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## Hearing assessment of forest loggers

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# **HEARING ASSESSMENT OF FOREST LOGGERS**

A Thesis  
Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Science in Industrial Engineering

In

The Department of Construction Management and Industrial Engineering

By  
Antonio A. Fonseca  
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## **ABSTRACT**

Forest logging is the process in which trees are cut down for forest management and/or timber harvest. According to OSHA, logging is the most dangerous occupation in the United States. It consistently represents one of the most hazardous industries, with a fatality rate more than 21 times higher than the rate for all workers in the United States. Yet, little research has been performed to determine the long term effect of noise on forest loggers. OSHA regulations state that the maximum permissible hearing in an 8 hour shift should not exceed 90 dB. Occupational noise exposure is recognized as a primary factor on permanent hearing loss (OSHA, 2007). The objective of this study is to determine whether long term hearing loss in forest loggers is associated with noise emitted by logging equipment.

This study compares the differences in hearing thresholds of the participants, applying the OSHA age correction tables for audiograms (OSHA, 2008). These tables present the hearing threshold of a normal population at ages ranging from 20 to 60 years. Hearing threshold shift is determined by subtracting the hearing threshold of each participant from age corrected hearing threshold as defined by OSHA (2008) for each specific age. These individuals had never experienced any type of acute or chronic hearing loss. Participants were also separated into age groups of 10 year intervals (20 to 29, 30 to 39, 40 to 49, and 50 to 59) and experience groups of 10 year intervals (1 to 10, 11 to 20, 21 to 30, and 31 to 40).

The hearing tests on forest loggers determined that at 4000 Hz, the mean hearing threshold of the participants was significantly higher than the rest of the frequencies. Furthermore, a significant increase in hearing threshold between the participant population and the hearing threshold of a normal population was also determined. The hearing threshold shifts at 1000, 2000, and 4000 Hz were of 4.9, 9.5 and 18.0 dB respectively. A significant decrease in the

hearing threshold (of 3.4 dB) was found between those participants who wore hearing protection and those who did not.

# **CHAPTER 1**

## **INTRODUCTION**

Forest logging is the process in which trees are cut down for forest management and/or timber harvest. Logging consistently represents one of the most hazardous industries, having a fatality rate over 21 times higher than the rate for all workers in the United States. Most of the forest loggers involved in the tree cutting process operate tools such as chainsaws and heavy equipment on uneven and sometimes unstable terrain. Loggers also deal with severe environmental conditions such as rough weather and extreme temperatures. According to the Bureau of Labor Statistics (2005), the logging industry in the United States employed 106,000 workers. Out of those 106,000 workers, 91 workers were fatally injured, resulting in a fatality rate of 85.8 deaths per 100,000 workers.

Extensive research is performed in developing programs and techniques to minimize potential hazards that may cause the injury or even death of workers. Equipment design is aimed to chiefly to protect the safety of the operator. Although a great amount of research has been performed to develop the most effective ways to protect workers' physical well being, very little research is performed to determine whether the noise of logging equipment is associated with the negative effects on the hearing capabilities of the operators.

Noise is defined by the American Speech-Language-Hearing Association (ASHA, 2008) as any unwanted sound. It is also described as a pollutant and a hazard to human health and hearing. It has been described as the most pervasive pollutant in the United States. Kryter (1996) defines noise as acoustic signals that can negatively affect the physiological and psychological well-being of an individual. According to the National Institute on Deafness and other Communication Disorders (NIDCD, 2008) more than 30 million people in the United States are exposed to hazardous hearings on a regular basis. Out of the 28 million people in the United

States who have some degree of hearing loss, over one-third has been affected, at least in part by noise.

When being exposed to noise, both the level and the time of exposure to noise determine the ability to damage hearing. Noise (sound) levels are measured in decibels (dB). The higher the decibel level, the louder the noise (Appendix H). According to OSHA (2007), hearings higher than 89 decibels (dB) are considered hazardous. Table 1.1 illustrates the maximum permissible duration a worker can perform a task with respect to noise, according to OSHA.

**Table 1.1.** Maximum permissible levels of sound, according to OSHA (29 CFR 1910.95)

<u>Exposure Duration (hrs.)</u>	<u>Hearing (dB)</u>
8	90
4	95
2	100
1	105
0.5	110

Exposure to extended periods of high levels of noise has other negative effects on humans. Noise has been associated with cardiovascular health problems (Ising *et al.*, 1999). The World Health Organization concluded that available evidence suggested a weak association between long-term noise exposure above 67-70 dB and hypertension (Berglund *et al.* (1999). More recent studies have suggested that noise levels of 50 dB at night may also increase the risk of myocardial infarction (heart attack) by chronically elevating cortisol production (Lercher *et al.* 1993). Other effects of high noise levels are increased frequency of headaches, fatigue, stomach ulcers, and vertigo (EPA, 1978).

The American Speech-Language-Hearing Association (ASHA, 2008) provides the following information on warning signs of hazardous noise:

1. You must raise your voice to be heard.

2. You can't hear someone two feet away from you.
3. Speech around you sounds muffled or dull after leaving a noise area.
4. You have pain or ringing in your ears after exposure to noise.

Table 1.2 illustrates an idea of average decibel levels of everyday sound to which average people are subjected (ASHA, 2008):

**Table 1.2.** Examples of everyday sound

	Hearing (dB)	Example
<b>Faint Sound:</b>	30 dB	whisper, quiet library
<b>Moderate Sound:</b>	40 dB	quiet room
	50 dB	moderate rainfall
<b>Very Loud:</b>	60 dB	conversation, dishwasher
	70 dB	busy traffic, vacuum cleaner
	80 dB	alarm clock, busy street
<b>Extremely Loud:</b>	90 dB	lawnmower, shop tools, truck traffic, subway
	100 dB	snowmobile, pneumatic drill
	105 dB	chainsaw, timpani, and bass drum rolls
	110 dB	rock music, model airplane
<b>Painful Sound:</b>	120 dB	amplified rock music at 4-6 ft.
	130 dB	jackhammer
	140 dB	air raid siren
	150 dB	firearms, military jet engine at 20 ft.

Logging operations produce noise that may be harmful to the operators in the immediate area. Forest logging involves noise producing operations such as felling (cutting tree down) and moving trees, which are moved from the stump to the point of delivery by transporting vehicles. Logging is performed in various ways, depending on terrain, environment, and types of trees to be cut. The most common type of tree logging involves an array of different heavy machinery. On site equipment includes tree cutters (felling machines), skidder (which transport tree trunks to

the loading area), loaders (which load the tree trunks on the transport trucks), and the chainsaw operators who cut tree limbs to make tree transportation more convenient.

The objective of this study is to determine whether long term hearing loss in forest loggers is associated with noise emitted by logging equipment. This study compared the differences in hearing thresholds of the participants with the OSHA age correction tables for audiograms (OSHA, 2008). These tables present the hearing threshold of a normal population at ages ranging from 20 to 60 years. These individuals have no medical history of acute or chronic hearing loss. Participants were also separated into age groups of 10 year intervals (20 to 29, 30 to 39, 40 to 49, and 50 to 59) and experienced groups of 10 year intervals (1 to 10, 11 to 20, 21 to 30, and 31 to 40). To effectively complete the hearing test, a Beltone audiometer is used for evaluating hearing loss. The hearing capacity of each participant is measured by the obtaining the lowest possible hearing (in decibels) needed to hear a pure tone signal at a predetermined frequency. The participants are 26 male forestry workers (forest loggers), directly involved with the operation of logging equipment. This equipment includes chainsaws, loaders, skidders, and cutters. The age ranges varied from 20 through 59 years.

The OSHA age correction to audiogram tables determines a normal population's hearing loss as age progresses. It has been understood that as age progresses, hearing capabilities decrease, especially as frequency increases (Gacek and Schuknecht, 1969). According to noise tests performed on forestry equipment (de Hoop et al., 2003), it was observed that the noise emitted by forestry equipment exceeds the normal permissible amount established by OSHA (90 decibels over an 8 hour shift). The hearing tests on loggers determined if considerable hearing loss has occurred, due to a constant exposure to the noise emitted by the equipment.



## **CHAPTER 2**

### **BACKGROUND AND LITERATURE REVIEW**

The main focus of this study is to determine whether noise emitted by logging equipment is associated with long term hearing loss in its operators. This research indicates whether abnormal hearing loss occurs, due to the elevated levels of noise to which forest loggers are exposed. It is of vital importance to understand what is considered to be noise and how noise is measured. The following section will explain the different levels of noise, how sound pressure is measured, and the levels of noise at various industries. The proceeding section explains the role of noise in hearing loss, where hearing loss occurs, and how such loss happens, together with the components of the human ear and what constitutes traumas to the ear. The sections following will illustrate studies of noise effects on hearing capacity and the effects of noise to human health. Assessments on noise emitted by logging equipment and safety hearing equipment will be illustrated and explained.

#### **2.1 Past Studies about Noise**

Passchier *et al.* (2000) defined sound as a physical phenomenon consisting of the alternating compression and expansion of air that propagates in all directions from a source. These alternating compressions and expansions may be described as small changes in pressure around atmospheric pressure. The frequency of the alternations determines the pitch of a sound: a high-pitched tone (e.g., 4,000 Hz) has a squeaking sound; a low-pitched tone (e.g., 200 Hz), emits a humming sound. Sound pressures, relative to the atmospheric pressure, range from  $< 20$  micropascal to  $> 200$  pascal, a range of 1-10 million. Therefore, in acoustics, the logarithm of sound pressure, relative to a reference sound pressure, is used as a basis for a sound (and noise) exposure measure: the physical quantity sound pressure level, expressed in decibel (dB).

Passchier also explained that the human hearing organ is not equally sensitive to sounds of different frequencies. Therefore, a spectral sensitivity factor is used that rates sound pressure levels at different frequencies in a way comparable to that of the human hearing organ; this is called *weighting*. The biophysical quantity of a weighted sound pressure level is expressed as dB and is referred to as *sound level*. Sound level is the basic metric from which other biophysical metrics, present in long-term exposure to noise, are derived.

It has been hypothesized that noise may have various effects on a person's response, depending on its source. Kozou *et al.* (2004) evaluated the effect of different types of real-life noise on an individual's central auditory processing of speech and non-speech sounds through mismatch negativity (MMN) and behavioral responses. Participants (19–34 years old; 6 males, 4 females) were presented in separate conditions, with either speech or non-speech stimuli of approximately equal complexity in five background conditions: babble noise, industrial noise, traffic noise, wide band noise, and silent condition. No effects of stimuli or noise on the behavioral responses were found. The MMN results revealed that speech and non-speech sounds are processed differently, both in silent and noisy conditions. Speech processing was more affected than non-speech processing in all noise conditions. Moreover, different noise types had a differential effect on the pre-attentive discrimination, as reflected in MMN, on speech and non-speech sounds. Babble and industrial noises dramatically reduced the MMN amplitudes for both stimulus types, while traffic noise affected only speech stimuli.

### **2.1.1 Noise Levels in Different Industries**

Occupational noise exposure exists in every industrial cohort, and may be present at different levels within each facility. When being exposed to noise, both the level and the time of exposure to noise determine the ability to damage hearing. Noise levels are measured in decibels (dB). The higher the decibel level, the louder the noise. According to OSHA (2007), hearings

higher than 89 decibels (dB) are considered hazardous. Table 2.1.1.1 illustrates the maximum permissible duration a worker can perform a task with respect to noise, according to OSHA.

**Table 2.1.1.1.** Maximum permissible levels of sound according to OSHA (29 CFR 1910.95)

<u>Exposure Duration (hrs.)</u>	<u>Hearing (dB)</u>
8	90
4	95
2	100
1	105
0.5	110

Even though OSHA provides guidelines for exposure at different noise (sound) levels, it is the company's responsibility to perform assessments and to determine the noise levels to which workers are subjected. Table 2.1.1.2 provides a research summary of the average noise levels at present for different industries and activities:

**Table 2.1.1.2.** Noise levels at different industries and activities

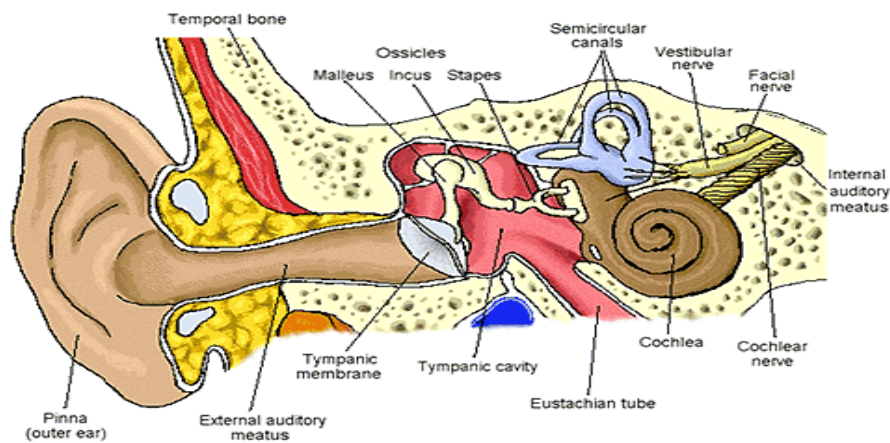
<b>Type of Industry, Work, or Activity</b>	<b>Noise Levels (dB)</b>	<b>Source</b>
Insulation Workers	78	Neitzel and Seixas (2005)
Electricians	81	Neitzel and Seixas (2005)
Ironworkers	83	Neitzel and Seixas (2005)
Plumbers (Welding Confined)	90	Chambers, R.M. <i>et. al.</i> (1989)
Foundry Industry	91	Daniell W. <i>et. al.</i> (2002)
Farming	94	Yearout and Brown (1991)
Wood Crafting	98	Yearout and Brown (1991)
Forest Loggers	85 to 100	Taoda <i>et al.</i> (1987)
Wood Pallet Manufacturing	95 to 104	Malkin <i>et. al.</i> (2005)
Drop Forging	99 to 108	Taylor <i>et. al.</i> (1984)
Drag Racing	120	Yearout and Brown (1991)

## 2.2 The Human Ear

The ear consists of three basic parts: the outer ear, the middle ear, and the inner ear. Each part of the ear performs a completely different task which ultimately aids in the detection and interpretation of sound. The three parts of the ear are illustrated on Figure 2.2.1.

### 2.2.1 The Outer Ear

The outer ear consists of an ear flap and approximately a 2-cm long ear canal. The ear flap provides protection for the middle ear in order to prevent damage to the eardrum. The outer ear also channels sound waves which reach through the ear canal to the eardrum of the middle ear. Because of the length of the ear canal, it is capable of amplifying sounds with frequencies of approximately 3000 Hz. As sound travels through the outer ear, the sound is still in the form of a pressure wave, with an alternating pattern of high and low pressure regions. It is not until the sound reaches the eardrum at the interface of the outer and the middle ear that the energy of the mechanical wave becomes converted into vibrations for the inner bone structure of the ear.



**Figure 2.2.1.** Parts of the human ear (ZME Science, 2008)

### 2.2.2 The Middle Ear

The middle ear is an air-filled cavity which consists of an eardrum and three tiny, interconnected bones - the hammer, anvil, and stirrup. The eardrum is a very durable and tightly stretched membrane, which vibrates as the incoming pressure waves reach the eardrum. As shown below, a compression forces the eardrum inward and the rarefaction forces the eardrum outward, thus vibrating the eardrum at the same frequency of the sound wave.

Being connected to the hammer, the movements of the eardrum will set the hammer, anvil, and stirrup into motion at the same frequency of the sound wave. The stirrup is connected to the inner ear; thus, the vibrations of the stirrup are transmitted to the fluid of the inner ear to create a compression wave within the fluid. The three tiny bones of the middle ear act as levers to amplify the vibrations of the sound wave. Due to a mechanical advantage, the displacements of the stirrup are greater than that of the hammer. Furthermore, since the pressure wave striking the larger area of the eardrum is concentrated into the smaller area of the stirrup, the force of the vibrating stirrup is nearly 15 times larger than that of the eardrum. This feature enhances our ability to hear the faintest of sounds. The middle ear is an air-filled cavity which is connected by the Eustachian tube to the mouth. This connection allows for the equalization of pressure within the air-filled cavities of the ear. When this tube becomes clogged during a cold, the ear cavity is unable to equalize its pressure; the unequal pressure often leads to earaches and other pains.

### **2.2.3 The Inner Ear**

The inner ear consists of a cochlea, the semicircular canals, and the auditory nerve. The cochlea and the semicircular canals are filled with a water-like fluid. The fluid and nerve cells of the semicircular canals provide no role in the task of hearing; they merely serve as accelerometers for detecting accelerated movements and assisting in the task of maintaining balance. The cochlea is a snail-shaped organ, capable of stretching to approximately 3 cm. In addition to being filled with fluid, the inner surface of the cochlea is lined with over 20,000 hair-like nerve cells which perform one of the most critical roles in one's ability to hear. These nerve cells differ in length by minuscule amounts, and also have varying degrees of resiliency to the fluid which passes over them. As a compressional wave moves from the interface between the hammer of the middle ear and the oval window of the inner ear, through the cochlea, the small hair-like nerve cells are set into motion. Each hair cell has a natural sensitivity to a particular

frequency of vibration. When the frequency of the compressional wave matches the natural frequency of the nerve cell, that nerve cell resonates with a larger amplitude of vibration. This increased vibration amplitude induces the cell to release an electrical impulse, which passes along the auditory nerve toward the brain. In a process which is not clearly understood, the brain is capable of interpreting the qualities of the sound upon reception of these electric nerve impulses.

#### **2.2.4 Ear Trauma**

##### **2.2.4.1 Outer Ear Trauma**

The auricle can be easily damaged, because it is a skin-covered cartilage, with only a thin padding of connective tissue. Any rough handling of the ear can cause enough swelling to jeopardize the blood-supply to the auricle framework, its cartilage. The entire cartilage framework is fed by a thin-covering of membrane called the perichondrium (meaning literally, “around the cartilage”). Any fluid from swelling or blood from injury that collects between the perichondrium and the underlying cartilage puts the cartilage in danger of being separated from its supply of nutrients. If portions of the cartilage starve and die, the ear never heals back to its normal shape. Instead, the cartilage becomes lumpy and distorted. Wrestler's Ear is one term used to describe the result, because wrestling is one of the most common ways such an injury occurs. Cauliflower ear is another name for the same condition, because the thickened auricle can resemble that vegetable.

The lobule of the ear (ear lobe) is the one part of the human auricle that normally contains no cartilage. Instead, it is a wedge of adipose tissue (fat) covered by skin. There are many normal variations to the shape of the ear lobe, which may be small or large. Tears of the earlobe can be generally repaired with good results. Since there is no cartilage, there is no risk of deformity from a blood clot or pressure injury to the ear lobe. Other injuries to the external ear

occur fairly frequently, and can leave a major deformity. Some of the more common ones include laceration from glass, knives, and bite injuries, avulsion injuries, cancer, frostbite, and burns.

Ear canal injuries can come from firecrackers and other explosives, and mechanical trauma comes from placement of foreign bodies into the ear. The ear canal is most often self-traumatized from efforts at ear cleaning. The outer part of the ear canal rests on the flesh of the head; the inner part rests in the opening of the bony skull (called the external auditory meatus). The skin is very different on each part. The outer skin is thick, and contains glands as well as hair follicles. The glands make cerumen (also called ear wax). The skin of the outer part moves a bit if the pinna is pulled; it is only loosely applied to the underlying tissues. The skin of the bony canal, on the other hand, is not only among the most delicate types of skin in the human body, it is tightly applied to the underlying bone. A slender object used to blindly clean cerumen out of the ear often results instead with the wax being pushed inward; contact with the thin skin of the bony canal is likely to lead to laceration and bleeding.

#### **2.2.4.2 Middle Ear Trauma**

Like outer ear trauma, middle ear trauma most often comes from blast injuries and insertion of foreign objects into the ear. Skull fractures that go through the part of the skull containing the ear structures (the temporal bone) can also cause damage to the middle ear. Small perforations of the tympanic membrane usually heal on their own, but large perforations may require grafting. Displacement of the ossicles (tiny bone inside ear) will cause a conductive hearing loss that can only be corrected by surgery. Forcible displacement of the stapes (tiny bone inside ear) into the inner ear can cause a sensory neural hearing loss that cannot be corrected even if the ossicles are put back into proper position. Because human skin has a top waterproof layer of dead skin cells that is constantly shedding, displacement of portions of the tympanic

membrane or ear canal into the middle ear or deeper areas by trauma can be particularly traumatic. If the displaced skin lives within a closed area, the shed surface builds up over months and years and forms a cholesteatoma. The “-oma” ending of that word indicates a tumor in medical terminology, and although cholesteatoma is not a neoplasm (but a skin cyst), it can expand and erode the ear structures. The treatment for cholesteatoma is surgical.

#### **2.2.4.3 Inner Ear Trauma**

There are two principal damage mechanisms to the inner ear in industrialized society, and both injure hair cells. The first is exposure to elevated hearings (noise trauma), and the second is exposure to drugs and other substances (ototoxicity).

### **2.3 Noise Effects on Hearing Capacity**

Different studies on the correlation of noise and hearing loss have been performed to determine a significant relationship. Being subjected to high levels of noise for extended periods of time may lead to chronic hearing loss, which applies to any industrial cohort. Tunay and Melemez (2008) performed audiometric tests in 114 forest loggers in order to determine whether there was significant hearing loss. The participants in this study operated chainsaws and tractors. Results indicated that the degree of hearing loss (hearing threshold) was in the range of 40 to 50 dB. The study found the hearing threshold at 4000 Hz to be 42 dB.

Iki (1984) conducted an epidemiological study including audiometry of forestry workers, who underwent a medical checkup on vibration disease and results were analyzed for acute hearing loss. Among these participants were 360, men who had not been exposed to heavy noise other than from chain saws, bush cleaners or winches and had no history of hearing abnormality. The hearing threshold at 4000 Hz was significantly higher than the threshold recognized as a function of age in every age group. The participants with greater number of operating hours for the three tools developed greater hearing loss than those with fewer hours. Similar results were



obtained in the analysis of those men who had worked with chain saws only, in the comparison among the three groups, whose hours of work with bush cleaners and winches were matched and divided by operating hours for chain saws. The workers who used the three tools for more hours exhibited more advanced audiogram types of noise-induced hearing loss than men who had operated the three tools for fewer hours.

Most industrial noises are broadband with the major frequency content well below 3000 Hz, but the maximum threshold shift seems to occur at a frequency half an octave above the frequency (doubles) of the exposure (Davis et al, 1950). Various studies have shown threshold shifts due to industrial noise to be strongest at the frequency region around 4000 Hz (Taylor et al, 1965; Bauer et al, 1991; Lutman & Spencer, 1991), and little or no damage seems to occur below 2000 Hz (ISO 1999, Annex E, 1990).

Ferrite and Santana (2005) examined the hypothesis that smoking, noise and age jointly affect hearing acuity. This cross-sectional study was carried out in 535 male adult workers in a metal processing factory. Pure-tone audiometric tests were utilized to assess hearing loss. Noise exposure assessment was based on a job exposure matrix, constructed with industrial hygienist scoring and job titles. Each participant answered questionnaires about socio-demographic, life-style, occupational, and health-related data. Results indicated that age and occupational noise exposures were separately and positively associated with hearing loss. For all the factors combined, the estimated effect on hearing loss was higher than the sum of the effects from each isolated variable (especially for smoking and noise) among those 20–40 years of age, and for smoking and age among those non-exposed to occupational noise.

Rabinowitz *et al.* (2006) examined the relationship between rates of high frequency hearing loss and measured levels of noise exposure in a modern industrial workforce. Ten-year hearing loss rates were determined for 6217 employees of an aluminum manufacturing company.

Hearing loss rates were compared to ANSI 3.44 predictions based on age and noise exposure. Associations between hearing loss, noise exposure, and covariate risk factors were assessed. Results indicated that workers in higher ambient noise jobs tended to experience less high frequency hearing loss than co-workers exposed at lower noise levels. At higher noise exposure levels, the magnitude of hearing loss was less than predicted by ANSI 3.44 formulae. There was no indication that a healthy worker effect could explain these findings. The majority of 10 dB standard threshold shifts (STS) occurred in workers whose calculated ambient noise exposures were less than or equal to 85 dB. A standard threshold shift (STS) is the average shift from the baseline measurement of 10 dB or more in either ear; at 2000, 3000 and 4000 Hz.

Tambs *et al.* (2006) performed a study to compare the frequency specific effects of noise on hearing acuity across the range 250 to 8000 Hz and the extent to which the patterns of frequency-specific threshold shifts differ between occupational noise and impulse noise. Pure-tone audiometry was administered to an adult general population sample with 51,975 participants. Threshold shifts induced by life-long occupational noise and impulse noise (mostly shooting) were estimated separately in six age and gender groups for eight frequencies. The shifts induced by impulse noise reached approximately 8 dB among men 45-65 years. The effects of impulse noise were strongest at 3000-8000 Hz and varied little within this frequency range.

Table 2.3.1 illustrates studies aimed to determine hearing thresholds of workers in different industries.

### **2.3.1 Hearing Loss due to Age**

The gradual loss of hearing that occurs as most individuals grow older is known as *presbycusis*. The effect of aging on hearing thresholds has been studied for many decades now. Since the effect of hearing loss due to age is a gradual one, there is no precisely defined

beginning of this process. Some studies use a limit of 55 years of age for the start of a detectable age-induced hearing loss (Chen *et al.*, 1992; Hasan and Beg, 1994). According to the National Institute on Deafness and Other Communication Disorders (NIDCD, 2008); about 30-35 percent of adults between the ages of 65 and 75 years have a hearing loss. It is estimated that 40-50 percent of people 75 and older have a hearing loss. The loss associated with presbycusis is usually greater for high-pitched sounds. There are many causes of presbycusis. Most commonly it arises from changes in the inner ear of a person as he or she ages, but presbycusis can also result from changes in the middle ear or from complex changes along the nerve pathways leading to the brain. Presbycusis most often occurs in both ears, affecting them equally. Since the process of loss is gradual, those who have presbycusis may not realize that their hearing is diminishing.

**Table 2.3.1.** Hearing thresholds in different industries

<b>Type of Industry, Work, or Activity</b>	<b>Hearing thresholds (dB)</b>	<b>Source</b>
Forest Workers	42	Tunay and Melemez (2008)
Hydro-electric Plant	32	Celik <i>et al.</i> (1998)
Farmers	36	Thelin <i>et al.</i> (1983)
Construction Industry	30	Hong (2005)
Aluminum Manufacturing	10 (STS)	Rabinowitz <i>et al.</i> (2006)
Lumber Mill	10 (STS)	Daivies <i>et al.</i> (2008)

In determining whether a standard threshold shift has occurred, OSHA (2008) developed the standard 1910.95(F) which introduced calculations and application of age corrections to audiograms at 1000, 2000, 4000, and 6000 Hz of frequency. The age corrected tables illustrates the hearing threshold of a normal population from 20 to 60 years of age. The standard considers the gradual decline in hearing threshold as age progresses. The procedure and the age correction tables were developed by the National Institute for Occupational Safety and Health in the criteria

document entitled "Criteria for a Recommended Standard Occupational Exposure to Noise," ((HSM)-11001). Complete age corrected tables can be found in Appendix A.

According to the National Institute on Deafness and Other Communication Disorders (NIDCD, 2008), individuals with presbycusis may experience several of the following:

- The speech of others seems mumbled or slurred.
- High-pitched sounds such as "s" and "th" are difficult to hear and tell apart.
- Conversations are difficult to understand, especially when there is background noise.
- A man's voice is easier to hear than the higher pitches of a woman's voice.
- Certain sounds seem annoying or overly loud.
- Tinnitus (a ringing, roaring, or hissing sound in one or both ears) may also occur.

Presbycusis is caused by sensorineural hearing loss, which indicates disorders of the inner ear or auditory nerve. It is most commonly caused by ongoing changes in the inner ear. The cumulative effects of repeated exposure to daily noise such as traffic sounds, construction work, loud music and/or noisy equipment can cause sensorineural hearing loss. Sensorineural hearing loss is most often due to a loss of hair cells (sensory receptors in the inner ear). This can occur as a result of hereditary factors as well as aging, various health conditions, and side effects of some medicines.

Presbycusis may be caused by changes in the blood supply to the ear because of heart disease, high blood pressure, or vascular (pertaining to blood vessels) conditions caused by diabetes, or other circulatory problems. The loss may be mild, moderate, or severe. Sometimes presbycusis is a conductive hearing disorder, meaning the loss of sound sensitivity is caused by abnormalities of the outer ear and/or middle ear. Such abnormalities may include reduced function of the tympanic membrane (the eardrum) or reduced function of the three tiny bones in

the middle ear that carry sound waves from the tympanic membrane to the inner ear (NIDCD, 2008).

Gacek and Schuknecht (1969) identified four sites of aging in the cochlea and divided presbycusis into four types, based on these sites. The histological changes are correlated approximately with symptoms and auditory test results.

- Sensory presbycusis: This refers to epithelial atrophy with loss of sensory hair cells and supporting cells in the organ of Corti. This process originates in the basal turn of the cochlea and slowly progresses toward the apex. These changes correlate with a precipitous drop in the high-frequency thresholds, which begins after middle age. The abrupt downward slope of the audiogram begins above the speech frequencies; therefore, speech discrimination is often preserved. Histologically, the atrophy may be limited to only the first few millimeters of the basal end of the cochlea. The process is slowly progressive over time. One theory proposes that these changes are due to the accumulation of lipofuscin pigment granules.
- Neural presbycusis: This refers to the atrophy of nerve cells in the cochlea and central neural pathways. Schuknecht estimated that 2100 neurons are lost every decade (of 35,000 total). This loss begins early in life and may be genetically predetermined. Effects are not noticeable until old age because pure-tone average is not affected until 90% of the neurons are gone. Atrophy occurs throughout the cochlea, with the basilar region only slightly more predisposed than the remainder of the cochlea. Therefore, no precipitous drop in the high-frequency thresholds on audio is observed. A disproportionately severe decrease in speech discrimination is a clinical correlate of neural presbycusis and may be observed before hearing loss is noted because fewer neurons are required to maintain speech thresholds than speech discrimination.

- Metabolic (i.e., stria) presbycusis: This condition results from atrophy of the stria vascularis. The stria vascularis normally maintains the chemical and bioelectric balance and metabolic health of the cochlea. Atrophy of the stria vascularis results in hearing loss, represented by a flat hearing curve, because the entire cochlea is affected. Speech discrimination is preserved. This process tends to occur in people aged 30-60 years. It progresses slowly and may be familial.
- Mechanical (i.e., cochlear conductive) presbycusis: This condition results from thickening and secondary stiffening of the basilar membrane of the cochlea. The thickening is more severe in the basal turn of the cochlea, where the basilar membrane is narrow. This correlates with a gradually sloping, high-frequency, sensorineural hearing loss that is slowly progressive. Speech discrimination is average for the given pure-tone average.

Johansson and Arlinger (2002) investigated the hearing threshold levels (HTL) of an otologically unscreened population in Sweden. The participants were males and females aged from 19 to 81 years of age, selected from the province of Sweden. Participants exposed to occupational noise were excluded and in total, 603 persons were included in the analysis. The research determined that the deterioration of hearing threshold level accelerates at an age above 50 to 60 years.

Morrell et. al. (1996) presented age-specific reference ranges for both the hearing level and the change in hearing level for men and women at 500, 1000, 2000, and 4000 Hz. Results indicated that in 30-year-old men, there is little change in the mean hearing level. At 500 Hz, the percentiles show an increase in the spread with time, but at 1000 and 4000 Hz, the percentiles are almost parallel to the mean curves. Men in the 40-, 50-, 60-, and 70- year-old groups show a small decline in the hearing level over 15 years of follow-up at all frequencies. At 500 Hz, the

percentiles spread out for 60-year-olds and at 1000 Hz, the percentiles spread out for 70-year-old men. At 2000 Hz, the percentiles spread out slightly in the 50, 60, and 70 age groups and more so in the 80-year-old group, and at 4000 Hz the percentiles spread out for both 50- and 60-year-olds. Among the oldest men, there is a sharp decline in the hearing level at 1000, 2000, and 4000 Hz, with the percentiles rapidly spreading out at 2000 and 4000 Hz. At 500 Hz, there is only a small change in hearing level in 80-year-olds.

At present, a large volume of current research is being conducted to determine the exact primary cause of presbycusis. Much of the current research focuses on finding underlying genetic abnormalities that may cause, contribute to, or present predisposition to the development of this disease. One of the most widely-investigated potential causes is a genetic mutation in mitochondrial DNA. Reduced perfusion of the cochlea associated with age may contribute to the formation of reactive oxygen metabolites, which may adversely affect the inner ear neural structures as well as cause damage to mitochondrial DNA. In turn, damaged mitochondrial DNA may cause reduced oxidative phosphorylation, which may lead to problems with neural functioning in the inner ear. A study by Dai et al also suggested that damaged mitochondrial DNA may also cause anatomic changes of the inner ear (Dai *et al.*, 2004). Specifically, researchers found a more severe narrowing of the vaso nervorum in the internal auditory meatus in temporal bones with a mitochondrial DNA deletion. Damaged mitochondrial DNA has also been linked to a greater rate of apoptosis of certain cells in the inner ear (Pickles, 2004).

Nutritional and anatomic causes of presbycusis have also been researched. Berner et al (2000) investigated the relationship between vitamin B12 and folate deficiency with age-related hearing loss but did not find a statistically significant relationship. However, Villares et al (2005) did, however, find a positive relationship between high cholesterol levels and hearing loss. In general, the exact cause of age-related hearing loss is still not known today. Nevertheless,

promising research is currently underway in an effort to elucidate the etiology, whether it be genetic, anatomic, or a combination of factors.

#### **2.3.1.1 Determining the Hearing Threshold and Hearing Loss**

Hearing loss is measured as threshold shift in dB units, using an audiometer. The 0 dB threshold shift reading of the audiometer represents the average hearing threshold level of an average young adult with disease-free ears. The PTS (permanent threshold shift), as measured by audiometry, represents a dB level of sounds of different frequencies that are just barely audible to an individual. A positive threshold shift represents hearing loss and a negative threshold shift means better-than-average hearing, when compared with the standard.

A standard method of determining hearing threshold shift, widely accepted in North America is the formula from the American Medical Association (AMA)/ American Academy of Otolaryngology (AAO) formula. The current method recommended by AMA/AAO is as follows:

1. The average hearing threshold level at 500, 1000, 2000, and 4000 Hz should be calculated for each ear.
2. Multiplying should calculate the percentage of impairment for each ear (the monaural loss) by 1.5 times the amount by which the above average exceeds 25 dB (low fence). Hearing impairment is 100% for a 92 dB average hearing threshold level.
3. The hearing disability (binaural assessment) is obtained by applying the American Medical Association Formula. The calculation is performed by multiplying the smaller percentage (better ear) by 5, adding it to the larger percentage (poorer ear), and dividing the total by 6.

The Center for Hearing Loss Help classifies the hearing threshold into the following categories:



- Normal hearing                -10 to 15 dB
- Slight hearing loss        16 to 25 dB
- Mild hearing loss         26 to 40 dB
- Moderate hearing loss    41 to 55 dB
- Moderately severe loss   56 to 70 dB
- Severe hearing loss       71 to 90 dB
- Profound hearing loss    91 to 120 dB
- Deaf                            over 120 dB

## **2.4 Noise Effects on Human Health**

Reactions to a stressor can be psychological (feelings of fear, depression, sorrow), behavioral (social isolation, aggression, excessive use of alcohol, tobacco, food, drugs), and somatic (cardiovascular, gastrointestinal, respiratory illnesses) in nature.

### **2.4.1 Cardiovascular Effects**

A large number of laboratory experiments have shown noise-induced temporal changes in the cardiovascular system (Passchier-Vermeer, 1993). These findings led to several investigations into possible long-term effects associated with noise exposure, e.g., stress-related cardiovascular disorders. Epidemiologic environmental noise studies on changes in blood pressure and increased risk for ischemic heart disease in adults demonstrated no obvious effects on mean diastolic and mean systolic blood pressure from noise exposure, but some effects were observed, such as an increase in the percentage of people with hypertension (including those who use medication for hypertension). The Health Council of the Netherlands (1994) suggested that the observation threshold for ischemic heart disease is estimated to correspond to a sound pressure level of 70 dB for environmental noise exposure. Xu *et al.* (1997) conducted a study among a large sample of more than 20,000 residents in rural communities. The results indicate that self-reported exposure to noise is an important determinant of systolic and diastolic blood pressure.

Babisch *et al.* (1998) performed a longitudinal study on the effect of road traffic noise exposure on the incidence of ischemic heart disease. In this study, two groups of about 2,500 middle-aged men in the United Kingdom participated for a study of the predictive power of already-known, as well as new risk factors for ischemic heart disease. Noise measurements were performed in each of the streets where the participants lived. Even the highest noise exposure did not exceed 70 dB(A). Statistical analysis on the relationships between incidence of ischemic heart disease (classified in a standardized way) and environmental noise exposure revealed that the average annual incidence rate of ischemic heart disease appeared to be 1.4% during the second phase of the study (6 year follow-up; mean age of the men, 57 years). This study provided no support for lowering the observation level of 70 dB for ischemic heart disease.

Effects of noise on the cardiovascular system in children have also been studied. Cohen *et al.* (1980) and Karsdof *et al.* (1968) showed an increase in systolic and diastolic blood pressure in children exposed to very high road traffic noise levels or aircraft noise levels. The increases were assumed to be of a transient nature. Regecova *et al.* (1995) studied 1,542 children from 3 to 7 years of age in kindergartens. Significantly, a higher systolic and diastolic blood pressure among children in noisy environments (> 60 dB) was observed, compared to those among children in quieter environments.

#### **2.4.2 Noise Effects on Sleep**

Sleep is the natural state of bodily rest where the recovery process takes place in order for humans to function properly. Adverse health effects are expected from chronic noise-induced interference with sleep, as it impairs the functions of sleep such as brain restoration and provision of a period of respite for the cardiovascular system (Carter, 1998). Passchier *et al.* (2000) states that sleep quality may be adversely affected by:

- changes in the cardiovascular system

- changes in sleep pattern, such as increased sleep latency time and reduced sleep time due to premature awakening
- changes in sleep stages from deeper to less-deep sleep
- increases in motility during the sleep period
- increases in number of awakenings during the sleep period
- changes in subjectively experienced sleep quality
- changes in the hormonal and immune systems

Epidemiologic studies indicate a relationship between exposure to night-time noise and changes in sleep pattern, sleep stages, awakenings, subjective sleep quality, heart rate, and mood the next day (Health Council of the Netherlands, 1994). There still is an urgent need for a tested model on sleep disturbance, environmental noise exposure, and secondary effects, in which causal and modifying factors and their mutual relations are assessed (Passchier *et al.*, 2000).

#### **2.4.3 Effects of Noise on Performance**

Overwhelming evidence from laboratory experiments suggests that the presence of uncontrollable noise can significantly impair cognitive performance. Noise can induce learned helplessness, increase arousal, alter the choice of task strategy, and decrease attention to the task. Noise may also affect social performance, mask speech and other sound signals, impair communication, and distract attention from relevant social clues. Hygge *et al.* (1996) conducted a study in which reading comprehension and long-term memory were impaired in children attending schools located around the old Munich airport; reading comprehension improved after the closing of the airport. However, reading comprehension deteriorated in children subjected to aircraft noise exposure near the new Munich airport.

Recently in the United Kingdom, a field study with tests repeated annually was conducted to assess whether the association between aircraft noise exposure and reading comprehension was mediated through sustained attention, and whether it was confounded by social deprivation and language spoken at home. The 340 children who participated were about 9 to 10 years of age. They attended a school classified either as a high-noise school ( $> 66$  dB) or as a low-noise school ( $< 57$  dB). There appeared to be a high correlation between the noise at school and the aircraft noise exposure at home. Results show that the average reading comprehension of children attending the high-noise schools was poorer at both measuring times, compared with that of children from the low-noise schools. Sustained attention, measured only at follow-up, was poorer in children at the high-noise schools than in children at the low-noise schools. Sustained attention did not play a significant role in explaining the relation between reading comprehension and aircraft noise exposure.

#### **2.4.4 Absences and Accidents due to Noise**

Melamed *et al.* (1992) suggested that the absentee rate of industrial workers increases when the workers are exposed to equivalent hearings during working hours of over 75 dB. This study also showed that the number of accidents increases when hearings rise during working hours. Barreto *et al.* (1997) studied the mortality rates from injury in more than 20,000 steelworkers. On the basis of job and workplace information, industrial hygienists estimated noise exposure as high ( $> 95$  dB), medium (90-95 dB), low (85-90 dB), and minor ( $< 85$  dB). Hearing damage and noise exposure in the high and medium noise classes appeared to be factors that contributed significantly to mortality. The impact of using personal hearing protectors is unclear. Hearing protection, when worn by workers with substantial noise-induced hearing impairment, reduces the possibility of hearing moving sound sources, warning signals, or

colleagues shouting, and hampers the localization of moving sound sources, due to a reduced capacity to determine the direction of a sound source.

## **2.5 Noise Emitted by Logging Equipment**

Taoda *et al.* (1987) examined eighty-one national forestry workers who were using chain saws, log cutters, log cutting machines, bush cleaners, timber-collecting cable machines and forklifts. They were examined for their level of noise exposure in a working day by using a portable sound meter. The equivalent continuous noise level (Leq) for eight hours daily for a year were estimated, based on the measured noise levels and on the number of noise exposure days and hours in a year, as recorded in work documents. The survey extended from July to December, 1988. The maximum noise levels with all the machines except for the forklift were above 100 dB; with most chain saws, the maximum noise levels were above 110 dB. The amount of time that workers were exposed to the noise of logging and lumbering with chain saws, cutting by bush cleaners, and timber-collecting cable machines without a cabin, was longer than the allowable time for 90 dB and 95 dB. The estimated Leq (8 h) for 32 out of 34 lumbermen surveyed was more than 85 dB, and for 5 lumbermen, the Leq (8 h) was more than 90 dB. From these results, it can be concluded that there is a danger of noise-induced hearing loss in national forestry workers using chain saws, log cutters, log cutting machines, and timber-collecting cable machines without a cabin.

Neitzel and Yost (2001) performed a study to describe the occupational exposure of forestry workers in the US Pacific Northwest, to sources of hand-arm vibration (HAV), whole-body vibration (WBV), and noise. The results on noise exposure revealed that the NIOSH time weighted average of noise exposure was 90.3 dB, while the OSHA time weighted average was 86.1 dB. The highest mean NIOSH and OSHA time weighted averages by operation were felling

(cutting the trees) and road construction (process of making a path through the woods in order for equipment to move in to the cutting zone).

## **2.6 Safety Equipment**

The use of hearing protective devices (HPD) has increased ever since the last quarter of the 20<sup>th</sup> century. Toppila *et al.* (2005) tracked the usage rate of hearing protective devices (HPD) from 1953 to 1995 at a paper mill, a shipyard, and in selected areas of forestry work. For each work period, observations were made of HPD use among workers. In the paper mill, the usage rate increased steadily from 1965. In 1990, 39% of workers used HPDs full-time. At the shipyard, the usage rate remained low up to the mid-1980s, but thereafter the proportion of full-time users rose to 70%. A similar trend was noted in forest workers, with the full-time use at 97% by the 1990s. Due to the increased usage rate in all measured industries, the mean effective noise level at the ear has decreased to below 85 dB.

Workers lack motivation to wear hearing protective devices; therefore, it is important to understand the reasons why. One important factor is the condition of the hearing protective device. If the device is in poor condition, it is less probable that workers would be motivated to make use of the device. The usage rate of hearing protective devices becomes an important parameter when measuring its performance (Toppila et al., 1998). Usage rate is the ratio of time the worker uses a hearing protector in relation to the duration of exposure to noise above 85 dB (Comite Europeen de Normalisation, 1993). When applying this equation, if the usage rate does not approach 100%, the type of protector is insignificant.

As previously noted, the condition of the hearing protective device will motivate the worker to use or not make use of the device. As shown in Figure 2.6.1, it is of great importance for hearing protective devices to be under optimal conditions in order to perform efficiently. Hearing protection devices may reduce the sound pressure level by 30 dB if properly worn.



**Figure 2.6.1.** Hearing protection devices in optimal conditions

## CHAPTER 3

### THE STUDY

#### 3.1 Rationale

Iki (1984) reported that participants who spent longer operating hours using noise emitting tools developed greater hearing losses than those with shorter hours. Ferrite and Santana (2005) concluded that age and occupational noise exposures were independently associated with hearing loss. For all the factors (age, noise exposure, and smoking) combined, the estimated effect on hearing loss was higher than those of participants who had been exposed to only one and/or two factors. Other research on noise emission concluded that the hearing emitted by saws, log cutters, log cutting machines and timber-collecting cable machines without a cabin went over 90 decibels (Taoda *et al.*, 1987). This poses a threat of noise-induced hearing loss to national forestry workers.

Tambs *et al.* (2006) illustrated that in the higher 2% of exposure to occupational noise reaching 13 dB (3000 Hz) threshold shifts averaging over both ears among men and were generally largest at 3000-4000 Hz. On the other hand, Rabinowitz assessed the associations between hearing loss, noise exposure, and covariate risk factors. Results indicate that workers in higher ambient noise jobs tend to experience less high frequency hearing loss than co-workers exposed to lower noise levels (Rabinowitz *et al.*, 2006).

#### 3.2 Objective

This study differentiates from the rest due to the following reasons:

- Forest loggers participating in the study operated heavy equipment (section 2.5.1) as opposed to Iki's (1984) and Tunay *et al.* (2008) study which was on the operation of light equipment (such as chainsaws).



- Research such as Taoda *et al.* (1987), determined in fact that there are elevated levels of noise to which forest loggers are exposed. This study determines whether the elevated levels of noise emitted by these equipment are actually associated hearing loss.
- Similarly, Ferrite (2005) and Tambs (2006) concluded that high levels of noise exposure and age are related factors leading to hearing loss. This study may conclude similar results. What differentiates this study is the background of the participants (forest loggers), as opposed to an industrial environment.

### **3.3 Hypothesis**

#### **Hypothesis 1**

**H<sub>0</sub>:** Forest loggers do not suffer from chronic hearing loss due to noise exposure.

**H<sub>1</sub>:** Forest loggers' hearing thresholds are higher than that of a normal population.

#### **Hypothesis 2**

**H<sub>0</sub>:** Hearing protection has no effect on the participants' hearing thresholds.

**H<sub>1</sub>:** Forest loggers' hearing thresholds are higher for those who do not use hearing protection on a daily basis than those who wear hearing protection.

#### **Hypothesis 3**

**H<sub>0</sub>:** Forest loggers' years of experience has no relationship with the increase in hearing threshold shift.

**H<sub>1</sub>:** Forest loggers' hearing threshold shift increases as their years of experience increase.

### **3.4 Audiometric Testing**

Audiometric testing was employed to measure the hearing capacity of participants at different frequencies. The results answered the following questions:

1. What is the hearing threshold of each participant at a certain frequency?

2. Has the participant, who is never subjected to elevated levels of noise, suffered hearing loss?
3. Is the hearing threshold of forest loggers equal to that of a person who is never subjected to elevated levels of noise?

## CHAPTER 4

### METHODS AND PROCEDURES

The objective of this study is to determine whether long term hearing loss in forest loggers is associated with noise emitted by logging equipment. Forestry equipment that is usually operated by loggers includes cutters, skidders, loaders, and chainsaws. To achieve this objective, 26 males between the ages of 21 to 60 years of age participated in the experiment. A hearing test was performed on all of the participants to determine their hearing thresholds. The results were then compared to the OSHA age-corrected tables for hearing loss due to age for 1000, 2000, and 4000 Hz of frequency.

#### 4.1 Participants

For this research, a total of 28 participants were interviewed. Out of the 28 participants, 2 had suffered from a chronic illness which resulted in permanent hearing loss. There were 26 healthy males who participated in the study and work full-time as forest loggers. As previously stated, the participant age range was from 20 to 60 years. All participants were informed of the demands of the testing procedure, and all of them signed the informed consent form (Appendix B) approved by IRB, Louisiana State University (Appendix C). Table 4.1.1 illustrates demographic information of the participants.

**Table 4.1.1.** Demographic information of the participants

	Forest Loggers (n=26)
Age (yrs)	43 $\pm$ 10.5
Gender	Male (100%)
Experience (Yrs)	17.4 $\pm$ 12
Avg Shift/Week	5 $\pm$ 0
Avg Hours/Shift	9 $\pm$ 1
Participants with HP	8
Participants without HP	18

## **4.2 Data Acquisition**

All participants involved in the experimental process were subjected to a hearing test using an audiometer (BELTONE Audiometer). A series of necessary steps are involved, prior to performing the hearing test. These involve the appropriate setting, preparation of each participant, and performing the hearing test, which also takes into account the acquisition of necessary data that will be utilized for further analysis.

### **4.2.1 Setting**

The appropriate setting for performing hearing tests on the participants is a completely silent environment, i.e., no one enters while the test is being performed. When measuring the hearing capacity on participants, two settings were utilized: a closed office space and the interior of a pickup truck. While testing each participant, no one was allowed inside the office, thus making the office a completely quiet environment. It is also important to note that when any type of external noise is heard during the testing phase, the sound and frequency level being tested at that moment will be repeated. This will be explained in detail in Section 4.2.3.

A 2008 Dodge Ram pickup truck was used as a second setting. The reason why this was used instead of a closed office was due to distance issues. Participants work for five days a week, for an average of 10 hours each shift. Logging operations were generally performed in remote areas, lacking any type of enclosed construction in the proximities of the site. The truck was driven to a remote location where no sound other than a random bird sound was heard. The audiometer was powered by an A/C adapter connected to the battery. The tests were performed with the vehicle turned off and the windows closed.

### **4.2.2 Participant Preparation**

Before performing hearing tests on each participant, a questionnaire was given to complete (found in Appendix D). The questionnaire asked for general information, such as age,

amount of time working as a logger, hours of work per week, information on hearing protection, ear injuries, non-work related activity involving noise, and previous employment. Following the completion of the questionnaire, a brief explanation was given to each of the participants on what would take place and what they would have to do prior and during the hearing test. The explanation read as follows:

“I am going to place these earphones on your ears. Through them you will hear some musical tones (beeps, whistles, noises). Some will be high, some low, and some medium. Every time you hear a tone, or think you hear a tone, raise your finger (or hand); when you no longer hear the tone, lower your finger. In which ear do you hear best? I will test that ear first. Some of these tones will be loud enough to hear, others will be very, very soft. Listen carefully. Whenever you hear the tone, or think you hear the tone, raise your finger, hold it up as long as you hear it, and when you no longer hear it, and lower your finger. Do you understand? Any questions?”

If the participant had any questions, these were answered before testing started. Answers given for any question had to be completely understood by the participant. Any doubts that the participant may have on the testing process may result in false data which would, without a doubt, alter and confer erroneous conclusions. If the participant has no further questions, the testing phase was administered.

#### **4.2.3 Hearing Test**

In this phase, as previously stated, participants should be completely knowledgeable of the process involving the testing. Participants should sit, facing directly in front of the audiometer operator. The audiometer controls should face toward the operator and the participant should sit, positioned where there is absolutely no visual of the controls. Figure 4.2.3.1 illustrates

and example of the position of the operation, participant, and audiometer during the testing phase.

The hearing test started by sending each participant a set of test tones to be sure he could hear and/or recognize the tones and also to confirm that each participant knew when and how to signal. The test tones were presented at a frequency of 1000 Hz with a hearing of 70 dB. The hearing test were be performed by setting a series of frequencies in a predetermined order of which the participant is not aware. Table 4.2.3.1 illustrates the order in which the frequencies (in Hz) were emitted.



**Figure 4.2.3.1.** Example of how readings are taken

Each ear was tested separately. The first ear tested was the one that the participant said he/she heard with the best. In case the participant was unsure what ear heard the best, the right ear was tested first. The testing followed the order of the frequencies listed in Table 4.2.3.1. At each frequency, the sound level started at 70 dB. Figure 4.2.3.2 illustrates the hearing and frequency adjusting controls on the audiometer.

If the participant signals that he hears it, the hearing is decreased in ten dB steps, presenting the tone at each step, until it is no longer indicated that the tone is heard. If the participant does not signal that he/she hears the tone, it is then be raised by five dB steps until the participant signals that he/she heard a tone. When the tone is heard, the signal is repeated four times at the same hearing. If the participant signals that he/she heard the tone four times, the tone is lowered in five dB steps, followed by a repetition of the previous step. When the participant does not hear a tone, then the tone is increased five dB steps (to the last tone signaled) and the process is repeated to assure that the proper threshold is obtained for the specific frequency.



**Figure 4.2.3.2.** Sound pressure and frequency adjusting controls

**Table 4.2.3.1.** Threshold recording table

Frequency (Hz)	Threshold (dB)	
	Right Ear (red)	Left Ear (blue)
1000		
750		
2000		
500		
4000		
250		
8000		
125		

The threshold mark  $w$  is then recorded for further analysis, as illustrated in Table 4.2.3.1 (complete form found in Appendix E). The process is then repeated at each determined frequency and for each ear. It is very important to enforce that the tone is presented for one second every try.

## **4.3 Experimental Design**

### **4.3.1 Independent Variables**

The two independent variables are:

1. Frequencies of pure tone (125 Hz to 8000 Hz)
2. Age/age groups
3. With and without using hearing protection
4. Experience groups

### **4.3.2 Dependent Variables**

The dependent variable is the hearing threshold at each frequency.

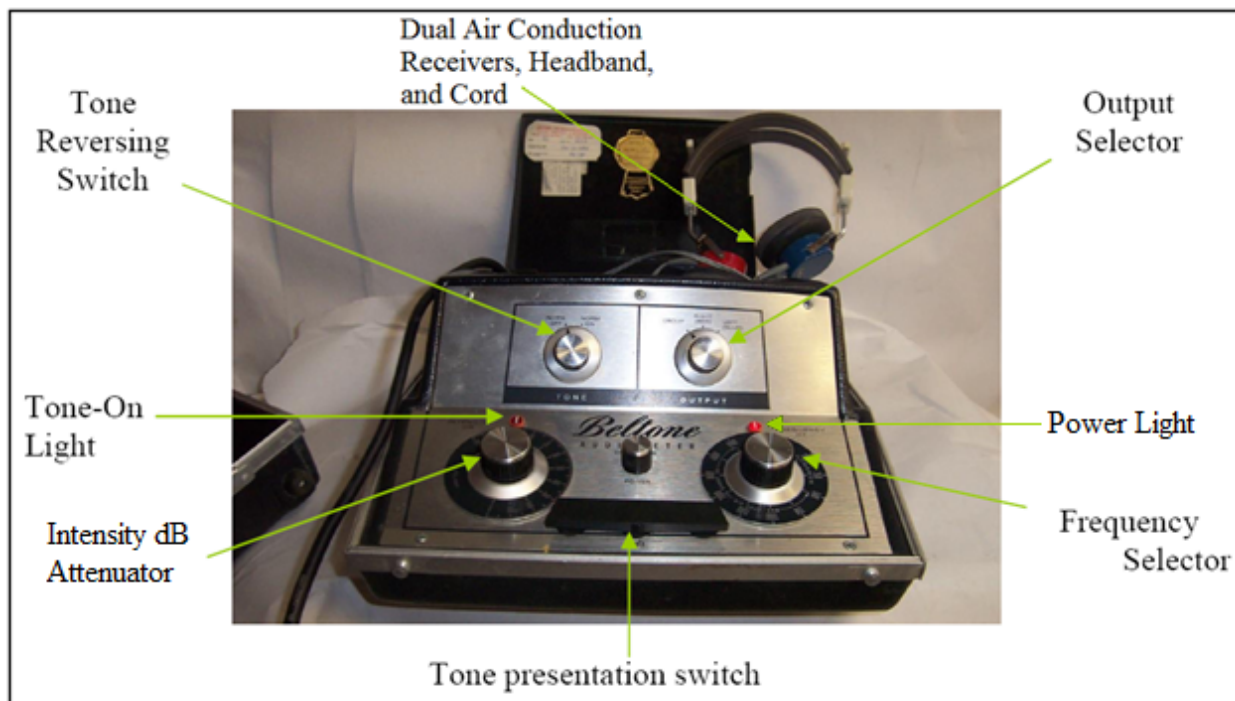
## **4.4 Equipment**

The equipment used in the study to measure hearing capacity was a Beltone® D-series audiometer model 9-D. Figure 4.4.1 displays the audiometer's controls.

- 1. Tone reversing switch:** Controls the method of tone production. The tone is OFF when the switch is turned OFF, until the tone bar is depressed. The tone is ON when the switch is turned ON, until the tone bar is depressed. For the study, the switch is left OFF.
- 2. Tone-on light:** Illuminates when pure tones are presented.
- 3. Intensity dB attenuator:** Regulates intensity (loudness) of the pure tone. The numbers refer to decibels (dB) and are related to hearing level ASA 1951 or ISO 1964 or ANSI 1969.



4. **Tone presentation switch:** Controls the presentation of pure tones. The light above the intensity dial will illuminate when the tone is being presented. Two methods of tone control may be made. In one, the tone will be OFF until the bar is depressed; in the other, the tone will be ON until the bar is depressed.
5. **Power light:** Illuminates when the power in the audiometer is turned ON.
6. **Frequency selector:** Controls the frequency of the pure tone produced by the audiometer. All 11 audiometric frequencies are provided in full octaves from 125 to 8000 Hz and half-octaves from 750 to 6000 Hz.



**Figure 4.4.1.** Controls of Beltone audiometer

7. **Output selector:** Selects the earphone to which the signal (pure tone or speech) shall be delivered. If the switch is to the far right position, signal is sent to left ear. If the switch is to the middle position, the signal is sent to the right ear. The far left position of the switch is for group testing.

**8. Dual air conduction receivers, headband, and cords:** Project the sound to the ears of the participant. The earphones are color coded; red is for the right and the blue is for left ears.

#### **4.4.1 Equipment Calibration**

The device is to be calibrated at the authorized distributors or at the manufacturing site, in order to maintain continued accuracy.

#### **4.4.2 Forest Logging Equipment**

Each type of equipment utilized by forest loggers generates a different noise level. In many cases, loggers operate different equipment on various shifts, depending on the daily conditions. The following, is a brief overview of tree logging equipment and their noise emissions.

Skidders are heavy vehicles used in a logging operation for pulling cut trees out of a forest in a process called "skidding". The logs are transported from the cutting site to a landing where a loader places the logs on a transporting vehicle. Figure 4.4.2.1 illustrates a CAT 525B skidder transporting a number of logs to the loading area. The percentage of noise exposure generated by this vehicle for an eight hour shift was measured to be 280% of the exposure limit established by OSHA. This means that the average level of noise emitted by this equipment is calculated to be 97 dB.

Loaders are utilized to organize and pile up the logs on the transport trucks, which then take the wood to the lumber mills. Figure 4.4.2.2 illustrates a Prentice 2280 loader while lifting multiple logs at the same time. The noise emitted by this type of equipment averages to be 88 dB which is below the maximum permissible exposure level established by OSHA (90 dB) for an eight hour shift.

A cutter, as the name depicts, is the equipment used for cutting trees (illustrated on Figure 4.4.2.3). The cutting is performed by the rapid rotation of a saw blade an inch and a half

thick with a diameter ranging from 24 to 48 inches. When performing the cutting, elevated hearings of a high frequency impulse noise are generated. The average noise level to which the operator of this equipment is subjected on average over an eight hour period, is 93 dB. When operated at full throttle (not felling), the noise level generated was of 87 dB. The increase in average noise emission while felling can be accounted to the high frequency noise generated at the exact moment the cutting of the tree is performed.



**Figure 4.4.2.1.** Caterpillar 525B skidder ([www.ironplanet.com](http://www.ironplanet.com))



**Figure 4.4.2.2.** Prentice 2280 loader ([www.prenticeforestry.com](http://www.prenticeforestry.com))



**Figure 4.4.2.3.** Tigercat 724E cutter ([www.tigercat.com](http://www.tigercat.com))

The chainsaw is a portable, mechanical, motorized saw, most commonly used in logging activities such as felling, limbing, and bucking. Figure 4.4.2.4 illustrates a Husqvarna 372XP chainsaw. The noise level emitted by this machine can go up to 113 dB at full throttle. Besides hazardous levels of noise emitted by these equipment and dangerously exposed saw, this pose other to the musculoskeletal system due the postures operators are subjected for extended periods of time.



**Figure 4.4.2.4.** Husqvarna 372XP chainsaw ([www.husqvarna.com](http://www.husqvarna.com))

## 4.5 Data Analysis

The effects of exposure of occupational noise on hearing were estimated. A standard t-test of two equal sample sizes and unequal variances was performed, using statistical software

(Statistix Software). Each pure tone frequency utilized in this study was analyzed independently. The participants' hearing threshold is specified as a dependent variable in consecutive analyses. The analyses were also conducted separately for all age groups (20 to 29 years, 30 to 39 years, 40 to 49 years and 50 to 59 years) and experience groups (1 to 10, 11 to 20, 21 to 30, and 31 to 40 years of experience). A 5% significance level was chosen for all analyses.

The participants' hearing threshold was normalized in order to compare and determine if a hearing threshold shift has occurred within the whole sample. A standard t-test was performed with the normalized data to determine whether there is a significant threshold shift among the whole participant sample. In addition to analyzing any significant increase in the hearing threshold shift, other secondary analyses were performed. The hearing threshold shift was compared among the participants who used hearing protection and those who use no hearing protection when operating the equipment. The participants' years of experience in the logging industry were also used to determine differences in threshold shift among each group. The hearing threshold was categorized as well, to determine the participants hearing loss classification at each frequency.

#### **4.5.1 Performing the T-test**

The two sample t-tests determined if the hearing threshold of the participants was significantly higher than that of an average person at each specific age. A 5% level of significance was chosen for the analyses. As previously mentioned, a statistical software (Statistix) was utilized to perform the regression analysis and to determine whether the hearing threshold shift was significantly higher than that of a normal population.

#### **4.5.2 Normalizing Data**

Normalization is a systematic way of ensuring that a database structure is suitable for general purpose querying and is free of certain undesirable characteristics such as insertion,

update, and deletion anomalies; that could lead to a loss of data integrity (Codd, 1990). Data was normalized in order to compare the whole sample at each frequency. The reason for normalizing is to disregard age (as age progresses, hearing threshold increases) to obtain more significant results. Before normalizing the hearing level at all ages, the hearing threshold for both ears was calculated, using the 5 to 1 ratio equation, computed as follows:

$$SLT_x = \frac{(\text{Min}(RE_x:LE_x)*5) + \text{Max}(RE_x:LE_x)}{6} \quad (4.1)$$

The normalization equation that was utilized for each observation in the analysis is as follows:

$$Obs_x = SLT_x - AT_y \quad (4.2)$$

As stated, the above equation was applied to each observation obtained at each frequency. In the equations above,  $RE_x$  is the hearing threshold of the right ear and  $LE_x$  is the hearing threshold of the left ear.  $AT_y$  is the average hearing threshold for a normal population at a specific age. The end result yielded a value that can be compared and analyzed with all the age ranges.

## CHAPTER 5

### RESULTS

The purpose behind the evaluation of the analyzed data was to determine whether there was a hearing threshold shift among the participant sample. Results of the hearing threshold shift are analyzed under the following sections:

1. Hearing threshold among the participant sample
2. Hearing threshold shift among participants
3. Effect of hearing protection on hearing thresholds and threshold shifts
4. Hearing threshold between age ranges
5. Correlation of experience and hearing threshold shift
6. Hearing loss classification

#### 5.1 Hearing Threshold among the Participant Sample

Eight predetermined frequencies were analyzed using the paired *t-test*. The hearing threshold at each frequency was utilized to determine whether there was a significant increase or decrease from the previous frequency. All comparisons were performed at a significance level of  $\alpha = 0.05$ . The following sections illustrate the changes in hearing threshold within each frequency.

##### 5.1.1. Hearing Threshold at 125 Hz

Results of the hearing threshold at 125 Hz indicated a mean hearing threshold of 17.0 dB with a standard deviation of 8.2 dB. Table 5.1.9.1 illustrates the hearing thresholds (hearing threshold) of each of the participants. Since this frequency is the lowest tested, statistical testing was not performed to determine a significant increase or decrease in threshold from the previous frequency. A detailed data analysis of the participants' hearing threshold at 125 Hz can be found in Appendix F.

### **5.1.2. Hearing Threshold at 250 Hz**

At 250 Hz, the results of the hearing threshold indicated a mean hearing threshold of 15.2 dB and a standard deviation of 9.2 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each participant. A significant decrease in hearing threshold ( $p < 0.05$ ) of 1.8 dB was found between 125 Hz and 250 Hz. Detailed data analysis of the participants' hearing threshold at 250 Hz can be found in Appendix F.

### **5.1.3. Hearing Threshold at 500 Hz**

The hearing levels at 500 Hz indicated a mean hearing threshold of 12.1 dB and a standard deviation of 7.9 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each participant. A significant decrease in the hearing threshold ( $p < 0.05$ ) of 3.1 dB was found between 250 Hz and 500 Hz. A detailed data analysis of the participants' hearing threshold at 500 Hz can be found in Appendix F.

### **5.1.4. Hearing Threshold at 750 Hz**

At 750 Hz, the results of the hearing threshold indicated a mean hearing threshold of 12 dB and a standard deviation of 7.6 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each participant. No significant decrease or increase in hearing threshold ( $p > 0.05$ ) was found between 500 Hz and 750 Hz. The mean difference in hearing threshold between both frequencies was a decrease of 0.1 dB. A detailed data analysis of the participants' hearing threshold at 750 Hz can be found in Appendix F.

### **5.1.5. Hearing Threshold at 1000 Hz**

The results of the hearing threshold at 1000 Hz indicated a mean hearing threshold of 12.9 dB and a standard deviation of 8.3 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each of the participants. No significant decrease or increase in hearing threshold ( $p > 0.05$ ) was found between 750 Hz and 1000 Hz. The mean difference in hearing threshold between both



frequencies was an increase of 0.9 dB. A detailed data analysis of the participants' hearing threshold at 1000 Hz can be found in Appendix F.

#### **5.1.6. Hearing Threshold at 2000 Hz**

At 2000 Hz, the results of the hearing threshold indicated a mean hearing threshold of 16.9 dB and a standard deviation of 13.6 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each participant. A significant increase in hearing threshold ( $p < 0.05$ ) of 4.0 dB was found between 1000 Hz and 2000 Hz. A detailed data analysis of the participants' hearing threshold at 2000 Hz can be found in Appendix F.

#### **5.1.7. Hearing Threshold at 4000 Hz**

At 4000 Hz, the results of the hearing threshold indicated a mean hearing threshold of 35.8 dB and a standard deviation of 20.8 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each of the participants. A significant increase in hearing threshold ( $p < 0.05$ ) of 18.9 dB was found between 2000 Hz and 4000 Hz. A detailed data analysis of the participants' hearing threshold at 4000 Hz can be found in Appendix F.

#### **5.1.8. Hearing Threshold at 8000 Hz**

Hearing levels at 8000 Hz indicated a mean threshold of 19.4 dB and a standard deviation of 20.1 dB. Table 5.1.9.1 illustrates the hearing thresholds (SLT) of each participant. A significant decrease in hearing threshold ( $p < 0.05$ ) of 16.3 dB was found between 4000 Hz and 8000 Hz. A detailed data analysis of the participants' hearing threshold at 8000 Hz can be found in Appendix F.

#### **5.1.9. Analysis of All Frequencies**

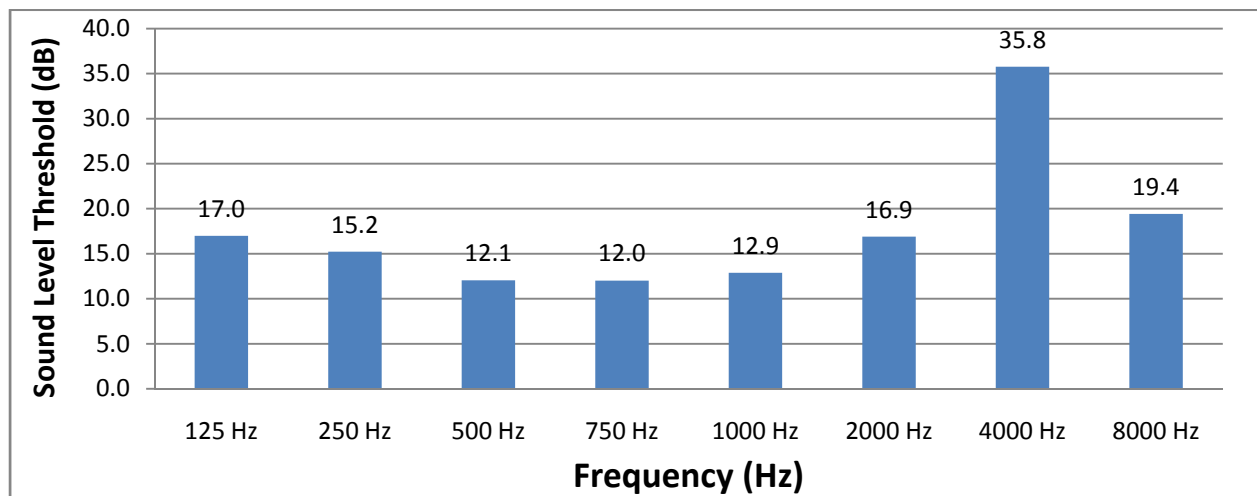
The hearing thresholds of all frequencies followed a parabolic trend which was disrupted at 4000 Hz (as shown in Figure 5.1.9.1). The hearing threshold at 4000 Hz was significantly higher than at 2000 Hz by 18.9 dB and 8000 Hz by 16.3 dB ( $p < 0.05$ ). This indicates an

abnormal increase in threshold at this frequency. The average hearing threshold of all frequencies combined was 17.7 dB (Table 5.1.9.1).

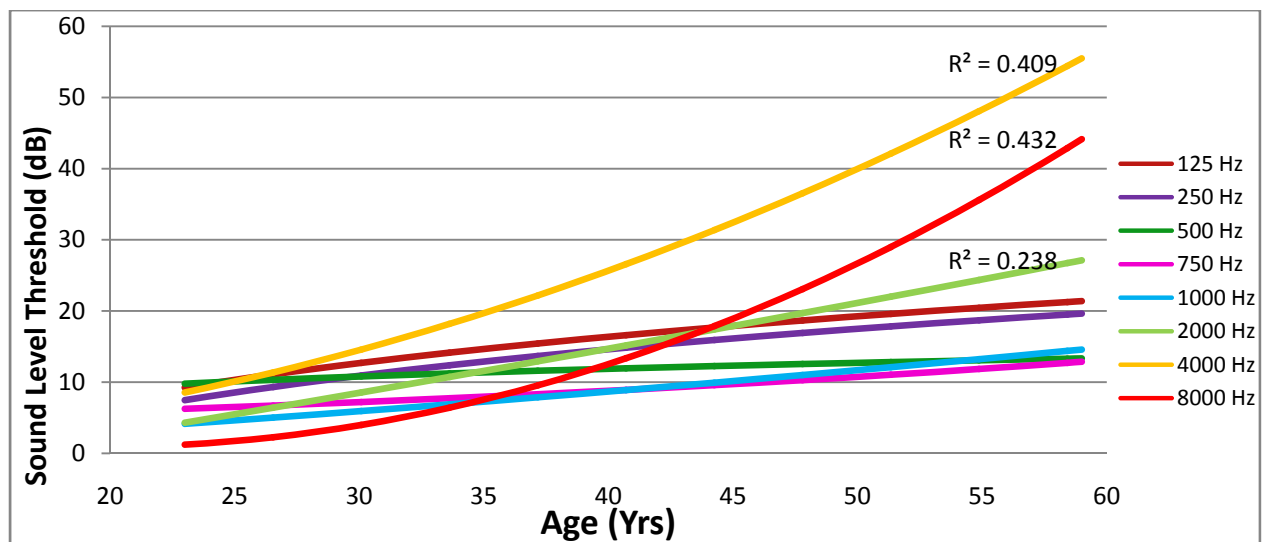
**Table 5.1.9.1.** Hearing thresholds averages for all participants, at each frequency, and for the total population. Paired t-test is illustrated at the lowest row compared to the previous frequency.

#	Age	125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Avg
1	23	5	5	5	5	1	0	6	0	3.3
2	26	10	5	5	5	5	5	11	5	6.4
3	27	5	2	5	2	6	1	3	0	2.8
4	29	10	10	6	11	10	5	16	1	8.5
5	33	17	15	17	11	11	11	41	10	16.5
6	35	11	10	15	16	15	25	27	0	14.8
7	35	18	13	15	15	16	30	71	7	22.9
8	38	20	21	23	18	22	16	33	5	19.6
9	38	30	26	22	11	11	10	21	6	17.0
10	39	21	16	20	16	20	20	22	12	18.2
11	40	16	17	7	5	2	5	36	1	10.9
12	42	10	13	12	18	22	32	55	50	26.3
13	43	37	40	26	20	20	18	67	53	35.0
14	44	25	25	11	6	10	11	26	17	16.3
15	47	16	15	5	1	1	1	19	6	7.9
16	48	15	11	10	10	6	6	27	20	13.0
17	48	5	1	0	6	3	11	11	1	4.6
18	50	16	11	10	15	15	22	52	23	20.4
19	52	21	21	21	25	21	35	65	57	33.1
20	53	16	11	7	6	10	21	45	30	18.1
21	54	26	24	28	34	33	21	35	43	30.5
22	54	5	2	0	5	5	5	17	11	6.1
23	54	28	28	18	17	16	13	51	17	23.2
24	54	17	17	7	11	27	55	56	22	26.3
25	59	20	16	15	15	15	21	71	59	29.0
26	59	25	25	6	11	16	43	51	51	28.3
Avg		17.0	15.2	12.1	12.0	12.9	16.9	35.8	19.4	17.7
St Dev		8.22	9.22	7.87	7.55	8.28	13.62	20.82	20.10	9.55
T-test (previous)			0.00	0.01	0.49	0.15	0.02	0.00	0.00	

Figure 5.1.9.1 illustrates the mean hearing thresholds of all frequencies. As the statistical analysis demonstrated, no significant difference was found between frequencies of 500, 750, and 1000 Hz. A regression analysis performed at all frequencies yielded positive r-squared values of hearing threshold increase as a function of age (Figure 5.1.9.2). The frequencies with a more noticeable increase in the hearing threshold as a function of age were at 4000, 8000, and 2000 Hz..



**Figure 5.1.9.1.** Hearing threshold for all frequencies



**Figure 5.1.9.2.** Regression lines of all frequencies

Table 5.1.9.2 illustrates a pair-wise comparison in which “X” equals no significant increase or decrease in hearing threshold between frequencies. Numbers at a cell mean the amount of decibels the hearing threshold significantly increased or decreased with frequencies on the top row.

**Table 5.1.9.2.** Pair-wise table indicating significant increase or decrease ( $p < 0.05$ ) in SLT between frequencies

	125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
125 Hz	--	-1.8	-4.9	-5.0	-4.1	X	18.8	X
250 Hz		--	-3.2	-3.2	X	X	20.5	X
500 Hz			--	X	X	4.8	23.7	7.4
750 Hz				--	X	4.9	23.8	7.4
1000 Hz					--	4.0	22.9	6.5
2000 Hz						--	18.9	X
4000 Hz							--	-16.3
8000 Hz								--

## 5.2 Hearing Threshold Shift among the Participant Sample

Three frequencies (1000 Hz, 2000 Hz, and 4000 Hz) were analyzed, using the paired *t*-test. The hearing threshold at each frequency was utilized to determine whether there was a significant increase in threshold shift from the average population. The OSHA age correction tables for the hearing threshold were used for the analysis. All comparisons were performed at a significance level of  $\alpha = 0.05$ . The following sections illustrate the changes in hearing threshold within each frequency.

### 5.2.1. Hearing Threshold Shift at 1000 Hz

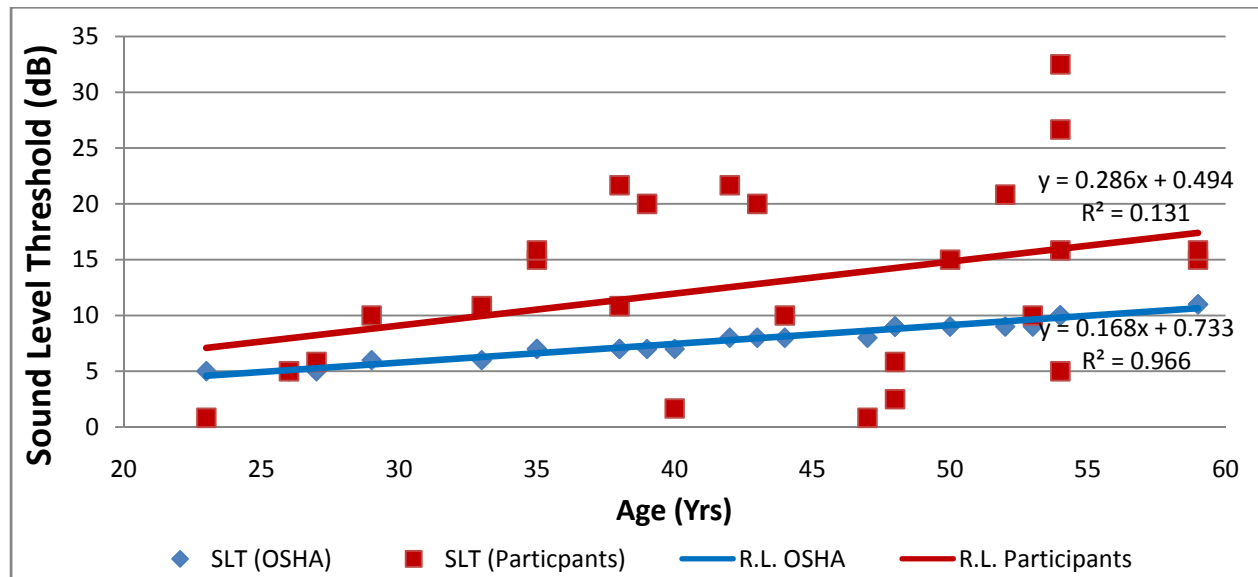
Results of the hearing threshold shift at 1000 Hz indicated a significant threshold increase of 4.9 dB ( $p < 0.05$ ). The increase in hearing threshold shift was 77% consistent at 1000 Hz, which meant that 6 out of 26 participants did not suffer from a positive threshold shift. Table

5.2.1.1 displays the hearing threshold shifts among the participants. The lowest threshold shift recorded was negative 7 dB from the age-corrected threshold established by OSHA. Figure 5.2.1.1 illustrates the regression line between the threshold shift of the participant population and the hearing threshold of the age correction tables (OSHA, 2008). The regression analysis performed (Figure 5.2.1.1) illustrates the regression line of the threshold with respect to age among the participant sample, together with the r-squared value. This illustrates a consistent increase in gap between both trend lines as age progresses. All together for the entire population, the statistical analysis indicated a significant increase ( $p < 0.05$ ) in hearing threshold shift at 1000 Hz, among a population between the ages of 20 to 59 years. Detailed data of the participants' hearing threshold shifts at 1000 Hz can be found in Appendix G.

#### **5.2.2. Hearing Threshold Shift at 2000 Hz**

Results of the sound audiometric testing at 2000 Hz indicated a significant positive threshold shift of 9.5 dB ( $p < 0.05$ ). The threshold shift at 2000 Hz was significantly higher ( $p < 0.05$ ) than at 1000 Hz, by a difference of 4.6 dB between both frequencies. The increase in the hearing threshold shift was 77% consistent at 2000 Hz, which meant that 6 out of 26 participants did not suffer from positive threshold shift. Table 5.2.2.1 displays the hearing threshold shifts (HTS) among the participants. The lowest threshold shift recorded was negative 7.2 dB from the age-corrected hearing thresholds established by OSHA. The performed regression analysis (Figure 5.2.2.1) illustrates the regression line of the threshold with respect to age among the participant sample, together with the r-squared value. Figure 5.2.2.1 illustrates the regression line of both the threshold shift of the participant population and hearing threshold of the age correction tables (OSHA, 2008). This illustrates a consistent increase in gap between both trend lines as age progresses. All together for the total population, statistical analysis indicated a significant increase ( $p < 0.05$ ) in hearing threshold shift at 2000 Hz among a population between

the ages of 20 to 59 years of age. Detailed data of the participants' hearing threshold shifts at 2000 Hz can be found in Appendix G.



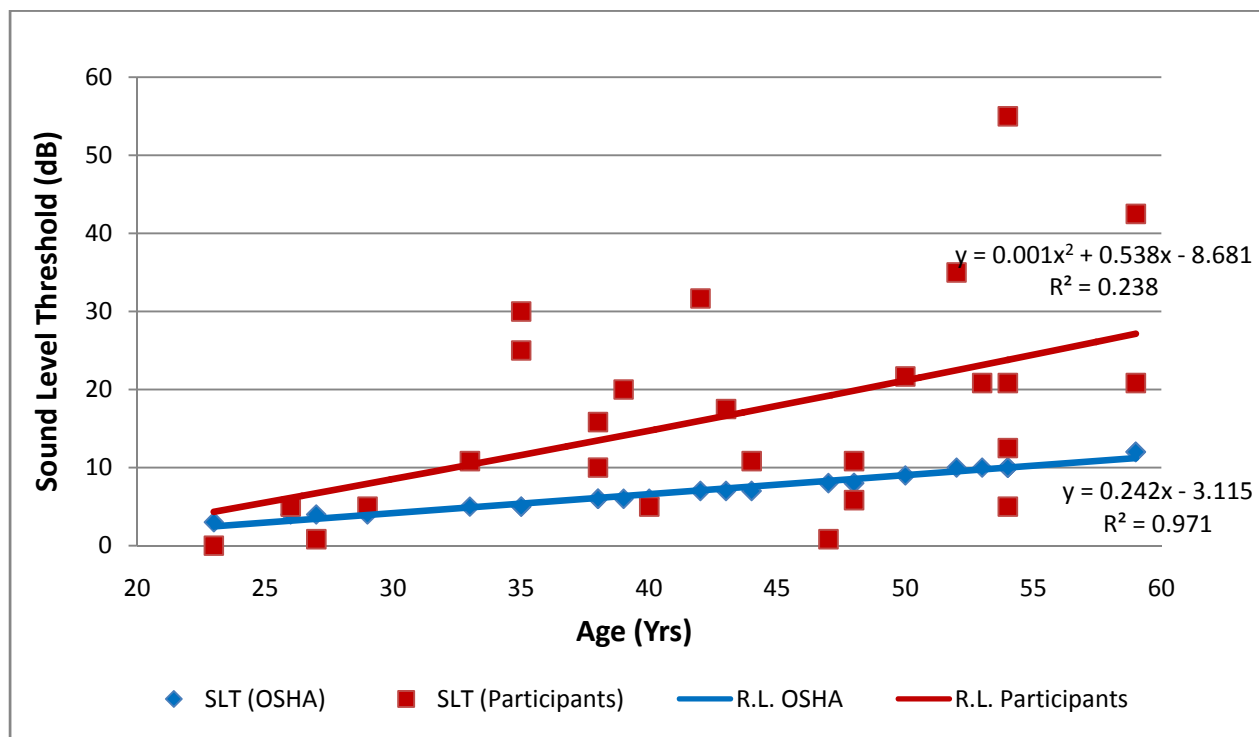
**Figure 5.2.1.1.** Hearing threshold shift at 1000 Hz

**Table 5.2.1.1.** Age corrected (OSHA, 2008), hearing threshold (Loggers), and hearing threshold shift for all participants at 1000 Hz

1000 Hz									
Part. #	Age	SLT (OSHA)	SLT (Loggers)	HTS (dB)	Part. #	Age	SLT (OSHA)	SLT (dB)	HTS (dB)
1	23	5	1	-4	14	44	8	10	2
2	26	5	5	0	15	47	8	1	-7
3	27	5	6	1	16	48	9	6	-3
4	29	6	10	4	17	48	9	3	-7
5	33	6	11	5	18	50	9	15	6
6	35	7	15	8	19	52	9	21	12
7	35	7	16	9	20	53	9	10	1
8	38	7	22	15	21	54	10	33	23
9	38	7	11	4	22	54	10	5	-5
10	39	7	20	13	23	54	10	16	6
11	40	7	2	-5	24	54	10	27	17
12	42	8	22	14	25	59	11	15	4
13	43	8	20	12	26	59	11	16	5
Average							8.0	12.9	4.9
Standard Deviation							1.8	8.3	7.8

**Table 5.2.2.1.** Age corrected (OSHA, 2008), hearing threshold (Loggers), and hearing threshold shift for all participants at 2000 Hz

2000 Hz									
Part. #	Age	SLT (OSHA)	SLT (Loggers)	HTS (dB)	Part. #	Age	SLT (OSHA)	SLT (dB)	HTS (dB)
1	23	3	0	-3	14	44	7	11	4
2	26	4	5	1	15	47	8	1	-7
3	27	4	1	-3	16	48	8	6	-2
4	29	4	5	1	17	48	8	11	3
5	33	5	11	6	18	50	9	22	13
6	35	5	25	20	19	52	10	35	25
7	35	5	30	25	20	53	10	21	11
8	38	6	16	10	21	54	10	21	11
9	38	6	10	4	22	54	10	5	-5
10	39	6	20	14	23	54	10	13	3
11	40	6	5	-1	24	54	10	55	45
12	42	7	32	25	25	59	12	21	9
13	43	7	20	11	26	59	12	43	31
Average							7.4	17.0	9.5
Standard Deviation							2.6	13.6	12.5



**Figure 5.2.2.1.** Hearing threshold shift at 2000 Hz

### 5.2.3. Hearing Threshold Shift at 4000 Hz

Results of the sound audiometric testing at 4000 Hz indicated a significant positive threshold shift of 18.0 dB ( $p < 0.05$ ). The threshold shift at 4000 Hz was significantly higher ( $p < 0.05$ ) than at 2000 Hz by a difference of 8.5 dB between both frequencies. The increase in hearing threshold shift was 89% consistent at 4000 Hz, which meant that 3 out of 26 participants did not suffer from positive threshold shift. Table 5.2.3.1 displays the hearing threshold shifts (HTS) among the participants. The lowest threshold shift recorded was negative 9 dB from age-corrected hearing thresholds established by OSHA. The regression analysis performed (Figure 5.2.3.1) illustrates the regression line of the threshold with respect to age among the participant sample, together with the r-squared value. Figure 5.2.3.1 illustrates the regression line of both the threshold shift of the participant population and hearing threshold of the age correction tables (OSHA, 2008). This illustrates a consistent exponential increase in gap between both trend lines as age progresses. All together for the entire population, statistical analysis indicated a significant increase ( $p < 0.05$ ) in the hearing threshold shift at 4000 Hz among a population between 20 to 59 years of age. Detailed data of the participants' hearing threshold shifts at 4000 Hz can be found in Appendix G.

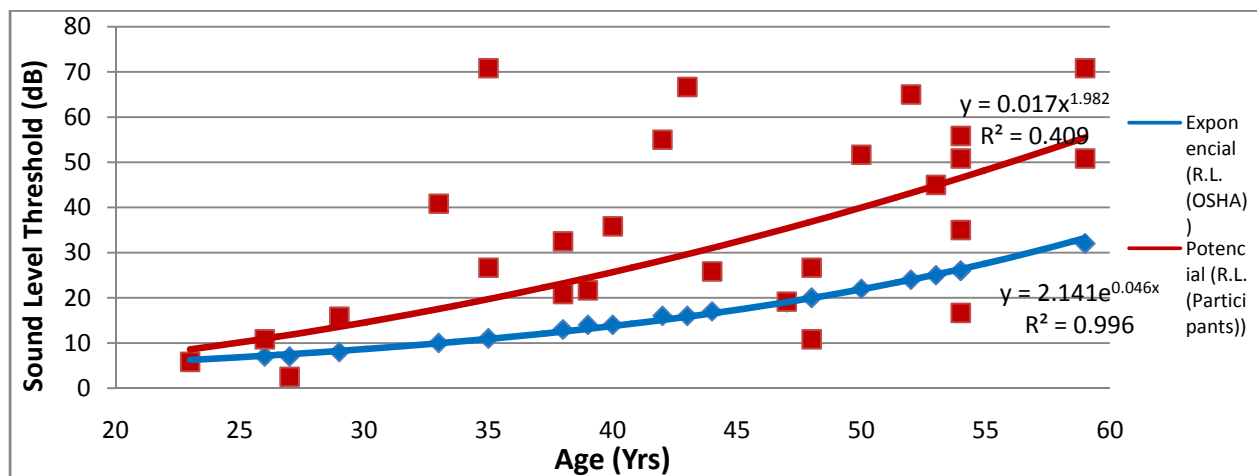


Figure 5.2.3.1. Hearing threshold shift at 4000 Hz



**Table 5.2.3.1.** Age corrected (OSHA, 2008), hearing threshold (Loggers), and hearing threshold shift for all participants at 4000 Hz

<b>4000 Hz</b>									
<b>Part. #</b>	<b>Age</b>	<b>SLT (OSHA)</b>	<b>SLT (Loggers)</b>	<b>HTS (dB)</b>	<b>Part. #</b>	<b>Age</b>	<b>SLT (OSHA)</b>	<b>SLT (dB)</b>	<b>HTS (dB)</b>
<b>1</b>	23	6	6	0	<b>14</b>	44	17	26	9
<b>2</b>	26	7	11	4	<b>15</b>	47	19	19	0
<b>3</b>	27	7	3	-5	<b>16</b>	48	20	27	7
<b>4</b>	29	8	16	8	<b>17</b>	48	20	11	-9
<b>5</b>	33	10	41	31	<b>18</b>	50	22	52	30
<b>6</b>	35	11	27	16	<b>19</b>	52	24	65	41
<b>7</b>	35	11	71	60	<b>20</b>	53	25	45	20
<b>8</b>	38	13	33	20	<b>21</b>	54	26	35	9
<b>9</b>	38	13	21	8	<b>22</b>	54	26	17	-9
<b>10</b>	39	14	22	8	<b>23</b>	54	26	51	25
<b>11</b>	40	14	36	22	<b>24</b>	54	26	56	30
<b>12</b>	42	16	55	39	<b>25</b>	59	32	71	39
<b>13</b>	43	16	67	51	<b>26</b>	59	32	51	19
<b>Average</b>							<b>17.7</b>	<b>35.8</b>	<b>18.0</b>
<b>Standard Deviation</b>							<b>7.7</b>	<b>20.8</b>	<b>18.1</b>

#### 5.2.4. Analysis within All Frequencies

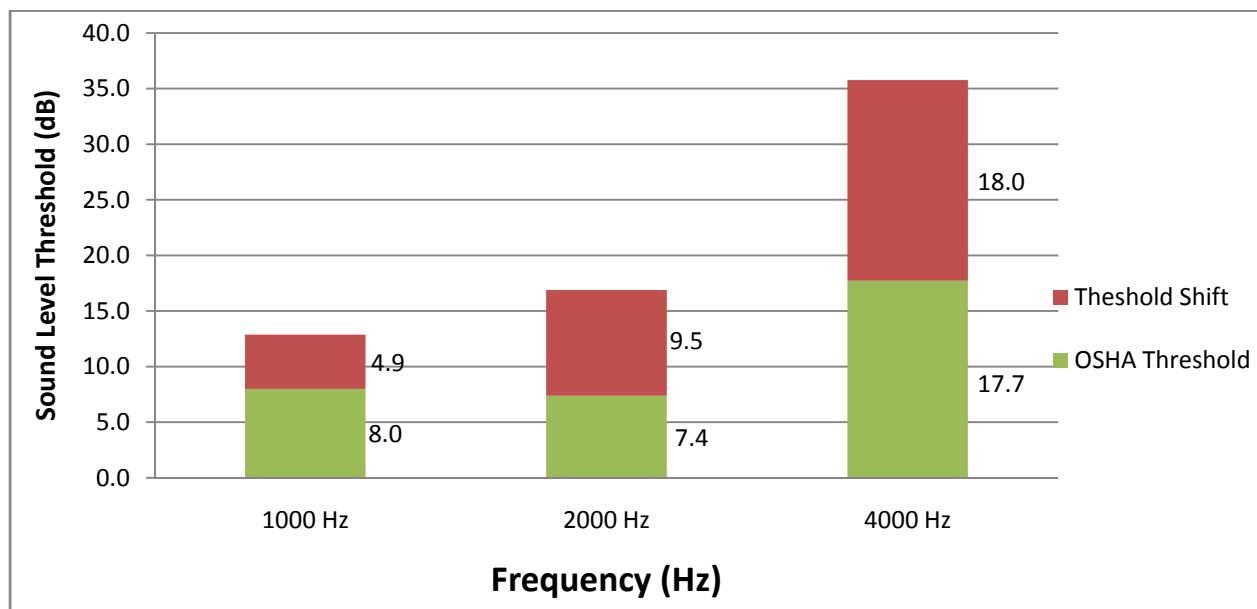
As previously stated, the hearing threshold shifts at frequencies 1000, 2000, and 4000, determined to be significantly higher ( $p < 0.05$ ) on average. Table 5.2.4.1 demonstrates the hearing threshold of the participants (S.L.T. (dB)), the hearing threshold for an average person as age progresses (S.L.T. (OSHA)), and the hearing threshold shift (HTS). The HTS is determined by subtracting the S.L.T. (dB) minus the S.L.T. (OSHA). Computations determined the threshold shifts of forest loggers to be an average of 10.8 dB higher than the average threshold shift for a normal male person, as established by the OSHA age correction tables for audiograms (OSHA, 2008).

Figure 5.2.4.2 illustrates the comparison of the average hearing threshold of forest loggers at each frequency and the normal hearing threshold for a normal person. The graph

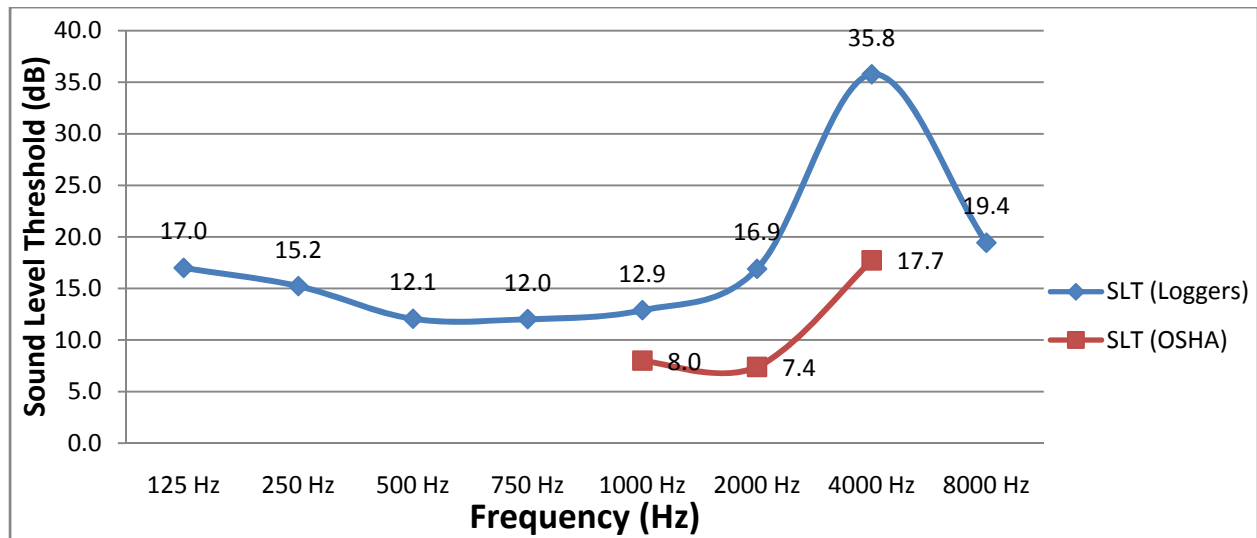
shows a slightly polynomial trend for both of the data sets. This pattern is disturbed by an abrupt increase in hearing threshold which increases the slope 97% between the 2000 and 4000 Hz frequencies. Figure 5.2.4.1 illustrates a stacked graph the showing average hearing threshold for a normal person compared to forest loggers at each frequency. The abrupt increase of the hearing threshold shift between 2000 Hz and 4000 Hz shows an increase in shift of 18.9 dB. This shows that there is an exponential increase between hearing thresholds of the participant population and OSHA age-corrected hearing thresholds (Figure 5.2.4.2).

**Table 5.2.4.1.** Hearing threshold shift averages for all frequencies

	<b>S.L.T (OSHA)</b>	<b>S.L.T (Loggers)</b>	<b>HTS</b>
<b>1000 Hz</b>	8.0	12.9	4.9
<b>2000 Hz</b>	7.4	16.9	9.5
<b>4000 Hz</b>	17.7	35.8	18.0
<b>Averages</b>	<b>11.0</b>	<b>21.8</b>	<b>10.8</b>



**Figure 5.2.4.1.** Graph showing average hearing threshold for a normal person hearing threshold shift of forest loggers



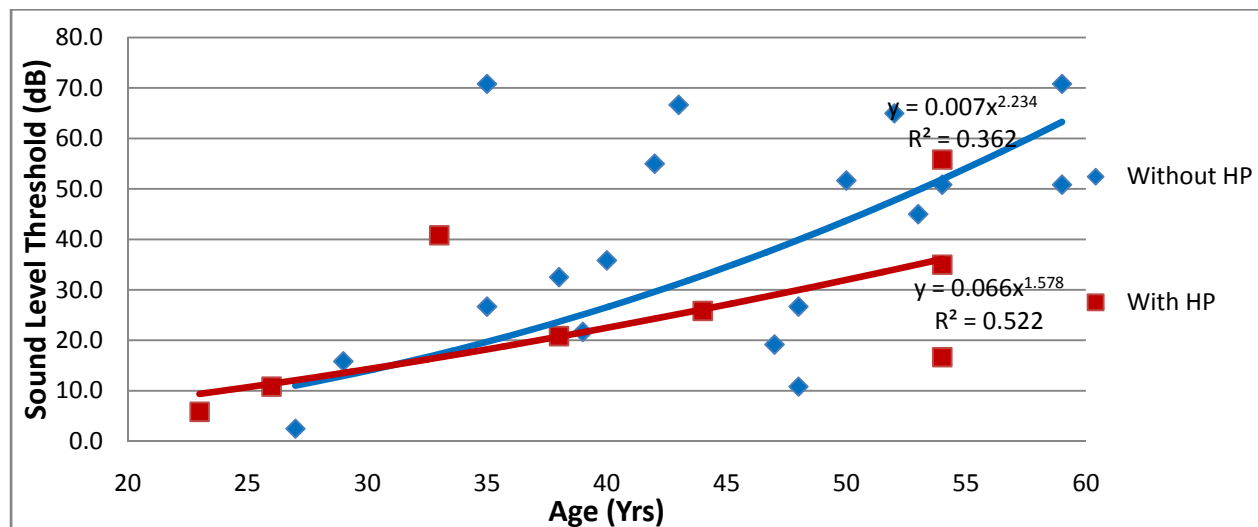
**Figure 5.2.4.2.** Graph showing average hearing threshold for an average person (OSHA) hearing threshold shift of forest loggers

### 5.3. Association between Hearing Protection and Hearing Threshold

In this section, participants' hearing threshold was divided between those who wore hearing protection and those who wore no hearing protection when operating the equipment. Eight out of twenty-six participants said to have worn hearing protection at all times on the work site. Although the mean hearing threshold of those who did not use hearing protection was always higher, as Table 5.3.1 illustrates, no significant difference ( $p > 0.05$ ) was found between those participants who wore and those who did not wear hearing protection at 125, 250, 500, 750, 1000, 2000, and 8000 Hz of frequency.

At 4000 Hz, the mean hearing threshold difference was of 13.4 dB (Table 5.3.1). This yielded a significant increase ( $p < 0.05$ ) between those participants who did not wear hearing protection and those who did. The regression analysis performed (Figure 5.3.1) illustrates the regression line of the threshold with respect to age among the participant sample, together with the r-squared value. This illustrates a consistent increase in gap between both trend lines as age

progresses. The trend lines in the regression analysis for the rest of the frequencies followed an inconclusive pattern, as shown in Figure 5.3.2.



**Figure 5.3.1.** Regression analysis of data sets at 4000 Hz

**Table 5.3.1.** Hearing threshold with and without hearing protection

Ear Protection	%Use H.P.	Hearing Threshold (HP)							
		125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Without HP	69%	17.1	15.4	12.2	12.5	13.0	17.9	39.9	21.8
With HP	31%	16.8	14.8	11.8	10.9	12.7	14.7	26.5	14.2
SLT Difference		0.3	0.6	0.4	1.6	0.3	3.2	13.4	7.6

Table 5.3.2 illustrates mean hearing thresholds of all frequencies tested between those participants who wore ear protection and those who did not. As previously stated, only at 4000 Hz was there a significantly lower difference in hearing threshold between participants who wore ear protection and those who did not. When including all frequencies in a single analysis, the t-test determined that there is a significant increase in hearing threshold with those participants who did not wear ear protection (Table 5.3.2). Figure 5.3.3 demonstrates the 13.4 dB gap at 4000 Hz as opposed to the rest of the frequencies which yielded slight increases in hearing threshold with no significant difference.

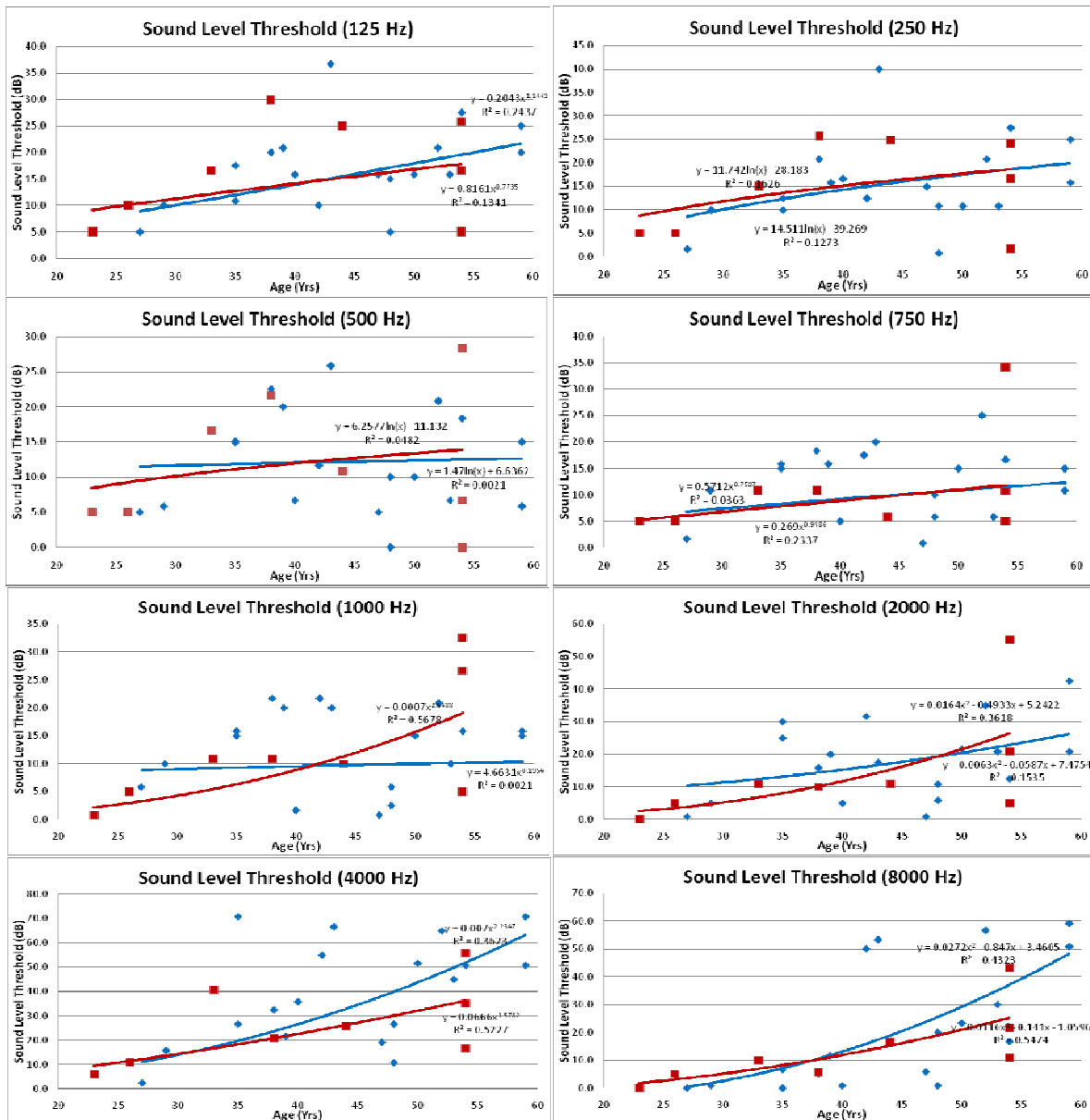
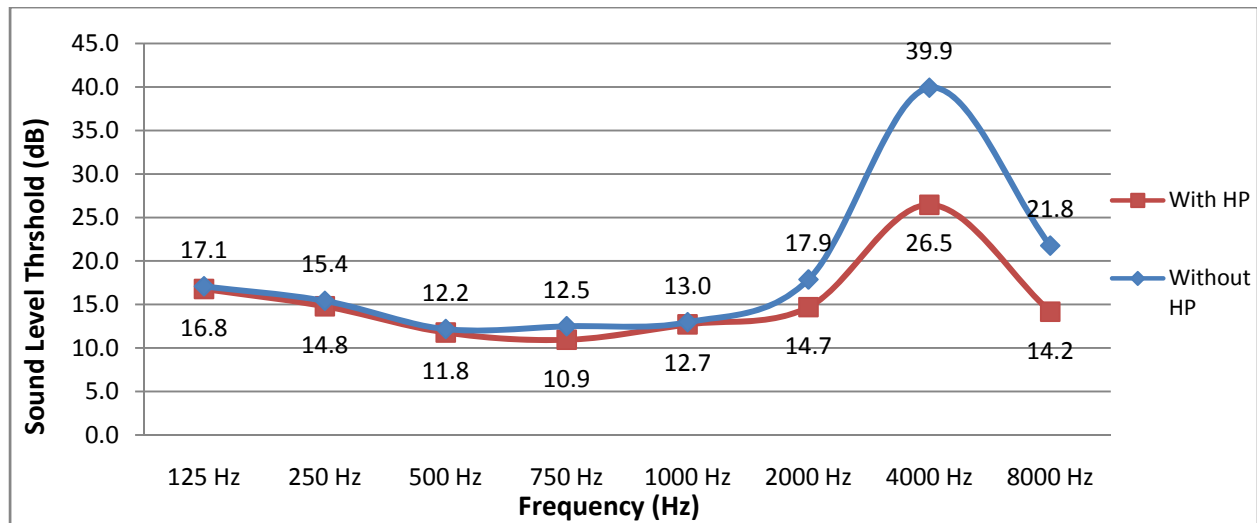


Figure 5.3.2. Regression analysis of data sets on all frequencies

Table 5.3.2. Mean hearing threshold with and without use of hearing protection

Hearing Threshold (HP)									
HP?	125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Avg
No	17.1	15.4	12.2	12.5	13.0	17.9	39.9	21.8	18.7
Yes	16.8	14.8	11.8	10.9	12.7	14.7	26.5	14.2	15.3
SLT Difference	0.3	0.6	0.4	1.6	0.3	3.2	13.4	7.6	3.4
T-test									0.0485

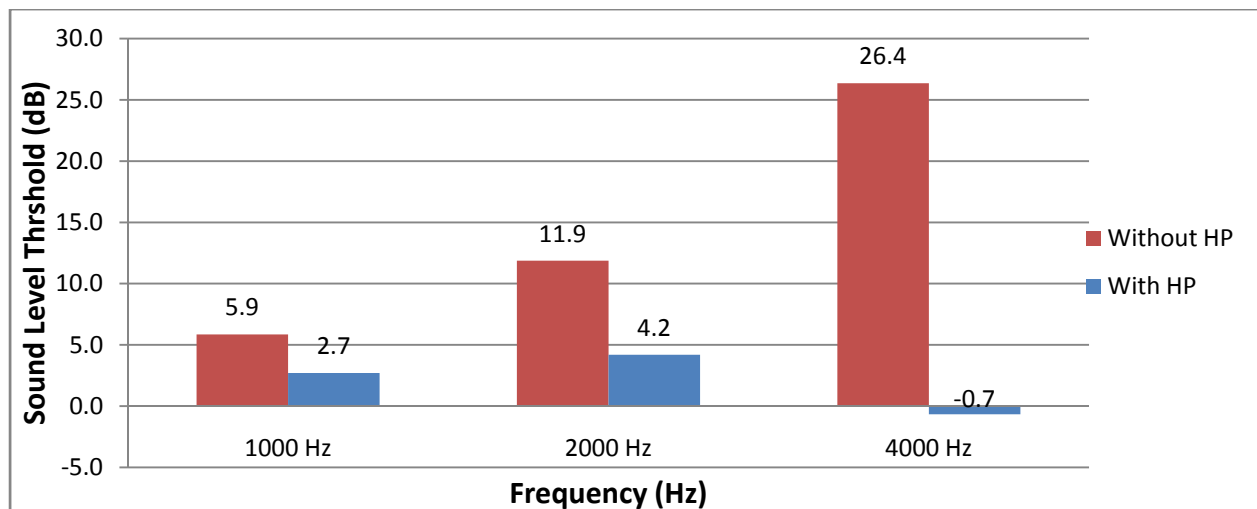


**Figure 5.3.3.** Mean hearing threshold with and without use of hearing protection

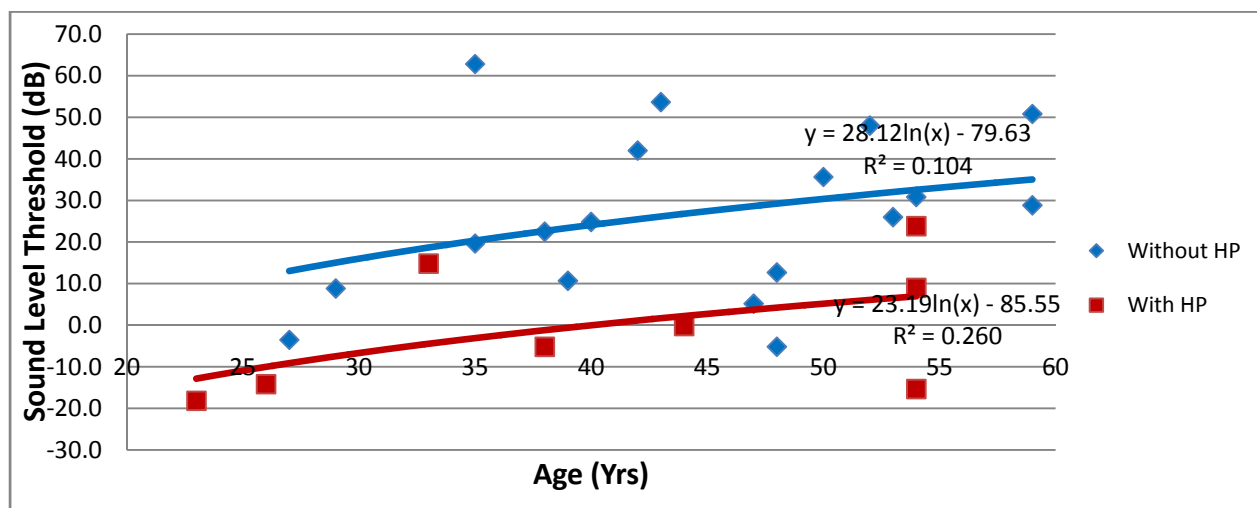
#### 5.4. Association between Hearing Protection and Hearing Threshold Shift

In this section, participants' hearing threshold shift was divided between those who wore hearing protection and those who wore none when operating the equipment. Although the mean hearing threshold shift of those who did not use hearing protection was always higher, as Figure 5.4.1 illustrates, no significant difference ( $p > 0.05$ ) was found between those participants who wore and those who did not wear hearing protection at 1000 and 2000 Hz of frequency.

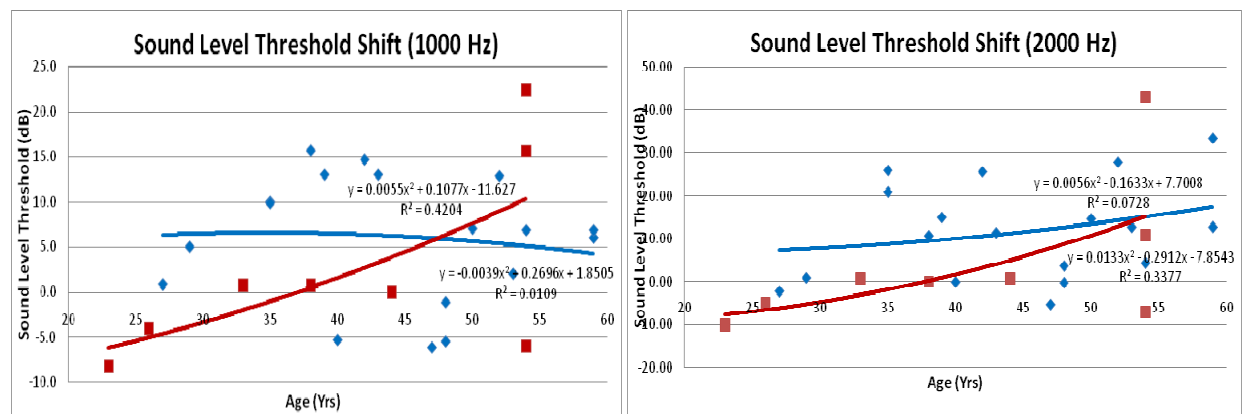
At 4000 Hz, the mean hearing threshold difference was of 27.1 dB (Table 5.4.1). This yielded a significant increase ( $p < 0.05$ ) between those participants who did not wear hearing protection and those who did. The regression analysis performed (Figure 5.4.2) illustrates the regression line of the threshold with respect to age among the participant sample, together with the r-squared value. This illustrates a consistent gap between both trend lines, following a parallel path as age progresses. The trend lines in the regression analysis for the rest of the frequencies followed an inconclusive pattern, as shown in Figure 5.4.3. It is important to note that the mean gap in hearing threshold between participants without and those with hearing protection for the first five frequencies is less than 1 dB.



**Figure 5.4.1.** Mean hearing threshold shift with and without use of hearing protection



**Figure 5.4.2.** Regression analysis of data sets at 4000 Hz with and without use of HP



**Figure 5.4.3.** Regression analysis of data sets at 1000 and 2000 Hz with and without use of HP

Table 5.4.1 illustrates the mean hearing threshold shifts of all frequencies, tested between those participants who wore ear protection and those who did not. As previously stated, only at 4000 Hz was the differences in hearing threshold significantly lower between participants who wore ear protection and those who did not. When including all frequencies in a single analysis, t-test determined that there is a significant increase in hearing threshold with those participants who wore no hearing protection.

**Table 5.4.1.** Mean hearing threshold shift with and without use of hearing protection

<b>Hearing Threshold (HP)</b>				
<b>HP?</b>	<b>1000 Hz</b>	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>Avg</b>
No	5.9	11.9	26.4	14.7
Yes	2.7	4.2	-0.7	2.1
<b>HTS Difference</b>	<b>3.1</b>	<b>7.7</b>	<b>27.0</b>	<b>12.6</b>
<b>T-test</b>				<b>0.00051</b>

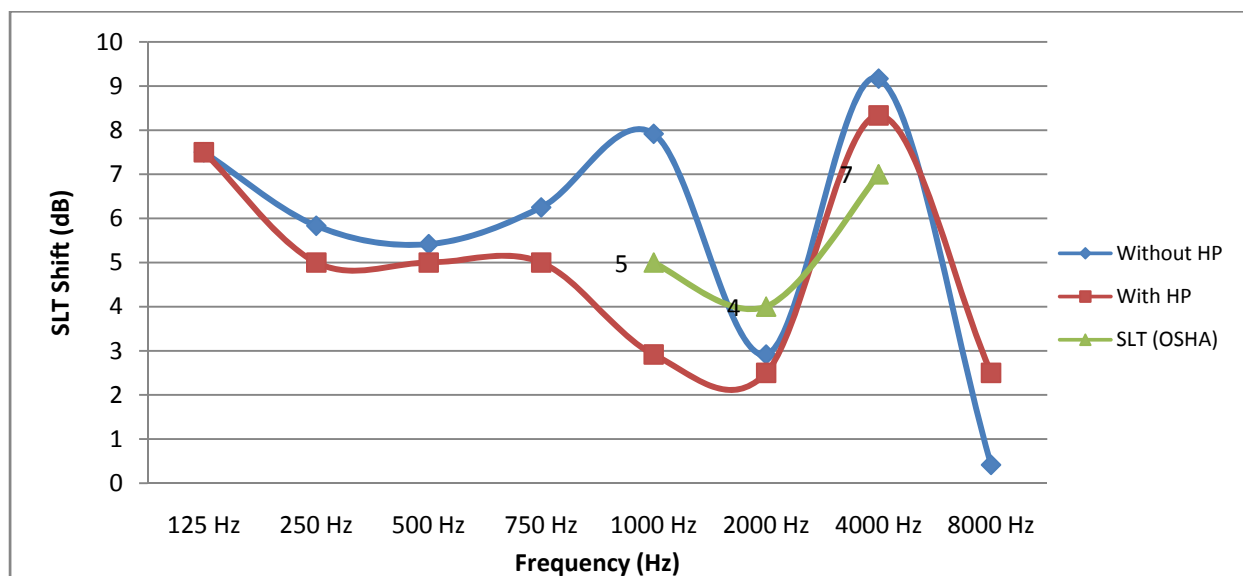
## 5.5 Hearing Threshold between Age Groups with Use of Hearing Protection

The participant population was divided into four age groups. These ranged from the age of 20 to 29, 30 to 39, 40 to 49, and 50 to 59. The objective was to determine whether any significant differences in hearing threshold appeared in participants who used hearing protection and those who did not. The hearing thresholds were also combined for all frequencies at each age group; significant differences between age groups were determined. Also, the mean hearing threshold for each age group was computed (disregarding use of hearing protection) and significant differences in hearing thresholds between all age groups were established.

No significant decrease in the hearing threshold of the age group from 20 to 29 years of age was found between participants who wore hearing protection and those who did not wear hearing protection (Table 5.5.1). As Figure 5.5.1 illustrates, the difference in hearing threshold between participants with hearing protection and those without the use of hearing protection is



up to 1 dB. The only abrupt increase in gap is found at 1000 Hz with a difference of 5 dB (Table 5.5.1). At this same frequency, the age-corrected hearing threshold is 2 dB higher (non-significant  $p > 0.05$ ) than the hearing threshold of the participants who wore hearing protection, and 3 dB lower (non-significant  $p > 0.05$ ) than participants who did not wear hearing protection. At 2000 Hz and 4000 Hz, no significant decrease or increase in hearing threshold was found between the age-corrected hearing threshold (OSHA, 2008) and participant hearing threshold with and without the use of hearing protection.

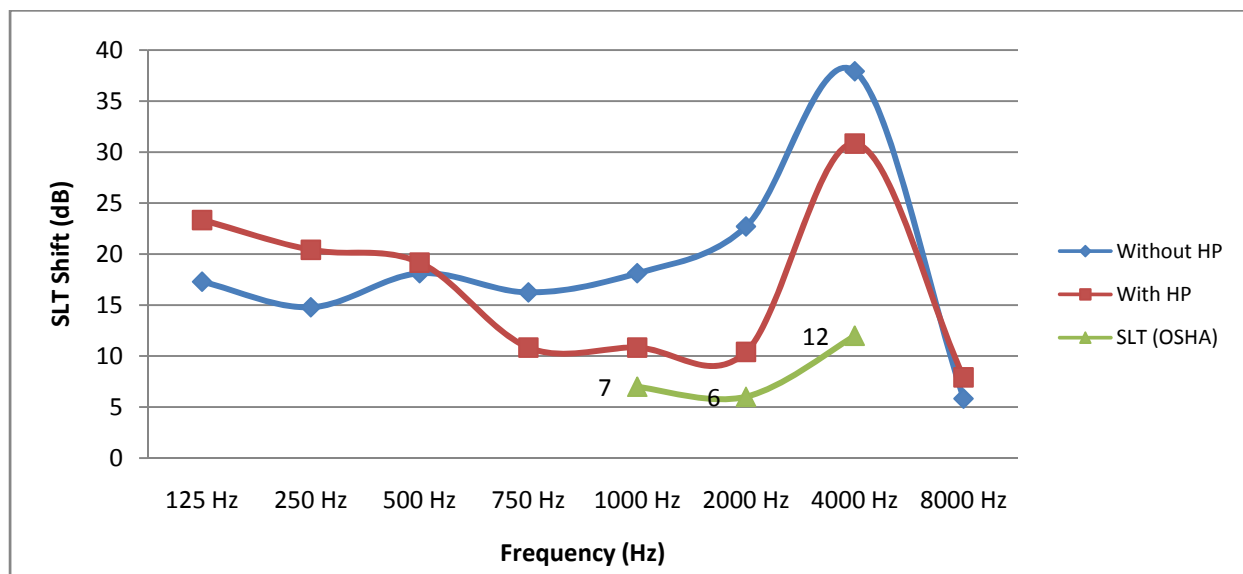


**Figure 5.5.1.** Hearing threshold with (n=2) and without (n=2) the use of hearing protection for age group of 20 to 29 years

**Table 5.5.1.** Hearing threshold with (n=2) and without (n=2) the use of hearing protection for age group of 20 to 29 years

Hearing Threshold (20-29)								
	125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Without HP	8	6	5	6	8	3	9	0
With HP	8	5	5	5	3	3	8	3
SLT Diff	0	1	0	1	5	0	1	-2
t-test	0.50	0.44	0.25	0.42	0.12	0.49	0.49	0.28

A significant increase in hearing threshold ( $p < 0.05$ ) was found at 750, 1000, and 2000 Hz of 5, 7, and 12 decibels respectively, in the age group from 30 to 39 years of age between participants who wore hearing protection and those who wore no hearing protection (Table 5.5.2). As Figure 5.5.2 illustrates, the difference in hearing threshold between participants with hearing protection and those without the use hearing protection can be seen at these frequencies. At 1000 Hz and 2000 Hz, a significant decrease in hearing threshold was found between the age-corrected hearing threshold (OSHA, 2008) and the participants' hearing threshold with and without the use of hearing protection. No significant increase or decrease was found at 4000 Hz with or without the use of hearing protection.

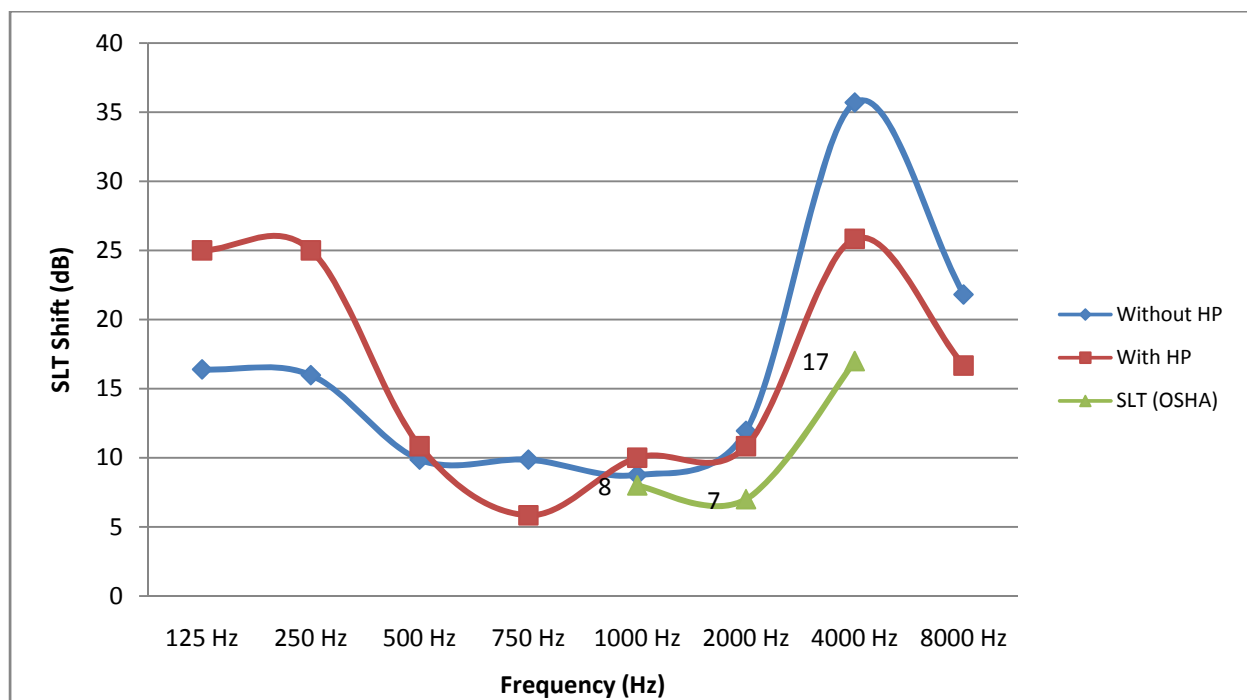


**Figure 5.5.2.** Hearing threshold with (n=2) and without (n=4) the use of hearing protection for age group of 30 to 39 years

No significant decrease in the hearing threshold in the age group from 40 to 49 years of age was found between participants who wore hearing protection and those who did not wear hearing protection (Table 5.5.3). No statistical analysis could be performed due to the fact that only one participant at this age group reported wearing hearing protection. As Figure 5.5.3 illustrates, no correlation exists between those with and without hearing protection.

**Table 5.5.2.** Hearing threshold with (n=2) and without (n=4) the use of hearing protection for age group of 30 to 39 years

<b>Hearing Threshold (30-39)</b>								
	<b>125 Hz</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>750 Hz</b>	<b>1000 Hz</b>	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>8000 Hz</b>
<b>Without HP</b>	17	15	18	16	18	23	38	6
<b>With HP</b>	23	20	19	11	11	10	31	8
<b>SLT Diff</b>	-6	-6	-1	5	7	12	7	-2
<b>t-test</b>	<b>0.26</b>	<b>0.24</b>	<b>0.38</b>	<b>0.00</b>	<b>0.01</b>	<b>0.02</b>	<b>0.36</b>	<b>0.28</b>



**Figure 5.5.3.** Hearing threshold with (n=1) and without (n=6) the use of hearing protection for age group of 40 to 49 years

No significant decrease in hearing threshold in age group of 50 to 59 years of age was found between participants who wore hearing protection and those who did not wear hearing protection (Table 5.5.4). As Figure 5.5.4 illustrates, the difference in hearing threshold between participants with hearing protection and those without the use of hearing protection ranges between -2 dB to 20 db. Abrupt increases in gap were found at 4000 Hz and 8000 Hz, with a

difference of 20 and 14 dB, respectively (Table 5.5.4). Although the age-corrected hearing threshold is lower than those with and without the use of hearing protection at 1000, 2000, and 4000 Hz frequencies, a significant increase was found only for those who wore hearing protection.

**Table 5.5.3.** Hearing threshold with (n=1) and without (n=6) the use of hearing protection for age group of 40 to 49 years

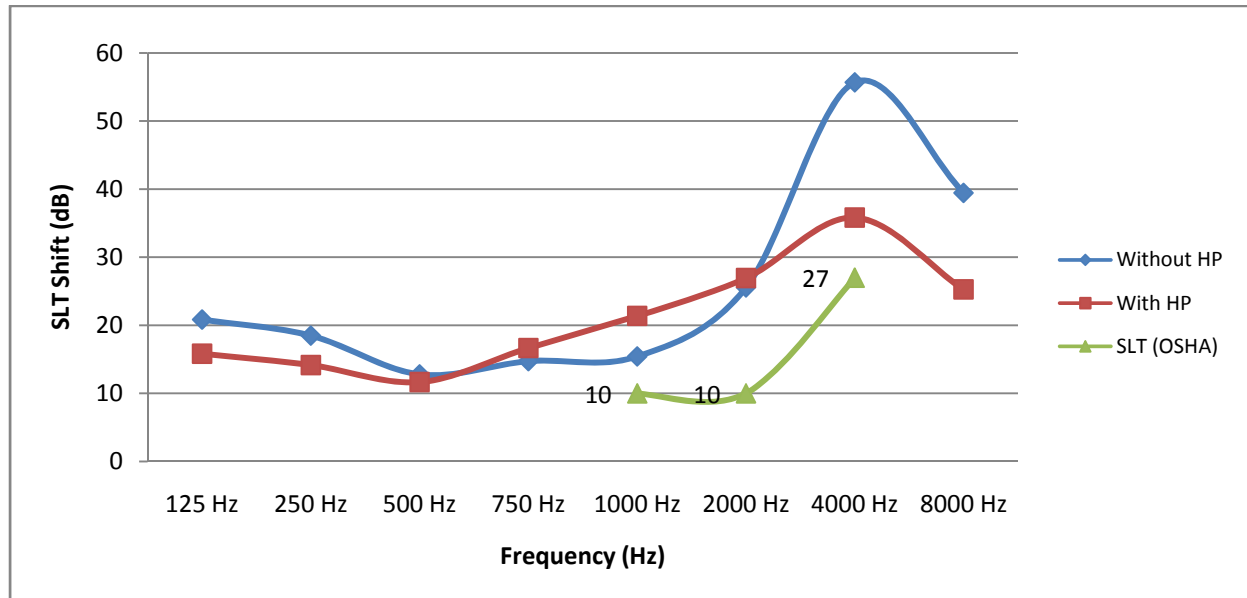
<b>Hearing Threshold (40-49)</b>								
	<b>125 Hz</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>750 Hz</b>	<b>1000 Hz</b>	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>8000 Hz</b>
<b>Without HP</b>	16	16	10	10	9	12	36	22
<b>With HP</b>	25	25	11	6	10	11	26	17
<b>SLT Diff</b>	-9	-9	-1	4	-1	1	10	5
<b>t-test</b>	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

**Table 5.5.4.** Hearing threshold with (n=3) and without (n=6) the use of hearing protection for age group of 50 to 59

<b>Hearing Threshold (50-59)</b>								
	<b>125 Hz</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>750 Hz</b>	<b>1000 Hz</b>	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>8000 Hz</b>
<b>Without HP</b>	21	18	13	15	15	26	56	39
<b>With HP</b>	16	14	12	17	21	27	36	25
<b>SLT Diff</b>	5	4	1	-2	-6	-1	20	14
<b>t-test</b>	<b>0.25</b>	<b>0.30</b>	<b>0.46</b>	<b>0.43</b>	<b>0.28</b>	<b>0.46</b>	<b>0.11</b>	<b>0.15</b>

Although the mean hearing threshold for each age group of those participants who did not wear hearing protection was higher (Table 5.5.5), no significant difference was found ( $p > 0.05$ ). However, when performing statistical analysis on the mean hearing thresholds (disregarding the use of hearing protection), Table 5.5.6 illustrates a pair-wise comparison in which “X” equals no significant increase. Numbers by cell indicate the amount of decibels the hearing threshold significantly increased with respect to the age group row. Figure 5.5.5 illustrates slight, not

significant increases in the hearing threshold between participants who used hearing protection and those who didn't. The slight increase in threshold as age groups progress is disrupted at 40 to 49 years of age where the hearing threshold decreases.



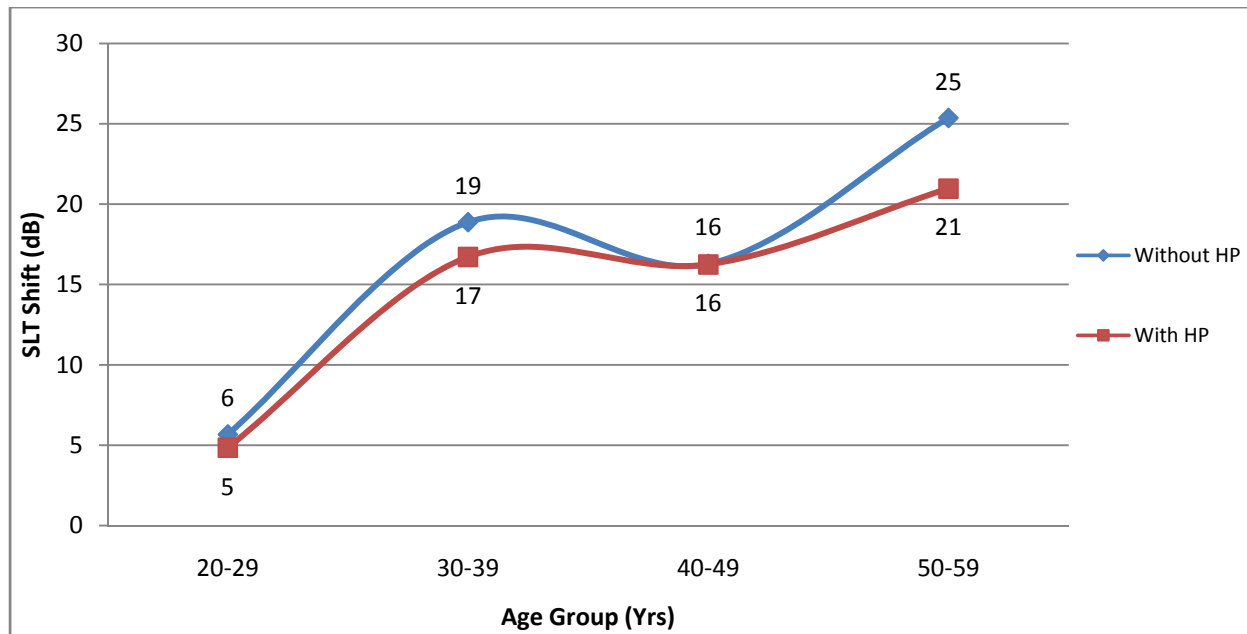
**Figure 5.5.4.** Hearing threshold with (n=3) and without (n=6) the use of hearing protection for age group of 50 to 59 years

**Table 5.5.5.** Average hearing thresholds at each age group with and without hearing protection and average SLT (disregarding use of hearing protection)

Age Group	Without HP (Avg)	With HP (Avg)	SLT (Avg)
20-29	6	5	5
30-39	19	17	18
40-49	16	16	16
50-59	25	21	24

**Table 5.5.6.** Pair-wise table indicating significant increase or decrease ( $p < 0.05$ ) in SLT between age groups (disregarding use hearing protection)

	20-29	30-39	40-49	50-59
20-29	0	13	11	18
30-39		0	X	6
40-49			0	8
50-59				0



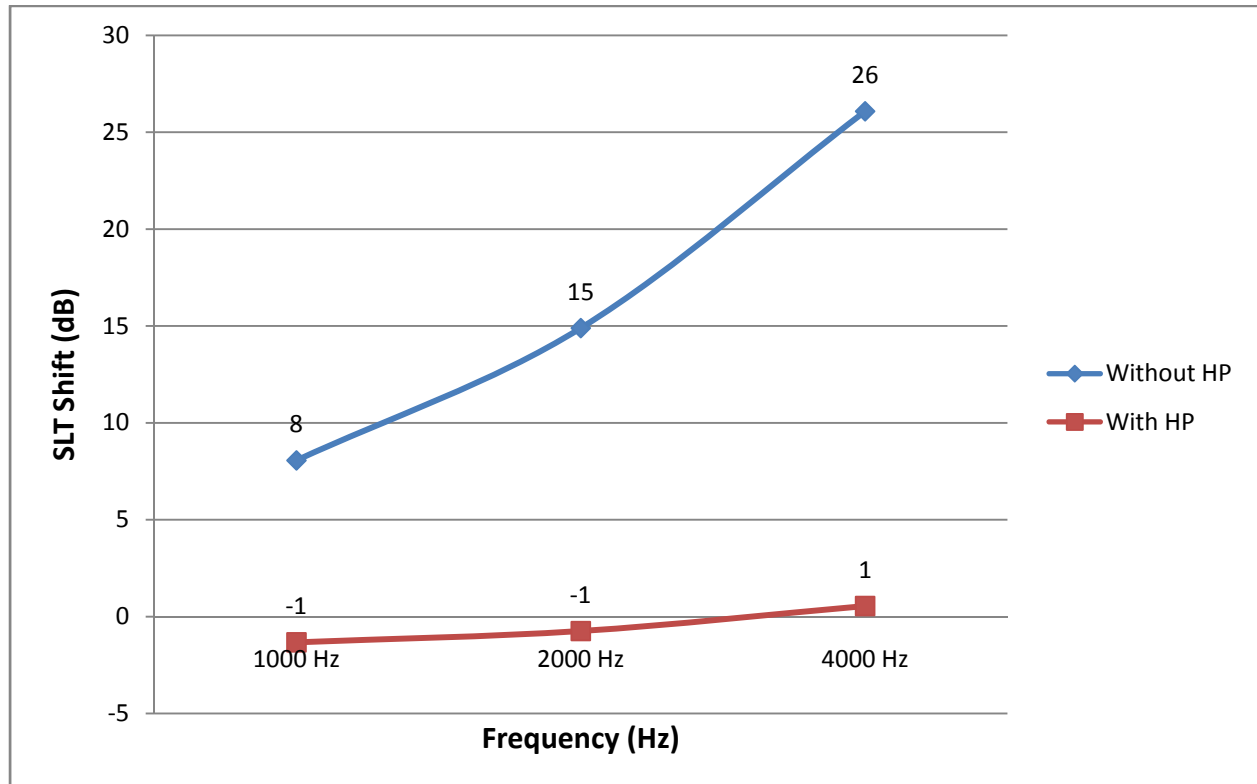
**Figure 5.5.5.** Average hearing thresholds between age groups with and without hearing protection and average SLT (disregarding use of hearing protection)

### 5.6 Hearing Threshold Shift between Experience Groups with Use of Hearing Protection

The participant population was divided into four experience groups. This meant that participants were divided into groups depending on the years working as a forest logger. These groups ranged from 1 to 10, 11 to 20, 21 to 30, and 31 to 40 years of experience. The objective was to determine whether any significant differences in the hearing threshold shift appeared in participants who used hearing protection and those who did not. The hearing threshold shifts were also combined for all frequencies (1000, 2000, and 4000 Hz) at each experience group; significant differences between groups were determined. Also, the mean hearing threshold shift for each experience group was computed (disregarding use of hearing protection); significant differences in hearing threshold shifts between all groups were established.

Significant increases in hearing threshold shift ( $p < 0.05$ ) were found at 1000, 2000, and 4000 Hz of 9, 16, and 26 decibels, respectively, in the experience group from 1 to 10 years, and between participants who wore hearing protection and those who wore no hearing protection

(Table 5.6.1). As Figure 5.6.1 illustrates, the difference in hearing threshold shift increased in gap as the frequency increased between participants with hearing protection and those without the use of hearing protection, as seen at these frequencies.



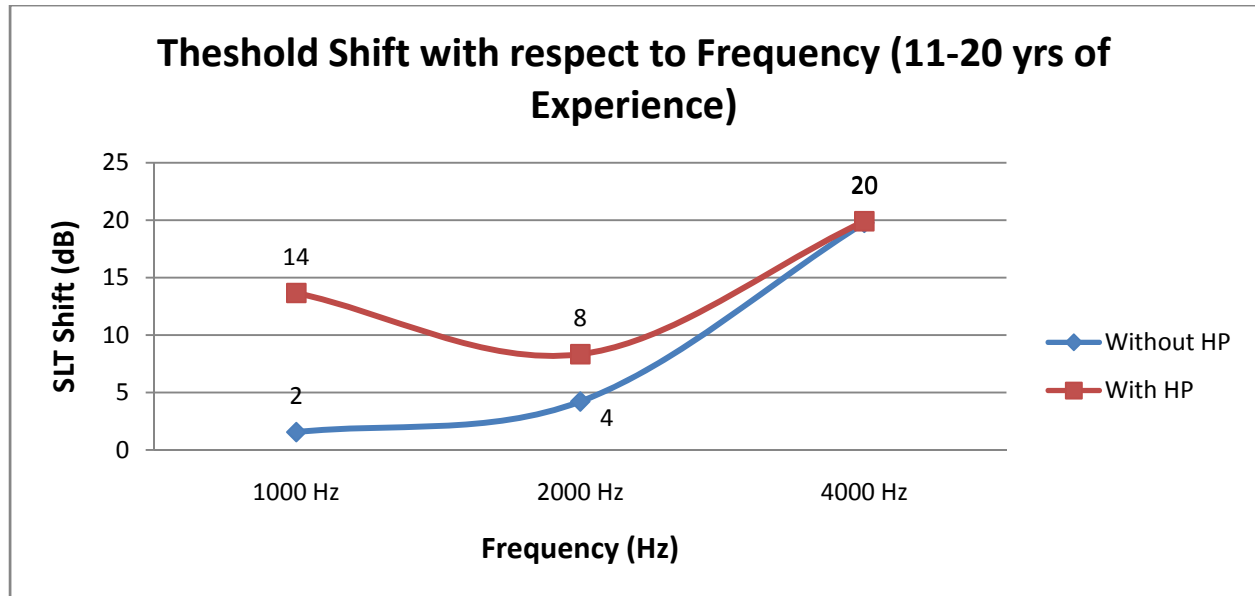
**Figure 5.6.1.** Hearing threshold shift with (n=4) and without (n=6) the use of hearing protection in the experience group from 1 to 10 years

**Table 5.6.1.** Hearing threshold shift with (n=4) and without (n=6) the use of hearing protection at experience group from 1 to 10 years

	1000 Hz	2000 Hz	4000 Hz
<b>Without HP</b>	8	15	26
<b>With HP</b>	-1	-1	1
<b>SLT Diff</b>	<b>9</b>	<b>16</b>	<b>26</b>
<b>t-test</b>	<b>0.006</b>	<b>0.008</b>	<b>0.024</b>

No significant differences in the hearing threshold shift ( $p < 0.05$ ) were found at 1000, 2000, and 4000 Hz in the experience group from 11 to 20 years between participants who wore hearing protection and those who wore no hearing protection (Table 5.6.2). As Figure 5.6.2

illustrates, participants who did not use hearing protection had lower hearing threshold shifts than participants who wore hearing protection. Furthermore, as opposed to the previous experience group, the difference in hearing threshold shift decreased in gap as frequency increased between participants who used hearing protection and those did not use hearing protection.



**Figure 5.6.2.** Hearing threshold shift with (n=2) and without (n=3) the use of hearing protection at experience group from 11 to 20 years

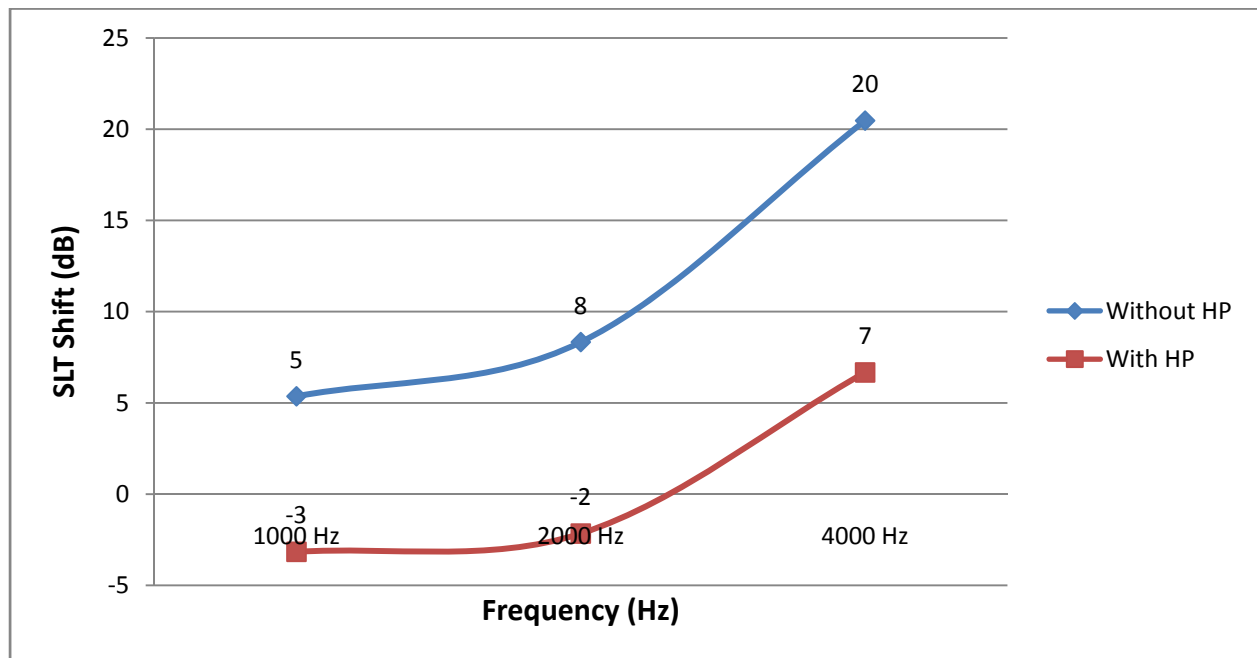
**Table 5.6.2.** Hearing threshold shift with (n=2) and without (n=3) the use of hearing protection at experience group from 11 to 20 years

	1000 Hz	2000 Hz	4000 Hz
<b>Without HP</b>	2	4	20
<b>With HP</b>	14	8	20
<b>SLT Diff</b>	-12	-4	0
<b>t-test</b>	<b>0.191</b>	<b>0.234</b>	<b>0.496</b>

No significant differences in hearing threshold shift ( $p < 0.05$ ) were found at 1000, 2000, and 4000 Hz on the experience group from 21 to 30 years, between participants who wore hearing protection and those who did not wear hearing protection (Table 5.6.3). It was



impossible to establish a statistical significance, due to the fact that only one participant at this experience group used hearing protection. As Figure 5.6.2 illustrates, the difference in hearing threshold shift increased in gap as the frequency increased between participants with hearing protection and those with no hearing protection.



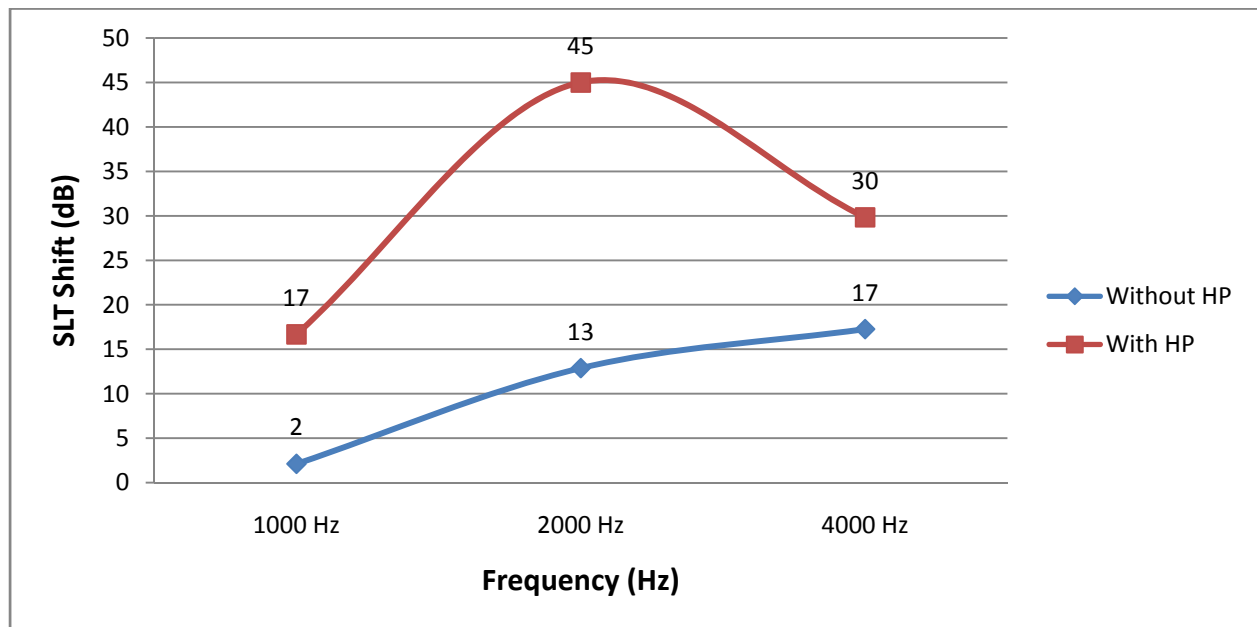
**Figure 5.6.3.** Hearing threshold shift with (n=1) and without (n=6) the use of hearing protection at experience group from 21 to 30 years

**Table 5.6.3.** Hearing threshold shift with (n=1) and without (n=6) the use of hearing protection at experience group from 21 to 30 years

	1000 Hz	2000 Hz	4000 Hz
<b>Without HP</b>	5	8	20
<b>With HP</b>	-3	-2	7
<b>SLT Diff</b>	9	11	14
<b>t-test</b>	N/A	N/A	N/A

In the experience group from 31 to 40 years, no significant differences in hearing threshold shift ( $p < 0.05$ ) were found at 1000, 2000, and 4000 Hz, between participants who wore hearing protection and those who wore no hearing protection (Table 5.6.4). Figure 5.6.4

illustrates that participants who did not use hearing protection had lower hearing thresholds shifts than participants who wear hearing protection. Furthermore, the hearing threshold shift of participants who did wore hearing protection follows a parabolic trend, indicating that the threshold shift increased from 1000 to 2000 Hz and decreased from 2000 to 4000 Hz.



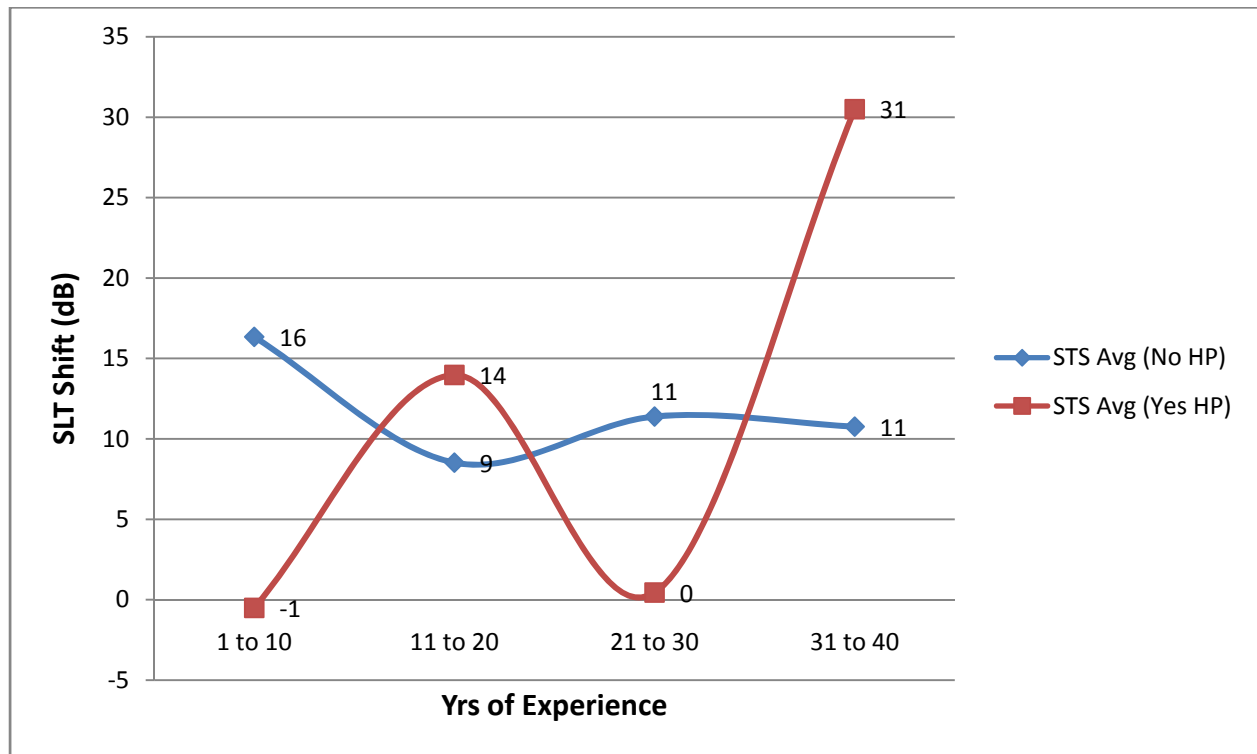
**Figure 5.6.4.** Hearing threshold shift with (n=1) and without (n=3) the use of hearing protection at experience group from 31 to 40 years

**Table 5.6.4.** Hearing threshold shift with (n=1) and without (n=3) the use of hearing protection in the experience group from 31 to 40 years

	1000 Hz	2000 Hz	4000 Hz
<b>Without HP</b>	2	13	17
<b>With HP</b>	17	45	30
<b>SLT Diff</b>	-15	-32	-13
<b>t-test</b>	N/A	N/A	N/A

When combining all frequencies, a significant increase ( $p > 0.05$ ) in hearing threshold shifts of those participants who did not wear hearing protection was found in experience groups having 1 to 10 years and 21 to 30 years of experience (Table 5.6.5). Figure 5.6.5 illustrates the variations in hearing threshold shift between the experience groups. No significant differences in

hearing threshold shift were found between the experience groups, disregarding the use of hearing protection.



**Figure 5.6.5.** Average hearing threshold shifts between experience groups with and without hearing protection and average HTS (disregarding use of hearing protection)

**Table 5.6.5.** Average hearing threshold shifts at each experience group with and without hearing protection and average SLT (disregarding use of hearing protection)

	1 to 10	11 to 20	21 to 30	31 to 40
<b>Without HP</b>	16	9	11	11
<b>With HP</b>	-1	14	0	31
<b>SLT Diff</b>	<b>17</b>	<b>-5</b>	<b>11</b>	<b>-20</b>
<b>SLT Average</b>	10	11	10	16
<b>t-test</b>	<b>0.000</b>	<b>0.178</b>	<b>0.022</b>	<b>0.058</b>

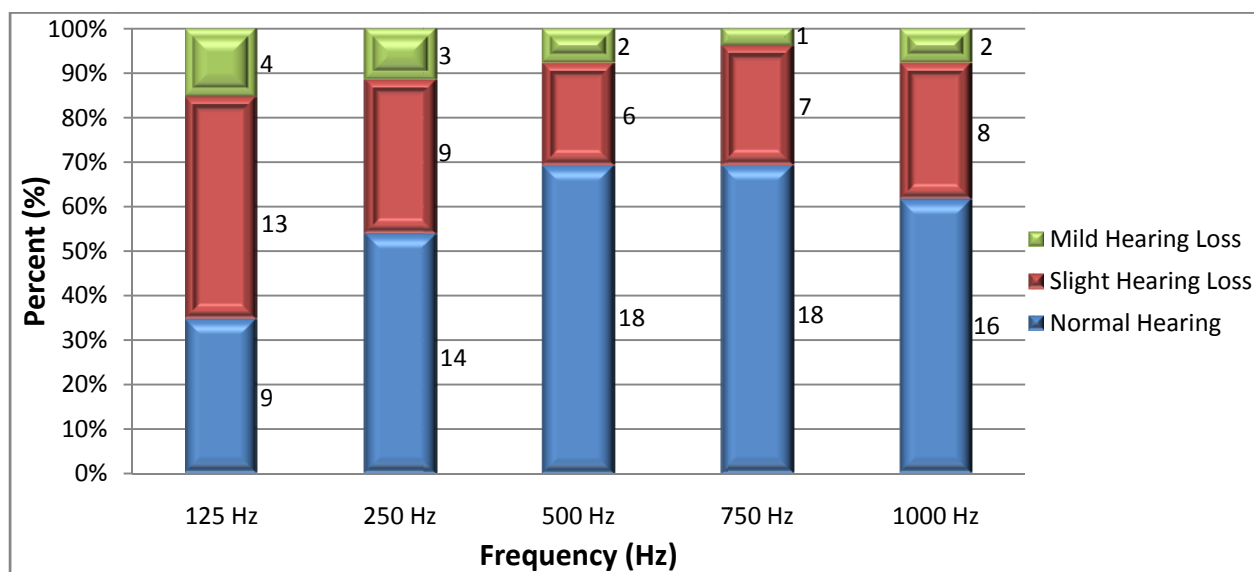
## 5.7 Hearing Loss Classification

Hearing loss can be classified into multiple categories which translate a range of values regarding hearing threshold into a specific word denomination. This simplifies the understanding

of the term *hearing threshold*. As previously mentioned, the Center for Hearing Loss Help classifies the hearing threshold into the following categories:

- Normal hearing                -10 to 15 dB
- Slight hearing loss        16 to 25 dB
- Mild hearing loss         26 to 40 dB
- Moderate hearing loss    41 to 55 dB
- Moderately severe loss   56 to 70 dB
- Severe hearing loss       71 to 90 dB
- Profound hearing loss    91 to 120 dB
- Deaf                         over 120 dB

Figure 5.7.1 illustrates the hearing loss classifications at 125 Hz, 250 Hz, 500 Hz, 750 Hz and 1000 Hz. At these five frequencies, participants suffered from slight (33%) and mild hearing loss (9%). Table 5.7.1 illustrates that 58% of the participants did not suffer from hearing loss at these frequencies (125, 250, 500, 750 and 1000 Hz). As determined by the age-corrected tables for audiograms established by OSHA (2008), a normal population at 1000 Hz should have a mean hearing threshold which indicates normal hearing for 100% of the population.



**Figure 5.7.1.** Number of participants at each hearing loss classification for 125 Hz, 250 Hz, 500 Hz, 750 and 1000 Hz

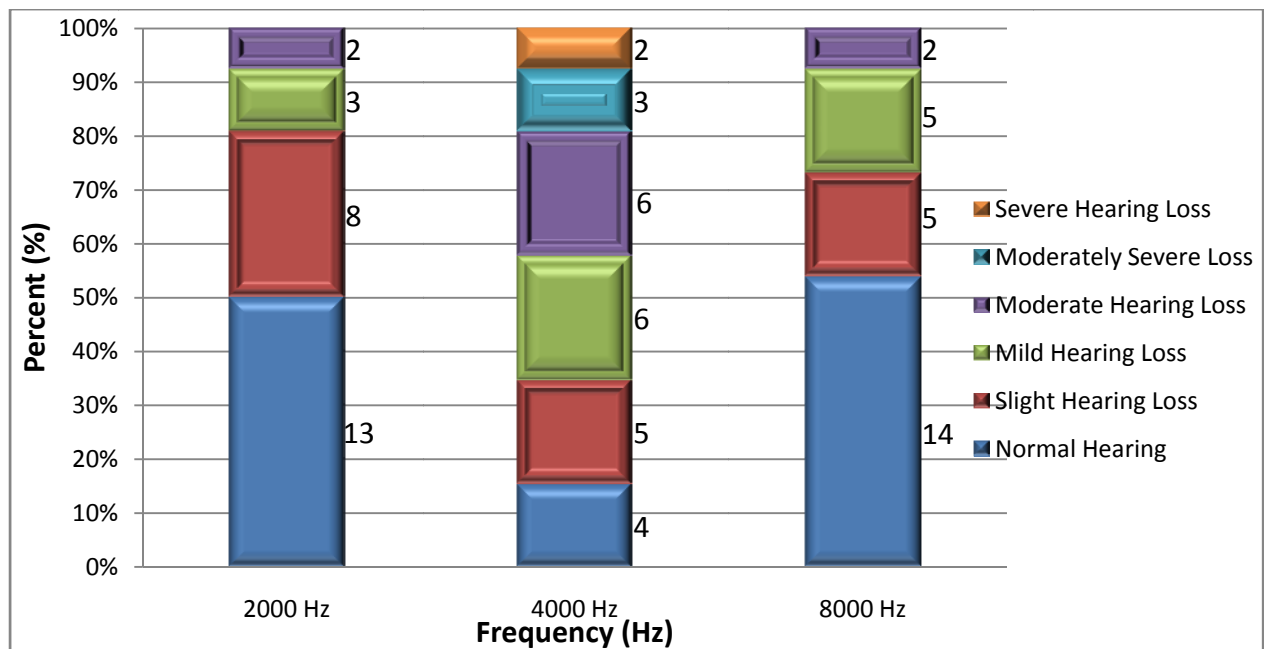
At 2000 Hz, 4000 Hz, and 8000 Hz, the number of hearing loss categories increased. Figure 5.7.2 illustrates the hearing loss classifications at these frequencies. At the three frequencies, participants suffered from slight, mild, moderate, moderately severe, and severe hearing loss. Figure 5.7.2 shows that 2 out of 26 participants suffered from moderate hearing loss at 2000 and 8000 Hz of frequency. At 4000 Hz, 3 out of 26 participants suffered from moderately severe hearing loss, and 2 out of 26 suffered from severe hearing loss. Table 5.7.2 illustrates that 40% of the participants did not suffer from hearing loss at these frequencies (consistent with the lower frequencies). Moderate severe and severe hearing loss was present on 7% of the participant population.

**Table 5.7.1.** Percentage of participants at each hearing loss classification (125 Hz, 250 Hz, 500 Hz, 750 Hz and 1000 Hz combined)

<b>Hearing Loss Classification</b>							
	<b>125 Hz</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>750 Hz</b>	<b>1000 Hz</b>	<b>Total</b>	<b>Percent</b>
<b>Normal Hearing</b>	9	14	18	18	16	75	58%
<b>Slight Hearing Loss</b>	13	9	6	7	8	43	33%
<b>Mild Hearing Loss</b>	4	3	2	1	2	12	9%
<b>Sum</b>						<b>130</b>	<b>100%</b>

**Table 5.7.2.** Percentage of participants at each hearing loss classification (2000 Hz, 4000 Hz, and 8000 Hz combined)

<b>Hearing Loss Classification</b>					
	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>8000 Hz</b>	<b>Total</b>	<b>Percent</b>
<b>Normal Hearing</b>	13	4	14	31.00	40%
<b>Slight Hearing Loss</b>	8	5	5	18.00	23%
<b>Mild Hearing Loss</b>	3	6	5	14.00	18%
<b>Moderate Hearing Loss</b>	2	6	2	10.00	13%
<b>Moderately Severe Loss</b>		3		3.00	4%
<b>Severe Hearing Loss</b>		2		2.00	3%
<b>Sum</b>				<b>78.00</b>	<b>100%</b>



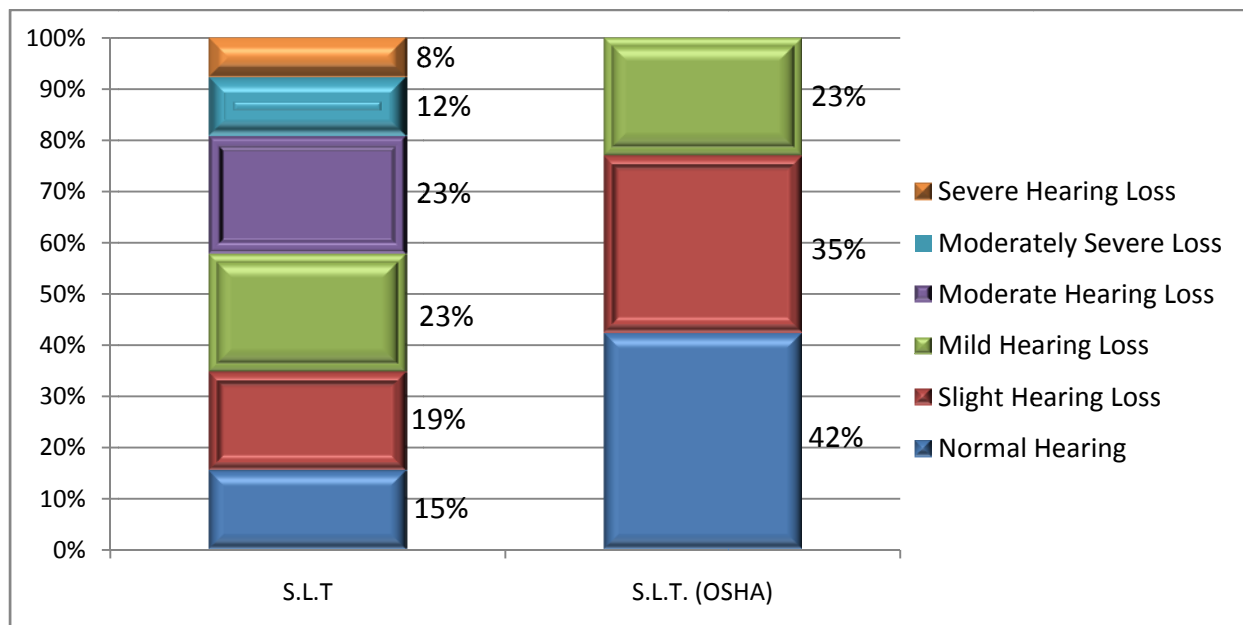
**Figure 5.7.2.** Number of participants at each hearing loss classification for 2000 Hz, 4000 Hz, and 4000 Hz

At 4000 Hz, the participant population suffered from slight, mild, moderate, moderately severe, and severe hearing loss. Figure 5.7.3 illustrates the comparison of hearing loss classification between the participants and a normal population. The normal population was determined by using OSHA age-corrected tables for hearing threshold as age progresses. As observed in Figure 5.7.3, a normal population of the same age range as the participant population should only suffer from slight and mild hearing loss.

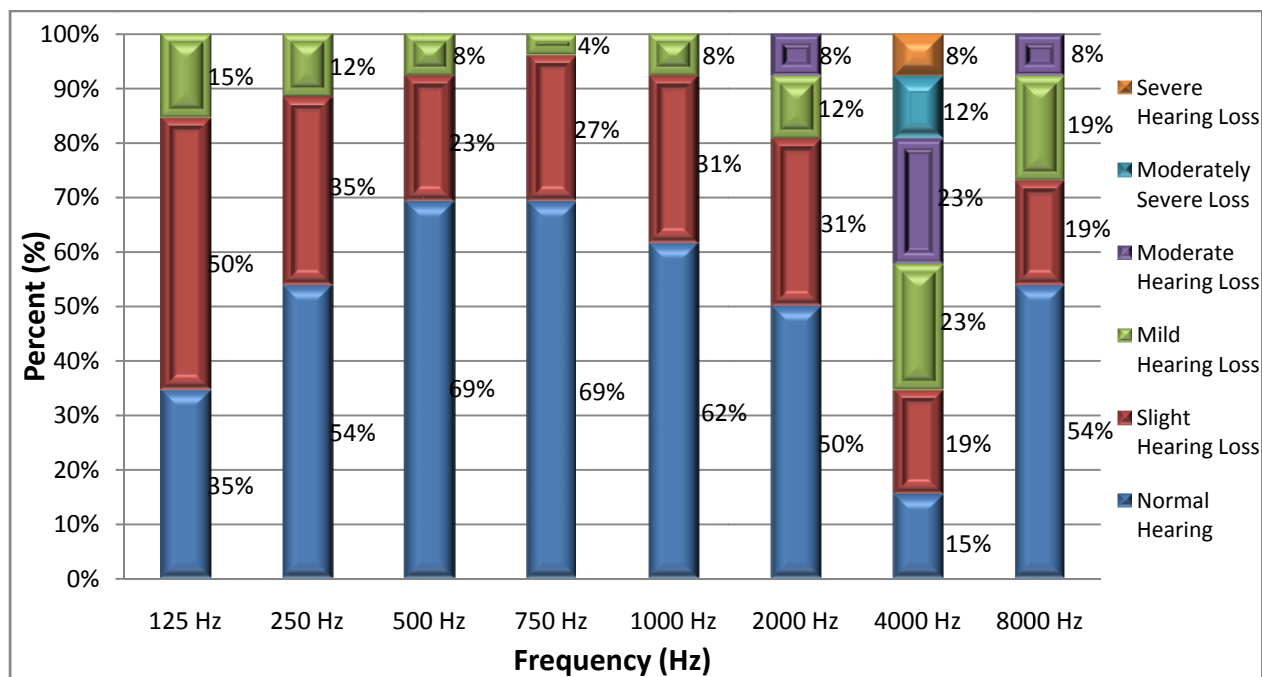
### 5.7.1. All Frequencies

It is shown in Figure 5.7.1.1, that as frequency increased, the hearing loss classifications deteriorated and reached a peak at 4000 Hz (frequency at which hearing loss classification increased to an apex). Table 5.7.1.1 illustrates that 51% of the participant population were within the normal hearing parameters. Figure 5.7.1.2 demonstrates a hearing loss classification when combining frequencies of 1000, 2000, and 4000 Hz for the participant population, in comparison with the normal population. It is shown that normal population at this age range may suffer from

slight (12%) and mild (8%) hearing losses. It is apparent that this is not the case with the participants in this research, who suffered from slight, mild, moderate, moderately severe, and severe hearing losses.



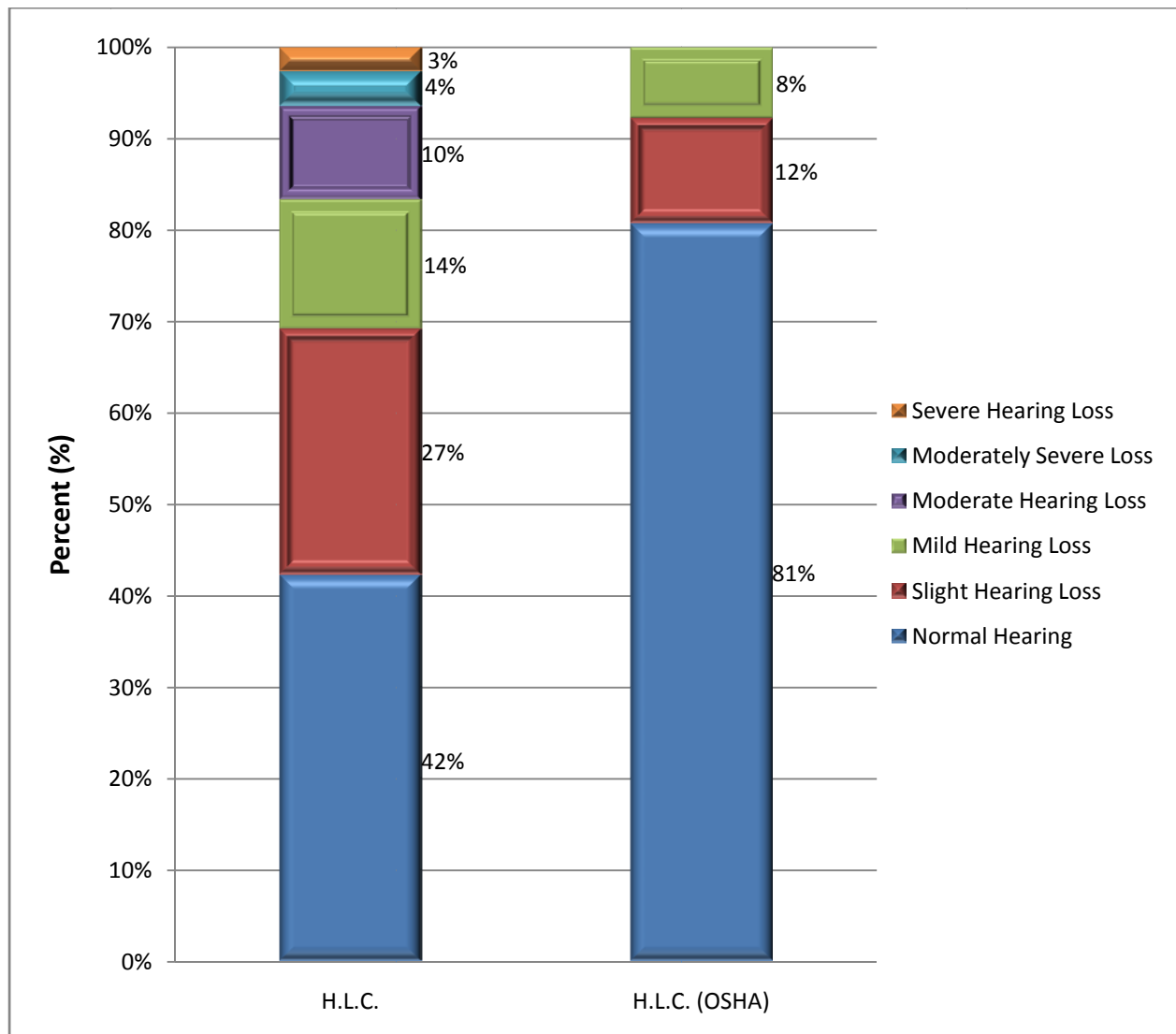
**Figure 5.7.3.** Hearing loss classification at 4000 Hz for forest participants and normal population



**Figure 5.7.1.1.** Hearing loss classification for frequencies of forest loggers from 125 to 8000 Hz

**Table 5.7.1.1.** Hearing loss classification data for all frequencies

<b>Hearing Loss Classification Percentages</b>										
	<b>125 Hz</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>750 Hz</b>	<b>1000 Hz</b>	<b>2000 Hz</b>	<b>4000 Hz</b>	<b>8000 Hz</b>	<b>Total</b>	<b>Percent</b>
<b>Normal Hearing</b>	9	14	18	18	16	13	4	14	<b>106.00</b>	<b>51%</b>
<b>Slight Hearing Loss</b>	13	9	6	7	8	8	5	5	<b>61.00</b>	<b>29%</b>
<b>Mild Hearing Loss</b>	4	3	2	1	2	3	6	5	<b>26.00</b>	<b>13%</b>
<b>Moderate Hearing Loss</b>						2	6	2	<b>10.00</b>	<b>5%</b>
<b>Moderately Severe Loss</b>							3		<b>3.00</b>	<b>1%</b>
<b>Severe Hearing Loss</b>							2		<b>2.00</b>	<b>1%</b>



**Figure 5.7.1.2.** Hearing loss classification for 1000, 2000, and 4000 Hz, combined



## **CHAPTER 6**

### **DISCUSSION AND CONCLUSION**

The effect of being subjected to elevated levels of noise in hearing threshold (SLT) was the basic motive behind this research. Hearing threshold was tested and understood by performing hearing tests (audio testing) with an audiometer. All of the eight frequencies (125 Hz, 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz) showed levels of hearing loss by at least 31% (up to 85%) of the participants. The effect of aging on hearing thresholds has been studied for many decades now. Since the effect of hearing loss due to age is a gradual one, there is no precise and defined beginning of this process. Some studies use a limit of 55 years of age for the start of a detectable age-induced hearing loss (Chen et al., 1992; Hasan and Beg, 1994). Only two of the twenty-six participants in this study were over 55 years of age.

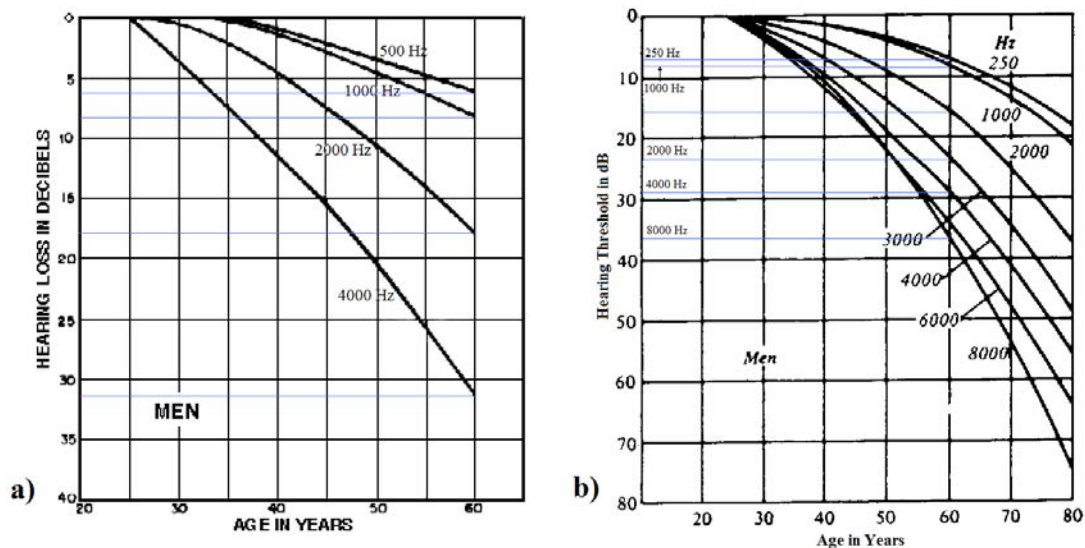
In this study, the hearing threshold appeared to have an abrupt increase at 4000 Hz. On average, the hearing threshold at this frequency was 20.7 dB higher than the rest of the frequencies (125 Hz, 250 Hz, 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, and 8000 Hz) with a range from 23.8 to 16.3 dB. Similar results of hearing threshold were reported by Tunay and Melemez (2008) and Iki (1984) in the forestry industry. In other industries, similar results were reported by Celik et al. (1998), Tambs et al. (2006), Thelin et al. (1983), Chambers et al. (1989), Taylo et al. (1965), Bauer et al. (1991), Lutman and Spencer (1991).

The common approach to maximum hearing threshold increase at 4000 Hz may have several explanations. These two explanations have already been generally accepted:

1. The greater sensitivity of the human ear to frequencies between 1000 and 5000 Hz (probably related to outer and middle ear transmission characteristics, since mid-range frequencies are emphasized) (Pierson, 1994).

2. After an exposure to intense sound, there is a shift in the maximum basilar membrane vibration towards the basal cochlea by about half an octave upon loss of an active cochlear mechanism (Cody and Johnstone, 1981). This means that 2000 Hz pure tone will be perceived as 3000 Hz by the pathologic cochlea.

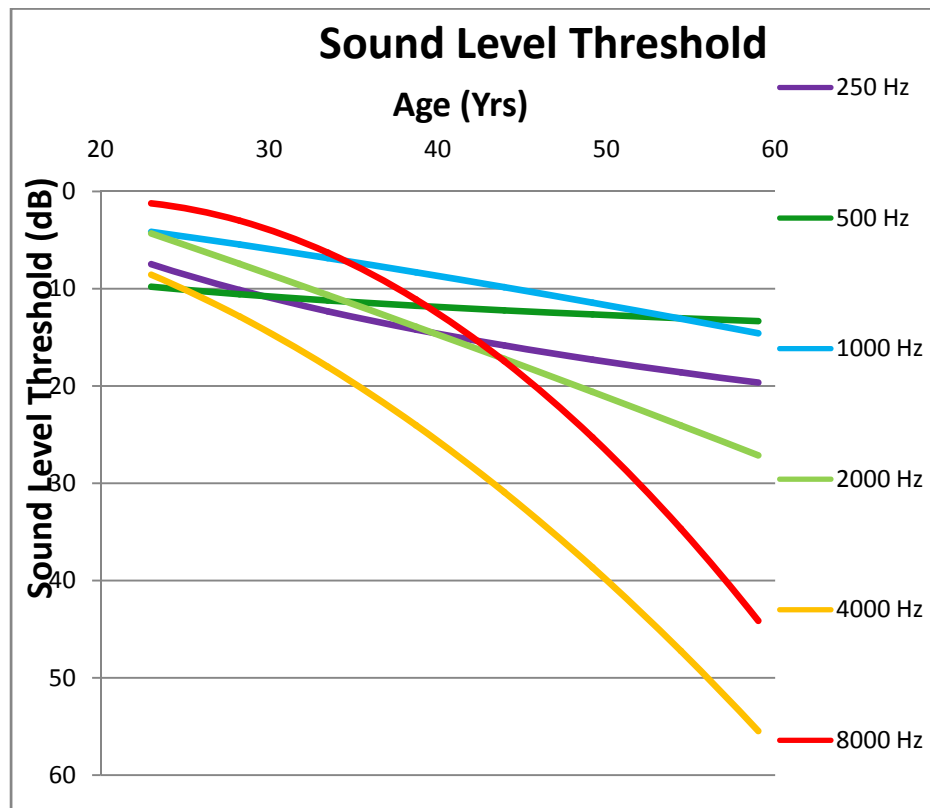
The growth rate of hearing loss around the 4000 Hz region as a function of age does not present a linear relationship (Burns and Robinson, 1970). In this study, the growth rate of hearing loss at high (2000, 4000, and 8000 Hz) frequencies was exponential. At frequencies from 125 Hz to 1000 Hz, the growth rate of hearing threshold as a function of age increased with age (with a positive r-squared value), but no exponential increase was determined. Figure 6.1 illustrates the normal growth of hearing threshold as age progresses at 250, 500, 1000, 2000, 4000 and 8000 hertz (ASA Subcommittee, 1954). Figure 6.2 shows the hearing threshold growth for the participant population at the same frequencies.



**Figure 6.1.** SLT of normal population (a) (ASA, 1954), (b) (Chan, 2009)

When comparing hearing threshold trend lines of the participants (forest loggers) with a normal population, one thing is clear - the end of the regression lines of forest loggers' hearing threshold is higher at all frequencies. This means that for forest loggers, the slope of the

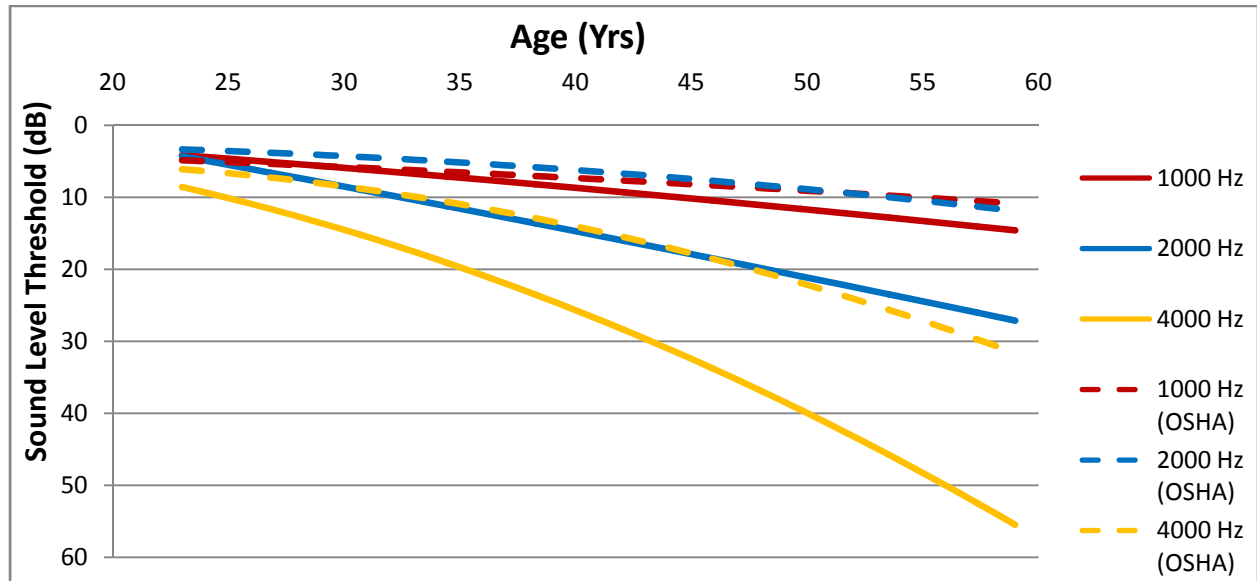
regression line is higher than that of a normal population. Although at 8000 Hz, the mean hearing threshold was (19.4 db) significantly lower than the mean SLT at 4000 Hz (35.8 dB), the regression lines indicate that eventually, as age progresses, the SLT of participants will become higher at 8000 Hz.



**Figure 6.2.** Hearing threshold regression line of forest loggers at 250, 500, 1000, 2000, 4000, and 8000 Hz

The frequencies analyzed for hearing threshold shift (HTS) were 1000, 2000, and 4000 Hz. The OSHA (2008) age corrected tables for hearing loss were utilized to determine the significant threshold shift at these frequencies. These three frequencies (1000, 2000, and 4000 Hz) were used due to the fact that OSHA considers that a person suffers from hearing loss if their hearing threshold is higher than the threshold in the table for a specific age. Results indicated a significant increase at 1000, 2000 and 4000 of 4.9, 9.5, and 18 dB, respectively. The increase in threshold shift was exponential as frequencies increased. The mean threshold shift was at 10.8

dB. Figure 6.3 illustrates the regression lines at each frequency for both the SLT of forest loggers and the OSHA age corrected SLT for a normal population. This confirms that forest loggers are suffering from hearing loss and with the progression of age, the shift increases.



**Figure 6.3.** Hearing threshold regression lines at 1000, 2000, and 4000 Hz for forest loggers (solid line) and normal population (dashed line)

When analyzing the effect of hearing protection on participants, this study found that with hearing threshold, the only significant shift between those participants who used hearing protection and those who did not was at 4000 Hz. The inadequacy of using hearing protection has also been reported by Neitzel and Seixas (2005). At 4000 Hz, the gap between both groups was of 13.4 dB, in which participants who use hearing protection yielded a lower mean hearing threshold than participants who did not wear hearing protection. No significant increase at 7 out of 8 frequencies was found in hearing threshold. Yet when averaging all frequencies together, the mean hearing threshold was significantly higher for participants who did not use hearing protection. The average hearing threshold was 3.4 dB higher for these participants.

Furthermore, the mean threshold shift difference at 4000 Hz was almost 27 dB (significantly,  $p < 0.05$ ) higher for participants who did not use hearing protection. When

combining all frequencies (1000, 2000, and 4000 Hz) there was also a 12.6 dB significant increase for participants who did not use hearing protection. It is important to mention that threshold shift at 4000 Hz was the lowest out of the three frequencies for participants who used hearing protection. This correlates with the findings of Taylor et al. (1965), Bauer et al. (1991), and Lutman and Spencer (1991), where noise initially affects at 4000 Hz and then gradually affects the other frequencies. Hearing protection revealed a counter effect in the participants who used hearing protection in which a negative threshold shift was found (instead of a positive threshold shift).

Analysis on age groups in consideration of hearing protection proved to be inconclusive. No significant differences were found in the hearing threshold between participants who wore hearing protection and those who did not within each age group. When disregarding the use of hearing protection, there was a non-significant decrease in the hearing threshold of 1 dB between age groups 30 to 39 years and 40 to 49 years. This rejects the fact that as age increases, the hearing threshold should increase (Hong, 2005).

Furthermore, the hearing threshold shift (HTS) was analyzed by grouping participants by years of experience. These participants were placed into four groups ranging from 1 to 40 years of experience. A significant threshold shift increase for participants who did not use hearing protection was found in groups ranging from 1 to 10 years of experience at all three frequencies. This yielded a significant increase in mean HTS for all frequencies of 17 dB. A mean HTS significant increase of 11 dB was also found when combining all frequencies at group ranging from 21 to 30 years of experience (no significant increase within each frequency was found). It is interesting to note that the other two experience groups showed a non-significant threshold shift decrease for those participants who did not wear hearing protection; this findings brought inconclusive results.

Many approaches can be taken in order understand why these last two analyses (age and experience groups) yielded inconclusive results. Participants were asked to fill out a questionnaire (Appendix D) in which several questions were posed, one of which asked whether the participants used hearing protection when operating the logging equipment. Eight out of twenty-six answered that they used hearing protection when operating the equipment, indicating that 18 out 26 participants affirmed not using hearing protection. When talking to supervisors, some said they did not think any of the workers used hearing protection at all times. Therefore, it is not a fact that participants who stated using hearing protection really did on a daily basis or have always used in the past. It is also important to note the condition of hearing protection equipment, such as ear plugs. Ear plugs should be replaced every shift; in visual judging, ear plugs did not seem to be replaced daily by some operators. The last and obvious fact is the small amount of participants who stated using hearing protection, which does help to obtain significant results. In some age or experience groups, only one participant stated a personal use hearing protection.

Thus, the final conclusions of the present study revealed that:

- A significant positive shift in hearing threshold at 1000, 2000, and 4000 Hz has been found in forest loggers operating heavy equipment.
- The hearing threshold tends to increase more rapidly at 4000 Hz and then gradually decreases as frequencies decrease, reaching a low peak at 750 Hz and then slowly increasing again.
- The use of hearing protection can be associated in minimizing positive shift in hearing threshold especially at higher frequencies such as 4000 Hz.

This study addresses the core of a health issue for forest loggers – hearing loss due to loud noises in the working environment, establishing the fact that loss of hearing occurs over

time. Enforcing stricter hearing conservation programs to ensure maximum hearing protection would not only be a health issue towards the workers, but an effective economic approach to the employer as well. This goal will benefit both United States workers and international communities, who lack proper research and resources in the safety field.

### **6.1 Recommendations for Future Studies**

Future studies of hearing threshold could implement forest loggers over a prolonged period of time. Hearing tests should be performed periodically to determine the percent hearing loss while working in the same work scenario. The effects of hearing protection on the hearing threshold on forest loggers could be performed by enforcing strict supervision in order to affirm that the hearing protection is properly worn by participants. The participant pool should be divided equally between those who use hearing protection and those who don't. A third study of the hearing threshold increase between operators of heavy logging equipment who operate with cabin windows open and operators who operate cabin windows closed on a permanent basis is recommended. This could be applied to find the results of percent hearing loss between those two groups. Another study may involve the measurement of sound frequencies emitted by logging equipment. The measurements should be performed at operators' ear level when operating the equipment. This study could associate the frequencies of hearing loss with the frequencies of noise emitted by the equipment.

## REFERENCES

- American Speech-Language-Hearing Association (2008). Noise and Hearing Loss: Noise is difficult to define! <http://www.asha.org/public/hearing/disorders/noise.htm>
- ASA Subcommittee Z24-X-2 (1954) Presbycusis curves for women and men, showing the average threshold shift for pure tones as a function of age. "The Relations of Hearing Loss to Noise Exposure," New York, pp.16-17).
- Agarwal SK (2004) Noise Pollution. *Aph Publishing Corporations* **ISBN:** 817648833X
- Babisch W, Ising H, Gallacher JEJ, Sweetnam PM, Elwood PC (1998). The Caerphilly and Speedwell studies, 10 year followup. In: Proceedings of Noise as a Public Health Problem (Vols 1, 2), (Carter NL, Job RFS, eds). Sydney, Australia: University of Sydney, 230-235.
- Barreto SM, Swerdlow AJ, Smith PG, Higgins CD (1997). A nested case-control study of fatal work related injuries among Brazilian steel workers. *Occup Environ Med* 54:599-604.
- Bauer F, Korpert K, Neuberger M, Raber A, and Schwetz F (1992) Risk-factors for hearing-loss at different frequencies in a population of 47388 noise-exposed workers. *J Acoust Soc Am*, 6, 3086\_3098.
- Berglund B; Lindvall T, Schwela D, Goh KT (1999). "World Health Organization: Guidelines for Community Noise
- Berner B, Odum L, and Parving A (2000) Age-related hearing impairment and B vitamin status. *Acta Otolaryngol*. 120(5):63-7.
- Burns W and Robinson DW (1970) Hearing and Noise in Industry. London: HMSO. 381–385.
- Carter NL (1998). Cardiovascular response to environmental noise during sleep. In: Proceedings of Noise as a Public Health Problem, Vols 1, 2 (Carter NL, Job RFS, eds). Sydney, Australia:University of Sydney; 439-444.
- Celik O, Yalcin S, and Ozturk A (1998) Hearing parameters in noise exposed industrial workers. *Auris Nasus Larynx*. Volume 25, Number 4, pp. 369-375(7)
- Chambers R, Fernanadez J, and Marley R (1989). Noise exposure of plumbers in new home construction: a case study. *Advances in Industrial Ergonomics and safety I*, pp 559-566.
- Chan LS (2009) Frequency and Loudness Response of . *BST2522 Building Environmental Science 2*, City University of Hong Kong
- Chen TJ, Chiang HC, and Chen SS (1992) Effects of aircraft noise on hearing and auditory pathway function of airport employees. *J Occup Med*. 34:613–9.
- Codd EF (1990). *The Relational Model for Database Management: Version 2*. Addison-



Wesley, p. 271

Cody AR, Johnstone BM (1981) Acoustic trauma: single neuron basis for the 'half-octave shift'. *J Acoust Soc Am*. 70:707–11.

Cohen S, Evans GW, Krantz DS, and Stokols D (1980). Physiological, motivational and cognitive effects of aircraft noise on children: moving from the laboratory to the field. *Am Psychol* 35:231-243.

Comite Europeen de Normalisation, (CEN) (1993). Hearing Protectors - Recommendations for selection, use, care and maintenance - Guidance document (CEN Standard EN 458), Brussels: CEN, pp 19.

Dai P, Yang W, and Jiang S (2004). Correlation of cochlear blood supply with mitochondrial DNA common deletion in presbycusis. *Acta Otolaryngol*. 124(2):130-6.

Daniell WE, Swan SS, McDaniel MM, Stebbins JG, Seixas NS, Morgan MS (2002) Noise exposure and hearing conservation practices in an industry with high incidence of workers' compensation claims for hearing loss. *Am J Ind Med*. 42(4):309-17.

Davies H, Marion S, and Teschke K. (2008) The impact of hearing conservation programs on incidence of noise-induced hearing loss in Canadian workers. *Am J Ind Med*. 51(12):923-31

Davis H, Morgan CT, Hawkins JE Jr, Galambos R, and Smith FW (1950) Temporary deafness following exposure to loud tones and noise. *Acta Otolaryngol Suppl* 88, 1 \_56.

De Hoop C and Lalonde N. (2003) Some Measured Levels of Noise Produced by Logging Equipment in 1998. *Louisiana Forest Products Development Center*, Working Paper #58

Ferrite S and Santana V (2005). Joint effects of smoking, noise exposure and age on hearing loss. *Occupational Medicine*. 55:48–53.

Gacek RR and Schuknecht HF (1990). Pathology of presbycusis. *Int Audiol*. 8:199.

Hasan S and Beg MHA (1994). Noise induced hearing loss in industrial workers of Karachi. Pakistan *J Otolaryngol*. 10:200–5.

Have you Heard? Hearing Loss Caused by Farm Noise is Preventable (2007) *The National Institute for Occupational Safety and Health*. No. 2007-176. <http://www.cdc.gov/niosh/>

Hong O (2005) Hearing loss among operating engineers in American construction industry. *International archives of occupational and environmental health*. 78(7):565-74.

Husqvarna USA (2009) *Professional Forest and Tree Care*. Husqvarna 3129 XO  
<[www.husqvarna.com](http://www.husqvarna.com)>

Iki M (1984). Noise-induced deafness among forestry workers using vibrating tools. (Part 1)

Epidemiological study on the relationship between noise exposure and hearing loss. *Journal of Science of Labour*. Vol. 60, no. 5, pp. 203-213.

International Organisation for Standardisation. (1990) Acoustics-Determination of occupational noise-induced hearing impairment . ISO 1999. Geneva, Switzerland: ISO.

Ising H, Babisch W, Kruppa B (1999). "Noise-Induced Endocrine Effects and Cardiovascular Risk". *Noise Health* **1** (4): 37–48.

Johansson M and Arlinger SD (2002). 'Hearing threshold levels for an otologically unscreened, nonoccupationally noise-exposed population in Sweden', *International Journal of Audiology*, 41:3, 180 — 194

K.D. Kryter (1996) *The Handbook of Hearing and the Effects of Noise: Physiology, Psychology, and Public Health*. New York Academic Press.

Karsdorf G and Klappach H. (1968). Einflüsse des Verkehrslarms auf Gesundheit und Leistung bei Oberschulern einer Grossstadt [Effects of traffic noise on health and achievement of high school students of a large city]. *Z Gesamte Hyg* 14:52-54.

Kozou H, Kujala T, Shtyrov Y, Toppila E, Starck J, Alku P, and Naatanen R (2004) The effect of different noise types on the speech and non-speech elicited mismatch negativity. *Hearing Research* 199 (2005) 31–39.

Lercher P, Hörtnagl J, Kofler WW (1993) "Work noise annoyance and blood pressure: combined effects with stressful working conditions". *Int Arch Occup Environ Health* **65** (1): 23–8.

Lutman ME and Spencer HS (1991) Occupational noise and demographic factors in hearing. *Acta Otolaryngol* , Suppl. 476, 74\_84.

Malkin R, Hudock S, Hayden C, Lentz T, Topmiller J, and Niemeier R (2005). An Assessment of Occupational Safety and Health Hazards in Selected Small Businesses Manufacturing Wood Pallets—Part 1. Noise and Physical Hazards. *Journal of Occupational and Environmental Hygiene*, Volume 2, Number 4, pp. D18-D21

Melamed S, Luz J, Green MS. (1992). Noise exposure, noise annoyance and their relation to psychological distress, accident and sick- ness absence among blue-collar workers-the Cordis Study. *Isr J Med Sci* 28:629-635.

Morrell CH, Gordon-Salant S, Pearson JD, Brant LJ, and Fozard JL (1996) Age- and gender-specific reference ranges for hearing level and longitudinal changes in hearing level. *J Acoust Soc Am*. 100(4 Pt 1):1949-67.

National Institute on Deafness and Other Communication Disorders (2008) *Noise-Induced Hearing Loss*. <http://www.nidcd.nih.gov/health/hearing/noise.asp>

Neitzel R and Seixas N (2005). The Effectiveness of Hearing Protection Among Construction Workers. *Journal of Occupational and Environmental Hygiene*, 2: 227–238

Neitzel R and Yost M (2001). Task-based assessment on occupational vibration and noise exposures in forestry workers. *The International Mountain Logging and 11<sup>th</sup> Pacific Northwest Skyline Symposium*, pp 21-27.

Occupational Safety and Health Administration (2007) *Noise*. [www.osha.gov](http://www.osha.gov)  
Occupational Safety and Health Standards (2008) Calculations and application of age corrections to audiograms. *Occupational Health and Environment Control*. Subpart G, 1910.95 App F

Passchier-Vermeer W (1993). Noise and Health [Geluid en gezondheid]. The Hague:Health Council of the Netherlands, Review. nr A93/02E.

Passchier-Vermeer W and Passchier WM (2000). Noise Exposure and Public Health. *The National Institute of Environmental Health Sciences (NIEHS)*. Vol. 108, Supplement 1: Reviews in Environmental Health, pp. 123-131.

Pickles JO (2004). Mutation in mitochondrial DNA as a cause of presbycusis. *Audiol Neurotol*. 9(1):23-33.

Pierson LL, Gerhardt KJ, Rodriguez GP, and Yanke RB (1994) Relationship between outer ear resonance and permanent noise-induced hearing loss. *Am J Otolaryngol*. 15:37–40.

Prentice (2009) *Self Loaders*. 2280 Knuckleboom Loader  
<[www.prenticeforestry.com/images/products/2280.jpg](http://www.prenticeforestry.com/images/products/2280.jpg)>

Publiquip.com. (2009) Caterpillar 525B. *Heavy Equipment*  
<[https://www.publiquip.com/Heavy\\_Equipment\\_Truck/Caterpillar-525B-Skidder--319179788.htm](https://www.publiquip.com/Heavy_Equipment_Truck/Caterpillar-525B-Skidder--319179788.htm)>

Rabinowitz PM, Galusha D, Dixon-Ernst C, Slade MD, and Cullen MR (2007). Do ambient noise exposure levels predict hearing loss in a modern industrial cohort? *Occupational and Environmental Medicine*. 64:53-59

Regecova V and Kelleroval E (1995). Effects of urban noise pollution on blood pressure and heart rate in preschool children. *J Hypertens* 13:405-412.

Tambs K, Hoffman HJ, Borchgrevink HM, Holmen J, and Engdahl B (2006). 'Hearing loss induced by occupational and impulse noise: Results on threshold shifts by frequencies, age and gender from the Nord-Trøndelag Hearing Loss Study, *International Journal of Audiology*, 45:5, 309–317.

Taoda K, Watanabe S, Nishiyama K, Fukuchi Y, and Miyakita T (1987). Survey of noise exposure level of national forestry workers. Department of Preventive Medicine, Shiga University of Medical Science, Otsu, Japan.

Taylor W, Pearson J, Mair A, and Burns W (1965) Study of noise and hearing in jute weaving. *Journal Acoust Soc Am*, 38, 113\_120.

Taylor W, Lempert B, Pelmeur P, Hemstock I, and Kershaw J (1984). Noise levels and hearing thresholds in the drop forging industry. *The Journal of the Acoustical Society of America*, Volume 76, Issue 3, pp.807-819

The Hague: Health Council of the Netherlands (1994) Committee on Noise and Health. Noise and Health [Geluid en gezondheid]. nr 1994/15E.

Thelin, J, Joseph DJ, Davis W, Baker D, and Hosokawa MC (1983) High-frequency hearing loss in male farmers of Missouri. *Public Health Rep.*; 98(3): 268–273.

Tigercat (2009) *Drive-to-Tree Feller Bunchers*. Tigercat 724E feller buncher  
<<http://www.tigercat.com/724e.htm>>

Toppila E, Pyykko I, and Starck J (2005). The use of hearing protectors among forest, shipyard and paper mill workers in Finland--a longitudinal study. *Noise and Health*. 7; 26 Page: 3-9.

Toppila E, Starck J, Philstrom A, and Pyykko I (1998). The evaluation of protection efficiency of hearing protectors for hearing conservation programs. *Advances in Noise Research*. Vol. 2. Protection against noise. Prasher D., Luxon, L., Pyykko, I. eds., Whurr Publishers Ltd, London. 167-176.

Tunay M and Melemez K (2008). Noise Induced Hearing Loss of Forest Workers in Turkey. *Pakistan Journal of Biological Sciences*. Vol: 1; Issue: 17; pp: 2144-2148

United States Environmental Protection Agency (1978). *Noise: A Health Problem* Office of Noise Abatement and Control, Washington, DC 20460.

United States Environmental Protection Agency (1978). *Noise: A Health Problem*. Office of Noise Abatement and Control, Washington, DC 20460

Villares M and Carbajo SR (2005). Lipid profile and hearing-loss aged-related. *Nutr Hosp*. 20(1):52-7.

Vincent P and Laursen B (1993) A national cross-sectional study of the working environment in the Danish wood and furniture industry – air pollution and noise. *The Annals of Occupational Hygiene*. 37 (1) pp 25-34.

Yearout R and Brown P (1991). The impact of leisure activity noise levels on the industrial worker. *Advances in Industrial Ergonomics and Safety III*, pp 617-622.

ZME Science (2008) Ear infections make fat foods sound better.  
<http://www.zmescience.com/ear-infections-make-fat-foods-sound-better>

## APPENDIX A

### AGE CORRECTION VALUES IN DECIBELS FOR MALES (OSHA, 2008)

Years	Audiometric Test Frequency (Hz)				
	1000	2000	3000	4000	6000
20 or younger.....	5	3	4	5	8
21 .....	5	3	4	5	8
22 .....	5	3	4	5	8
23 .....	5	3	4	6	9
24 .....	5	3	5	6	9
25 .....	5	3	5	7	10
26 .....	5	4	5	7	10
27 .....	5	4	6	7	11
28 .....	6	4	6	8	11
29 .....	6	4	6	8	12
30 .....	6	4	6	9	12
31 .....	6	4	7	9	13
32 .....	6	5	7	10	14
33 .....	6	5	7	10	14
34 .....	6	5	8	11	15
35 .....	7	5	8	11	15
36 .....	7	5	9	12	16
37 .....	7	6	9	12	17
38 .....	7	6	9	13	17
39 .....	7	6	10	14	18
40 .....	7	6	10	14	19
41 .....	7	6	10	14	20
42 .....	8	7	11	16	20
43 .....	8	7	12	16	21
44 .....	8	7	12	17	22
45 .....	8	7	13	18	23
46 .....	8	8	13	19	24
47 .....	8	8	14	19	24
48 .....	9	8	14	20	25
49 .....	9	9	15	21	26
50 .....	9	9	16	22	27
51 .....	9	9	16	23	28
52 .....	9	10	17	24	29
53 .....	9	10	18	25	30
54 .....	10	10	18	26	31
55 .....	10	11	19	27	32
56 .....	10	11	20	28	34
57 .....	10	11	21	29	35
58 .....	10	12	22	31	36
59 .....	11	12	22	32	37
60 or older .....	11	13	23	33	38

**APPENDIX B**

**PARTICIPANT CONSENT FORM**

## Sample Consent Form for a Non-Clinical Study

1. Study Title: Hearing Assessment of Forest Loggers
2. Performance Site: Louisiana State University and Agricultural and Mechanical College
3. Investigators: The following investigators are available for questions about this study,  
M-F, 2:00 p.m. - 4:30p.m.  
Antonio Fonseca 578-5377
4. Purpose of the Study: The objective of this study is to determine whether long term hearing loss in loggers is associated with noise emitted by logging equipment.
5. Participant Inclusion: Individuals between the ages of 20 and 60 who do not report physical, psychological, or neurological conditions.
6. Number of participants: 26
7. Study Procedures: The study will involve audiometric testing on forest loggers. This will determine the hearing capabilities of the participant. Each ear will be tested separately. Pure tones will be emitted by the audiometer with frequencies ranging from 125 Hz to 8000 Hz. The sound pressure level of the pure tone will not exceed 80 dB. The tests will determine the hearing threshold each participant can hear at a predetermined frequency of pure tone.
8. Benefits: Participants will obtain a copy of the results of their hearing capabilities.
9. Risks: The only potential risk is the unintended release of the participants' hearing threshold (hearing capabilities) results. However, each participant will have a reference name which will not involve his/her first and/or last names. Information will be kept in a secure location which only the investigator has knowledge of.
10. Right to Refuse: Participants may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.
11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Participant identity will remain confidential unless disclosure is required by law.
12. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692, [irb@lsu.edu](mailto:irb@lsu.edu), [www.lsu.edu/irb](http://www.lsu.edu/irb). I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Participant Signature: \_\_\_\_\_ Date: \_\_\_\_\_



Institutional Review Board  
Dr. Robert Mathews, Chair  
203 B-1 David Boyd Hall  
Baton Rouge, LA 70803  
P: 225.578.8692  
F: 225.578.6792  
[irb@lsu.edu](mailto:irb@lsu.edu) | [lsu.edu/irb](http://lsu.edu/irb)

**APPENDIX C**  
**LSU IRB EXEMPTION FORM**



## Application for Exemption from Institutional Oversight

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.



Institutional Review Board  
Dr. Robert Mathews, Chair  
203 B-1 David Boyd Hall  
Baton Rouge, LA 70803  
P: 225.578.8692  
F: 225.578.6792  
irb@lsu.edu | lsu.edu/irb

- Applicant, Please fill out the application in its entirety and include the completed application as well as parts A-E, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at <http://www.lsu.edu/irb/screeningmembers.shtml>
- A Complete Application Includes All of the Following:
  - (A) Two copies of this completed form and two copies of parts B thru E.
  - (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1 & 2)
  - (C) Copies of all instruments to be used.
    - If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
  - (D) The consent form that you will use in the study (see part 3 for more information.)
  - (E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB.  
Training link: ( <http://phrp.nihtraining.com/users/login.php>.)

1) Principal Investigator: Antonio A. Fonseca Rank: Teaching Assistant Student\*? Y/N Y  
Dept.: I.E. Ph: (225) 578-5377 E-mail: afonseca@lsu.edu

2) Co Investigator(s): please include department, rank, phone and e-mail for each  
\* If student, please identify and name supervising professor in this space  
Supervising Professor: Fereydoun Aghazadeh, Ph.D., P.E.  
Department: Construction Management and Industrial Engineering  
Rank: Associate Professor; Georgia Gulf Distinguished Professor  
Phone: 225-578-5367  
E-mail: aghazadeh@lsu.edu

3) Project Title: Hearing Assessment of Forest Loggers

4) LSU Proposal?(yes or no) NO If Yes, LSU Proposal Number \_\_\_\_\_  
Also, if YES, either ☐ This application completely matches the scope of work in the grant  
OR ☐ More IRB Applications will be filed later

5) Subject pool (e.g. Psychology Students) Forest Loggers, Engineering Students and Faculty  
• Circle any "vulnerable populations" to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature [Signature] \*\* Date 3/26/07 (no per signatures)  
\*\*I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted ☒ Not Exempted \_\_\_\_\_ Category/Paragraph 2  
Reviewer Mathews Signature [Signature] Date 3/26/07

Study Exempted By:  
Dr. Robert C. Mathews, Chairman  
Institutional Review Board  
Louisiana State University  
203 B-1 David Boyd Hall  
Baton Rouge, LA 70803  
225-578-8692 | [www.lsu.edu/irb](http://www.lsu.edu/irb)  
Exemption Expires: 3-25-2012

IRB# F4505 LSU Proposal# \_\_\_\_\_  
☒ Complete Application  
☒ Human Subjects Training

**APPENDIX D**  
**PARTICIPANT QUESTIONNAIRE**

Participant First Name \_\_\_\_\_

1. Age \_\_\_\_\_

2. Gender   M / F  

3. Weight \_\_\_\_\_

4. Height \_\_\_\_\_

5. Approximate time of working as tree logger?

Years \_\_\_\_\_ Months \_\_\_\_\_ Days \_\_\_\_\_

6. Hours of work per shift? \_\_\_\_\_

7. Shifts per week? \_\_\_\_\_

8. Do you wear ear protection when operating machinery?.....Yes    No

9. Do you wear ear protection at all time at worksite?.....Yes    No

10. Have you ever had an injury that lead to partial hearing loss?.....Yes    No

If yes, was the partial hearing loss permanent? .....Yes    No

11. What other jobs have you had besides tree logging?

Job: \_\_\_\_\_ Years: \_\_\_\_\_ Months \_\_\_\_\_ Days: \_\_\_\_\_

Job: \_\_\_\_\_ Years: \_\_\_\_\_ Months \_\_\_\_\_ Days: \_\_\_\_\_

Job: \_\_\_\_\_ Years: \_\_\_\_\_ Months \_\_\_\_\_ Days: \_\_\_\_\_

Job: \_\_\_\_\_ Years: \_\_\_\_\_ Months \_\_\_\_\_ Days: \_\_\_\_\_

Job: \_\_\_\_\_ Years: \_\_\_\_\_ Months \_\_\_\_\_ Days: \_\_\_\_\_

## APPENDIX E

### PARTICIPANT THRESHOLD FORM

Initials: \_\_\_\_\_

Age: \_\_\_\_\_

Age Group:      20-29      30-39      40-49      50-60

	Threshold (dB)	
Frequency (Hz)	Right Ear (red)	Left Ear (blue)
1000		
750		
2000		
500		
4000		
250		
8000		
125		

I am going to place these earphones on your ears. Through them you will hear some musical tones (beeps, whistles, noises). Some will be high, some low, and some medium. Every time you hear a tone, or think you hear a tone, raise your finger (or hand); when you no longer hear the tone, lower your finger. In which ear do you hear best? I will test that ear first. Some of these tones will be loud enough to hear, others will be very, very soft. Listen carefully. Whenever you hear the tone, or think you hear the tone, raise your finger, hold it up as long as you hear it, and when you no longer hear it, and lower your finger. Do you understand? Any questions?

Existing Injuries or Conditions:

**APPENDIX F**

**HEARING THRESHOLD OF THE PARTICIPANTS**

**125, 250, 500, 750, 1000, 2000, 4000, AND 8000 HZ**

<b>125 Hz</b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	5	5	5	5	5.0
2	26	10	10	10	10	10.0
3	27	5	5	5	5	5.0
4	29	10	10	10	10	10.0
5	33	15	25	15	25	16.7
6	35	10	15	10	15	10.8
7	35	30	15	15	30	17.5
8	38	15	45	15	45	20.0
9	38	30	30	30	30	30.0
10	39	25	20	20	25	20.8
11	40	20	15	15	20	15.8
12	42	10	10	10	10	10.0
13	43	35	45	35	45	36.7
14	44	25	25	25	25	25.0
15	47	15	20	15	20	15.8
16	48	15	15	15	15	15.0
17	48	5	5	5	5	5.0
18	50	20	15	15	20	15.8
19	52	25	20	20	25	20.8
20	53	20	15	15	20	15.8
21	54	20	55	20	55	25.8
22	54	5	5	5	5	5.0
23	54	40	25	25	40	27.5
24	54	25	15	15	25	16.7
25	59	20	20	20	20	20.0
26	59	25	25	25	25	25.0
Avg	43.2	18.5	19.6			17.0

<b>250 Hz</b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	5	5	5	5	5.0
2	26	5	5	5	5	5.0
3	27	10	0	0	10	1.7
4	29	10	10	10	10	10.0
5	33	15	15	15	15	15.0
6	35	10	10	10	10	10.0
7	35	25	10	10	25	12.5
8	38	15	50	15	50	20.8
9	38	30	25	25	30	25.8
10	39	20	15	15	20	15.8
11	40	25	15	15	25	16.7
12	42	25	10	10	25	12.5
13	43	40	40	40	40	40.0
14	44	25	25	25	25	25.0
15	47	15	15	15	15	15.0
16	48	15	10	10	15	10.8
17	48	5	0	0	5	0.8
18	50	10	15	10	15	10.8
19	52	25	20	20	25	20.8
20	53	10	15	10	15	10.8
21	54	20	45	20	45	24.2
22	54	10	0	0	10	1.7
23	54	40	25	25	40	27.5
24	54	25	15	15	25	16.7
25	59	15	20	15	20	15.8
26	59	25	25	25	25	25.0
Avg	43.2	18.3	16.9			15.2

<b><u>500 Hz</u></b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	5	5	5	5	5.0
2	26	5	5	5	5	5.0
3	27	5	5	5	5	5.0
4	29	10	5	5	10	5.8
5	33	15	25	15	25	16.7
6	35	15	15	15	15	15.0
7	35	15	15	15	15	15.0
8	38	20	35	20	35	22.5
9	38	30	20	20	30	21.7
10	39	20	20	20	20	20.0
11	40	15	5	5	15	6.7
12	42	20	10	10	20	11.7
13	43	25	30	25	30	25.8
14	44	15	10	10	15	10.8
15	47	5	5	5	5	5.0
16	48	10	10	10	10	10.0
17	48	0	0	0	0	0.0
18	50	10	10	10	10	10.0
19	52	25	20	20	25	20.8
20	53	15	5	5	15	6.7
21	54	25	45	25	45	28.3
22	54	0	0	0	0	0.0
23	54	35	15	15	35	18.3
24	54	15	5	5	15	6.7
25	59	15	15	15	15	15.0
26	59	10	5	5	10	5.8
Avg	43.2	14.6	13.1			12.1

<b><u>750 Hz</u></b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	5	5	5	5	5.0
2	26	5	5	5	5	5.0
3	27	10	0	0	10	1.7
4	29	15	10	10	15	10.8
5	33	10	15	10	15	10.8
6	35	15	20	15	20	15.8
7	35	15	15	15	15	15.0
8	38	15	35	15	35	18.3
9	38	15	10	10	15	10.8
10	39	20	15	15	20	15.8
11	40	5	5	5	5	5.0
12	42	30	15	15	30	17.5
13	43	20	20	20	20	20.0
14	44	10	5	5	10	5.8
15	47	5	0	0	5	0.8
16	48	10	10	10	10	10.0
17	48	10	5	5	10	5.8
18	50	15	15	15	15	15.0
19	52	25	25	25	25	25.0
20	53	5	10	5	10	5.8
21	54	30	55	30	55	34.2
22	54	5	5	5	5	5.0
23	54	25	15	15	25	16.7
24	54	15	10	10	15	10.8
25	59	15	15	15	15	15.0
26	59	15	10	10	15	10.8
Avg	43.2	14.0	13.5			12.0

<b>1000 Hz</b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	0	5	0	5	0.8
2	26	5	5	5	5	5.0
3	27	5	10	5	10	5.8
4	29	10	10	10	10	10.0
5	33	10	15	10	15	10.8
6	35	15	15	15	15	15.0
7	35	20	15	15	20	15.8
8	38	20	30	20	30	21.7
9	38	15	10	10	15	10.8
10	39	20	20	20	20	20.0
11	40	0	10	0	10	1.7
12	42	30	20	20	30	21.7
13	43	20	20	20	20	20.0
14	44	10	10	10	10	10.0
15	47	0	5	0	5	0.8
16	48	10	5	5	10	5.8
17	48	15	0	0	15	2.5
18	50	15	15	15	15	15.0
19	52	20	25	20	25	20.8
20	53	10	10	10	10	10.0
21	54	30	45	30	45	32.5
22	54	5	5	5	5	5.0
23	54	20	15	15	20	15.8
24	54	35	25	25	35	26.7
25	59	15	15	15	15	15.0
26	59	20	15	15	20	15.8
Avg	43.2	14.4	14.4	12.1	16.7	12.9

<b>2000 Hz</b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	0	0	0	0	0.0
2	26	5	5	5	5	5.0
3	27	5	0	0	5	0.8
4	29	5	5	5	5	5.0
5	33	10	15	10	15	10.8
6	35	25	25	25	25	25.0
7	35	30	30	30	30	30.0
8	38	10	45	10	45	15.8
9	38	10	10	10	10	10.0
10	39	20	20	20	20	20.0
11	40	5	5	5	5	5.0
12	42	30	40	30	40	31.7
13	43	15	30	15	30	17.5
14	44	10	15	10	15	10.8
15	47	0	5	0	5	0.8
16	48	10	5	5	10	5.8
17	48	10	15	10	15	10.8
18	50	30	20	20	30	21.7
19	52	35	35	35	35	35.0
20	53	15	50	15	50	20.8
21	54	15	50	15	50	20.8
22	54	5	5	5	5	5.0
23	54	10	25	10	25	12.5
24	54	55	55	55	55	55.0
25	59	15	50	15	50	20.8
26	59	40	55	40	55	42.5
Avg	43.2	16.2	23.7	15.4	24.4	16.9

<b>4000 Hz</b>						
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.
1	23	5	10	5	10	5.8
2	26	10	15	10	15	10.8
3	27	15	0	0	15	2.5
4	29	20	15	15	20	15.8
5	33	45	40	40	45	40.8
6	35	25	35	25	35	26.7
7	35	70	75	70	75	70.8
8	38	30	45	30	45	32.5
9	38	20	25	20	25	20.8
10	39	30	20	20	30	21.7
11	40	35	40	35	40	35.8
12	42	55	55	55	55	55.0
13	43	75	65	65	75	66.7
14	44	25	30	25	30	25.8
15	47	40	15	15	40	19.2
16	48	35	25	25	35	26.7
17	48	10	15	10	15	10.8
18	50	60	50	50	60	51.7
19	52	65	65	65	65	65.0
20	53	40	70	40	70	45.0
21	54	25	85	25	85	35.0
22	54	25	15	15	25	16.7
23	54	50	55	50	55	50.8
24	54	60	55	55	60	55.8
25	59	75	70	70	75	70.8
26	59	50	55	50	55	50.8
Avg	43.2	38.3	40.2	34.0	44.4	35.8

<b>8000 Hz</b>							
	Age	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T (avg)	S.L.T.
1	23	0	0	0	0	0.0	0.0
2	26	5	5	5	5	5.0	5.0
3	27	0	0	0	0	0.0	0.0
4	29	5	0	0	5	2.5	0.8
5	33	10	10	10	10	10.0	10.0
6	35	0	0	0	0	0.0	0.0
7	35	15	5	5	15	10.0	6.7
8	38	0	30	0	30	15.0	5.0
9	38	10	5	5	10	7.5	5.8
10	39	20	10	10	20	15.0	11.7
11	40	0	5	0	5	2.5	0.8
12	42	50	50	50	50	50.0	50.0
13	43	70	50	50	70	60.0	53.3
14	44	15	25	15	25	20.0	16.7
15	47	10	5	5	10	7.5	5.8
16	48	20	20	20	20	20.0	20.0
17	48	5	0	0	5	2.5	0.8
18	50	20	40	20	40	30.0	23.3
19	52	55	65	55	65	60.0	56.7
20	53	25	55	25	55	40.0	30.0
21	54	30	110	30	110	70.0	43.3
22	54	10	15	10	15	12.5	10.8
23	54	15	25	15	25	20.0	16.7
24	54	20	30	20	30	25.0	21.7
25	59	80	55	55	80	67.5	59.2
26	59	55	50	50	55	52.5	50.8
Avg	43.2	21.0	25.6			23.3	19.4



**APPENDIX G**  
**HEARING THRESHOLD SHIFTS**  
**1000, 2000, AND 4000 HZ**

<b>1000 Hz</b>								
	Age	S.L.T (OSHA)	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.	HTS
1	23	5	0	5	0	5	0.8	-4.2
2	26	5	5	5	5	5	5.0	0.0
3	27	5	5	10	5	10	5.8	0.8
4	29	6	10	10	10	10	10.0	4.0
5	33	6	10	15	10	15	10.8	4.8
6	35	7	15	15	15	15	15.0	8.0
7	35	7	20	15	15	20	15.8	8.8
8	38	7	20	30	20	30	21.7	14.7
9	38	7	15	10	10	15	10.8	3.8
10	39	7	20	20	20	20	20.0	13.0
11	40	7	0	10	0	10	1.7	-5.3
12	42	8	30	20	20	30	21.7	13.7
13	43	8	20	20	20	20	20.0	12.0
14	44	8	10	10	10	10	10.0	2.0
15	47	8	0	5	0	5	0.8	-7.2
16	48	9	10	5	5	10	5.8	-3.2
17	48	9	15	0	0	15	2.5	-6.5
18	50	9	15	15	15	15	15.0	6.0
19	52	9	20	25	20	25	20.8	11.8
20	53	9	10	10	10	10	10.0	1.0
21	54	10	30	45	30	45	32.5	22.5
22	54	10	5	5	5	5	5.0	-5.0
23	54	10	20	15	15	20	15.8	5.8
24	54	10	35	25	25	35	26.7	16.7
25	59	11	15	15	15	15	15.0	4.0
26	59	11	20	15	15	20	15.8	4.8
Avg	43.2	8.0	14.4	14.4	12.1	16.7	12.9	4.9
							T-Test	0.003

<b>2000 Hz</b>								
	Age	S.L.T (OSHA)	S.L.T (right)	S.L.T (left)	Min	Max	S.L.T.	HTS
1	23	3	0	0	0	0	0.0	-3.0
2	26	4	5	5	5	5	5.0	1.0
3	27	4	5	0	0	5	0.8	-3.2
4	29	4	5	5	5	5	5.0	1.0
5	33	5	10	15	10	15	10.8	5.8
6	35	5	25	25	25	25	25.0	20.0
7	35	5	30	30	30	30	30.0	25.0
8	38	6	10	45	10	45	15.8	9.8
9	38	6	10	10	10	10	10.0	4.0
10	39	6	20	20	20	20	20.0	14.0
11	40	6	5	5	5	5	5.0	-1.0
12	42	7	30	40	30	40	31.7	24.7
13	43	7	15	30	15	30	17.5	10.5
14	44	7	10	15	10	15	10.8	3.8
15	47	8	0	5	0	5	0.8	-7.2
16	48	8	10	5	5	10	5.8	-2.2
17	48	8	10	15	10	15	10.8	2.8
18	50	9	30	20	20	30	21.7	12.7
19	52	10	35	35	35	35	35.0	25.0
20	53	10	15	50	15	50	20.8	10.8
21	54	10	15	50	15	50	20.8	10.8
22	54	10	5	5	5	5	5.0	-5.0
23	54	10	10	25	10	25	12.5	2.5
24	54	10	55	55	55	55	55.0	45.0
25	59	12	15	50	15	50	20.8	8.8
26	59	12	40	55	40	55	42.5	30.5
Avg	43.2	7.4	16.2	23.7	15.4	24.4	16.9	9.5
							T-Test	0.001

<b>4000 Hz</b>								
	<b>Age</b>	<b>S.L.T (OSHA)</b>	<b>S.L.T (right)</b>	<b>S.L.T (left)</b>	<b>Min</b>	<b>Max</b>	<b>S.L.T.</b>	<b>HTS</b>
<b>1</b>	23	6	5	10	5	10	5.8	-0.2
<b>2</b>	26	7	10	15	10	15	10.8	3.8
<b>3</b>	27	7	15	0	0	15	2.5	-4.5
<b>4</b>	29	8	20	15	15	20	15.8	7.8
<b>5</b>	33	10	45	40	40	45	40.8	30.8
<b>6</b>	35	11	25	35	25	35	26.7	15.7
<b>7</b>	35	11	70	75	70	75	70.8	59.8
<b>8</b>	38	13	30	45	30	45	32.5	19.5
<b>9</b>	38	13	20	25	20	25	20.8	7.8
<b>10</b>	39	14	30	20	20	30	21.7	7.7
<b>11</b>	40	14	35	40	35	40	35.8	21.8
<b>12</b>	42	16	55	55	55	55	55.0	39.0
<b>13</b>	43	16	75	65	65	75	66.7	50.7
<b>14</b>	44	17	25	30	25	30	25.8	8.8
<b>15</b>	47	19	40	15	15	40	19.2	0.2
<b>16</b>	48	20	35	25	25	35	26.7	6.7
<b>17</b>	48	20	10	15	10	15	10.8	-9.2
<b>18</b>	50	22	60	50	50	60	51.7	29.7
<b>19</b>	52	24	65	65	65	65	65.0	41.0
<b>20</b>	53	25	40	70	40	70	45.0	20.0
<b>21</b>	54	26	25	85	25	85	35.0	9.0
<b>22</b>	54	26	25	15	15	25	16.7	-9.3
<b>23</b>	54	26	50	55	50	55	50.8	24.8
<b>24</b>	54	26	60	55	55	60	55.8	29.8
<b>25</b>	59	32	75	70	70	75	70.8	38.8
<b>26</b>	59	32	50	55	50	55	50.8	18.8
<b>Avg</b>	<b>43.2</b>	<b>17.7</b>	<b>38.3</b>	<b>40.2</b>	<b>34.0</b>	<b>44.4</b>	<b>35.8</b>	<b>18.0</b>
							<b>T-Test</b>	<b>0.000</b>

## APPENDIX H

### MICROBAR VS DECIBEL TABLE

Comparison of sound pressure (microbar) with sound pressure level (dB) and recognized sources of noise in our daily experiences (Agarwal, 2004).

Sound pressure, $\mu\text{bar}$	SPL, dBA	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	Studio for sound pictures
0.0063	30	Studio for speech broadcasting
0.02	40	Very quiet room
0.063	50	Residence
0.2	60	Conventional speech
0.63	70	Street traffic at 100 ft
1.0	74	Passing automobile at 20 ft
2.0	80	Light trucks at 20 ft
6.3	90	Subway at 20 ft
20	100	Looms in textile mill
63	110	Loud motorcycle at 20 ft
200	120	Peak level from rock and roll band
2,000	140	Jet plane on the ground at 20 ft

## **VITA**

Antonio Fonseca was born in San Pedro Sula, Honduras, in August, 1985. San Pedro Sula is known as the Industrial Capital of Honduras. Most of the textile companies in the country are located around the city. He was raised in this city and graduated from high school at the Escuela Internacional Sampedrana (International School of San Pedro Sula) in June of 2003.

He completed his undergraduate studies at Louisiana State University in the spring of 2007. He earned a degree in industrial engineering with minors in occupational health and safety and business administration.

He joined the Department of Industrial Engineering and as a graduate student in the fall of 2007. He worked for the department as a graduate assistant. He expects to receive a Master of Science in Industrial Engineering degree in the fall of 2009.