, Noguchi, Sugimoto & Komatsukazi, 1999). Some authors found that there are significant differences in hearing sensitivity between divers and non-divers. Sensori-neural hearing loss, caused by conditions associated with diving, is considered to be an occupational hazard to professional scuba divers (Edmonds & Freeman, 1985). Coles (1976), mentioned the insidious development of high frequency sensori-neural hearing loss, which may be associated with diving. More emphasis is placed on the continuing suspicion that career divers develop a degree of high frequency hearing loss that is

disproportionately greater in both degree and frequency than could readily be attributed to noise exposure.

Haraguchi et al. (1999), mentions that in almost all their cases, a progressive sensori-neural hearing loss appeared with continuation of diving and that only one case had a past history of acute sensori-neural hearing loss, possibly caused by inner-ear barotrauma. They mention a relation between the number of years of diving and the severity of the hearing loss. Their results clearly show that divers' hearing deteriorate faster than that of normal subjects, which was consistent with findings of Molvaer and Albreksten (1990). A study done by Brady, Summit & Berghage (1976), suggests that conditions associated with diving have a minimal effect on the auditory sensitivity of navy divers, when compared to a group of non-divers. They further state that it would be compelling; both intuitively and medically to suggest that diving has a detrimental effect on hearing. Other studies found a high incidence of professional divers with hearing impairment, especially in the high frequencies from 4000Hz to 8000Hz (Edmonds, 1985; Edmonds & Freeman, 1985; Molvaer & Lehmann, 1985; Molvaer & Albreksten, 1990; Skogstad, Haldorsen & Arnesen, 2000).

Sensori-neural or nerve hearing loss due to dysfunction in the inner ear, auditory nerve or brain can occur. This may be due to blockage of blood vessels, trauma or bubbles in these structures, leakage of fluid, inflammation or trauma including degeneration as is also found in excessive noise exposure. Combinations of the above can also occur (Campbell, 2002). Hearing loss can be purely conductive, but according to Coles (1976), conductive disorders amongst divers are almost completely absent. Although changes in the middle ear occur, it does not necessarily result in a conductive hearing loss. Pure tone testing, immittance measurements and speech discrimination testing can be used to determine the presence and the type of hearing loss.

## 2.7 Possible causes

The exact cause of hearing problems as a result of scuba diving is uncertain. Several causes of hearing problems related to diving have been described. Mendel, Knafelc and Cudahy (2000), mention noise exposure (during chamber diving) and high atmospheric pressure. Wilson (1972), emphasizes the influence of temperature change, prolonged immersion and pressure changes (both in water and in inhaled air). Haraguchi, et al. (1999), places the emphasis on repeated compression and decompression as a possible cause and refers to a study done by Wilkes et al. (1989), on mini-pigs, where cochlear damage was observed after a degree of repeated compression-decompression exposure, which is generally thought to be safe for humans. The results suggest that minute hair cell damage might occur with repeated long-term compression-decompression cycles in divers. Edmonds and Freeman (1985), describes possible reasons for the high incidence of hearing loss and ear problems and these include barotrauma, decompression sickness, infections and noise exposure. This might be seen in the pure tone results and confirmed by speech discrimination scores.

The pathology related to hearing loss and tinnitus as a long-term effect of diving, is not well understood (Taylor, O'Toole & Ryan, 2003). According to these authors, possible causes of aural symptoms may be repeated minor barotrauma or possibly the scarring that results from overt rupture of the tympanic membrane or the round and/or oval window. The high prevalence of hearing difficulties and tinnitus may be the result of aural barotraumas and requires further research (Taylor, O'Toole & Ryan, 2002). Their findings further suggest that research is needed into the possible association between scuba diving and chronic middle and inner ear disease.

Another conceivable possibility is that subclinical decompression sickness with localized central nervous system degeneration, could be the mechanism of aural

symptoms. Inner ear decompression sickness may represent with symptoms such as hearing loss, tinnitus, vertigo and nausea. Clinical symptoms of hearing loss and tinnitus due to either barotraumas or decompression sickness may be ambiguous. According to Taylor, O'Toole & Ryan (2003) previous studies indicate that central nervous system degeneration is demonstrable among experienced divers. Although the exact mechanism of this degeneration remains unclear, subclinical decompression sickness is possible. This study however does suggest that chronic disabilities directly attributable to diving are uncommon.

## **2.8 The need for a more comprehensive test battery**

As mentioned in chapter one and discussed in the first section of this chapter, it is evident that in previous research studies in the field of diving medicine, the audiometric test battery only included pure tone air conduction testing or tympanometry. In none of the studies have they performed a full audiometric test battery.

A comprehensive audiological test battery should include both the behavioural evaluation of peripheral hearing functions as well as the physiologic evaluation of the auditory system (Katz, 2002). The next section provides a theoretical background to the test battery that was selected for the purposes of the current research endeavour and aims to answer the question; **how can the hearing acuity and middle ear functioning of the recreational scuba diver comprehensively be assessed?** In the conclusion of the study there will be a critical evaluation of the selected test battery and the author will aim to answer the question; **is a standard audiological test battery sufficient to evaluate the possible influence that scuba diving has on the hearing and middle ear functioning of a diver?**

## **2.9 Behavioral evaluation of peripheral hearing functions**

### **2.9.1 Pure tone audiometry (Air- and bone conduction audiometry)**

Establishing a pure tone audiogram forms the cornerstone of a hearing evaluation (Stach, 1998). The purpose of air conduction audiometry is to determine a person's auditory sensitivity through a range of frequencies (Katz, 2002; Martin 1991, Stach; 1998). Pure tone thresholds obtained by using only air conduction, is however limited in diagnostic value (Katz 2002). Air conduction thresholds can determine whether a hearing loss exists but not whether the deficit is a cause of an abnormality or lesion in the conductive or sensori-neural mechanism or both (Martin, 1991).

There are two modes by which pure-tone test signals are presented to the auditory system: either through air, via earphones or directly to the bones of the skull through a bone-conductor (Stach, 1998)

Bone conduction audiometry theoretically determines the person's sensori-neural sensitivity (Martin, 1991). It is used to ascertain the presence or absence of an external or middle ear lesion and to determine quantitatively the degree of the conductive hearing impairment (Katz, 2002).

The results of the audiogram are interpreted as the amount of hearing loss by air conduction and bone conduction and then the relationship between air conduction and bone conduction thresholds. It is important to remember that the air-conduction loss reflects disorders along the entire conductive and sensori-neural systems from the middle ear to the cochlea and auditory nerve (Stach, 1998). The bone-conducted thresholds reflect function of the cochlea regardless of the status of outer and middle ear (Stach, 1998). The amount, by which the air conduction and bone conduction threshold at the same frequency differ, is known as the air-bone gap (Martin, 1991). The air-bone gap (ABG) is indicative of the conductive involvement and will indicate whether the hearing loss is



conductive, sensori-neural or mixed or whether the hearing threshold is within normal limits (Katz, 2002; Martin, 1991; Stach, 1998).

### **2.9.2 Masking**

Where cross-hearing is suspected, it is important to perform masking. This is a procedure necessary to remove the influence of the non-test ear from the test procedure (Martin, 1991). During masking, the test ear is isolated by presenting noise in the non-test ear (Stach, 1998). The need to mask the non-test ear is related to the amount of interaural attenuation (Stach, 1998).

### **2.9.3 Speech reception thresholds and word recognition testing**

The most important measurable aspect of auditory function, is the ability to understand speech (Katz, 2002). Pure tone audiometry provides valuable information regarding hearing sensitivity but limited information about auditory communication ability (Katz, 2002). There appears to be no accurate means of predicting speech understanding from pure tone tests results alone and the evaluation of hearing sensitivity for speech and discrimination of speech through the use of speech stimuli forms a fundamental part of a comprehensive audiologic evaluation (Katz, 2002; Stach, 1998). Two tests using speech signals are routinely administered as part of a basic audiological test battery. The first is a threshold measure for speech understanding, known as speech reception threshold, using speech material with two syllable words with a spondaic stress pattern. It is expected of the listener to repeat 50% of the material presented, correctly (Katz, 2002). The second is known as speech discrimination testing or word recognition testing and is measured by using monosyllabic words to determine the listener's ability to understand speech under ideal listening conditions (Katz, 2002).

Historically, speech discrimination testing has been for several purposes, like assisting in the determination of site of peripheral lesion, evaluating effectiveness

and social adequacy of communication, determining candidacy for surgery, planning of aural rehabilitation programs, evaluating hearing aid candidacy and assessing central auditory processing (Katz, 2002; Stach, 1998). It is however important to remember that speech discrimination test results should be viewed and interpreted as part of an audiological battery and is one of many factors that should be considered in the clinical decision making process (Katz, 2002). To summarize, speech audiometry is used to measure threshold for speech, can serve as a cross-check on the validity of the pure-tone audiogram, assess central auditory processing ability, quantify suprathreshold speech recognition ability, assist in differential diagnosis and estimate communicative function (Stach, 1998).

## **2.10 Physiologic evaluation of the auditory system**

A physiologic evaluation of the auditory system can include tympanometry, static immittance and the measurement of acoustic reflexes. Also referred to as immittance audiometry, it is one of the most powerful tools available for the evaluation of an auditory disorder (Stach, 1998). Immittance audiometry is sensitive in detecting middle ear disorders, can be useful in differentiating cochlear from retro-cochlear disorders and is useful in the estimation of peripheral hearing sensitivity (Stach, 1998). It can further be used as an objective cross check for behavioural audiometry.

Three immittance measures are commonly used in clinical assessment of middle ear function: Tympanometry, static immittance and acoustic reflex thresholds (Stach, 1998).

### **2.10.1 Tympanometry and static immittance**

As air pressure in the external ear canal is varied, the tympanic membrane is displaced from its resting position. Tympanometry reflects the change in the physical properties of the middle ear system and tympanic membrane (Katz,

1994; Martin, 1997). It requires an airtight seal between the immittance probe cuff and external ear canal (Katz, 1994). Tympanometry is generally conducted using a low frequency probe tone of 226Hz (Katz, 1994; Martin, 1997). The purpose of tympanometry, is to determine the point and magnitude of the greatest compliance of the tympanic membrane (Martin, 1997).

The tympanogram is a graphic representation of a pressure-compliance function (Martin, 1997). Tympanograms are classified as Type A, B or C according to Jerger's (1970) system (Katz, 1994; Martin, 1997; Stach, 1998). Type A has a peak near or at normal atmospheric pressure, within the range of 0 to 100daPa or slightly positive and is considered a normal tympanogram (Katz, 1994; Martin, 1997). Type B doesn't have a distinct point of maximum admittance and most commonly suggests fluid in the middle ear space (Katz, 1994; Martin, 1997). Type C has a distinct point of maximum admittance peak when air pressure in the ear canal is below normal atmospheric pressure (-100daPa) (Katz, 1994; Martin, 1997). Type C usually reflects a Eustachian tube dysfunction or serous otitis media (Katz, 1994; Martin, 1997).

In contrast to the dynamic measure of middle ear function represented by the tympanogram, the term static immittance, refers to the isolated contribution of the middle ear to the overall acoustic immittance of the auditory system (Stach, 1998). Static immittance or compliance is acoustic immittance of the middle ear under normal atmospheric pressure (Katz, 2002). Normal static immittance values range from about 0.30 to 1.60 cm<sup>3</sup>. Static immittance is characteristically altered by most common middle ear disorders and can serve as an important clinical measure of middle ear status when interpreted in conjunction with other audiometric tests (Katz, 2002).

Tympanogram gradient is another clinically useful tympanometric parameter that can be used to supplement measurement of ear canal volume, pressure for peak

admittance and static admittance (Katz, 2002). Its actual clinical value, is not certain but findings of de Jonge (1986) and Koebse and Margolis (1986) speculate that tympanogram gradient may have more desirable sensitivity and specificity characteristics for detection of high impedance middle ear disease (Katz, 1994). Katz (2002) stresses the importance of interpreting tympanometric results in correlation with other clinical audiometric test results.

A study done by Green; Rothrock; Hummel & Green (1993), where they investigated the incidence of middle ear barotraumas in recreational scuba diving, revealed through tympanometry, a significant decrease in middle ear pressures but no middle ear effusions with repetitive scuba diving. They mentioned the possibility that middle ear barotraumas might represent a more benign disorder that has been previously assumed.

Paaske et al. (1991), performed impedance measurements on divers during a scuba-diving training programme and found that there was a significant increase in middle ear compliance when diving. They concluded that the strain exerted on the tympanic membrane and middle ear from barotraumas, results in a reversible impairment but mentioned that if barotraumas continued; the changes could be irreversible. The increase in compliance could be the first measurable change in elasticity of the tympanic membrane (Paaske, et al., 1991).

### **2.10.2 Acoustic reflexes**

One of the most powerful diagnostic techniques is the interpretation of the bilateral stapedius muscle reflex in the presence of a sufficiently loud sound (Katz, 2002). The acoustic reflex response depends on adequate physiologic function of the entire reflex arc. This includes the sensory receptors (cochlea), afferent neurons (eighth nerve), interneurons (brainstem), efferent neurons (seventh nerve) and an effector organ (stapedial muscle) (Katz, 2002). By comparing stapedial reflexes between contra-lateral and ipsi-lateral, the specific

site of pathologic involvement can be determined (Katz, 2002). The acoustic reflex threshold (ART) is the lowest intensity, at which a change in the middle ear compliance of an acoustic signal, can be measured (Katz, 2002). The median threshold level for normal hearing subjects is between 70 and 100dB hearing level for ipsi-lateral reflexes and approximately 85dB hearing level for pure tone signals (Katz, 2002). Acoustic reflex measurements should be examined in correlation with other audiological tests (Katz, 2002).

Again it is important to note that immittance measures are very useful in quantifying middle ear disorders but should always be viewed in combination with the totality of the audiometric examination (Stach, 1998).

### **2.11 Conclusion**

A comprehensive audiological assessment is critical to determine in which part of the ear pathology can occur during recreational diving. With the increased interest in scuba diving, especially on a recreational level, the importance of future research into the possible risks for the individual cannot be emphasized enough. This study endeavours to assess and describe the hearing abilities and middle ear functioning of the recreational scuba diver and investigates the possibility that diving, on a recreational level may have an influence on the middle ear functioning and hearing abilities of the scuba diver.

### **2.12 Summary**

Chapter two aimed to provide a theoretical framework as support for the rationale and research question of the current research endeavour. It is of notable importance to mention that the research literature relating to the influence of scuba diving on the auditory system are very limited and the audiological element of these studies should be build on in future research.

This chapter was divided into three sections with the first section of this chapter exploring the hyperbaric environment and its influence on the auditory system. Attention was also given to medical standards that divers have to adhere to before starting a scuba diving career. The second section of chapter two provided a discussion of relevant literature related to the acute and chronic medical implications of scuba diving. The final section of this chapter placed the emphasis on the need for a comprehensive audiological test battery in the evaluation of auditory function and provided a description of the test battery selected for the current study.

# CHAPTER THREE

## RESEARCH METHODOLOGY

### AIM OF CHAPTER THREE

*In this section the experimental design of this study will be discussed. The first comments will deal with the aims, research design, selection criteria and material and equipment used. This section will conclude with a discussion of the procedure related to data collection, documentation and analysis.*

**To behold is to look beyond the fact; to observe to go beyond the observation**

(Leedy, 1993, p. 185)

### 3.1 Introduction

In chapter one the problem surrounding the current research endeavour was introduced and provided an orientation to, as well as a description of terminology used in the study. In chapter two the research questions and research aim was discussed. A theoretical perspective was given describing scuba diving, its medical implications and the possible long term effects on the hearing system of divers. Chapter two provided a critical evaluation and interpretation of the current and relevant literature available. An emphasis was placed on the importance of a more comprehensive audiological test battery during evaluation of scuba divers' hearing acuity and a description of such a battery, was provided. Building on the literature provided, this chapter aims to describe the procedures used for participant selection as well as for data collection and analysis to achieve the aims that have been identified.

## **3.2 Research Aims**

### **3.2.1 Main Aim**

The study endeavours to describe the hearing abilities and middle ear functioning of the recreational scuba diver (RSD), through the use of a comprehensive audiological test battery.

### **3.2.2 Sub Aims**

The following sub aims were compiled to determine the hearing acuity of the selected participants and in so achieving the above mentioned main aim:

- To collect normative data in 90 ears within three controlled groups of participants. The groups are; recreational scuba divers (RSD) between the ages of eighteen and forty with a diving history of less than one hundred dives, RSD with a diving history of more than one hundred dives and a group of non-divers (control group).
- To describe specific audiometric characteristics as measured in the three demographic groups of participants.
- To compare specific audiometric characteristics as measured in the three demographic groups of participants and determine possible predictable patterns in the audiometric test results.
- To determine possible correlations between the audiometric measured characteristics and how it relates to demographical group characteristics.

## **3.3 Research Design**

In order to achieve the aims of this study a descriptive, correlation research design was selected. This design was used to determine any correlation between the selected groups, to predict outcomes and to draw conclusions for this study. A descriptive, correlation research design examines the extent to which differences in one characteristic or variable are related to differences in one or more other characteristics (Leedy & Ormrod, 2005). According to Leedy



& Ormrod (2005), a correlation exists if with the increase in one variable, another increases or decreases in a somewhat predictable fashion.

In correlational studies data is gathered concerning two or more characteristics for a particular group of people (Leedy & Ormrod, 2005). These data are numbers that reflect specific measurements of the characteristics in question. In this study numeric data was collected, reflecting specific audiometric measurements of different functions of the auditory system. Correlational studies do not aim to infer a cause-and-effect relationship between specific characteristics on the basis of correlation alone. It is important to remember that correlation does not, in and of itself, indicate causation but rather serves to examine differences in specific characteristics and to determine relationship between these characteristics (Leedy & Ormrod, 2005). This study has a descriptive, quantitative research design.

The characteristics that were measured for the purposes of description, comparison and of possible correlation were as follows:

### **3.3.1 Measured and calculated characteristics**

Through the use of pure tone behavioural threshold audiometry and immittance measurements, the following characteristics were measured or calculated from the measured characteristics:

- Pure tone air conduction thresholds at 125, 250, 500, 1000, 1500, 2000, 3000, 4000, 6000, 8000Hz
- Pure tone bone conduction thresholds at 250, 500, 1000, 1500, 2000, 3000, 4000Hz
- Speech discrimination thresholds
- Ear canal volume, static compliance, middle ear pressure, tympanogram width and gradient on the tympanogram
- Acoustic Reflexes: 500, 1000, & 2000 – Ipsi and Contra lateral

The calculated characteristics that were derived from the measured characteristics included:

- The air-bone gap at 250, 500, 1000, 1500, 2000, 3000 and 4000Hz
- The pure tone average for each participant
- Speech discrimination thresholds where a 100% speech discrimination was achieved
- The difference between ipsi- and contra lateral acoustic reflexes at 500, 1000 and 2000

### **3.3.2 Controlled characteristics**

Through the use of specific selection criteria and procedure, that will be discussed in more detail later in this chapter the controlled characteristics included:

- Age – adult participants between ages 18 – 40 years
- Gender – an even gender distribution was selected as far as practically possible
- Amount of dives performed by each RSD participant through their diving careers

## **3.4 Description of the Participants**

The participants who took part in this research included recreational scuba divers and non-divers between the ages of eighteen and forty. A total number of 45 individuals participated in the study, which allowed for 90 ears to be included in this study. The purpose of descriptive study is to determine the nature of how things are (Leedy & Ormrod, 2005). A group of participants needs to be selected so that the results obtained from this group can be used to make generalizations about the entire population. The external validity of a research study depends strongly on the selection of this group, referred to as a sample (Leedy & Ormrod, 2005). In the current study purposive sampling was selected. In purposive sampling, participants are selected for a particular purpose and the researcher

will select participants that are typical to a specific population (Leedy & Ormrod, 2005). It is of notable importance though to provide a rationale explaining the selection of a particular sample of participants (Leedy & Ormrod, 2005).

### **3.4.1 Selection criteria for the two groups of recreational scuba diver participants**

#### **3.4.1.1 Participant age**

Participants were required to be between the ages of 18 and 40. The reason for this age criteria was that participants could respond to the behavioural audiometry reliably and accurately and understand instructions given during evaluation. A further consideration was to include participants from a large representative age group without including those that might be affected by age related risks to hearing abilities. The participants were divided into three age groups to determine possible age related correlation and determine the performance of specific audiometric test measurements. The three age groups were 18 – 24, 25 – 30 and 31 – 40 years.

#### **3.4.1.2 Participant Gender**

The sample selected for a descriptive correlation study needs to be truly representative of the entire population in order to allow group generalization (Leedy & Ormrod, 2005). For the purposes of this study an even gender distribution was sustained as far as practically possible to maintain a sample that would meet the criteria for the research design of the study.

#### **3.4.1.3 Diving history**

Participants that were included in the two diving groups had to be recreational scuba divers.

The recreational scuba diver participants were divided into two groups:

- The first group had performed between one and one hundred dives at the date of evaluation
- The second group of scuba divers had performed more than one hundred dives at the date of evaluation

There was no specific theoretical motivation for the division of the two diving groups but rather practical considerations. From discussions with divers that dive for recreational purposes it was concluded that the average recreational scuba diver performed an estimated average of 20 dives per year, this would allow for interrupted diving experience between 0-5 years in the first group. Divers that have performed more than a hundred dives a year tend to have either a longer diving career or dive more frequently. Another motivation for the group division was to allow for comparisons to be made between the diving groups, to determine the influence that more frequent exposure to the hyperbaric environment might have on the hearing acuity of the individual. The division of diver groups were done on the amount of dives performed and not on the amount of hours that each individual have been exposed to a hyperbaric environment. An important point to remember is that the greatest volume change occurs between zero and ten meters (SAUU, 1992). This is the depth that every diver, partaking in recreational or professional diving, is inevitably exposed to. The influence of the hyperbaric environment relates more to the initial descend and ascent than the time spent in the environment.

The dives that the divers have done over the course of their diving careers, varied between depths of 0 – 30 meters, which is the limit for advanced recreational diving (Shreeves, Wohlers & Shuster, 1991; Shreeves, 1999). Divers who had participated in commercial, scientific, technical or military diving were excluded from this study. There are several reasons for this exclusion which would include the additional risks involved in the nature of their diving (Kinsella, Hornsby, Shreeves & Yakzan , 2001). These divers use specialized equipment which is very different to that of the recreational scuba equipment, stay under

water for extended periods and may dive to greater depths than what is required for the purposes of this study. The training for these divers are also more complex and in depth than the training of the recreational scuba diver (Kinsella et al., 2001).

#### **3.4.1.4 Medical History**

Participants were selected by using a medical history questionnaire to ensure that there were no medical contraindications which could have influenced the hearing ability of the participants (Appendix A). The content of and motivation for this medical history questionnaire will be discussed later in this chapter under the heading; material and equipment.

### **3.4.2 Selection criteria for the non-diver participants**

#### **3.4.2.1 Participant age**

Participants in the non-diver or control group were required to be between the ages of 18 and 40.

#### **3.4.2.2 Participant Gender**

For the purposes of this study an even gender distribution was sustained as far as practically possible to maintain a sample that would meet the criteria for the research design of this study.

#### **3.4.2.3 Diving history**

A prerequisite for the non-diver participants were that they should not have participated in any recreational scuba diving, snorkelling or skin diving.

#### **3.4.2.4 Medical History**

Participants were selected by using a medical history questionnaire to ensure that there were no medical contraindications which could have influenced the hearing ability of the participants (Appendix A). The content and motivation for

this medical history questionnaire will be discussed later in this chapter under the heading; material and equipment for data collection.

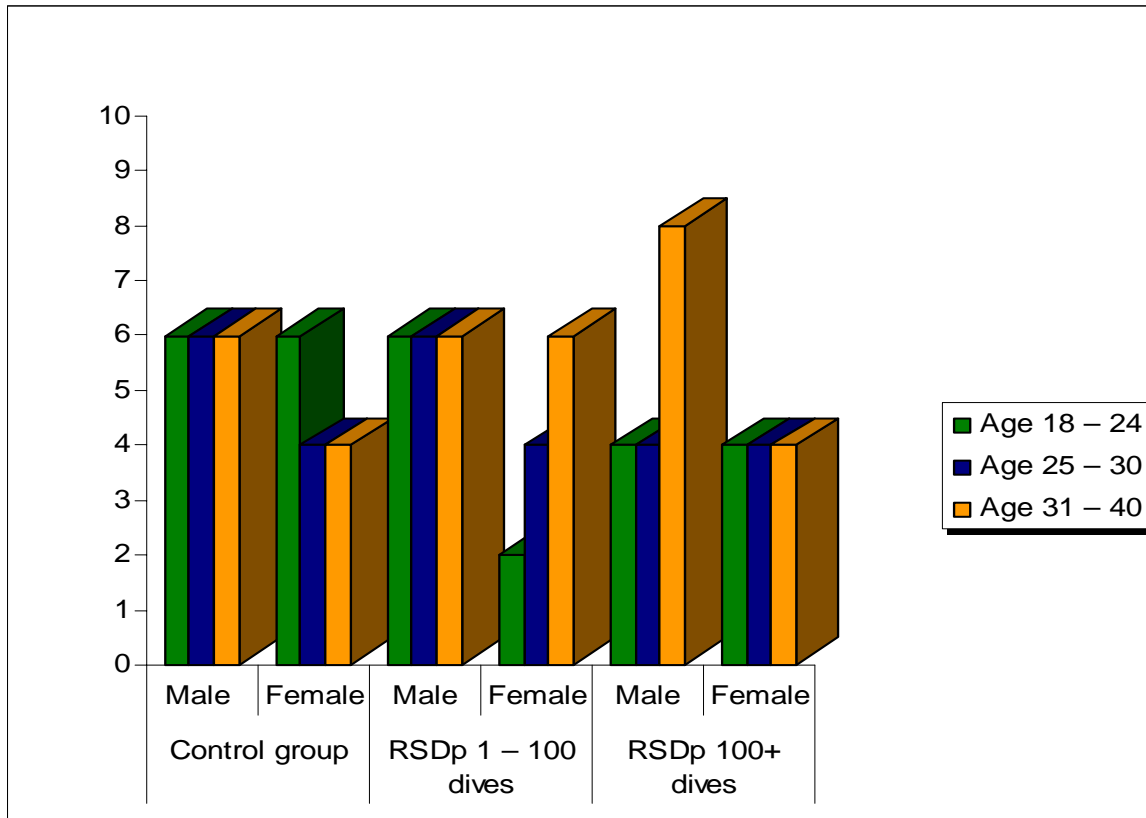
### 3.5 Distribution of participants

In Table 3.1 the distribution of the participants is explained. The purpose of the selection was to make the sample of the three groups of participants as representative as possible, considering age, gender and number of dives. A total of 45 individuals were used in this study, which meant a total of 90 ears.

**Table 3.1: Distribution of the Non-diver (Control group) and Recreational Scuba Diver Participants**

	CONTROL GROUP		RSDP 1 – 100 DIVES		RSDP 100+ DIVES	
	Male	Female	Male	Female	Male	Female
<b>Total</b>	9	7	9	6	8	6
<b>Age 18 – 24</b>	3	3	3	1	2	2
<b>Age 25 – 30</b>	3	2	3	2	2	2
<b>Age 31 – 40</b>	3	2	3	3	4	2

For the purposes of this study the results of the evaluation of the participants will be discussed as 90 ears and not as 45 participants. Figure 4.1 (available on the following page) illustrates the age, gender and group distribution of the 90 ears of the participants.



**Figure 3.1: Distribution of the non-diver (control group) and recreational scuba diver participants**

The frequency procedure was performed with the assistance of the Department of Statistics at the University of Pretoria. The purpose of this procedure is to confirm an even distribution of participants through the three demographical groups namely gender, age and dive group. Table 3.2 (available on the following page) provides an exposition of the frequency and percentage of participants for each demographical group.

**Table 3.2: Frequency and Percentage distribution of participants through the three demographical groups**

Demographical characteristic	Frequency	Percentage
Female	38	42.22
Male	52	57.78
Age – 18-24	28	31.11
Age – 25-30	28	31.11
Age – 31-40	34	37.78
Control group	32	35.56
Divers 1-100 group	30	33.33
Divers 100+ group	28	31.11

The gender distribution according to Table 3.2 indicates that 42.22% of the participants were female and 57.78%, male. Through the demographical characteristics; age and participant group, there was an even distribution of participants of between 31% and 38%.

### **3.6 Participant selection procedure**

The ethics involved in research of human subjects should not go without careful scrutiny (Leedy, 1993). The principals of ethical propriety lying at the base of most of these guidelines, resolve into simple considerations of fairness, honesty, openness of intent, disclosure of method, the ends for which the research is executed, respect for the integrity of the individual, the obligation of the researcher to guarantee individual privacy and informed willingness of the part of the participant, to participate voluntarily in the research activity (Leedy, 1993). The responsible author makes ensures that what is published has a sound thesis, that the data are ethically obtainable and scientifically valid, that the research report is written by the author, properly documented, intelligible and readable (Leedy, 1993).



To select the participants suitable for the purposes of this study, a research proposal was submitted to the University of Pretoria Research and Ethics Committee to obtain permission for the research to be implemented. The letter of confirmation to this effect is included in Appendix I. Once permission for conducting the study was obtained, contact was made with the two main dive centres in Port Elizabeth. Their input concerning the best way to approach and select suitable candidates for the study was considered. A letter explaining the purpose of this study and requesting their cooperation was then provided to the management of the two dive centres. After the selection of the participants, a similar letter was provided to each participant. A copy of each of these letters is included in Appendix B and C. Divers had to be qualified through one of the main internationally accredited associations. The divers, who were included in this study, had a recognized qualification from either the Professional Association of Diving Instructors (PADI) or the National Association of Underwater Instructors (NAUI). The management of the two dive schools assisted with the confirmation of the credibility of each diver's qualification.

A medical case history questionnaire was used to document the medical history and determine whether the individual was suitable for the purposes of the study and to determine in which group he/she could participate. A copy of the questionnaire is included in Appendix A. Once the participants were selected and each individual signed an agreement form for participation (Appendices D & E), interviews were scheduled, during which the audiological test battery was performed.

### **3.7 Material and Equipment**

#### **3.7.1 Participant selection material**

As part of the selection criteria a medical history questionnaire had to be completed by each prospective participant. The participants had to be free of

any of the conditions included in the medical history questionnaire. The motivation for this criterion was to aim for a purer sample, which would be truly representative of the diver population. As discussed earlier in this chapter, purposive sampling was used in the selection of the participants. This would imply that participants are selected for a particular purpose and are typical to a specific population (Leedy & Ormrod, 2005). The aim was to select participants for all three groups with the main defining difference between them, being their diving history. To some extent the size of an adequate research sample depends on how alike or different its members are with respect to the characteristics of research interest, (Leedy & Ormrod, 2005). This study aimed for homogeneity in the research sample and participants were identified by adhering to a comprehensive medical history questionnaire with specified criteria.

The medical history questionnaire ensured that participants were selected with no medical contraindications which could have influenced their hearing ability. A copy of the questionnaire is available in Appendix A. There are a number of conditions that might have an adverse influence on a person's hearing ability or middle ear functioning (Campbell, 2002; Haraguchi et al., 1999; Johnston & Burger, 1971; Katz, 2002; Martin, 1991; McNicoll, 1982; Schuknect, 1993; Shipley & McAfee, 1992). By completing the medical case history questionnaire, the researcher ensured that the conditions listed in Table 3.3 (available on the following page) were not present in any of the participants included in this study.

**Table 3.3: Selection criteria concerning medical conditions**

<b>Condition</b>	<b>Possible inclusions</b>
<b>A family history of hearing problems</b>	-
<b>A history of hearing or ear problems</b>	-
<b>Any diagnosed condition relating to outer-, middle-, inner ear or hearing problems</b>	<ul style="list-style-type: none"> <li>▪ Otitis externa</li> <li>▪ Severe wax problems</li> <li>▪ Tympanic membrane perforation</li> <li>▪ Otitis media [recurrent / repeated]</li> <li>▪ Ear fullness or pain</li> <li>▪ Acoustic trauma</li> <li>▪ Any operations on the ear</li> <li>▪ Otosclerosis</li> </ul>
<b>Any condition relating to the nose and sinuses</b>	<ul style="list-style-type: none"> <li>▪ Allergic rhinitis</li> <li>▪ Colds / flu-like symptoms</li> <li>▪ Acute upper respiratory infection</li> <li>▪ Paranasal sinus disease</li> <li>▪ Nasal allergies</li> </ul>
<b>Other considerations and conditions that may have an influence on the hearing abilities of the participant</b>	<ul style="list-style-type: none"> <li>▪ Head injury</li> <li>▪ Noise exposure</li> <li>▪ Dizziness or vertigo</li> <li>▪ Hypertension</li> <li>▪ Diabetes or other diseases associated with hearing loss</li> <li>▪ Medication (that may have an influence on hearing)</li> </ul>

Although these criteria could exclude injuries or conditions that might have been diving related, it was important for the purposes of this study to exclude medical conditions related to hearing in order to make generalisations about the possible influence of diving specifically.

### **3.7.2 Material and apparatus for data collection**

The following apparatus and material were utilized during the data collection procedure:

- **Otoscope**

A Heine Mini 2000, otoscope was used to perform the otoscopic examination

- **Tympanometer**

A Madsen Zodiac 901 Middle Ear Analyzer with test probes was used to perform immittance measurements and to obtain ipsi- and contra lateral acoustic reflexes. The test probes for this specific instrument that are used to obtain a closure of the ear canal, are inserted reasonably deep into the ear canal and therefore measure lower ear canal volumes than which are normally expected. The instrument complied with **IEC 1027**: Instruments for the measurement of Aural Acoustic Impedance / Admittance, **IEC 601 – 1**: Safety of Medical Electric Equipment. Testing was performed within eight to nine months after calibration.

- **Audiometer:**

The examiner made use of an Interacoustics Diagnostic Audiometer AD27 with integrated speech microphone, Telephonics TDH-39P Earphones [Left and Right] and a Danavox Bone Vibrator X7 to perform pure tone and speech audiometry.

This audiometer was certified as calibrated in accordance with SABS 0154-1&2:1996 for Pure-Tone Audiometers, ISO 389-4 for narrow band and masking noise and IEC 645-2 for speech audiometry. Testing was performed within eight to nine months after calibration.

#### ▪ **Sound Proof Booth**

The audiometric assessment was performed in a sound proof booth. The measured sound pressure levels for this booth were below the recommended pressure levels for diagnostic audiometry according to SABS 0182-1998 and complied with requirements. The Booth provided an acoustic environment suitable for diagnostic testing and testing was performed within eight to nine months after evaluation.

All the equipment used in this study was calibrated by NS Clinical Technologies (Pty) Ltd. The materials used to document the results during the study were as follows: a case history questionnaire, immittance measurement printouts and an audiogram to document pure tone and speech audiometry results.

### **3.8 Procedure related to data collection and documentation**

With any type of measurement, two considerations are very important; validity and reliability. Validity is concerned with the soundness, the effectiveness of the measuring instrument. Reliability deals with accuracy of the measure (test, instrument, inventory, and questionnaire) and whether it measures what it intends to measure (Leedy, 1993). The researcher can either make use of existing instrumentation or design or construct his/her own (Mouton, 2001).

There are six types of validity as described by Leedy, (1993). The focus in this study was specifically on three of these types of validity namely; face, internal and external validity. Face validity asks two questions; are the instruments measuring what it is suppose to measure and is the sample being measured

adequate to be representative of the behaviour or trait being measured. As described in more detail under the heading; material and apparatus for data collection, all equipment used in this study was calibrated in accordance with the SABS standards. Internal validity is a freedom from bias, informing conclusion in view of the data, it seeks to ascertain that the changes in the dependant variable are the results of the influence of the independent variable rather than the manner in which the research was designed. External validity is concerned with the possibility of generalisation of the conclusion reached through observation of a sample to the universe. It asks the question whether conclusions can be drawn from the sample and be generalised to other cases. Validity looks to the end results of measurement. The principal question that validity asks is; are we really measuring what we think we are measuring (Leedy, 1993)?

Data was collected through systematic assessment in a controlled situation. All the audiometrical testing was performed by one researcher to ensure uniformity and add to the reliability and validity of the test results. An average of one hour per participant was allowed for the audiometric evaluation.

The procedure followed for each participant was as follows:

An otoscopic evaluation was performed in both ears as part of the selection criteria. The purpose of the otoscopic evaluation was to determine if the ear canal was clear of any obstruction that could affect the conduction of sound to the tympanic membrane (Martin 1997). Immittance measurements which included tympanometry, static immittance and acoustic reflex measurements were obtained next. After immittance measurements were obtained, pure tone behavioural testing (air and bone conduction) and speech audiometry were performed. After completion of the full battery of tests, a short period was given for feedback with each individual.

The test results were documented throughout the evaluation by the use of immittance printouts and a pure tone- and speech audiogram. All the evaluation data for each participant were collected on the same day to ensure consistency in hearing acuity and therefore reliability of test results.

### **3.9 Analysis and processing of data obtained**

Prepared data was processed and analyzed with statistical measures to determine any correlation. The Department of Statistics at the University of Pretoria assisted with the statistical analysis. The data obtained from all the measurements were well within audiological normal parameters and it was of notable importance to look for differences and correlations that had both statistical and practical significance.

The two principal functions of statistics are to assist the researcher in the description of the data and draw inferences from the data. Both of these functions ultimately involve summarizing the data. It can assist the researcher to note patterns and relationships in the data that might otherwise go unnoticed. More generally, statistics help the human mind comprehend disparate data as an organised whole (Leedy & Ormrod, 2005)

The General Linear Model (GLM) procedure in SAS version 8.2 was used to determine whether statistically significant differences between the three demographic characteristics (age, gender and participant group) existed. The means were determined for certain measurements to make multiple comparisons and to determine where the statistical differences be found. The means are given in its original measurement e.g. % or dB. Further analysis using the GLM procedure was performed to determine whether interaction between the three demographic characteristics influenced the test results.

Some of the measurements were not normally distributed and some of the demographic groups had different variances. For these reasons the data was transformed to apply to the conditions of normality and homogeneity of variance for the GLM procedure. Statistical significance was determined, working with a statistical significance level of 0.05 (P-value).

Further analysis was performed to determine any correlations between the specific audiometric test results and how it related to the three demographical characteristics and the interaction between them.

One function of statistics is to determine and describe the strength of such relationships. The statistical process by which we discover the nature of relationships among different variables is called correlation (De Vos, Strydom, Fouche & Delport, 2002). The resulting statistic is called a correlation coefficient and is a number between +1 and -1. A correlation coefficient for two variables simultaneously tells us two different things about the relationship between those variable i.e. direction and strength. The direction of the relationship is indicated by the sign of the correlation coefficient. A positive number indicates a positive relationship: As one variable increases the other variable also increases. A negative number indicates an inverse relationship or negative correlation: As one variable increases the other variable will decrease. The strength of a relationship is indicated by the size of the correlation coefficient. A correlation of +1 or -1 indicates a perfect correlation. A number close to either +1 or -1 (e.g. 0.89 or -0.76) indicates a strong relationship. A number close to 0 however (e.g. +0.15 or -0.22) indicates a weak correlation. Correlations in the middle range (e.g. +0.40 or -0.50) is indicative of a moderate correlation (De Vos, et al., 2002).

The strength or degree of relationship between two variables can be measured and expressed through one or more of the available correlation coefficients, (De



Vos, et al., 2002). Direction of the relationship in a correlation are indicated by a positive (+) or negative (-) indicator (De Vos et.al., 2002). A correlation coefficient provides a numerical representation or measure for indicating both the strength and direction of a bivariate relationship. This measure can be viewed as a continuum ranging from +1.0 to -1.0 with 0.0 as the midpoint. The closer the numerical value of the correlation is to either side of the continuum, the stronger the relationship between the two variables is. It is important to remember that the purpose of correlation data is to indicate a relationship between two variables and doesn't allow us to draw clear-cut conclusions about cause-and-effect relationships (Leedy & Ormrod, 2005).

One of the most frequently employed correlational procedures, is the Pearson's product moment correlation (Pearson's  $r$ ). Pearson's  $r$  is utilised where the levels of measurement of both variable assume the properties of interval-level (numerical) data (Delport et.al, 2002). Pearson's product moment correlation coefficient ( $r$ ) is indicative of a linear relationship between two variables, refers to parametric statistics and both variables involve continuous data (Leedy & Ormrod, 2005).

It can however also be valuable or necessary to measure association (dependence) between two variables of ordinal scale. Spearman's rank correlation coefficient (Spearman's rho) ( $\rho$ ) can be calculated to determine such a correlation and is indicative of a non-linear relationship between two variables, refers to nonparametric statistics and both variables involve rank-ordered data and so are ordinal in nature (Leedy & Ormrod, 2005)

Correlations using Pearson and Spearman Correlation Coefficients were made between specific measurements that might have an influence on or interaction between them. Only correlation coefficients that were statistically significant i.e.  $P = 0.05$  (5% level of significance), were considered. The standard by which it

was decided to evaluate the strength and value of a certain correlation is shown in Table 3.4 (Dawson & Trap, 2001).

**Table 3.4: Correlation standard**

<b>r – value</b>	<b>Strength</b>
0.25	Weak correlation
0.25 – 0.5	Medium correlation
0.5 – 0.75	Strong correlation
0.75 +	Very strong correlation

It was decided to focus only on relationships where there were strong or very strong correlations and where there were notable predictable patterns.

### **3.10 Summary**

This chapter described the method that was used to accomplish the aim of the study. The methodology for this study was described and stipulated the procedures that were followed as well as the apparatus that were used to accomplish the main aim of the study. This section concluded with a discussion of the procedure related to data collection, documentation and analysis as well as a summary, highlighting the content of this chapter.

# CHAPTER FOUR

## RESULTS AND DISCUSSIONS

### AIM OF CHAPTER FOUR

*In this chapter the collected and processed data will be presented, interpreted, compared and discussed. The data will be compared to the relevant literature as discussed in Chapters 1 and 2. A summary of the data for all 90 ears are given, where after a discussion of the statistical and practical significance of the measurements will follow. Correlations between the different audiometric measurements and their relationship to the demographical characteristics and interaction between the results will be discussed. This chapter will conclude with a summary of the results discussed.*

**Observation is a skill over and above passive reception of the raw data of sensory experience**

Weimer (1979, p. 21)

### 4.1 Introduction

In the first part of this study the rationale and relevant literature concerning the research question have been described. The results discussed in Chapter 4 will aim to address the main aim of this study namely: **Describing the hearing abilities and middle ear functioning of the recreational scuba diver (RSD), through the use of a comprehensive audiological test battery.** The sub aims were formulated to fulfil the main aim of the study and are stipulated in Chapter 3. The results will be discussed in relation to the sub aims and according to the specific audiometric measurement performed. The reason for this is to allow for comparisons to be made between the demographical groups and the interaction possibilities between them on each individual

measurement. Further analysis that was performed to determine any correlation between the audiometric measurements and its relation to demographic group interaction will be discussed.

#### **4.2 Results from all the participants (90 ears)**

The first sub aim of the study was to collect normative data on specific audiometric measurements, in 90 ears within three controlled groups of participants. The groups were; recreational scuba divers (RSD) between the ages of eighteen and forty with a diving history of less than one hundred dives, RSD with a diving history of more than one hundred dives and a group of non-divers (control group).

Prepared data was processed and analyzed with statistical measures to determine consistent and predictable patterns. As mentioned in Chapter three, the Department of Statistics at the University of Pretoria assisted with the statistical analysis. Table 4.1 provides an exposition of the data obtained from all the measurements for all 90 ears. The results were mostly well within audiological normal parameters. This complicated the analysis of the data and it was of notable importance to look for differences and correlations that had both statistical and practical significance. The instances where results were not within normal audiological limits were based on individual differences and no specific patterns were found relating to participant group, age or gender. This statement is further supported by the determined standard deviation for each audiometric measurement and will now be discussed in more detail.

**Table 4.1: Data summary for measurements obtained for the whole sample of participants**

Variable	Mean	Std deviation	Minimum	Maximum
PTA 125	8.7	6.12	0	40
PTA 250	12.1	6.36	5	45
PTA 500	10.9	5.40	0	30
PTA 1000	10.9	4.28	0	20
PTA 1500	11.2	5.71	-10	25
PTA 2000	11.7	6.04	-5	25
PTA 3000	7.2	5.90	-10	25
PTA 4000	10.1	6.51	-10	30
PTA 6000	11.7	7.08	0	35
PTA 8000	6.1	8.20	-10	25
PTA Average	11.7	4.18	1.7	20
PTB 250	- 6.4	4.93	-10	10
PTB 500	- 6.1	5.22	-10	10
PTB 1000	- 3.7	6.35	-10	15
PTB 1500	-5.8	5.04	-10	5
PTB 2000	2.9	6.10	-10	20
PTB 3000	3.0	5.84	-10	15
PTB 4000	-1.6	6.30	-10	10
ABG 250	18.5	6.76	0	40
ABG 500	17	5.94	0	35
ABG 1000	14.6	6.90	0	25
ABG 1500	17	6.65	0	30
ABG 2000	8.7	6.73	-5	25
ABG 3000	4.2	5.77	-10	25
ABG 4000	11.6	7.38	-10	30
SD1	100%	0%	100%	100%
DB1	36.5	3.55	30	45
SD2	90%	7%	64%	100%
DB2	26.6	3.64	20	35
SD3	76%	11%	40%	96%
DB3	21.5	3.55	15	30
SD1-PTA	24.1	4.60	10	33.33
ECV	0.8	0.46	0.26	2.39
MEP	- 12.9	13.92	- 75	20
SC	1.2	0.59	0.16	3.08
GRAD	0.7	0.13	0.26	0.90
TW	75.9	21.93	28	169
ARIR 500	81.6	8.99	65	NR
ARIR 1000	80.1	9.02	50	NR
ARIR 2000	80.8	9.00	60	NR
ARCR 500	82.3	10.92	55	NR
ARCR 1000	83.6	9.36	60	NR
ARCR 2000	82.7	9.72	65	NR
ARDIF 500	-0.25	10.425	-30	25
ARDIF 1000	-3.59	10.791	-30	25
ARDIF 2000	-1.06	10.267	-25	25

Although this study aimed to investigate group tendencies in audiometric results for specific demographical characteristics it was deemed important to consider audiological reliability for each individual participant. This implies that the test results obtained for each individual were consistent, correlated with each other where appropriate and can therefore be accepted as reliable. Audiological reliability adds to the internal as well as the external validity of the current study. A further statistical cross check procedure was also performed to add to the reliability and validity of the test results as can be seen in Table 4.1 with the determination of ARDIF and SD1-PTA. These two measurements refer to the difference between the ipsi lateral and contra lateral reflexes and the difference between the speech discrimination threshold where a 100% discrimination was reached and the pure tone average for each individual participant.

The results obtained with pure tone air conduction testing, indicate a mean performance of between 7dB and 12dB across the whole frequency spectrum. The pure tone average at 500Hz, 1000Hz and 2000Hz was 11.7dB with a standard deviation of only 4.18dB. This is well within normal hearing levels that are considered to be between -10dB and 15dB (Katz, 1994 & Martin, 1991). The standard deviation for the pure tone air conduction measurements ranged between 4dB and 7dB and supports the statement that measurements that were not within normal audiological parameters, were based on individual differences and not relating to demographical group characteristics.

The pure tone bone conduction threshold were between -6dB and 3dB, with a standard deviation between 5dB and 6dB. There was a mean performance of between 4dB and 18dB for the air-bone-gap measurements for the whole group of participants. Although this appears to be a notable difference between air and bone conduction thresholds, the practical implication was that there were no specific patterns in the demographical group interaction and the larger air-bone-gap measurements were consistently measured for all participants. Further

support for this statement is indicated by the low standard deviation between 5.77dB and 7.38dB for the whole group.

Three speech discrimination thresholds were measured and are indicated in Table 4.1 as DB1, DB2 & DB3. DB1 refers to the best threshold where a 100% speech discrimination was reached with a mean performance of 36.5dB and a standard deviation of only 3.55dB. The speech discrimination thresholds correlated with the pure tone average threshold with a mean difference of 24.1 dB and a standard deviation of 4.6dB as indicated in Table 4.1 as SD1-PTA.

The physiological evaluation of the auditory system included tympanometry, static immittance and acoustic reflex testing. Normal Type A tympanograms were measured for all ninety participants (Hall & Mueller, 1997; Martin, 1991). The mean ear canal volume was 0.8ml with a standard deviation of 0.46ml. According to Hall and Mueller (1997) values of 0.63ml to 1.46ml with a mean value of 1.05ml are considered normal for adults. All the participants had normal ear canal volumes. The mean value for middle ear pressure was -12.9daPa with a standard deviation of 13.92daPa and a minimum and maximum of -75daPa and 20daPa respectively, which is well within normal limits of between 0 and 100daPa, positive or negative (Katz, 2002). With the measurement of static compliance the mean performance was 1.2cm<sup>3</sup> and the standard deviation 0.59cm<sup>3</sup> which according to Katz (2002) should be between 0.3 and 1.6cm<sup>3</sup>. The mean gradient for all the participants was 0.7 with a standard deviation of 0.13. Tympanogram width measured a mean of 75.9daPa with a standard deviation of 21.93daPa.

Ipsi lateral acoustic reflexes were measured at 500, 1000 and 2000Hz with means of 81.6dB, 80.1dB and 80.8dB respectively with standard deviations of 8.99, 9.02 and 9dB. The means for contra lateral acoustic reflexes at 500, 1000 and 2000Hz were 82.3, 83.6 and 82.7dB respectively with standard

deviations of 10.92, 9.36 and 9.72dB. According to Katz (2002), normal acoustic reflexes should be between 70-100dB hearing level and an estimated 85dB for pure tone signals. The difference between acoustic reflexes measured ipsi and contra lateral indicated a mean of -0.25; -3.59 and -1.06dB at 500, 1000 and 2000Hz respectively with standard deviations of 10.425dB, 10.791dB and 10.267dB. There were no significant differences noticed between the ipsi and contra lateral reflexes for each individual. All the data obtained for acoustic reflexes were within normal limits and correlated with the pure tone air conduction test results.

#### **4.3 Results from audiometric characteristics as measured in the demographic groups**

The second and third sub aim of the study was to describe and compare specific audiometric characteristics as measured in the three groups of participants and to determine possible predictable patterns in the audiometric test results. In this section the focus will be on those measurements where a statistical significance ( $P < 0.05$ ) was present. As discussed in Chapter 3, the General Linear Model (GLM) procedure in SAS version 8.2 was used to determine whether statistically significant differences between the three demographic characteristics (age, gender and participant group) existed. The means were determined for certain measurements to make multiple comparisons and to determine where the statistical differences were. The means are given in its original measurement e.g. % or dB. Further analysis using the GLM procedure was performed to determine whether interaction between the three demographic characteristics influenced the test results. The seven possible groups that were used to make multiple comparisons between the three demographic characteristics, were the relation between gender, age and participant group; gender and age; gender and participant group; age and participant group; gender alone; age alone and participant group alone.



Some of the measurements were not normally distributed and some of the demographic groups had different variances. For these reasons the data was transformed to apply to the conditions of normality and homogeneity of variance for the GLM procedure. As mentioned earlier statistical significance was determined working with a statistical significance level of 0.05 or less (P-value). Table 4.2 provides an exposition of these measurements where a statistically significance where found either in one of the demographic characteristics or in the interaction between them.

**Table 4.2: Statistically significant measurements between the three demographical characteristic groups**

Variable	Demographic interaction characteristics	P-value
PTA 125	Gender-Group Age	0.0066 0.0507
PTA 1500	Gender-Group	0.0010
PTA 4000	Age	0.0027
PTA 6000	Gender	0.0372
ABG 1500	Gender-Group Gender Age	0.0366 0.0228 0.0241
ABG 4000	Gender-Age Gender-Group Gender Age	0.0215 0.0233 0.0080 0.0034
SD @ 100%	Gender-Age-Group Gender-Group Age	0.0046 0.0108 0.0034
ECV	Gender-Age-Group Gender-Age Gender	0.0019 0.0241 0.0001
SC	Gender-Group Age-Group Group	0.0302 0.0021 0.0086
TW	Gender	0.0035
ARIR 1000	Gender-Age-Group Age-Group	0.0011 0.0042
ARIR 2000	Gender-Age-Group Age-Group Age	0.0308 0.0026 0.0250

Statistical significance ( $P < 0.05$ ) was found with the pure tone air measurements at frequencies 125, 1500 and 4000Hz. There were no significant differences between the mean performances of the groups at any of the other pure tone air thresholds or on the mean pure tone averages of any of the demographical groups. The air-bone-gap measurements confirmed the significance of the pure tone air thresholds and showed statistically significant differences only at 1500 and 4000Hz. Speech discrimination thresholds where participants reached a 100% speech discrimination level indicated significant differences.

Immittance measurements indicated statistically significant differences between the demographical groups and the interaction between them on ear canal volume, static compliance and tympanogram width. There was no statistically significant difference on middle ear pressure between the groups. Acoustic reflexes (ipsi) showed statistically significant differences at 1000 and 2000Hz.

Tables of the number of participants, the means, standard deviation and minimum and maximum performances for each measurement where statistical significance was found are included in Appendix F. Only tables where significant statistical as well as practical significance relating to the current study were present, will be included in the body of chapter 5.

#### **4.3.1 Pure tone air threshold at 125Hz (PTA125)**

With the measurement of the pure tone threshold 125Hz, statistically significant differences were present between the participant groups and gender and secondly between the different age groups. The gender-group significance appeared to be more related to gender and was not dependant on the different diver and control groups. The gender differences was however not consistent through all the matching male and female groups but was evident in the 1-100 diver group where the mean threshold for the female participants was 7.5dB less

than the mean threshold for the male participants. Inconsistent differences were found between the three age groups and although the mean differences were statistically significant, there was no predictable pattern found at this measurement related to age. The statistical significance found at PTA125 appeared to be inconsistent through the three demographical characteristics of gender, age and diver or control group and no practical significance was found for this measurement.

#### **4.3.2 Pure tone air threshold at 1500Hz (PTA 1500)**

There was a statistically significance measured with the interaction between gender and group. The female divers 100+ group had a mean threshold of 14.2dB that is 6.4dB worse than the male divers 100+ group and worse than the other four groups. The differences relating to gender were inconsistent through the other groups as well as the differences relating to the amount of diving that the participants had performed. Female divers 100+ was the only group that performed consistently worse than the other groups, with the pure tone measurement of 1500Hz.

#### **4.3.3 Pure tone air threshold at 4000Hz (PTA 4000)**

At the measurement of 4000Hz pure tone air there was a statistically significant difference found between the three age groups. The gender and the amount of dives that each participant had performed did not appear to have any significance on this pure tone frequency. There was a statistically significant difference between the age group 31-40 and the other two groups that ranged between 3.8dB and 5.4dB. Practically this is a small difference between the age groups but could be related to the normal aging process of the ear, as 4000Hz is one of the pure tone frequencies that are normally affected by the aging process. It appears that although age had an influence on 4000Hz pure tone air results; this was however in no way related to gender or the amount of diving

that the participants had performed and not relevant for the purposes of this study.

#### **4.3.4 Air-bone-gap at 1500Hz (ABG 1500)**

Statistically significant differences were found with the air-bone-gap at 1500Hz relating to the demographical characteristics and the interaction between them. The differences were between gender and group, gender alone and age alone. Here again it was the group of female divers 100+ that showed a significant difference at this measurement. There is a consistent statistical significance of a 5dB mean difference between this group and all the other groups. Gender alone did not appear to have any significance and it appears that 1500Hz is a frequency that could be affected by diving, although this was only noticeable in the female divers. With a comparison between the three age groups, the air-bone-gap consistently increased with age, especially from ages 31-40 with a 5dB difference between this age group and the other two groups.

#### **4.3.5 Air-bone-gap at 4000Hz (ABG 4000)**

There were four levels on which statistically significant differences were measured in the air-bone-gap at 4000Hz. Compared to the pure tone air results however, there was only a significance difference between the three age groups. The air-bone-gap differences were significant between the three demographical groups and the interaction between them with relation to gender and age; gender and diver or control group; gender alone and age alone. With the comparison between gender and participant group, it appeared that the male divers were more affected +/- 5-7dB than the female divers, with mean threshold air-bone-gaps of 16.1dB for the male divers 1-100 and 15dB for the male divers 100+ participant group. The different participant groups did not appear to have a strong significance on its own and gender appeared to be the defining factor. Comparisons between genders alone, indicated that the male

groups had a mean average of 4.4dB greater than that of the female groups and confirmed the tendency. This was especially noticeable in the diver groups.

With the comparison between gender and age, the male participants again had a mean threshold of up to 7dB greater than the female participants. It appears that the tendency is for the air-bone-gap measurement at 4000Hz to get worse past the age of 30. There did not appear to be any relationship to age for the female participants. There was a statistical significance in the age group 31-40 of about 5dB greater than the other age groups. The air-bone-gap at 4000Hz seemed to increase mostly for the male participants with aging as well as with amount of diving performed.

In the research literature as discussed in chapter two of this study, several studies found a high incidence of professional divers with sensori-neural hearing impairment, especially in the high frequencies from 4000Hz to 8000Hz (Campbell, 2002; Coles, 1976; Edmonds, 1985; Edmonds & Freeman, 1985; Molvaer & Lehmann, 1985; Molvaer & Albreksten, 1990; Skogstad, Haldorsen & Arnesen, 2000). Contrary to these studies, a study by Brady, Summit & Berghage (1976), suggests that conditions associated with diving have a minimal effect on the auditory sensitivity of navy divers, when compared to a group of non-divers. The results for the current study indicates statistically significant differences in the pure tone test results between the control group and the two diver groups only at 1500Hz. These differences were however not consistent through the frequency spectrum, were only notable for female participants in the 100+ diver group and could not be generalised to the diving history of the individual participants.

#### **4.3.6 Speech discrimination threshold where a 100% discrimination was reached (SD@100%)**

Speech discrimination thresholds were measured at three levels and for the purposes of sensible analysis the GLM procedure was performed only at the lowest threshold where a 100% speech discrimination was reached. Statistical significance was measured with a comparison between the age groups alone and in the interaction between the demographical characteristics; gender and group and gender, age and group. The differences in age seemed to be random and were not practically sensible. The mean performance ranged between 32.8dB and 37.2dB. With the statistically significance relating to the interaction between group and gender no consistent patterns were found. All the measurements were well within audiological normal limits and ranged between 33.2 and 37.5dB.

The gender-age-group interaction indicated statistical significance but the results were very close together with group means ranging between 27.5dB and 40dB. Again the patterns were inconsistent and can probably be attributed to individual differences. It is important to note that with this level of analysis and the interaction of all three demographical characteristics included, the groups are very small and the practical significance of such differences are negligible. This statement is further supported by the fact that there were no predictable patterns in the results of the alternative demographical group interactions.

#### **4.3.7 Ear canal volume (ECV)**

With the immittance measurements, statistically significant differences were found between the three demographical characteristics and the interaction between them, relating to ear canal volume. These differences were between gender, age and group; gender and age and gender alone. The amount of diving that an individual performs, can not affect the ear canal volume and ear canal volume has no diagnostic relevance if it is within normal limits. Ear canal

volume was well within normal limits for all 90 participants. The reason for this statistical significance lies more within gender and age. With a comparison between gender and age, there appeared to be a statistically significant difference between the male and female participants as well as between the younger and older male participants. The same is not true for the female participants where ear canal volume stayed reasonably constant between age groups. The male participants had a mean average of 0.9ml ranging between 0.3ml and 2.4ml that was on average larger than the female participants with a mean average of 0.5ml, ranging from 0.3ml to 1.5ml. It is expected to find greater ear canal volumes in men than in women and that ear canal volumes could increase with age especially for men.

#### **4.3.8 Middle ear pressure (MEP)**

Divers experience continuous alterations in ambient pressure while ascending and descending (Green et al., 1993). The pathophysiological response to the middle ears which is observed with alterations in ambient pressure shows a decrease in middle ear pressure and otoscopic evidence of middle ear barotrauma, in proportion to diving frequency. In the study about the incidence and severity of middle ear barotrauma in recreational scuba diving as discussed in Chapters 1 and 2, tympanometry revealed a significant decrease in middle ear pressures during repetitive recreational scuba diving, (Green et al., 1993). The current study did not find any statistically significant differences in the middle ear pressure of the participants with an increase in diving activity.

#### **4.3.9 Static compliance (SC)**

With the measurement of static compliance there were statistically significant differences in the interaction between gender and participant group; age and participant group and in the participant groups alone. There appears to be a strong correlation between static compliance and the amount of diving that the individual participants have performed. Table 4.3 provides an exposition of the

results for the relation between gender and participant group with the measurement of static compliance. The mean performances of each participant group, standard deviation as well as the minimum and maximum results are included.

**Table 4.3: The results of the relation between gender and participant group with the measurement of static compliance**

Gender	Group	N	Mean	Std dev	Minimum	Maximum
Female	Control	14	0.83	0.387	0.21	1.47
Female	1-100	12	1.22	0.602	0.16	1.95
Female	100+	12	1.45	0.848	0.24	3.01
Male	Control	18	1.17	0.756	0.3	3.08
Male	1-100	18	0.98	0.364	0.4	1.76
Male	100+	16	1.37	0.245	0.94	2.03

The comparison between gender and participant group indicated statistically significant differences. These differences were more noticeable amongst the female participants where there was a consistent increase in the static compliance with an increase in diving activity. The means for the female control group, divers 1-100 and divers 100+ group were respectively 0.83cm<sup>3</sup>, 1.22cm<sup>3</sup> and 1.45cm<sup>3</sup> as indicated in Table 4.3. There was a greater difference between the male control group and male divers 100+ participant groups, where the control group had a mean static compliance of 1.17cm<sup>3</sup> and the male divers 100+ a mean of 1.37cm<sup>3</sup>. Further statistically significant differences were found between the two divers groups with a significant increase in static compliance measured in the diver group 100+. The female divers 100+ appeared to be more affected with increase in diving activity than the male divers.



With the comparison between age and participant group, the statistical significance was again indicated between the groups and no significant patterns were found relating to age. Age and gender alone did not seem to have a significant influence on the static compliance. These results again indicated the significance of diving activity when static compliance was measured. The group most affected were the age group 31-40, although the differences between this age group and the 18-24 group were negligible. Comparing the two diving groups though gave another picture and the two diver groups had a higher maximum compliance.

Table 4.4 gives an exposition of the results for the relation between the participants groups with the measurement of static compliance. The mean performances of each participant group, standard deviation as well as the minimum and maximum results are included.

**Table 4.4: The results for the relation between the participants groups with the measurement of static compliance**

Group	N	Mean	Std dev	Minimum	Maximum
Control	32	1.03	0.637	0.21	3.08
1-100	30	1.07	0.478	0.16	1.95
100+	28	1.40	0.573	0.24	3.01

Statistically significant differences were found between the control group and divers 100+. Divers 100+ showed a significantly higher mean static compliance of 1.4cm<sup>3</sup>, compared to the control group with a mean compliance of 1.03cm<sup>3</sup>. There was no statistically significant difference between the performance of the control group and that of the divers 1-100 but there was a consistent increase in the mean performance of the three groups relating to diving activity. No

statistically significant difference was measured between age and gender; gender alone or age alone.

In the study done by Paaske et al. (1991) on impedance measurement in divers during a scuba-diving training programme as discussed in Chapters 1 and 2, their results indicated a significant increase in static compliance on diving. They concluded that the strain exerted on the tympanic membrane and middle ear from barotraumas, due to diving, results in reversible impairment of the recoiling capacity of the elastic fibrils of the tympanic membrane. These authors indicated that the transient increase in static compliance could be the first measurable change in elasticity of the tympanic membrane. They mentioned the possibility that if barotraumas continued, the changes could be irreversible. The results of the current study, as discussed earlier in this chapter, confirms the finding that static compliance is influenced with continued diving activity.

#### **4.3.10 Tympanogram width (TW)**

With the measurement of tympanogram width during immittance testing, statistically significant differences were only present relating to gender. The female participants measured significantly lower tympanogram widths. The mean width was 67.16daPa for the females with a minimum of 35daPa and a maximum of 98daPa and 82.27daPa for the male participants, with a minimum of 28daPa and a maximum of 169daPa. There were no significant differences relating to age or diving activity.

#### **4.3.11 Ipsi lateral acoustic reflex at 1000Hz (ARIR 1000)**

There appeared to be statistical significance with the measurement of the acoustic ipsi reflex at a 1000Hz with the interaction between the age of the participants and the diving groups as well as with the interaction between the three demographical characteristics; gender, age and group. The age-group interaction indicated inconsistent patterns. Statistical significance was found

between the two diver groups in the age group 25-30 years with a 10dB mean difference. The 1-100 diver group had a mean of 76.5dB and the 100+ diver group a mean of 86.3dB. The same pattern was not found in the other two age groups. In the age group 31-40 there was a statistical significance between the mean performances of the two diver groups and the control group. The mean performance for the control, 1-100 diver and 100+ diver groups were respectively 74dB, 81.7dB and 80dB. The practical implication of this indicates a 7.7dB difference between the control and 1-100 diver group and a 6dB difference between the control and 100+ diver group. The same patterns were not detected with the pure tone air test results at a 1000Hz and the apparent significance of the differences is considered negligible.

The interaction between the three demographical characteristics revealed statistical significance but again no predictable or consistent patterns. This matches the findings as discussed, with the interaction between the two demographical characteristics; age and group.

#### **4.3.12 Ipsilateral acoustic reflex at 2000Hz (ARIR 2000)**

Acoustic reflexes (ipsi) measured at 2000Hz, indicated statistically significant differences relating to age alone and with the interaction between age and group. With the interaction between the three demographical characteristics; gender, age and group, there were statistically significant differences. With the comparison between the three age groups there appeared to be no predictable patterns and the statistically significant measurements were inconsistent. In the age and group interaction there again appeared to be no predictable or consistent patterns. It is however interesting to note that there seems to be a stronger pattern relating to the age group 31-40 years. The means for the control, 1-100 diver and 100+ diver group were respectively 73.5dB, 80dB and 78.73dB and these differences are considered statistically significant. The same

pattern was not found in the two other age groups or in the pure tone air results at this frequency and are therefore not practically significant.

The interaction between the three demographical characteristics revealed statistical significance but again no predictable or consistent patterns could be determined. This matches the findings as discussed with the interaction between the two demographical characteristics; age and group.

#### **4.4 Results from correlations drawn between specific audiometric test results**

The final sub aim of the current study was to determine possible correlations between the audiometric measured characteristics and how it relates to demographic group characteristics. Further analysis was performed to determine any correlations between the specific audiometric test results and how it related to the three demographical characteristics and the interaction between them.

Correlations using Pearson and Spearman Correlation Coefficients were made between specific audiometric measurements. Only correlation coefficients that were statistically significant i.e. a P-value of  $< 0.05$  (5% level of significance), were considered. The standard by which it was decided to evaluate the strength and value of a certain correlation was discussed in Chapter three of this study. It was decided to only focus on relationships where there were strong or very strong correlations. Correlations were discussed for each possible combination of the demographical characteristics leading to a total of eighteen groups. Table 4.5, Table 4.6 and Table 4.7 provide expositions of the audiometric measurements for each group where strong or very strong correlations were determined. Appendix G provides a summary table for all eighteen groups where correlations with statistical significance, were determined between static compliance and specific audiometric measurements. This summary tables also includes the weak and moderate correlations with statistical significance ( $P <$

0.05). The audiometric measurements that were compared to static compliance to determine possible correlations were; air-bone-gaps at 250Hz, 500Hz, 1000Hz, 1500Hz, 2000Hz, 3000Hz and 4000Hz as well as middle ear pressure, tympanogram gradient and ipsi lateral acoustic reflexes at 500Hz, 1000Hz and 2000Hz. Appendix H provides a similar summary table with correlations between middle ear pressure and specific audiometric measurements. The audiometric measurements that were compared to middle ear pressure were; air-bone-gaps at 250Hz, 500Hz, 1000Hz, 1500Hz, 2000Hz, 3000Hz and 4000Hz and static compliance.

#### **4.4.1 Correlations between static compliance and specific audiometric test results**

Table 4.5 (available on the following page) provides an exposition of the different air-bone-gaps that was compared to static compliance. The purpose of this was to determine whether specific frequencies were influenced by changes in static compliance and more specifically for each of the eighteen combinations of demographical characteristics. Only those measurements where statistical significance ( $P\text{-value} < 0.05$ ) was measured and where there was a strong or very strong correlation are included in Table 4.5. Data concerning the P-values of all the correlations included in Table 4.5, Table 4.6 and Table 4.7, are integrated in the summary tables, available in Appendix G and Appendix H.

**Table 4.5: Correlations between static compliance and air-bone-gaps**

	ABG 250	ABG 500	ABG 1500	ABG 2000	ABG 3000	ABG 4000
1-100 Group	Pr -0.491 Sr -0.452	-	-	-	-	-
100+ Group	Pr 0.535	-	Pr 0.503	-	-	-
Female 18-24 Control	-	-	-	-	Sr -0.845	Sr -0.828
Male 25-30 Control	-	-	-	Pr 0.933 Sr 0.828	-	-
Female 25-30 Control	-	-	Pr -0.988	-	-	-
Male 31-40 Control	-	-	-	-	Pr 0.822	-
Male 18-24 1-100	Sr -0.878	-	-	-	-	-
Male 31-40 1-100	Pr -0.851 Sr -0.956	-	-	-	-	-
Female 31-40 1-100	Pr -0.921	Pr -0.984 Sr -0.956	-	-	-	-
Male 18-24 100+	-	Pr -0.971	-	-	-	-
Male 31-40 100+	Pr 0.799	Pr 0.731	-	-	Pr 0.794	-

Comparisons between static compliance and air-bone-gaps at different frequencies indicated several very strong correlations. For the control groups these correlations, though very strong, were inconsistent and no predictable patterns could be determined. Interestingly for several of the diver groups there appeared to be a very strong correlation between static compliance measurements and air-bone-gaps at 250Hz and 500Hz. For the 1-100 diver group, both Pearson (Pr) and Spearman (Sr) correlation coefficients indicated a medium to strong negative correlation between static compliance and air-bone-gap thresholds at 250Hz. It is important to keep in mind that where the interaction between all three demographical characteristics namely gender, age and group are at play, the amount of participants in that group is significantly

reduced and generalisation of correlations should be critically considered. For the 100+ diver group there was a strong positive linear correlation ( $P = 0.035$ ) between static compliance and the air-bone-gap at 250Hz and it appeared that it was mostly the older male participants in the 100+ diver group that influenced this correlation. For this specific group, there also appeared to be a strong positive correlation between static compliance and the air-bone-gap at 500Hz. Two other groups where static compliance and the air-bone-gap at 500Hz appeared to be very strongly negatively correlated was the older female 1-100 diver group and the younger male 100+ diver group. The 100+ diver group including all ages and both genders indicated a strong positive linear correlation between static compliance and the air-bone-gap at 1500Hz. The other groups did not appear to have any statistically significant correlations at this frequency.

**Table 4.6: Correlations between static compliance and specific audiometric measurements**

	ARI 500	ARI 1000	ARI 2000	MEP	GRAD
Age 31-40	Pr -0.524	-	-	-	-
1-100 Group	-	-	-	Pr 0.708 Sr 0.647	-
Male 18-24 Control	-	-	-	-	Pr 0.966 Sr 0.943
Female 18-24 Control	-	-	-	Pr -0.882	Pr -0.855
Female 25-30 Control	Pr -0.960	-	Pr -0.999	Pr 0.992 Sr 1.000	-
Male 18-24 1-100	Sr 0.883	-	-	Pr 0.927 Sr 0.883	-
Female 25-30 1-100	-	-	-	Pr -0.956	-
Male 31-40 1-100	-	-	-	Pr 0.870	-
Female 31-40 1-100	-	-	-	Pr 0.836	-
Female 18-24 100+	-	Pr -0.968	-	-	-
Female 25-30 100+	-	-	Pr 0.980	-	-
Male 31-40 100+	-	-	-	-	Sr 0.762
Female 31-40 100+	-	-	-	-	Pr -0.979

The correlation between static compliance and the ipsi lateral acoustic reflexes indicated inconsistent and unpredictable patterns as can be seen in Table 4.6. The same was true for the correlation between tympanogram gradient and static compliance and although all these correlations had strong statistical significance it did not seem to allow for any practical predictions. What is of interest though, is that there appears to be a notable correlation between static compliance and middle ear pressure, especially for the 1-100 diver group. For this group both Pearson (Pr) and Spearman (Sr) correlation coefficients indicated a strong



positive correlation between static compliance. Two of the control groups also appeared to have strong correlation with these measurements. As indicated earlier in this chapter the table with all the statistically significant correlations can be seen in Appendix G and indicate that there were several weak and medium correlations between static compliance and middle ear pressure. It would be interesting to further investigate the nature of this correlation on a larger group of participants.

#### 4.4.2 Correlations between middle ear pressure and the measured air-bone-gaps

Statistical analysis of the correlation between middle ear pressure and the measured air-bone-gaps was also performed. An exposition of these correlations can be seen in Table 4.7.

**Table 4.7: Correlations between middle ear pressure and air-bone-gaps**

	ABG 250	ABG 500	ABG 1000	ABG 1500	ABG 2000	ABG 3000
Female 25-30 Control	Pr -0.946	-	-	Pr -0.981	-	-
Male 18-24 1-100	Sr -0.905	Pr -0.878	-	-	-	-
Male 25-30 1-100	-	-	-	-	-	Pr 0.802 Sr 0.801
Male 31-40 1-100	-	-	-	-	Sr 0.836	Pr 0.878 Sr 0.823
Female 31-40 1-100	Pr -0.919 Sr -0.939	-	Sr -0.985	-	-	-
Female 18-24 100+	-	-	-	-	Pr 1.000 Sr 1.000	-
Female 25-30 100+	-	-	Pr 0.980	-	Pr 0.962	-
Male 31-40 100+	-	-	Pr 0.744 Sr 0.744	-	-	-

There appeared to be inconsistent correlations between middle ear pressure and the measured air-bone-gaps through the frequency spectrum. There were no consistent correlations relating to diving activity specifically.

#### **4.5 Summary**

This chapter reported and discussed the results obtained, while implementing the method of the current study. The data was discussed in accordance with the sub aims specified in chapter three. These sub aims were specifically selected to address the main aim of the study. Conclusions will subsequently be drawn from the results discussed in this chapter. These conclusions will be discussed in the final chapter and aim to provide insight relating to the main aim of the study.

# CHAPTER FIVE

## CONCLUSION OF THE STUDY

### AIM OF CHAPTER FIVE

Chapter five aims to summarize the results obtained through statistical analysis. Significant results and their contribution to the current research literature are highlighted. A conclusion regarding the current study will be formulated. A critical evaluation of the study, highlighting the limitations of the study and subsequent recommendations for future research is provided.

**Research results are not timeless, mainly because the world itself is dynamic. Changes in research results can themselves become the focus of research.**

Dane, (1990, p. 19)

### 5.1 Introduction

As discussed in chapter one, the popularity of scuba diving as a recreational sport is increasing rapidly. The hyperbaric environment that scuba divers are exposed to, poses definite medical risks for the individual. According to Taylor, O'Toole and Ryan (2003) repeated exposure to the hyperbaric environment and the breathing of compressed gas for prolonged periods may cause impaired physical and psychological health.

It is clear from the research that the ears are the sense organs most affected by the hyperbaric environment. The research literature pertaining to the specific influence of scuba diving on the ears are however very limited. The focus in earlier research was mostly on the acute effects that scuba diving may have on the ears and not on the long term or chronic implications of scuba diving (Taylor,

O'Toole & Ryan, 2002). A further shortcoming in the available research literature is that studies were mostly performed on professional or technical scuba divers, leaving the question of the effect of scuba diving when performed recreationally. The final shortcoming of the already limited research material is that the studies only included one or two audiometric tests and not complete audiological test batteries.

Considering these shortcomings in the available research literature, the current study aimed to describe the hearing abilities and middle ear functioning of the recreational scuba diver through the use of a comprehensive test battery and in so doing, aim to shed light on the research question: **Does scuba diving on a recreational level have an influence on the hearing and middle ear functioning of the individual?** The sub aims as described in chapter three aimed to address the research question and support the main aim of the study. The next section of this chapter will aim to summarize the conclusions drawn from the results obtained, in accordance with the formulated sub aims.

## **5.2 Conclusions of the sub aims**

The descriptive, correlation research design that was implemented in this study allows the researcher to draw conclusions and predict outcomes based on the extend to which differences in one variable are related to differences in one or more variable (Leedy & Ormrod, 2005). In order to answer the research question, conclusions will be discussed according to each sub aim.

### **5.2.1 Collect normative data for 90 ears within three controlled groups of participants.**

The three groups mentioned in this sub aim are; recreational scuba divers (RSD) between the ages of eighteen and forty with a diving history of less than one hundred dives; RSD with a diving history of more than one hundred dives and a group of non-divers (control group).

The data obtained for all ninety ears, indicated results that were mostly within normal audiological parameters. This statement was strongly supported by the low standard deviation for each of the individual measurements as discussed in chapter 4. The few instances where measurements were not within normal expected parameters, were inconsistent, did not appear to indicate any predictable patterns and were related to individual differences.

As mentioned in chapter 4, the fact that group means obtained for all the audiometric measurements were well within normal parameters, complicated the analysis of the data. Statistical analysis was performed with the assistance of the Department of Statistics at the University of Pretoria to find statistically significant differences in the data. Statistics can assist the researcher to note patterns that might otherwise go unnoticed (Leedy & Ormrod, 2005)

#### **5.2.2 Describe and compare specific audiometric characteristics as measured in the three demographical groups of participants and determine possible predictable patterns in the audiometric test results**

In chapter three the analysis and processing of the data were discussed. For the purposes of the second and third sub aim as combined under the heading of this section; the data was statistically analyzed by making use of the General Linear Model (GLM) procedure. This procedure allowed for comparisons between the three demographic characteristics and the interaction between them for each audiometric measurement. As described in chapter 4, there were several audiometric measurements where statistically significant differences were noted. In many of these differences the patterns were inconsistent and no predictable patterns relating to the demographical characteristics could be determined. The rest of this section will focus on those measurements where there were not only statistical significance but also definite patterns and practical significance.

The behavioural evaluation of peripheral hearing included pure tone testing as well as speech audiometry. Pure tone audiometry remains the most basic and most used test procedure in audiology and a clinical mastery of pure tone techniques forms the foundation for clinical competency in all areas of audiology (Katz, 2002). The pure tone results for the current study indicated statistically significant differences for pure tone air thresholds at 125, 1500 and 4000Hz and for the air-bone-gaps at 1500 and 4000Hz. The differences at 125Hz were inconsistent with no predictable patterns. 1500Hz indicated an increase in the threshold for this frequency only for the female divers in the 100+ dive group. The statistically significant differences that were noted in the air-bone-gap for this frequency were more age related and the female divers in the 100+ group showed on average a 5dB difference to the other groups. Practically this is a very small difference and does not allow for any generalizations. The speech discrimination threshold where a 100% was reached, indicated differences without any specific pattern or consistency.

According to a number of authors, there is a high rate of hearing impairment amongst scuba divers and the hearing loss appears to be a progressive sensori-neural hearing loss especially in the high frequencies (Coles, 1976; Edmonds, 1985; Edmonds & Freeman, 1985; Haraguchi et al. 1999; Molvaer & Lehmann, 1985; Molvaer & Albreksten, 1990; Skogstad, Haldorsen & Arnesen, 2000). A study by Brady, Summit & Berghage (1976), suggests the opposite and indicates that it would be compelling to suggest that diving has a detrimental effect on hearing. The results of the current study do not indicate any noticeable differences in the hearing acuity of divers and non-divers, relating to the pure tone results. Further discussion on the possibilities for this finding, will be discussed in the final conclusions of this chapter.

With the physiologic evaluation of the auditory system, statistically significant differences were noted with the measurement of ear canal volume, static compliance, tympanogram width and the ipsi lateral reflexes at 1000Hz and 2000Hz. There were no statistically significant differences in the demographical characteristic interaction relating to middle ear pressure for the participants of the current study. Research by Green et al. (1993) revealed a significant decrease in middle ear pressure with diving but this phenomenon was not supported by the current findings.

The statistically significant differences noted for ear canal volume, were age and gender related, as was expected. Tympanogram width indicated only statistically significant differences that were gender related. The data for ipsi lateral reflexes at both 1000 and 2000Hz indicated differences that were inconsistent with no predictable patterns relating to group interaction.

The measurement that is of significant interest to the current research endeavour, is static compliance. There were consistent statistically significant differences specifically relating to the diver groups. Interaction was noted between the gender and participant group; age and participant group and between the different participant groups.

With the gender and group interaction, there was a consistent increase in static compliance relating to diving activity. The female divers performed worse than the male divers. With the interaction between age and participant group, the statistical significance were influenced by the participant groups and did not relate to age. The two diver groups performed consistently worse than the control group. Supporting the two previously discussed interactions, was the statistical significance measured for group interaction alone. There was a consistent increase in the mean performance on static compliance relating to diving activity.

There is limited information on static compliance in the research material relating to the long term effects of diving on the auditory system. Green et al. (1993) reported that tympanic membrane compliance remains unaffected by diving. Contrary to their findings Paaske et al. (1991) concluded that the strain exerted on the tympanic membrane and middle ear from barotraumas due to diving, results in reversible impairment of the recoiling capacity of the elastic fibrils of the tympanic membrane. The transient increase in static compliance could be the first measurable change in elasticity of the tympanic membrane. They mention the possibility that if barotraumas continue the changes could be irreversible. The current study supports the findings of Paaske et al. (1991) but further indicates that the influence of scuba diving on static compliance might be more drastic than what is indicated in the research literature. Keeping in mind that the current study was performed on divers that did not report previous barotraumas, it appears that the elastic fibrils of the tympanic membrane may be affected even without specific trauma to the ear. It appears that the inevitable compression and decompression that the middle ears are exposed to during scuba diving, might have a more permanent effect on the elasticity of the tympanic membrane and might not be as transient as previously believed. The results of the current study indicated consistent predictable patterns of increased static compliance with the increase of diving activity.

### **5.2.3 Determine possible correlations between the audiometric measured characteristics and how it relates to group characteristics**

The final sub aim of the study was formulated to determine possible correlations between the audiometric measured characteristics and how it relates to demographic group characteristics. Further analysis was performed to determine any correlations between the specific audiometric test results and how it related to the three demographical characteristics and the interaction between them.



Motivated by the significance in the data obtained for static compliance, further analysis was performed to determine any correlation between static compliance and other audiometric test results. Comparisons were made with the air-bone-gaps, ipsi lateral acoustic reflexes, middle ear pressure and tympanogram gradient. Although there appeared to be several strong and very strong correlations, most of the patterns were inconsistent. Three correlations that indicated predictable patterns, were the correlation between static compliance and the air-bone-gap at 250Hz; the air-bone-gap at 500Hz and middle ear pressure. The correlation between static compliance and the air-bone-gap at 250Hz was noticeable for the two diver groups, with a medium to strong negative correlation for the 1-100 diver group and a positive strong correlation with the 100+ diver group, especially pertaining to the male participants in this group. The correlation between static compliance and the air-bone-gap at 500Hz were negative for most of the diving participants but again positive for the male diver participants. The correlation between middle ear pressure and static compliance was strong to very strong, across almost all the demographical characteristics and the interaction between them. It was however inconsistently positive and negative. The correlation between these two measurements is notable but requires further investigation on a larger sample of participants. The same applies to the correlation between the air-bone-gaps at 250 and 500Hz and static compliance. Coles (1976) noted that hearing loss associated with diving activity can be conductive and cautioned that although changes in the middle ear occur, it does not necessarily result in a conductive hearing loss. The current study can not exclude the possibility that changes in static compliance might not indicate a conductive component but further research is of notable importance to investigate this possibility.

Further comparisons were also made between middle ear pressure and the air-bone-gaps. Again the correlations were inconsistent and no predictable patterns could be derived from these strong and very strong correlations.

### **5.3 Final conclusions of the study**

The results of the current study lead to three possible conclusions. The first is that scuba diving on a recreational level does not have a significant effect on the hearing and middle ear functioning of the individual, with the exclusion of static compliance. The second possibility is that the current study aimed to select participants that were completely free of any ear or hearing problems and in doing so excluded those individuals that might already have been affected by scuba diving. The third possibility is that the effect that scuba diving has on the individual is not effectively evaluated through the use of a basic comprehensive audiological test battery and that one needs to explore the auditory system of scuba divers through the use of a more advanced audiological test battery.

### **5.4 Critical evaluation of the current study**

A critical evaluation of any research endeavour is essential in determining its value and applicability. The contribution of a study does not only subside in the results but also in highlighting the strengths and weaknesses of the study (Neuman, 1997). A critical evaluation of the current study and its limitations will follow.

There were certain limitations in the current study relating to the selected participants. A greater number of participants would have allowed for more valid generalization of the obtained data and could possibly have indicated stronger statistical significance. The age of all the selected participants was below forty years. Although this selection criterion supported the purity of the participant groups, it prevents the researcher from truly evaluating the chronic implications of diving. As discussed in chapter two, the research literature supports the idea that divers' hearing deteriorate faster than the hearing abilities of non-divers (Haraguchi et al. 1999; Molvaer & Albreksten 1990). The final limitation in the selected groups of participants was the fact that participants had to be free of

any medical condition that could have an effect on the auditory system. Although this selection criterion again allowed for more purity in the sample, it allows for the possibility that individuals that were already affected by scuba diving, were excluded.

The last aspect identified in the critical evaluation of the current study relates to the selected audiological test battery. A more comprehensive test battery would have allowed for more accurate description of the hearing acuity of recreational scuba divers. It is recommended that otoacoustic emissions testing be included as part of the audiological test battery. Otoacoustic emissions testing would have allowed for further evaluation of the cochlea and more specifically, the outer hair cells in the cochlea. Otoacoustic emissions are sounds that originate in the cochlea and propagate through the middle ear, into the ear canal, where they can be measured using a sensitive microphone. Otoacoustic emissions are believed to be the by-products of the pre-neural mechanisms of the cochlea and are linked to the functioning of the outer hair cells.

## **5.5 Recommendations for future research**

As the opening quote to this chapter clearly states; research results are not timeless and changes in those results can lead to the focus of future research (Dane, 1990). The field of diving medicine, especially pertaining to the auditory system, is a research field that still requires comprehensive focus. There is notable controversy relating to the long term implications of scuba diving on the auditory system. The current study aimed to serve as part of a basis for future research in the field of diving related injuries to the auditory system. An exposition of recommendations regarding future research will follow.

- Several authors have motivated for further research in the field of diving medicine. Taylor, O'Toole & Ryan (2002) suggests that research is

needed into the possible association between scuba diving and chronic middle and inner ear disease.

- As discussed earlier in this chapter it would be advisable to perform a similar study on a greater number of participants, to allow for more valid generalization to the recreational scuba diving population.
- It is further recommended to perform studies relating to the hearing acuity of recreational scuba divers on older participants. This will provide a more accurate representation of the interaction between diving and the aging of the auditory system.
- A comprehensive audiological test battery that includes otoacoustic emissions testing would be valuable in the evaluation of the hearing acuity of the recreational scuba diver. Otoacoustic emissions testing will allow for further evaluation of the cochlea or more specifically the functioning of the outer hair cells in the cochlea.

## **5.6 Final comments**

With the increase in people's interest in recreational water sports, education regarding the risks of extreme middle ear pressure changes should be expanded. Divers more susceptible to barotraumas, either due to lifestyle, upper respiratory infections or after ear surgery, should take extra precautions to guard against, or simply avoid exposure of the ear to pressure changes where the risk of barotraumas is the greatest (Harrill, 1995). The majority of experienced divers had suffered diving-related injuries, mainly barotraumas. Diver education is of utmost importance to better document injury rates and minimize serious diving-related injuries as well as permanent disabilities (Taylor, O'Toole & Ryan, 2003)

Eustachian tube awareness should be taught to divers and new divers should always use pressurization to prevent middle ear barotraumas (Kay, 2000). If it does however occur, it is recommended that they discontinue diving immediately. Mild symptoms are expected to subside within two weeks after injury. Once equalization abilities and hearing are back to normal, a diver can return safely to diving. Kay (2000) places the emphasis on a medical opinion, if there are any questions concerning symptoms.

Divers with tympanic membrane and inner ear damage seem to continue diving and exposing themselves to the potential risk of repeated injury. This does not mean that divers should always refrain from future diving after a diving-related injury. Evidence indicates that careful diving is permissible, even after middle ear surgery and inner ear barotrauma (Taylor, O'Toole & Ryan, 2003)

Even experienced, recreational scuba divers continue to dive despite medical contraindications. This raises the question of divers holding medical information back at the initial medical screening evaluation or subsequent disease development. These authors noted a high prevalence of hearing difficulties and tinnitus amongst divers and mentioned the possibility that this might be the result of aural barotraumas but requires further research (Taylor, O'Toole & Ryan, 2002). Their findings indicated either that the risks of certain medical conditions are not of clinical significance, or that repeated screening assessments are indicated. These authors also noted that a number of divers commented on how easy it was to avoid the detection of medical conditions during their diving medical (Taylor, O'Toole & Ryan, 2003). This is a great concern indicating divers' lack of knowledge of the severe medical risks involved in diving and their indifference concerning their health.

It is important to evaluate the influence that diving might have on the hearing acuity of the recreational scuba diver, in order to evaluate the effectiveness of

the initial medical screening process, the need for repeated medical examinations and the safety of these conditions among recreational scuba divers (Taylor, O'Toole & Ryan, 2003). With the notable medical risks involved in scuba diving it is of utmost importance that divers should be educated about both the acute and chronic risks. Repeated hearing evaluations would be advisable to assess any long term implications that scuba diving may have on the auditory system. It would be advisable for individuals participating in scuba diving, for either professional or recreational purposes, to ensure that they have regular medical as well as audiological evaluations performed, to ensure good diver health. The increased popularity in scuba diving as a recreational activity places an onus on the audiologist, ear, nose and throat specialist and the general practitioner for greater education and awareness in this field.

## **5.7 Summary**

In this chapter conclusions had been drawn from the results obtained and discussed in chapter 4. Conclusions were discussed relating to the sub aims of the study as stipulated in chapter 3 to address the main aim of the study. A critical evaluation of the study highlighted its limitations. Recommendations for future research were made on the basis of the research literature as well as on the findings of the current study. This chapter concluded with a few final comments.

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