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Tinnitus as an Early Warning Sign of Noise-Induced Hearing Loss in Industrial Workers

Brennen Karl
University of Northern Colorado

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

TINNITUS AS AN EARLY WARNING SIGN OF NOISE-INDUCED HEARING LOSS IN INDUSTRIAL WORKERS

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Brennen Karl

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Accepted by the Capstone Research Committee

____
Deanna K. Meinke, Ph.D., CCC-A, Research Advisor

____
Donald S. Finan, Ph.D., Committee Member

____
Gregory A. Flamme Ph.D., Committee Member

Accepted by the Graduate School

____
Jeri-Anne Lyons, Ph.D.
Dean of the Graduate School
Associate Vice President of Research

ABSTRACT

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Occupational noise-induced hearing loss (NIHL) and tinnitus are two major health concerns that have high economic and personal costs for industrial workers in the United States. To monitor for NIHL in the workplace, employers are required to provide annual hearing tests for noise-exposed employees. Currently, workplace intervention to prevent NIHL is based upon the identification of a worsening of hearing thresholds called “significant threshold shifts” (STS) using various formulae.

Few studies have inspected the temporal relationship between the self-reporting of tinnitus and the identification of noise-induced hearing shifts in workers. The only study that appeared to have examined this relationship in detail was Griest and Bishop (1998). This current study was designed to expand upon Griest and Bishop and examine the prevalence and temporal relationship between the presence of self-reported severe tinnitus and the identification of an audiometric shift indicator of a significant change in hearing thresholds— Occupational Safety and Health Association (OSHA), standard threshold shift (OSTS), OSHA STS with age correction (OSTS-A), National Institute for Occupational Safety and Health (NIOSH) STS (NSTS), and the Griest and Bishop (1998) 4kHz maximum threshold shift (4KMax), suggestive of noise-induced hearing loss.

This was accomplished by analyzing a de-identified data set containing audiometric thresholds and otologic case histories including a single question asking about the presence of severe tinnitus from 146,792 industrial workers collected as part of OSHA (1983) or U.S. Mine Safety and Health Administration (1999) mandated hearing conservation programs from 1970 through 2020. The results of the temporal analysis of 1,766 workers with “severe tinnitus” indicated that with each of the four STS criteria, the STS condition was met significantly ($p \leq .01$) earlier than the self-report of severe tinnitus. Using the 4kMax criteria indicated the shortest mean lag time from an STS to a self-report of tinnitus, with a mean of 1.1 years, while the OSTS-A method resulted in the longest mean lag time of 2.3 years. These results underscored the existence of a temporal relationship between the development of NIHL and the onset of severe tinnitus in noise-exposed workers, which indicated a need for more tinnitus focused prevention and management in hearing conservation programs.

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LIST OF ABBREVIATIONS

4kMax: Griest & Bishop 4kHz Maximum Threshold Shift

AAOHNS: American Association of Otolaryngology, Head-Neck Surgery

ANSI: American National Standards Institute

AOR: Adjusted Odds Ratio

CAOHC: Council for Accreditation in Occupational Hearing Conservation

CI: Cochlear Implant

CRA: Comparative Risk Assessment

dBA: A-weighted Decibel

dB HL: Hearing Level Decibel

FRA: Federal Railroad Administration

HCP: Hearing Conservation Program

HLPP: Hearing Loss Prevention Program

HPD: Hearing Protective Device

HTL: Hearing Threshold Level

MSHA: Mine Safety and Health Administration

NIHL: Noise-Induced Hearing Loss

NIOSH: National Institutes of Occupational Safety and Health

NSTS: NIOSH Significant Threshold Shift

OHC: Outer Hair Cell

OHL: Occupational Hearing Loss

OSHA: Occupational Safety and Health Administration

OSTS-A: Age Corrected OSTS

OSTS: OSHA Standard Threshold Shift

PEL: Permissible Exposure Limit

PS: Professional Supervisor

REL: Recommended Exposure Limit

SPL: Sound Pressure Level

STS: Standard Threshold Shift

THI: Tinnitus Handicap Inventory

TWA: Time-weighted Average

VA: Veterans Affairs

WHO: World Health Organization

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Occupational noise-induced hearing loss (NIHL) and tinnitus are two major health concerns for workers in the United States. The U.S. Centers for Disease Control and Prevention (as cited in Carroll et al., 2017) estimated that NIHL affects around 24% of the adult population. Over 30 million U.S. industrial workers are exposed to hazardous levels of noise. As such, this population is at risk for NIHL (Carroll et al., 2017; National Institute for Occupational Safety and Health [NIOSH], 1998). The prevalence of tinnitus in adults is notable as well; researchers have estimated the prevalence ranges from 5% to 43% depending on how tinnitus is defined (Gibrin et al., 2013; Quaranta et al.,1996; Sindhusake et al., 2003; Sugiura et al., 2008; Welch & Dawes, 2008).

The economic cost of NIHL and tinnitus is high and presents a difficult challenge for worker's compensation claims and for the U.S. Department of Veterans Affairs (VA). The NIOSH (2014) estimated that $242 million was spent toward worker's compensation claims for disabilities attributed to NIHL each year. The VA (2018) reported that in 2017, the two most prevalent worker compensation claims for veterans were tinnitus and hearing loss.

Noise-induced hearing loss and tinnitus could result in high personal costs for workers as well. These health concerns could result in workers experiencing increased difficulty with communication and with localizing sound sources. This could increase the risk of workplace accidents around heavy machinery and equipment (Hétu et al., 1995). Hétu et al. (1995) also found stigmas surrounding hearing loss could affect the self-images of workers with NIHL, leading to changes in behavior such as avoidance of everyday activities, isolation, restricted social participation, and a reduced autonomy.

To monitor for NIHL in the workplace, employers are required to provide access to annual hearing tests for noise-exposed employees and ensure these employees are each evaluated. Early identification of NIHL provides an opportunity to intervene before the hearing loss can further progress. Currently, workplace intervention is based upon a worsening (shift) of hearing thresholds that might be either temporary or permanent at the time.

To determine whether a shift in hearing threshold has occurred, a significant threshold shift (STS) can be calculated. Multiple audiometric shift criteria might be used for calculating an STS. This capstone used four such methods: the Occupational Safety and Health Association (OSHA) STS (OSTS), OSHA STS with age correction (OSTS-A), NIOSH STS (NSTS), and the Griest and Bishop 4kHz maximum threshold shift (4KMax). The OSHA method calculated an STS by finding an average shift of at least 10 dB from the baseline hearing thresholds at 2000, 3000, and 4000 Hz in either of the two ears (OSHA, 1983). Additionally, OSHA (1983) allowed the option to apply an age adjustment to allow for the effects of aging using values found in the OSHA 29 CFR 1910.95 Appendix F. Per NIOSH (1998), a shift of at least 15 dB from the baseline hearing thresholds at any frequency might be calculated as an STS.

Otologic history questions are often asked during annual hearing examinations and self-reports of ear pain, tinnitus, and/or ear fullness might be recorded by the audiologist or audiometric technician. Vernon (1977) recognized the potential for tinnitus to signal a risk of permanent noise-induced hearing loss.

Few studies have inspected the temporal relationship between the self-reporting of tinnitus and the identification of NIHL in workers. The only study that appeared to have examined this relationship in detail was Griest and Bishop (1998). In this study, the researchers examined 15 years of longitudinal data from 91 workers enrolled in a hearing conservation program provided by a single employer. The researchers found 30% of the workers reported tinnitus symptoms with at least a single occurrence during the previous 15 years and 74% of the workers first reported tinnitus before a maximum hearing threshold shift occurred. The researchers defined a maximum threshold shift as the greatest shift in hearing threshold that occurred during the study period at 4000 Hz in the left ear. Based on these results, the researchers suggested the presence of self-reported tinnitus on a worker's health history questionnaire might prove to be a useful early indicator of noise-induced hearing loss that should be evaluated immediately at the time of a worker's annual audiometric testing to prevent further progression (Griest & Bishop, 1998).

This capstone project expanded on the study by Griest and Bishop (1998) using an existing occupational audiometric database from multiple employers to further examine the prevalence and temporal relationship between the presence of self-reported tinnitus symptoms and the presence of an audiometric indicator of a significant change in hearing thresholds, suggestive of noise-induced hearing loss. If there was a relationship, self-reported tinnitus might provide an opportunity to implement intervention strategies to help protect millions of workers from the high professional, personal, and monetary costs associated with noise-induced hearing loss.

Occupational NIHL and tinnitus are two major health concerns which affect industrial workers exposed to hazardous levels of noise. The economic and personal costs of NIHL and tinnitus are high and can impact worker communication, safety, and self-images. Workplace intervention to reduce the risk of NIHL includes annual hearing tests for noise exposed workers as well as enrollment in hearing conservation programs. To determine a worsening shift in hearing thresholds, multiple STS formulae can be calculated, such as an OSTS, OSTS-A, NSTS, and a 4KMax. Otologic history questions asked during annual hearing evaluations often ask about the presence of tinnitus, which has the potential to signal a risk of permanent noise-induced hearing loss. This capstone project expanded on Griest & Bishop (1998), which was the only study in the literature which appeared to have examined the temporal relationship between self-reporting of tinnitus and the identification of NIHL in workers.

Research Questions

Q1 What is the prevalence of self-reported tinnitus compared to confirmed audiometric shift criteria: OSHA STS, OSHA STS-A, NIOSH STS, and the Griest & Bishop 4 kHz maximum threshold shift (4kMax)

Q2 What is the temporal relationship between self-reported tinnitus to audiometric hearing shift criteria: an OSHA STS, OSHA STS-A, NIOSH STS, and the Griest & Bishop 4 kHz maximum threshold shift (4kMax)

CHAPTER II

REVIEW OF THE LITERATURE

Overview of Noise-Induced Hearing Loss

A NIHL is an impairment due to physiological damage to the auditory system caused by repetitive long-term exposure to hazardous sound levels encountered in the environment or workplace. The U.S. Centers for Disease Control and Prevention (CDC; as cited in Carroll et al., 2017) estimated that almost one in four (24%) of the adult population in the United States has NIHL. Industrial workers are especially at high risk for NIHL; over 30 million workers in the United States are exposed to hazardous noise levels based on an 85 decibel (dB) eight-hour time weighted average (TWA; NIOSH, 1998). Both NIHL and exposure to high level noise are risk factors linked to workers reporting tinnitus symptoms—a ringing sensation in the ears (Axelsson & Prasher, 2000; Frederiksen et al., 2017; Henry et al., 2005; Vernon, 1977).

Multiple causes of hearing loss that are not preventable or difficult to prevent include presbycusis (the natural loss of hearing due to aging), Meniere's disease, ototoxicity, otosclerosis, and tumors on the auditory nerve. However, NIHL is preventable. There are two types of NIHL: gradual onset NIHL and acoustic trauma (Royster, 1996b). Gradual onset NIHL is caused by continuous high-level sound exposures from machinery in a workplace or repetitive exposure to impact/impulse noise. Acoustic trauma generally refers to instantaneous hearing loss due to exposure to sounds exceeding 150-160 dB. Brief extremely high-level sounds including both impact and impulse noises can cause NIHL too. An impact noise is a high-intensity sound that comes from objects such as machinery or metal slamming parts together and the resulting free vibration that follows collision. An impulse noise is a short burst of high-intensity sound from a rapid release of energy such as gunfire or explosions. Occupational workers exposed to brief high-level sounds are at risk for immediate damage to the auditory system. Repeated exposure to brief high-level sounds increases this risk. Additionally, brief high-level noises are often present in areas in which continuous noise is also present (Flamme & Murphy, 2021 in press). The fact that brief high-level noise can cause instantaneous and permanent hearing loss is not novel information (Coles et al., 1967, 1968; Murray & Reid, 1946) but research to assess the risk of it is underdeveloped and difficult to approach. To assess the risk of these sounds in human subjects, participants would be subjected more than minimal risk and measuring these sounds in a laboratory setting is difficult to do (Flamme & Murphy, In Press). Both gradual onset NIHL and acoustic trauma can damage multiple areas of the auditory system including sensory hair cells within the cochlea, neurons in the spiral ganglion, auditory nerve endings, and even the inner ear vascular supply (Henderson et al., 2007; Henderson & Hamernik, 1995; Kujawa & Liberman, 2015).

The most common cause of NIHL is occupational noise exposure (Brookhouser et al., 1992). According to OSHA (2017), in 2016, U.S. businesses paid over $1.5 million in penalties for failure to protect employees from harmful noise exposure. Occupational Safety and Health Association estimates that every year, $242 million is spent toward worker's compensation for disabilities caused by NIHL. Due to the high prevalence and costs of occupational NIHL, multiple governmental health and safety organizations have set guidelines and standards to help employers prevent such hearing loss. Although these governing bodies all deal with hearing loss, their scopes do not overlap. U.S. organizations include the OSHA (1983), the U.S. Mine Safety and Health Administration (MSHA, 1999), and the U.S. Federal Railroad Administration (FRA, 2006). Both FRA and MSHA follow the same exposure criteria as OSHA. Another major U.S. federal agency is NIOSH (1998). The NIOSH is charged with informing the evidence-based best practice for hearing loss prevention and their most recent guideline was published in 1998.

To understand these governmental policies and recommendations, it is important to note how noise exposures are measured. Hazardous noise levels are measured in decibel units; more specifically, A-weighted decibel (dBA) sound pressure level (SPL). A-weighting is a filter applied to sound measurement devices to account for the relative loudness the human ear perceives at low levels. This weighting cuts off the lower and higher frequencies human ears are less sensitive to. The use of A-weighting is also similar to the transfer function of the middle ear (Hohmann, 2015). The transfer function of the middle ear refers to the ratio of sound pressure at the tympanic membrane to the sound pressure at the stapes footplate (Aibara et al., 2001). Noise exposure integrates sound levels and time. The average noise exposure over an eight-hour period is termed a TWA. Repeated exposure to ≥85 dBA TWA has the potential to cause hearing loss. The OSHA (1983) standard integrates noise levels using a 5 dB exchange rate. The exchange rate means that for every 5 dB increase in sound, the maximum allowable time exposure is halved. The OSHA permits workers to be exposed to 90 dBA for eight hours. These regulations state that employees exposed to TWA noise levels above 90 dBA are required to wear hearing protection while in the workplace. In addition, employees who are exposed to noises at or above 85 dBA TWA must be enrolled in a hearing loss prevention program. The NIOSH (1998) is responsible for conducting research and making recommendations for the prevention of work-related injury and illness. The NIOSH recommended exposure limit (REL) is more conservative than OSHA's permissible exposure limit (PEL). The NIOSH REL is 85 dBA for eight hours and integrated with a 3 dB exchange rate, meaning that for every 3 dB increase above 85 dBA, the maximum allowable listening time is halved. The NIOSH suggests workers exposed at or above the REL be included in a hearing loss prevention program (HLPP). The OSHA terms such programs 'hearing conservation programs' or HCPs.

An important part of preventing NIHL relies upon enrolling workers into an HLPP. A hearing loss prevention program is comprised of several components: noise measurement, noise control, selecting, fitting and use of hearing protection, audiometric monitoring, and worker training. Required baseline audiometric testing is either transferred from a prior employer or obtained at or near a worker's date of hire. This worker is then tested annually thereafter. Those who perform these audiometric tests are responsible for sharing the test data with a professional supervisor, who might be a primary care physician or physician specializing in occupational health, but is more frequently an audiologist or otolaryngologist (Schaible & Swisher, 2014). Another important part of audiometric monitoring is to note other otologic symptoms that might be related to the use of hearing protection or hearing loss and make appropriate medical referrals for care. Referral conditions are specified by the American Academy of Otolaryngology: Head-Neck Surgery (AAOHNS, 1983) and include hearing loss with a history of ear infections and/or noise exposure, ear or head trauma, history of pain or bleeding from ear, sudden or rapidly progressing hearing loss, reoccurring episodes of dizziness, congenital or traumatic deformation of the ear, visible foreign body or blood in the ear canal, unexplained conductive hearing loss, abnormal tympanogram, asymmetric hearing loss, and unilateral or pulsatile tinnitus (AAOHNS, 2016). Referral conditions set by OSHA (1983) indicated a referral should be made if further testing is necessary and/or if an employer suspects a medical pathology of the ear is either worsened or created by hearing protection devices. Simpson et al. (1995) reported that occupational HCPs that use AAOHNS referral criteria might identify about 50% of 'red flags' for referral such as asymmetric hearing results, hearing thresholds above 25 dBHL, and changes in low or high frequency thresholds to be false-positives when retests are used to confirm prior results. This could help reduce over-referring. One symptom related to hearing loss AAOHNS (2016) listed as a condition that might be grounds for referral is the presence of tinnitus. Therefore, many programs ask workers to self-report the presence of tinnitus.

Overview of Tinnitus

Types of Tinnitus

Tinnitus is the perception of sounds with an absence of external stimulus (Frederiksen et al., 2017; Henry et al., 2005; Zenner et al., 2017). This perceived sound is often described as a high-pitched ringing or a cricket-like chirping and can be either constant or pulsating. It can be permanent or temporary as well as constant or intermittent. There are two main types of tinnitus: subjective and objective tinnitus. A patient can hear their objective tinnitus; a clinician can hear a patient's objective tinnitus as well, usually with the use of a stethoscope. Subjective tinnitus, however, is only perceived by the patient with the symptoms (Moller et al., 2016). Subjective tinnitus is classified by the patient's description of intensity and character (high frequency, low frequency, constant, intermittent, pulsatile) as well as if the symptoms are unilateral, bilateral, or whether it could be manipulated by moving the jaw, the eyes, or by applying pressure to the neck.

Hazell (1995) disagreed with these definitions and expressed that tinnitus is always subjective and, therefore, must be distinguished instead by if it is somatic or neurophysiological in origin. Somatic tinnitus is generated from blood flowing through the vascular system as well as from muscular, respiratory, or temporomandibular origin. These might be caused by contraction of muscles of the head and neck, disorders of the temporomandibular joint, or upper respiratory infection, respectively. The presence of somatic sounds is often a sign of an underlying medical condition such as vascular lesions, intracranial hypertension, and high cardiac activity or heart rate that warrant medical attention.

Subjective, or neurophysiological, tinnitus stems from abnormal neural activity along the eighth cranial nerve that is not caused by sound activation of the hair cells in the cochlea. Therefore, this type of tinnitus is likened to ‘phantom sounds,’ similar to ‘phantom limb’ symptoms and central neuropathic pain (Moller et al., 2016). High intensities of sound could damage tip links that hold outer hair cell (OHC) stereocilia together into hair cell bundles in the cochlea. Hair cell loss and/or damage caused by repeated exposure to loud noise levels could disrupt the efferent innervation, altering inhibitory auditory feedback. This disrupts the inhibitory and excitatory events, which could enhance spontaneous auditory nerve activity. It is also possible (although a less accepted theory) that permanent damage to the OHC causes a self-sustaining contraction of the OHC cell body, which causes spontaneous phantom sounds, triggering tinnitus symptoms (Saunders, 2007). Another theory about the generation of tinnitus is the central gain theory. In the central auditory system, there might be hyperactivity of neural firing meant to maintain neural homeostasis and adapt sensitivity to the reduced sensory inputs due to hearing loss. This increased sensitivity could result in an amplification of neural noise in addition to amplification of external sounds, which could result in the creation of tinnitus (Auerbach et al., 2014; Norena, 2011).

Prevalence of Tinnitus

The prevalence of tinnitus has been estimated based on data from multiple sources including research studies, census reports, and epidemiologic studies from around the world. These studies and reports did not have a standard way to ask about the presence of tinnitus and often did not differentiate between pathologic tinnitus and normal transient ear noises experienced by most individuals from time to time. Due to these limitations and methodological differences, researchers have estimated varied prevalence ranges for tinnitus in adults including 5-6% (Quaranta et al.,1996; Welch & Dawes, 2008), 10%-15% (Carroll et al., 2017; Fujii et al., 2011; Henry et al., 2005), and 20-26% (Nondahl et al., 2007; Shargorodsky et al., 2011; Xu et al., 2011), and even 30-43% (Gibrin et al., 2013; Sindhusake et al., 2003; Sugiura et al., 2008).

Bhatt et al. (2016) performed a cross-sectional analysis of the 2007 National Health Interview Survey that included 75,764 subjects and identified a sample of adults, 18 years and older, who had reported tinnitus in the preceding 12 months. Twenty-five percent of the participants with tinnitus reported a history of consistent loud noise exposure at work. These participants with regular noise exposure at the workplace had a prevalence of tinnitus at 19.2% while those without the history of work-related noise exposure had a tinnitus prevalence of 6.8%.

Nelson et al. (2005) used the World Health Organization's comparative risk assessment methodology to determine causes of disabling hearing loss in the world. The World Health Organization's 191 member states were organized into six geographical regions (the Western Pacific region, Southeast Asia, Eastern Mediterranean, Europe, Americas, and Africa). The researchers found that throughout the world, an average of 16% of disabling hearing loss could be attributed to occupational noise. Both the lowest and highest percentages were from the same geographical region. The low-end of the range (7%) came from one subregion of the Western Pacific and the highest value (21%) came from a different subregion of the Western Pacific region. Table 1 summarized the prevalence of tinnitus by U.S. study.

Table 1

Demographic Summary of Tinnitus Prevalence

	Karl (2021)	Kim et al. (2015)	Bhatt et al. (2016).	Fujii et al. (2011).	Shargorodsky et al. (2011)
			Tinnitus Prevalence (%)		
Gender					
Male	2.2	-	10.5	13.2	26.1
Female	0.4	-	8.8	10.7	24.6
Age Group (Years)					
20-29	0.8	-	**Least Prevalent**	-	-
30-39	0.9 **Most Prevalent**	-	-	-	21.6
30+	-	-	-	-	20.2
40-49	0.6	-	-	-	4.4 **Least Prevalent**
45-49	-	(45-59) 16.0 **Least Prevalent**	-	(45-49) 9.4 **Least Prevalent**	-
50-59	0.3	-	-	10.8	30.0
60-69	0.03 **Least Prevalent**	-	**Most Prevalent**	14.8	31.4 **Most Prevalent**
70-79	**-**	**-**	**-**	15.5 **Most Prevalent**	30.3
80+	-	36.0 **Most Prevalent**	**-**	**-**	28.1

Risk of Tinnitus

Kim et al. (2015) investigated the association of tinnitus in relation to different risk factors. The researchers analyzed data from the Korean National Health and Nutrition Examination Surveys (KNHANES) from 2009-2012. The data from 19,290 participants (8,244 male and 11,046 female) were included in the study. The study population ranged in age from 20 to 98 years old with a mean age of 45.49±0.21 years. The prevalence of tinnitus increased with age; the lowest prevalence was 16% in the 45-49 age group and highest at 36% in the 85 years and above age group. All age groups below 50 years old had a prevalence below 20%. Hearing loss and noise exposure increased the risk of tinnitus. The researchers defined hearing loss at hearing threshold average of above 25 dB at 500, 1000, 2000, and 4000 Hz. Hearing loss above 25 decibel hearing level (dB HL) increased the adjusted odds ratio (AOR) of tinnitus. Females had a higher AOR for tinnitus than males. The AOR was 1.0 for males (the reference group) in both simple and multiple logistic regression analysis, 1.32 for females for simple logistic regression, and 1.32 for females for multiple logistic regression ($p < 0.001$) with confidence intervals of 95%. The risk of tinnitus varied among occupations with workplace noise, indicating an increased risk. Those who experienced workplace noise exposure for over three months had an increased AOR of 1.28 when compared to the reference group; those who did not have over three months of workplace noise exposure had an AOR of 1.0. However, blue-collar jobs such as farmers, fishermen, engineers, and laborers had no difference in prevalence when compared to an unemployed group. The highest AOR was found among soldiers at 1.8 and 2.22 for simple and multiple logistic regression analysis, respectively. Other risk factors associated with higher risks of tinnitus included depression, greater stress level, smoking, osteoarthritis, rheumatoid arthritis, asthma, history of thyroid disease, and a history of middle ear pathologies. The researchers were not able to evaluate mediation history in the study.

Tinnitus Treatments

Due to the subjective nature of tinnitus, it could be difficult to determine the cause and nature of the symptoms. This could make treatment difficult. Currently, there is no cure for tinnitus. For those who experience temporary tinnitus, such as those who experience symptoms after a loud concert, the symptoms typically go away on their own (Henry et al., 2016). Relaxation training is a method that could be helpful. In one common relaxation method, progressive muscular relaxation, the patient tenses and relaxes different muscle groups in a sequential manor (Bernstein & Borkovec, 1973). Cognitive behavioral therapy is also used to help patients combat tinnitus by helping patients to self-control their thoughts and emotions. With cognitive re-structuring techniques, patients challenge their own common negative thoughts and learn to focus on constructive thoughts (Hallam et al., 1984; Henry & Wilson, 1996; Jakes et al., 1992). Another option includes attention control techniques in which the patient is taught to redirect their attention away from the tinnitus and onto feelings in their hands or feet, surrounding sounds, or by imagining the sounds of waterfalls or fountains (Jakes et al., 1986; Lindberg et al., 1988; Scott et al., 1985). Wearable masking devices that provide broad-band sound stimulation such as white noise or ocean waves could be used to reduce the effects of tinnitus symptoms (DeWeese & Vernon, 1975; Vernon, 1975). Hearing aids have been shown to help mask or reduce tinnitus symptoms, and hearing aid users might also use a specialized tinnitus program to act as a masker as well (Del Bo & Ambrosetti, 2007; Trotter & Donaldson, 2008). Patients with temporomandibular disorders and tinnitus might receive dental treatment and also reduce tinnitus symptoms in the process (Hilgenberg et al., 2012; Parker & Chole, 1995). Some other treatment methods include cervical spine therapy, drug therapy, dietary supplements with antioxidants and medications, electromagnetic procedures, retraining therapy, passive and active music therapy, acoustic neuromodulation, hyperbaric oxygen treatment, and acupuncture (Zenner et al., 2017). Tinnitus treatment and management might be planned by a multidisciplinary team of audiologists, dentists, neurologists, and psychologists due to the audiological, dental, cognitive, neurological, and psychological aspects of the condition. The treatment plan begins with the physician and opens to include these other members of the multidisciplinary team as referral needs come into play. Together, the professionals must decide what treatment options are most likely to address the patient's needs (Bohn Eriksson et al., 2018; Ruth & Hamill-Ruth, 2001; Wu et al., 2018).

A fair amount of published research supported the observation of a suppression of tinnitus symptoms in cochlear implant (CI) users. In 18 studies, including 1,104 CI candidates who were interviewed and examined, tinnitus prevalence ranged from 67% to 100% with an 80% as the mean. Several studies found the implantation of intracochlear electrodes in CI surgery reduced tinnitus symptoms in some patients and exacerbated it in other patients (Baguley & Atlas, 2007). Mirz et al. (2002) conducted functional imaging of CI patients' brains using positron emission tomography to examine the effect of CI use on tinnitus. The use of CIs reduced tinnitus-related brain activity in the primary auditory cortex and its associated cortices.

Consequences of Noise-Induced Hearing Loss and Noise-induced Tinnitus for Workers

Noise-induced hearing loss and tinnitus could dramatically affect the daily lives of individuals, both at work and in their personal lives, as they could make it more difficult for workers to understand speech in background noise (Hétu et al., 1995; Le & Clavier, 2017; Quist-

Hanssen et al., 1978) as well as increased difficulty with frequency selectivity (Ananthakrishnan et al., 2016; Hétu et al., 1995; Laroche et al., 1992). Many industrial workers also have trouble hearing auditory warning signals such as alarms frequently used in industrial workplaces (Hétu et al., 1995; Morata et al., 2005; Picard et al., 2008). Hétu et al. (1995) conducted a sound survey at a steel mill. There were 93 different types of warning signal conditions identified, each of which used a different signal and pattern with a specific meaning at a specific job site. Over one-third of these signals did not meet minimum sound level requirements for even normal listeners to be able to detect and recognize. As such, these signals were additionally inadequate for workers with NIHL. In fact, workers with NIHL required a signal-to-noise ratio that was 5-25 dB above those needed by listeners with normal hearing sensitivity due to higher masked thresholds. A masked threshold is the threshold at which a signal could be perceived in the presence of surrounding background noise (Hétu et al., 1995).

Hétu et al. (1995) identified other auditory and psychological effects that NIHL could have on workers. Workers with NIHL have increased difficulty localizing sound sources, which could lead to accidents in workplaces with heavy machinery and equipment. Difficulties with verbal communication are also common. Consequently, with the use of hearing protection, sound levels 2000 Hz and above become attenuated. This could pose risks when a worker misses an emergency warning from another speaker in a dangerous situation. Furthermore, Hétu et al. found stigmas attached to hearing loss could cause workers with NIHL to have damaged self-images, leading to feelings of incompetency, feelings of premature aging, physical weakness, or the feeling of being abnormal. This could lead to restricted social participation, isolation, reduced autonomy and self-reliance, and avoidance of everyday activities such as going to restaurants, places of worship, parties, and stores. These workers could become frustrated, fatigued, irritated, and full of resentment and guilt. Interactions between workers with NIHL and their family members could also be affected. Family members could become frustrated with having to repeat themselves and annoyed or fatigued at having to explain other conversations to the individual with hearing loss. Both conversation partners might experience communication breakdowns involving misunderstandings, inappropriate responses, requests to have things repeated, reduced interaction frequency, and interactions restricted to narrowed content (Hétu et al., 1995).

Tinnitus could add to these frustrations. In a study performed by Steinmetz et al. (2008), the Tinnitus Handicap Inventory was completed by workers with tinnitus and hearing loss at a meat packing facility. Results indicated the tinnitus, rather than the hearing loss, had the greatest effect on the participants' functional scale. Participants with both NIHL and tinnitus reported increased headaches and increased levels of frustration, anger, irritability, and depression than participants who had NIHL but no tinnitus.

Service members are also affected by tinnitus and NIHL. Hearing is critically important to the performance of military members and is integral in relaying instructions and information accurately and rapidly. Due to this, NIHL and tinnitus could severely impair military personnel by reducing situational awareness, general safety, job effectiveness, and quality of life. Annual disability payments for tinnitus and hearing loss for the VA exceeded $1.2 billion in 2009 and has increased every year (Yankaskas, 2013). The Department of Defense indicated that hearing loss was the most prevalent occupational health disability among members of the military. Worker compensation costs for the VA were about $56 million in 2003 and $1.102 billion in 2005 (Yankaskas, 2013). In 2010, tinnitus was the most prevalent worker compensation claim for veterans in 744,871 cases, which included 92,260 new tinnitus related cases compared to the previous year. The same year, the second most prevalent worker compensation claim for veterans was hearing loss (Yankaskas, 2013). This included an increase of 63,583 hearing loss cases compared to the previous year. In 2017, the VA (U.S. Department of Veterans Affairs, 2018) reported that tinnitus and hearing loss were again the top two most prevalent worker compensation claim for veterans with 1,786,980 cases for tinnitus and 1,157,585 cases for hearing loss. This included 159,800 new tinnitus cases and 81,529 new hearing loss cases from the previous year. Workers compensated for tinnitus made up 10.5% of all VA compensation recipients, while those compensated for hearing loss made up another 5.4% (U.S. Department of Veterans Affairs, 2018). This growth in tinnitus and noise-induced hearing loss disability benefits presents a major challenge for the VA.

Audiometric Monitoring for Noise-Induced Hearing Loss

To monitor for NIHL in the workplace, employers are required to have their employees' hearing tested every year to provide an opportunity to detect signs of NIHL and intervene before it can progress further. An important part of this process involves an employer's adherence to OSHA's (1983) specific audiometric monitoring requirements. According to the OSHA regulation, audiometric testing must be conducted by a tester certified through the Council for Accreditation in Occupational Hearing Conservation or the equivalent. The tester might use supra-aural headphones or insert earphones. The required test frequencies include 500, 1000, 2000, 3000, 4000, and 6000 Hz. Ambient background noise during testing must not exceed 40 dB at 500 and 1000 Hz, 47 dB at 2000 Hz, 57 dB at 4000 Hz, and 62 dB at 8000 Hz.

Audiometric monitoring programs might also be designed to follow NIOSH's (1998) best practices for audiometric testing. Those who follow NIOSH's criteria are still in compliance with OSHA's (1983) regulations as the recommendations are more conservative. Just as OSHA requires, NIOSH recommends that audiometric testing be conducted by a tester certified through

Council for Accreditation in Occupational Hearing Conservation. The recommended testing frequencies are identical to that of OSHA with the addition of the measuring thresholds at 8000 Hz. Ambient background noise during testing is recommended to follow the American National Standards Institute's (ANSI, 1999) S3.1 standard, which is more restrictive than the OSHA standard by 19 dB at 500 Hz and 13-25 dB more at other frequencies.

Per OSHA (1983), the initial hearing test, which becomes the baseline audiogram, must be performed for employees exposed to at 85 dBA TWA or higher within the first six months of a worker's exposure to noise. Workers must have 14 hours minimum without exposure to noise 85 dBA or higher before baseline testing, although the use of hearing protective devices (HPDs) is an acceptable alternative during that time period. For best practice, per NIOSH (1998), baseline testing should be performed within 30 days of workplace exposure, workers must have a quiet period of 12 hours without exposure to noise at or above 85 dB before testing, and the use of HPDs during that time is not allowed as an alternative. Audiograms are then completed annually if the worker is exposed to hazardous noise at or above 85 dBA TWA (NIOSH, 1998; OSHA, 1983). A licensed audiologist or otolaryngologist reviews these audiograms for any changes from an employee's baseline and to follow up on findings.

The reviewing audiologist or otolaryngologist determines changes in an audiogram from an employee's baseline to be a significant sign of NIHL by the calculation of a significant (or standard) threshold shift (STS). The NIOSH (1998) defines STS as a "significant threshold shift" while OSHA (1983) defines STS as a "standard threshold shift." Per OSHA, an STS is calculated as an average shift of 10 dB or greater from baseline testing hearing thresholds at 2000, 3000, and 4000 Hz in either ear. Per NIOSH, an STS is calculated as a shift of 15 dB or greater from the baseline at any frequency in either ear. The NIOSH opted to include all test frequencies out of concern for hazardous chemical/solvent exposures that also might cause hearing loss. It is important to note that NIOSH is a set of recommendations rather than regulations for adoption by OSHA and other regulatory agencies and therefore does not presently carry the same weight as the OSHA STS.

If an STS is identified, OSHA (1983) requires that the worker be notified of this change in hearing within 21 days. The worker must then be reinstructed on the use of HPDs and fit or re-fit HPDs with higher attenuation ratings if necessary. A 30-day follow up re-test must then be conducted. This new audiogram could replace the annual audiogram if an STS is not detected. If this follow up test validates the presence of an STS and this shift is determined to be work-related by a physician or audiologist and if the average absolute thresholds on the annual audiogram are greater than or equal to 25 dB at 2000, 3000, and 4000 Hz, the employer records the shift on the OSHA 300 log (OSHA, 1983). At this point, an audiologist or otolaryngologist might revise this new audiogram to serve as the new baseline reference to avoid identifying the same hearing change on subsequent exams (NIOSH, 1998; OSHA, 1983). According to the National Hearing Conservation Association (2013), following a confirmed OSHA STS, a six-month follow up test should be conducted to prevent a premature baseline revision if the shift is a result of a temporary medical condition or event.

In 1972, NIOSH published a *Criteria for a Recommended Standard: Occupational Exposure to Noise*, providing recommendations for defining an STS and reducing the risk of employees developing further permanent hearing loss due to occupational noise exposure. Further scientific studies and information led to a revision and revaluation of these recommendations, resulting in a 1998 recommendation. These new recommendations focused on preventing NIHL rather than simply conserving remaining hearing (NIOSH, 1972, 1998; OSHA, 2014).

The NIOSH's (1972) occupational noise exposure criteria recommended that an STS be defined as an increase in hearing threshold of 10 dB or greater at 500, 1000, 2000, or 3000 Hz, or 15 dB at 4000 or 6000 Hz, in either ear. The revised recommendation (NIOSH,1998) recommended that an STS be defined as "an increase of 15 dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000, or 6000 Hz in either ear, as determined by two consecutive audiometric tests" (p. iv). The 1972 criteria included an option for an age adjustment on individual audiograms; however, the 1998 recommendation no longer suggested this. The rationale behind this was an age adjustment was not scientifically valid and could delay intervention. The newer 1998 NIOSH guideline was also developed to consider the potential effects of workplace chemical exposure on hearing status. Overall, the 1998 criterion was found to have a higher identification rate and a lower false-positive rate than the 1972 criterion (NIOSH, 1972, 1998; OSHA, 2014). Royster (1992) found the criterion that would later become the NIOSH 1998 criterion to have a true positive at 70.9% compared to that of the NIOSH 1972 criterion at 46.1%. Daniell et al. (2003) found the 1972 rate to have 42% true positives and 54% false positives. The 1998 criterion was found to have a true positive to false positive rate of 1.9:1 while the 1972 rate was 0.7:1.

This differed from OSHA's (1983) definition and method for determining an STS; OSHA's standard criterion defined an STS as "a change in hearing threshold, relative to the baseline audiogram for that employee, of an average of 10 decibels (dB) or more at 2000, 3000, or 4000 hertz (Hz) in one or both ears" (1904.10(b)(1)). Both FRA (2006) and MSHA (1999) follow the same criteria as OSHA. Use of an aging correction factor is an option when calculating an OSHA STS, unlike in NIOSH's (1998) recommendation, but it is not required by federal legislation. This age adjustment allows for employers to consider the contribution of aging (presbycusis) on an annual audiogram and for a worker's audiogram to be adjusted accordingly. To determine the age adjustments, the employer must first look at Table F-1 Males and Table F-2 Females, in the OSHA 29CFR 1910.95 Appendix F (OSHA, 1983). The employer should then determine the age of the worker at the time of the most recent audiogram and then find the corresponding age adjustment values in the table for 1000 Hz through 6000 Hz. Following this, the employer should determine the age of the worker at the time of the baseline audiogram and find the corresponding age adjustment values in the table for 1000 Hz through 6000 Hz. The employer would then subtract the age adjustment values found for the baseline audiogram from the age adjustment values found for the recent audiogram. These calculated values then represent the amount of hearing loss that might be related to aging rather than noise exposure (OSHA, 1983). There are other definitions of an STS but NIOSH and OSHA's criteria are the most commonly used.

Royster (1992) and the follow-up Royster (1996a) examined the differences between eight STS criteria: 15 dB once, NIOSH (1972), 10-dB average 3000-4000 Hz, OSHA (1983), AAO-HNS, 15 dB Twice, 15 dB Twice 1000-4000 Hz, and OSHA STS Twice. These criteria are summarized in Table 2. Royster (1992) applied each of the eight criteria to 15 separate industrial hearing conservation databases. The first eight audiograms of male workers who had been tested at least eight times were used to examine the criteria. Overall, 2,903 workers were included in the study population. When a worker's audiogram met a criterion, a 'tag' was identified. When a worker's audiogram showed the same threshold shift as specified in that specific criterion for the next audiogram, a 'true positive' was identified.

Table 2

Summary of Audiometric Criteria for Change in Hearing Attributed to Noise-Induced Hearing Loss

Reference	Criteria Name	Threshold Shift Definition
OSHA, 1983	OSHA STS, Once	Greater than or equal to 10 dB average shift from baseline at 2000, 3000, and 4000 Hz in either ear, confirmed on 30-day retest
	OSHA STS, Twice	Greater than or equal to 10 dB average shift from baseline at 2000, 3000, and 4000 Hz in either ear, persistent on next annual audiogram
NIOSH, 1972	NIOSH STS 1972	Greater than or equal to 10 dB shift at 500, 1000, 2000, or 3000Hz OR 15dB shift or greater at 4000 or 6000 Hz, once
NIOSH, 1998	15 dB Shift Twice (NSTS)	Greater than or equal to 15 dB shift from baseline at any frequency (500, 1000, 2000, 3000, 4000, or 6000Hz), confirmed with follow up test
Royster (1992, 1996a)	15 dB Once	Shift of 15 dB or greater at any frequency from 500 to 6000 Hz, once
Royster (1992, 1996a)	10 dB Average 3000 - 4000 Hz	Shift greater than or equal to 10 dB average from 3000-4000 Hz, once
Royster (1992, 1996a)	15 dB Twice 1000 - 4000 Hz	Shift greater than or equal to 15 dB at 1000-4000 Hz, twice at the same ear and frequency
AAOHNS (1983)	AAOHNS Shift	Shift greater than or equal to 10 dB average at 500, 1000, and 2000 Hz OR greater than or equal to 15 dB average at 3000, 4000, and 6000 Hz

Table 3 summarizes the percentage of 'true positives' each of the eight criteria were used to identify a hearing threshold shift. The 15 dB Shift Once criterion (shift of 15 dB or greater at any frequency from 500 to 6000 Hz, once) had the lowest identification of true positives at 40.4% and the 15 dB Twice 1000-4000 Hz had the highest identification of true positives at 73.3%. The NIOSH (1972) shift identified the highest number of tags but only 46.1% of these tags were later identified as true positives. Thus, this criterion over-identified workers, many of whom did not have a true hearing threshold shift. While the 15 dB Twice 1000-4000 Hz criterion had the highest percentage of true positives, it identified less tags overall than the 15 dB Shift Twice criterion, which had the highest true positive percentage of the eight criteria. Royster (1992) determined that excluding 500 and 6000 Hz for the 1000-4000 method was part of the reason for less identified tags. Including 6000 Hz was valuable as it identified more noise-induced shifts. Therefore, due to this study, NIOSH changed from their 1972 criteria, which had a 46.1% rate of true positives, to using the 15 dB Twice criterion for their 1998 recommendation—the NSTS (Royster, 1992, 1996a; NIOSH, 1972, 1998).

Table 3

Summary of True Positives Identified Across Eight Criteria Examined in Royster (1992)

Criterion	Number of Tags	Number of Tags Also Identified as a True Positive	True Positives Identified
15 dB Once	2,126	858	40.4%
OSHA STS	958	412	43.0%
10 dB Average 3000-4000 Hz	1,175	524	44.6%
AAO-HNS Shift	1,291	578	44.8%
NIOSH (1972) Shift	2,268	1,045	46.1%
OSHA STS Twice	356	203	57.0%
15 dB Twice (NIOSH, 1998)	1,056	749	70.9%
15 dB Twice 1000-4000 Hz	726	532	73.3%

Daniell et al. (2003) also examined the differences between differing STS criteria. In this retrospective cohort study, researchers followed the audiograms of 1,220 workers at the Department of Energy nuclear facility at Hanford, Washington for eight years. The mean age of the population was 49.2 years old. The majority (85%) of workers were men. Eight threshold-shift criteria were examined—the same criteria examined by Royster (1992). For each criterion, the baseline, denoted as "year 0", was compared sequentially through Year 6. Data from Year 7 was only used to examine the persistence of shifts that occurred in Year 6. Four of the eight threshold-shift criteria required at least a 10 dB change in baseline at any one frequency. Two methods allowed a shift to be defined by any frequency having changed once. These two methods identified the largest percentage of employees as having had at least one shift in the seven years. One of these two methods identified 87% of workers as having had a hearing threshold shift while the other method of the two identified 97%. The criteria that required one frequency average to change twice only identified 16% of workers. The other criteria had similar ranges of identification. The NSTS method was found to most accurately and reliably detect a hearing loss out of the eight criteria (Daniell et al., 2003; NIOSH, 1998).

To determine the differences between the methods, Masterson et al. (2014) set out to compare the prevalence of workers determined to have an STS as defined by an NSTS (NIOSH, 1998), an STS as defined by OSHA (OSTS; OSHA, 1983), or an OSTS with age adjustment (OSTS-A). Masterson et al. examined previously conducted de-identified audiograms, primarily from workers exposed to high noise levels, and related information from the NIOSH Occupational Hearing Loss Surveillance Project. The NIOSH Occupational Hearing Loss Project, which was started in 2009, is a national surveillance program that partners with audiometric service providers to obtain de-identified worker audiograms and data. The purpose of this program was to establish estimates of hearing loss prevalence and incidence within different occupational industries as well as to identify groups of high risk for NIHL, to guide efforts into research for the prevention of NIHL, and to evaluate ongoing interventions (Centers for Disease Control and Prevention, 2019). Masterson et al. included 1,619,724 audiograms for 2001-2010 from 539,908 male and female workers at 17,348 companies as part of their data set. Workers were between the ages of 18 and 65. Workers who did not have at least three audiograms were excluded as this was necessary to calculate whether an STS was present. Both OSTS and OSTS-A calculations required two audiograms while an NSTS required at least three audiograms included in the calculation. The audiograms used to identify hearing threshold shifts included values at 500 Hz-8,000 Hz as well as gender, birthdates, and North American Industry Classification System codes. Information not included were race, income, education level, or noise exposure information.

Masterson et al. (2014) reported that an NSTS was more prevalent among males (22%) than females (16%). Men were found to be at a higher risk for having an NSTS, a risk that also increased with age. Employees who were between the ages of 56 and 65 years old were almost four times as likely to have an NSTS than workers between 18 and 25 years old. The overall prevalence of NSTS was 20.26%, the prevalence of OSTS was 13.85%, and the prevalence of OSTS-A was 6.41%. An NSTS was found to be more prevalent than OSTS by 28 to 33%. Workers who had OSTS-A were 65 to 72% less prevalent than those with NSTS. Table 4 summarizes the results of Masterson et al.

Table 4

Summary of Results of Masterson et al. (2014)

	Prevalence of NIOSH STS (NSTS)	Prevalence of OSHA STS (OSTS)	Prevalence of OSTS with Age Adjustment (OSTS-A)
Present	109,313 (20.26%)	74,785 (13.85%)	34,605 (6.41)
Not present	430,516 (79.74%)	465,123 (86.15%)	505,303 (93.59%)

All three criteria (NSTS, OSTS, and OSTS-A) were found to measure hearing threshold shifts but each had a different level of sensitivity. As the prevalence of NSTS to OSTS and OSTS-A suggested, NSTS criteria identified a far greater number of workers who were at risk for a loss in hearing than either of the other criteria. This was a significant enough difference that employers who used OSTS criteria were likely to miss 28-36% of workers who should have been identified as having a hearing threshold shift. A small number of workers were identified with an OSTS but not an NSTS. Masterson et al. (2014) assumed that these shifts were likely temporary and were not evident on the third test in the NIOSH dataset. The purpose of the age adjustment factor was to account for age related factors of hearing loss apart from noise related exposures. This rationale, though well intended, might lead to 65-74% of workers with a potential noise-induced shift in hearing not being identified. Overall, NSTS was found to be the more sensitive of the hearing threshold shift criterion and the most likely to detect future cases of NIHL. The researchers suggested this be the criterion audiologists should follow. Daniell et al. (2003) and Masterson et al. (2014) each found the NSTS method and criteria to be the most precise for identifying workers with hearing threshold shifts without too many false positives or false negatives. They also found this method to have higher specificity and sensitivity.

Tinnitus as an Early Indicator of Noise-Induced Hearing Loss

There have been several reports of an association between tinnitus and noise-induced hearing loss. Axelsson and Prasher (2000) examined the incidence and severity of tinnitus in correlation to occupational noise, leisure noise, and music exposure. They found the most common etiology for noise-induced permanent tinnitus was noise exposure and NIHL. The researchers created a 10-question tinnitus severity questionnaire using an arbitrary point system with a maximum severity score of 44 points. Participants exposed to occupational military noise had higher average scores of tinnitus severity than participants exposed to leisure noise. Workers who had not worked in noise scored an average of 22 points, which was below the average severity rating of 26 points for patients with tinnitus. For the workers who had worked in noise, there was an average score of 28-29 points regardless if exposure to noise at work was “seldom,” “often,” or “always.”

Ralli et al. (2017) examined chronic tinnitus in 136 patients between the ages of 26 and 84. The researchers divided the patients into two separate groups based on risk of hearing loss: one low-risk group and one high-risk group. Participants in the low-risk group were those who had previous employment in professions associated with lower risks for hearing impairment including the following: office workers, entrepreneurial positions, and hospital workers. Those placed in the high-risk group had previous employment in professions associated with higher exposure levels to occupational noise including the following: the armed forces, carpenters, manufacturing workers, drivers, miners, musicians, railroaders, schoolteachers, and construction workers. The researchers collected work and noise exposure history data as well as family history of hearing loss and/or tinnitus for each participant. Participants were also given self-assessment questionnaires including the Tinnitus Handicap Inventory, the Hearing Handicap Inventory, and the Hyperacusis questionnaire. To analyze the data collected, a p-value cutoff of $p = .05$ was used for statistical significance. A significant prevalence of males compared to females was present in the high-risk group (81%, $p < .001$). In the low-risk group, 45.6% were males ($p < .001$). Hearing thresholds were significantly worse in members of the high-risk group than the low-risk group at all tested frequencies from 500Hz to 8000 Hz (right ear mean: $p = .004$ for 500 Hz and $p < .001$ for 1000, 2000, 4000, and 8000 Hz; left ear mean: $p < .001$ for 500, 1000, 2000, 4000, and 8000 Hz; average right/left $p < .001$ for 1000, 4000, and 8000 Hz; $p = .002$ for 500 Hz, $p =.008$ for 2000 Hz). No significant difference between right and left ears was found for most frequencies but the left ears were worse than the right ears for 6000-8000 Hz ($p = .64$). Males within the high-risk group had significantly worse hearing thresholds than males in the low-risk group ($p < .001$) but for females, the differences between those in the two groups was not significant ($p = .12$). Tinnitus was bilateral more frequently in the high-risk group (67.6%) than in the low-risk group (52.9; $p = .05$). While there was no significant difference in scores on the Tinnitus Handicap Inventory between the two groups, there was a significant difference in the laterality of tinnitus as unilateral tinnitus occurred more commonly in the left ear than the right ($p = .05$). These researchers found a correlation between worse hearing thresholds and tinnitus symptoms with occupations associated with greater exposure to noise.

Rubak et al. (2008) surveyed 752 workers from 91 different workplaces and examined the relationship between tinnitus and noise exposure between workers with hearing loss and those with normal hearing. The workplaces chosen were all part of 10 industrial trades with the highest reported NIHL rates as identified in Danish occupational statistics. The researchers collected complete work-shift noise level recordings data, bilateral hearing thresholds, and questionnaire data for medical and occupational history of each participant. Hearing loss was defined as an average hearing threshold at 2000, 3000, and 4000 Hz above 20 dB HL in either ear. A total of three outcomes were defined: tinnitus without accompanying hearing loss, tinnitus with hearing loss, and a control group of those who reported no tinnitus. These groups consisted of 67 participants with tinnitus and no hearing loss, 50 with tinnitus and accompanying hearing loss, and 635 control participants with no hearing loss nor tinnitus. A higher percentage of hearing loss was present with participants who also reported tinnitus than with those who did not have tinnitus, 43% of workers with a hearing loss also had tinnitus, while only 22% of workers without tinnitus also had a hearing loss. Of all the participants, 85% of the control group, 87% of those with tinnitus without a hearing loss, and 96% of those with both tinnitus and a hearing loss worked in jobs that involved exposure to noise levels of at least 80 dBA. In the tinnitus only group, there was no correlation between tinnitus and current noise exposure level, cumulative noise exposure level, or duration of noise exposure. However, in the group with hearing loss and tinnitus, cumulative noise exposure had a significant correlation with tinnitus ($p = .02$). Overall, the researchers found the risk of tinnitus was increased with noise exposure for those with a hearing loss while no increase in risk of tinnitus was found for those with normal hearing sensitivity.

A search through the literature revealed few studies had examined the temporal relationship between self-reported tinnitus and NIHL. Griest and Bishop (1998) appeared to be the only study that had examined this relationship. They utilized 15 years of longitudinal data from 91 male employees who worked in areas with average noise levels of 85-101 dBA. These data were part of an ongoing hearing conservation program by ESCO Corporation, a steel foundry in Portland, Oregon. Workers' baseline audiograms were compared to later audiograms for signs of threshold shifts. Griest and Bishop defined an STS as a change relative to the baseline of at least 10 dB in the average hearing threshold at 2000, 3000, and 4000 Hz in either ear and defined a maximum threshold shift as the greatest threshold shift that occurred during the 15-year study period at 4000 Hz in the left ear. The workers were examined in sound-treated booths using pure tone air conduction audiometry. During the time of testing, workers reported whether they were experiencing tinnitus and an affirmative response was recorded as part of the audiometric results. Employees were included in the study if they had a hearing threshold better than 25 dB HL at 4000 Hz in the left ear at Year 1 of the study period and if they were exposed to work noise of 85 dBA TWA or greater for a minimum of 12 years. Workers included in this study ranged from 18 to 41 years with a mean of 27.2 years. Of the 91 workers studied, 29.7% reported tinnitus symptoms occurring at least once during the previous 15 years of the workplace annual testing (study period). Overall, 74% of workers first reported tinnitus prior to the occurrence of their maximum threshold shift. The remaining 26% of workers first reported tinnitus up to 11 years after the threshold shift occurred. The researchers suggested that based on the results, immediate evaluation should be done of workers who reported tinnitus at the time of their annual audiometric testing to prevent the possibility of further noise-induced hearing loss from occurring (Griest & Bishop, 1998).

The prevalence of noise-induced hearing loss among occupational workers is high and costly. Government agencies have recognized the importance of preventing NIHL and have made efforts toward protecting workers by producing regulations and guidelines as well as by identifying early indicators of NIHL, but there is still much room for improvement. The possibility that tinnitus might be a reliable early indicator of NIHL has wide reaching implications that might trigger early intervention and potentially help protect millions of workers from the high personal, professional, and monetary costs that come with hearing loss.

Since only one study (Griest & Bishop, 1998) has evaluated the utility of self-report of tinnitus as an early indicator of NIHL in a single workplace, additional research is needed to further investigate this relationship. This study further investigated the prevalence of tinnitus and the temporal relationship between self-report of tinnitus and multiple audiometric indicators of NIHL. These indicators included the AAO-HNS shift, OSTS, OSTS-A, and NSTS in a larger dataset representative of workers from a variety of industries and worksites.

CHAPTER III

METHODOLOGY

This retrospective study was conducted using longitudinal data found through a deidentified audiometric data set from industrial hearing conservation programs. The study was determined to be research not involving human subjects and was approved by the Institutional Review Board at the University of Northern Colorado (see Appendix A).

Audiometric Database

Software programs have been developed to collect, store, and analyze hearing test results for regulatory compliance. One such program, HearTrak, was utilized in this study. A HearTrak data set containing audiometric thresholds was collected as part of OSHA and MSHA mandated hearing conservation programs from 1970 through 2020. The HearTrak data set was used to identify participants who met the inclusion criteria for the study. The HearTrak data set included 699,275 audiograms from 165,023 workers who were exposed to noise ≥85 dBA TWA from 41 employers and 264 plants. The complete de-identified data set contained pure-tone air-conducted hearing thresholds (500-8000 Hz) and brief otologic case histories including a single question asking about the presence of severe tinnitus with a “yes” and a “no” response option. After applying the exclusion factors, the remaining data set contained 630,524 tests from 146,792 workers.

Inclusion/Exclusion

Audiometric records must have contained hearing thresholds for 500, 1000, 2000, 3000, 4000, and 6000 Hz. A worker’s hearing threshold data were excluded from analysis if fewer than three audiometric tests were performed within a three-year period. Data were also excluded if a hearing threshold shift was not confirmed by any or consecutive subsequent evaluation within one year. Both left and right ears were analyzed. Tests with a missing value at any frequency were excluded from the data set for the ear with the missing threshold(s). Hearing thresholds that were coded as NR (no response) were converted to 101 dB HL for analysis (1 dB above the maximum limits of the audiometer). In addition, audiometric records had to contain otologic history records that included a question regarding self-report of “severe tinnitus.” The remaining data set contained 630,524 tests from 146,792 workers.

Analysis

A significant threshold shift was identified using the following four criteria: OSTS, OSTS-A, NSTS, and the Griest and Bishop (1998) 4 kHz maximum threshold shift (4kMax). Audiometric records were analyzed to provide the following metrics;

1. Date of first true OSTS Twice in each ear
2. Date of first true OSTS-A in each ear
3. Date of first true NSTS (along with test frequency of occurrence) in each ear
4. Date of Griest and Bishop 4 kHz maximum threshold shift
5. Date of first self-report of tinnitus (and ear laterality if available)

The de-identified data set was exported into Excel and utilized for statistical analysis using a two-tailed, one-sample *t*-test, testing to alpha value of $p \leq .01$ by STATA software v15.0. Outcomes were presented regarding prevalence rates of the four STS approaches and the temporal relationship between the first self-report of severe tinnitus and each STS metric for the ear with tinnitus. The data logic used for analysis can be found in Appendix B.

CHAPTER IV

RESULTS

The purpose of this study was to investigate the prevalence and temporal relationship of self-reported severe tinnitus in industrial workers with significant hearing threshold shifts. This current study utilized four STS criteria: the OSTS, OSTS-A, NSTS, and 4kMax. This research was conducted under an approved University of Northern Colorado Institutional Review Board protocol (see Appendix A).

Study Population and Data Set

Full Dataset

Of the workers examined in the data set, 75.5% were male and 24.4% were female. An indication of sex was missing from 0.1% (n = 187) of the workers in the data set. The age of the workers at the time of the baseline (first) audiological test ranged from 20 to 69 years old with a mean age of 23.3 ± 9.4 years old. The mean age at which workers first self-reported severe tinnitus was 39.2 ± 12.3 years old while the mean age at baseline for those who did not report severe tinnitus was 33.3 ± 9.9 years old. The mean follow-up time from the first to the final audiometric testing that each individual worker participated in was 6.8 ± 7.9 years and ranged from 0.7 to 47.2 years.

Self-Reported Tinnitus Dataset

Of the workers observed in the data set, 1.2% (1,766 workers) self-reported having severe tinnitus at least once at the time of his or her hearing testing. Self-reporting of severe tinnitus was more prevalent among men than women; of the audiograms that included a self-report of tinnitus, 82.6% belonged to male workers and 17.3% belonged to female workers. There were 187 workers with unspecified sex included in the data set, three of whom self-reported severe tinnitus. The demographics of the total data set, self-reported severe tinnitus subset, and non-tinnitus subset are summarized in Table 5. The self-reported tinnitus dataset served as the data used for the analysis of the research questions.

Table 5
Total Data Set, Excluded, and Self-Reported Tinnitus Subset Demographics with Prevalence

Demographic	Full Data Set Workers % (n)	Self-Report Tinnitus Subset Workers % (n)	Non-Tinnitus Subset Workers % (n)
Sex			
Male	75.5 (110,760)	1.0 (1,458)	74.5 (109,302)
Female	24.4 (35,845)	0.2 (305)	24.2 (35,540)
Unspecified	0.1 (187)	0.002 (3)	0.1 (184)
Total	100.0 (146,792)	1.2 (1,766)	98.8 (145,026)
Age Group (Years) at Baseline			
20-29	46.2 (67,781)	0.4 (517)	45.8 (67,263)
30-39	28.6 (41,984)	0.3 (413)	28.3 (41,571)
40-49	17.0 (24,9640	0.3 (405)	16.7 (24,559)
50-59	7.1 (10,482)	0.2 (349)	7.0 (10,133)
60-69	1.1 (1,581)	0.06 (82)	1.0 (1,499)
Total	100.0 (146,792)	1.2 (1,766)	98.8 (145,026)

Audiometric Thresholds

The data sets were comprised of hearing thresholds for 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz for both right and left ears. Tests with a missing value at any frequency were excluded from the data set for the ear with the missing threshold(s). Table 6 summarizes the hearing thresholds and percentiles for workers reporting severe tinnitus and those not reporting tinnitus.

Figure 1 compares the mean hearing thresholds of the Non-Tinnitus subset versus that of the Self-Reported Tinnitus subset. The mean hearing thresholds for those who self-reported severe tinnitus was 2.0-13.2 dB higher (poorer) than for the mean thresholds of the total data set dependent upon test frequency in both ears. The mean thresholds of the total data set were within the ranges of normal hearing sensitivity (<25 dB HL) for all test frequencies in both ears based on adult normative data for degrees of hearing loss from Clark (1981). The mean thresholds of the tinnitus subset were in the range of normal (≤25 dB HL) hearing sensitivity in the low and middle frequencies (500-3000 Hz) and in the range for mild hearing loss (26-40 dB HL) in the high frequencies (4000-8000 Hz). Figure 1 shows the mean baseline thresholds for both the left and right ear for the Self-Report Tinnitus subset and the Non-Tinnitus subset.

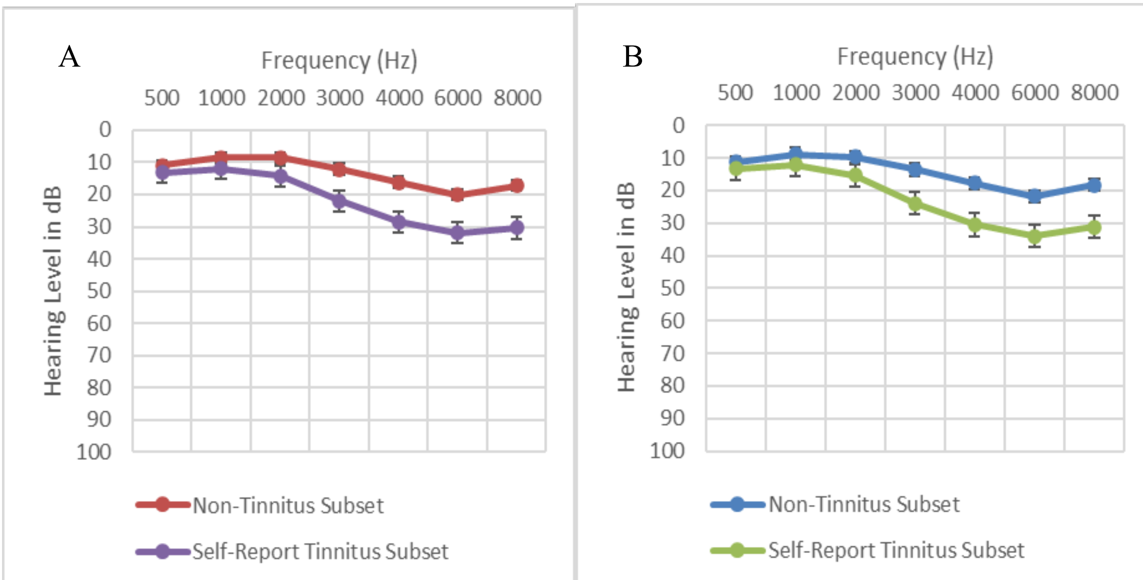
Table 6

Hearing Threshold Percentiles for Non-Tinnitus Subset and Self-Reported Tinnitus Subset Reported in Hearing Level Decibel

Ear	Frequency	Min	P1	P5	P25	P50	P75	P90	P95	P99	*N*	*M*	*SD*
Non-Tinnitus Subset													
Left	500 Hz	-5	0	0	5	10	15	20	25	50	144,943	11.3	9.8
Left	1000 Hz	-5	0	0	5	5	10	20	25	50	144,970	8.8	9.8
Left	2000 Hz	-5	0	0	0	5	15	20	30	60	144,944	9.7	11.6
Left	3000 Hz	-5	0	0	5	10	20	35	50	70	144,799	13.6	15.7
Left	4000 Hz	-5	0	0	5	10	25	45	60	80	144,889	17.8	18.0
Left	6000 Hz	-5	0	0	10	15	30	45	60	85	144,711	21.9	18.6
Left	8000 Hz	-5	0	0	5	15	25	45	60	85	139,587	18.4	18.9
Right	500 Hz	-5	0	0	5	10	15	20	25	50	144,905	11.0	9.5
Right	1000 Hz	-5	0	0	5	5	10	20	25	50	144,934	8.6	9.7
Right	2000 Hz	-5	0	0	0	5	10	20	25	55	144,785	8.6	9.7
Right	3000 Hz	-5	0	0	0	10	15	30	45	70	144,785	12.1	14.8
Right	4000 Hz	-5	0	0	5	10	20	40	55	80	44,870	16.2	17.4
Right	6000 Hz	-5	0	0	10	15	25	45	60	85	144,699	20.1	18.0
Right	8000 H	-5	0	0	5	10	25	40	60	80	139,506	17.2	18.2
Self-Reported Tinnitus Subset													
Left	500 Hz	0	0	0	5	10	15	25	30	55	1,766	13.3	10.8
Left	1000 Hz	-5	0	0	5	10	15	25	35	55	1,766	12.1	11.8
Left	2000 Hz	-5	0	0	5	10	20	40	50	70	1,766	15.4	16.0
Left	3000 Hz	-5	0	0	5	15	40	60	65	85	1,766	24.0	22.1
Left	4000 Hz	-5	0	0	10	25	50	65	75	95	1,765	30.6	24.4
Left	6000 Hz	-5	0	0	15	30	50	70	80	101	1,766	34.0	25.3
Left	8000 Hz	-5	0	0	1-	25	50	70	80	101	1,747	31.2	26.0
Right	500 Hz	-5	0	0	5	10	15	25	30	60	1,766	13.2	11.1
Right	1000 Hz	-5	0	0	5	10	15	25	35	60	1,766	12.0	12.1
Right	2000 Hz	-5	0	0	5	15	35	5	65	85	1,766	14.3	16.0
Right	3000 Hz	-5	0	0	5	15	35	55	65	85	1,766	22.0	21.5
Right	4000 Hz	-5	0	0	10	20	45	65	75	90	1,765	28.5	24.0
Right	6000 Hz	-5	0	0	10	25	50	70	80	101	1,764	32.0	25.0
Right	8000 H	-5	0	0	10	25	50	70	80	101	1,747	30.4	26.0

Figure 1

Mean Air Conduction Hearing Thresholds (dBHL) of Non-Tinnitus and Self-Report Tinnitus Subsets



A: Right ears, B: Left ears

Standard Threshold Shift

Audiometric shift criteria were calculated across all workers in the Self-Report Tinnitus subset and for each ear (right and left) separately. Therefore, the rate of each STS was the number of audiograms that had an STS (compared to the baseline/first test) in one or both ears, not the number of workers. Among the self-report tinnitus subset, there were 2,194 OSTS; 1,499 OSTS-A; 2,045 NSTS; and 1,591 4kMax occurrences.

First Report of Severe Tinnitus

Table 7 summarizes the mean ages of workers when first self-reporting severe tinnitus broken down by each STS method. The 4kMax method had the highest mean age at first instance of self-reporting (44.8 years), while the OSTS-A had the lowest mean age at first instance of self-reporting (42.2 years).

Table 7

Mean Age at First Tinnitus Self-Report by Standard Threshold Shift Method

STS Method	Mean Age at First Tinnitus Self-Report (Years)
OSTS	43.9
OSTS-A	42.2
NSTS	43.8
4kMax	44.6
Overall Mean	43.7

Temporal Relationship Between Standard Threshold Shift and Tinnitus Self-Report

The mean follow-up time from the first (baseline) test to the final hearing test for each individual worker who self-reported having severe tinnitus was 12 ± 10.3 years. In this study, the temporal relationship between the first self-report of severe tinnitus was evaluated by identifying the year at which severe tinnitus was first self-reported for each industrial worker, followed by subtracting the year at which the initial significant threshold shift occurred in either ear. This calculation was performed for each worker four times, once with each of the following audiometric shift criteria: OSTS, OSTS-A, NSTS, and the Griest and Bishop (1998) 4kHz maximum threshold shift (4kMax). Table 8 summarizes the results of this temporal analysis in terms of mean lag time and standard deviation within the Self-Reported Tinnitus group. In general, the self-report of severe tinnitus occurred *after* the STS occurred regardless of shift criterion.

Table 8

Temporal Analysis of Self-Reported Tinnitus Lag Time from Initial Threshold Shift in Either Ear

STS Method	*M* Lag Time (Years)	*SD* Lag Time (Years)
OSTS	1.6	±6.7
OSTS-A	2.3	±6.3
NSTS	2.1	±7.4
4kMax	1.1	±6.8

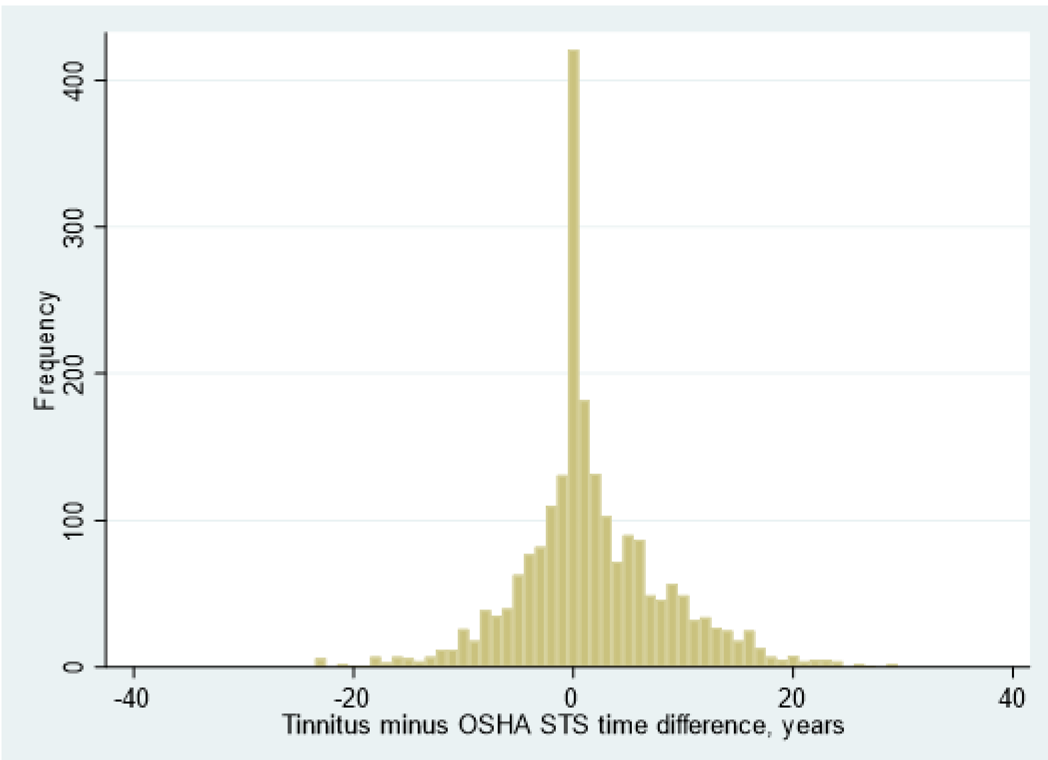
Occupational Safety and Health Administration Standard Threshold Shift

Utilizing the OSTS audiometric shift criteria, 2,194 significant threshold shifts were identified among the Self-Report Tinnitus subset. Of the 200 individual workers identified with an OSTS, 89.5% (171) were male and 14.5% (29) were female. The 60-69 years age group had the fewest identified shifts 1.1% (25) while the 30-39 years old age group had the greatest number of identified shifts 35.5% (778). A temporal analysis of self-reported tinnitus lag time from an OSTS revealed the mean lag time was 1.6 years with a standard deviation of 6.7 years. The occurrence of an OSTS and the self-report of severe tinnitus occurred at the same time for 14.4% ($n = 315$) of the tests. In a two-tailed *t*-test, testing to alpha value of $p \leq .01$, the p-value was $p = .00001$. This was a significant result that indicated 99% of the time, the self-reporting of severe tinnitus occurred after the identification of an initial OSTS. The 95% Confidence Interval (CI) revealed 95% of the time, tinnitus lagged from an OSTS by 1.3 to 1.9 years. A histogram of the lag time from an initial OSTS is included in Figure 2. In this figure, the X-axis represents the lag time (in years) between self-reporting of severe tinnitus and the identification of an STS. The

Y-axis in this figure represents the frequency (the number of times) that each lag time value occurred.

Figure 2

Temporal Analysis of Self-Reported Tinnitus Lag Time from an Occupational Safety and Health Administration Standard Threshold Shift



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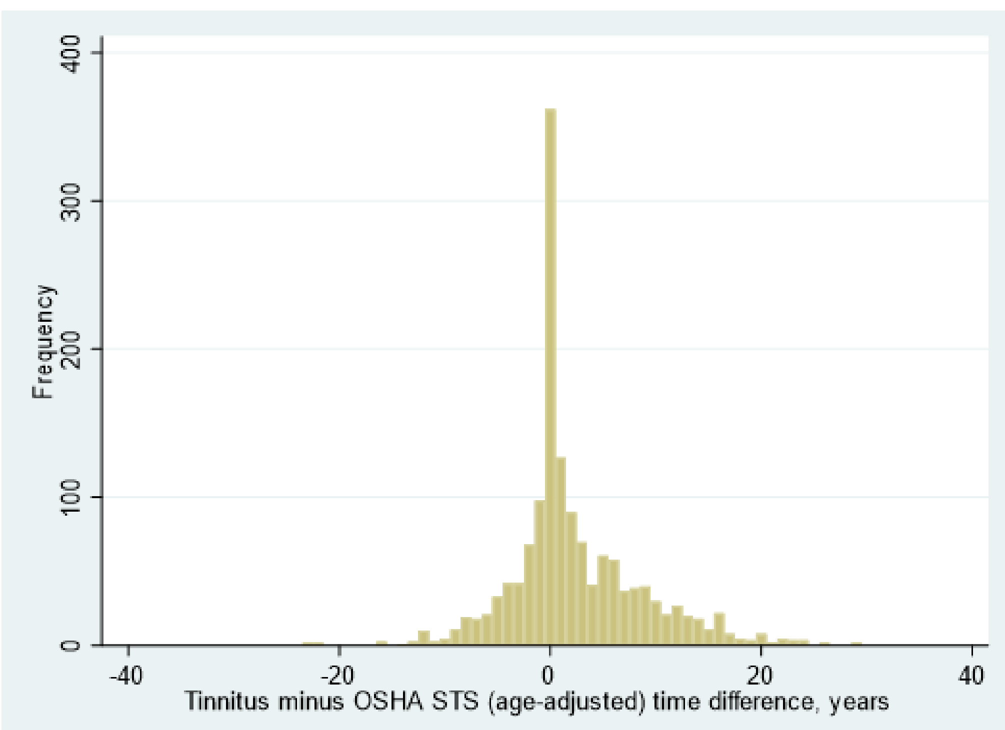
Occupational Safety and Health Administration Standard Threshold Shift Age-Corrected

Utilizing the OSTS-A audiometric shift criteria, 1,499 significant threshold shifts were identified among the Self-Report Tinnitus subset. Of the 124 individual workers identified with an OSTS-A, 83.9% (104) were male and 16.1% (20) were female. The 60-69 years age group had the fewest identified shifts (1.7%, 25), while the 30-39 years old age group had the greatest number of identified shifts (35%, 525). A temporal analysis of self-reported tinnitus lag time from an OSTS revealed the mean lag time was 2.3 years with a standard deviation of 6.3 years. The occurrence of an OSTS-A and the self-report of severe tinnitus occurred at the same time on 16.8% (n = 252) of the tests. In a two-tailed, one-sample t-test, testing to alpha value of $p \leq .01$, the p-value was $p = .00001$. This was a significant result that indicated 99% of the time, the self-reporting of severe tinnitus occurred after the identification of an OSTS-A. The 95% CI revealed that 95% of the time, self-reporting of severe tinnitus lagged from an OSTS-A by 2.0 to 2.7 years. A histogram summarizing the lag time from an OSTS-A is included in Figure 3.

Figure 3

Temporal Analysis of Self-Reported Tinnitus Lag Time from an Occupational Safety and Health Administration Age Corrected Standard Threshold Shift

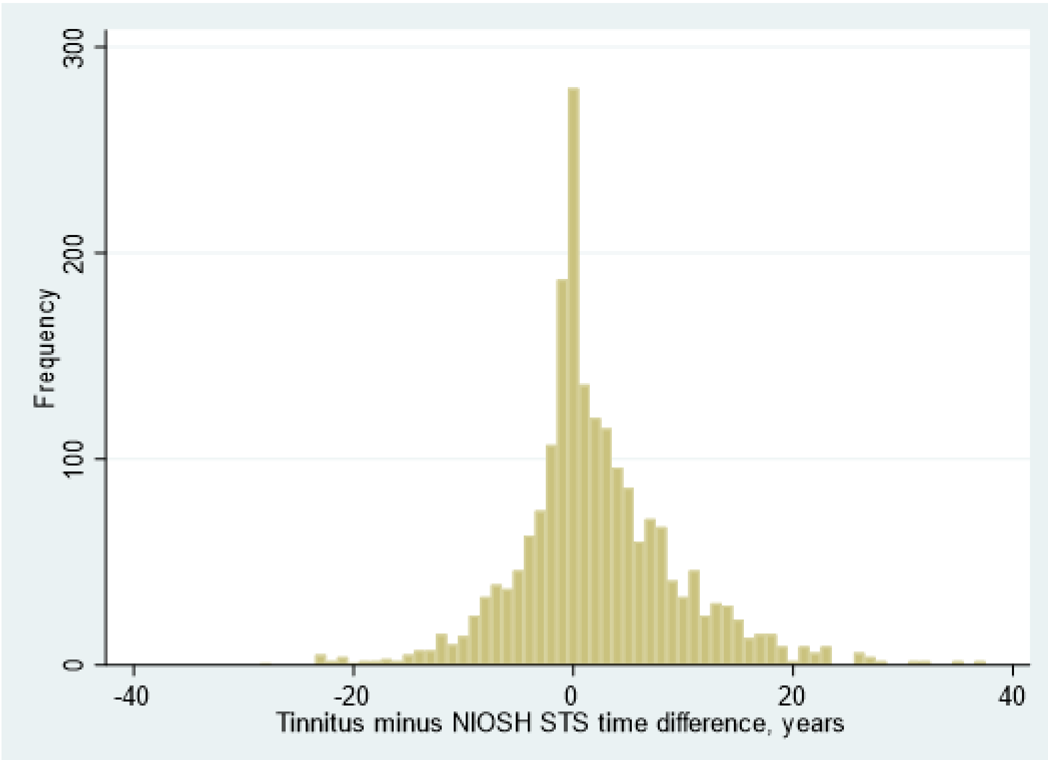


National Institutes of Occupational Safety and Health Standard Threshold Shift

Utilizing the OSTS-A audiometric shift criteria, 2,045 significant threshold shifts were identified among the Self-Report Tinnitus subset. Of the 175 individual workers identified with an NSTS, 89.7% (157) were male and 10.3% (18) were female. The 60-69 years age group had the fewest identified shifts (0.9%, 18), while the 30-39 years old age group had the greatest number of identified shifts (33.8%, 692). A temporal analysis of self-reported tinnitus lag time from an NSTS revealed the mean lag time was 2.1 years with a standard deviation of 7.4 years. The occurrence of a NSTS and the self-report of severe tinnitus occurred at the same time on 9.3% ($n = 191$) of the tests. In a two-tailed *t*-test, testing to alpha value of $p \leq .01$, the *p*-value was $p = .00001$. This was a significant result that indicated 99% of the time, the self-report of severe tinnitus occurred after the identification of an NSTS. The 95% CI revealed that 95% of the time, tinnitus lagged from an NSTS by 1.8 to 2.5 years. A histogram summarizing the lag time from an NSTS is included in Figure 4.

Figure 4

Temporal Analysis of Self-Reported Tinnitus Lag Time from a National Institutes of Occupational Safety and Health Significant Threshold Shift



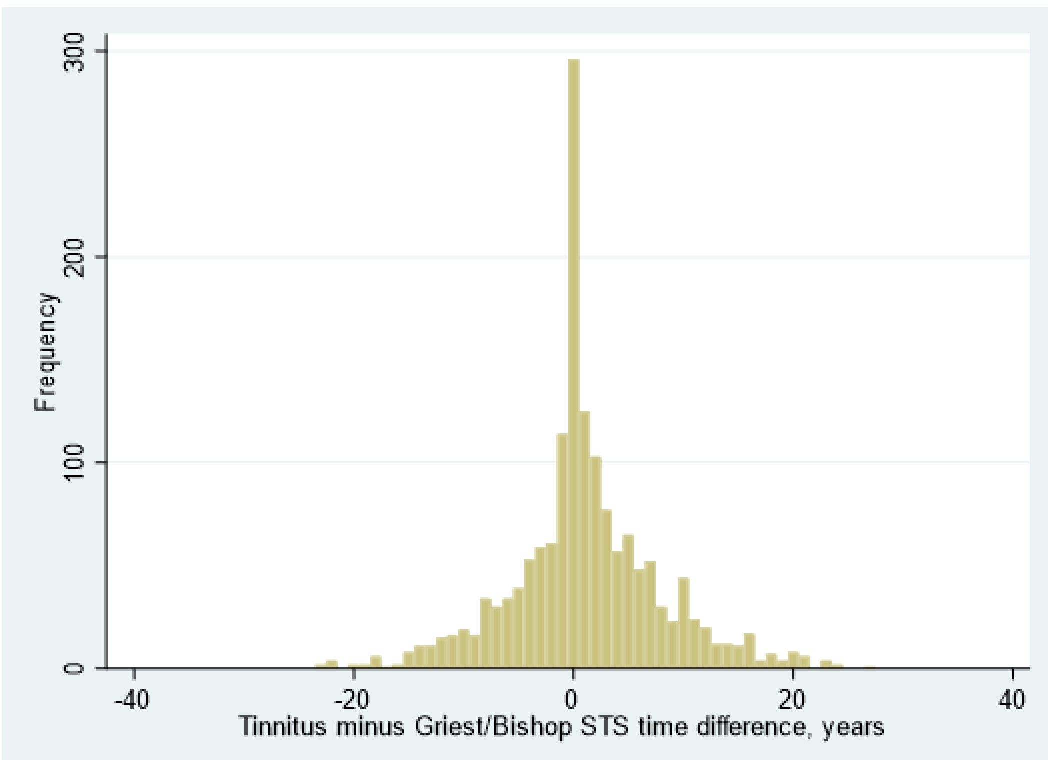
Griest and Bishop 4kHz Maximum Threshold Shift

Utilizing the 4kMax audiometric shift criteria, 1,591 significant threshold shifts were identified among the Self-Report Tinnitus subset. Of the 130 individual workers identified with an 4kMax, 87.7% (114) were male and 12.3% (16) were female. The 60-69 years age group had the fewest identified shifts (1.1%, 17), while the 30-39 years old age group had the greatest number of identified shifts (36.6%, 582). A temporal analysis of self-reported tinnitus lag time from an 4kMax revealed the mean lag time was 1.1 years with a standard deviation of 6.8 years. The occurrence of a 4kMax and the self-report of severe tinnitus occurred at the same time on

14.1% ($n = 225$) of the tests. In a two-tailed t-test, testing to alpha value of $p \leq .01$, the p-value was $p = .00001$. This was a significant result that indicated 99% of the time, the self-reporting of severe tinnitus occurred after the identification of a 4kMax. The 95% CI revealed that 95% of the time, self-reporting of severe tinnitus lagged from a 4kMaz by 0.7 to 1.4 years. A histogram summarizing the lag time from a 4kMax is included in Figure 5.

Figure 5

Temporal Analysis of Self-Reported Tinnitus Lag Time from a 4kMax Shift



Tinnitus Time Lag Comparison of Shift Criteria

With each of the four STS criteria, 99% of the time (alpha $p \leq .01$), the STS condition was met significantly earlier ($p = .00001$) than the self-reporting of severe tinnitus. An examination of the mean lag time indicated severe tinnitus was self-reported, on average, 1.6 (OSTS), 2.3 (OSTS-A), 2.1 (NSTS), and 1.1 (4kMax) years following the first occurrence of a significant threshold shift with a range of 1.1 years using the 4kMax to 2.3 years using the OSTS-A criteria. A minority of the workers in the Self-Reported Tinnitus subset (fewer than 25%) reported tinnitus prior to the identification of an STS. The OSTS was identified at the same time as the self-report of severe tinnitus most frequently of the four STS criteria. The lag time from identification of STS to a self-report of tinnitus ranged as follows: OSTS: -23.5 to 28.6 years, OSTS-A: -23.0 to 28.6 years, NSTS: -27.7 to 36.8 years, 4kMax: -23.5 to 26.7 years.

Summary

This study was designed to examine the prevalence and temporal relationship between the presence of self-reported severe tinnitus and the identification of an audiometric shift indicator of a significant change in hearing thresholds; OSHA STS, OSHA STS-A, NIOSH STS, and 4kMax, suggestive of noise-induced hearing loss among industrial workers. This was accomplished by analyzing a de-identified data set containing audiometric thresholds and otologic case histories including a single question asking about the presence of severe tinnitus from 630,000 industrial workers collected as part of OSHA or MSHA mandated hearing conservation programs from 1970 through 2020. The results of the temporal analysis between self-reported severe tinnitus to audiometric hearing shift criteria indicated that with each of the four STS criteria, the STS condition was met significantly ($p = .00001$) earlier than the self-report of severe tinnitus 99% of the time. Using the 4kMax criteria indicated the shortest mean lag time from an STS to a self-report of severe tinnitus with a mean of 1.1 years, while the OSTS-A method resulted in the longest mean lag time of 2.3 years.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The purpose of this study was to examine the prevalence of self-reported severe tinnitus in workers with significant hearing threshold shifts, as well as to analyze the temporal relationship between the two. Four STS criteria were used to identify threshold shifts: the OSTS, OSTS-A, NSTS, and Griest and Bishop (1998) 4kMax. The results of this preliminary analysis showed correlation between NIHL and self-reported severe tinnitus, indicating a need for tinnitus focused prevention and management in HCPs.

Worker Demographics

In this study, the population among the sample of noise-exposed workers in the workforce was dominated by males (78.6%). Other studies have had a similarly male-dominated sample such as Masterson et al. (2013), Masterson et al. (2014), Sekhon et al. (2020) with 78%, 81%, and 78% males, respectively. The full data set was dominated by younger workers in the 20-29 age group; the number of workers decreased with each decade of worker age. Masterson et al. (2013) used a similar age range for workers (18-65) with the highest percentage of workers in the 46-51 age group (25.9%) and with 26-35 age group not far behind (24.1%). Masterson et al. (2013) had the fewest workers in the 56-65 age group (10.3%). The age demographics of the current study similarly mirrored the age demographics in the general working population. The U.S. Department of Labor, Bureau of Labor Statistics reported that in 2019, the largest age group in manufacturing industries was the 45-54 age group (23.2%) and the lowest age group for manufacturing was in the 65+ age group (4.8%). For workers in the mining industry, the largest age group was 35-44 (28.3%) and the smallest age group was 65+ (3.7%).

Tinnitus

Prevalence

The data analysis in this current study suggested self-reported severe tinnitus had the higher prevalence among males than females with 1% prevalence for males and 0.2% for females. The data in this analysis also indicated the prevalence of self-reported severe tinnitus was highest in the 20-29 age group (0.4%) and the least prevalent in the 60-69 (0.06%) age group. However, conclusions could not be drawn as this study only included workers who self-reported "severe" tinnitus. Workers who had tinnitus but did not classify it as "severe" were not reported on the health history questionnaire and were not included in the analysis. Additionally, comparisons could not be made with the tinnitus prevalence found in other studies as studies in the literature did not all share the same method for asking about the presence of tinnitus and differentiated the severity differently. No comparable studies asked about the presence of tinnitus in the same way as did this current study.

Hearing Status of Workers with Tinnitus

The hearing thresholds of the workers with self-reported severe tinnitus were higher than of those workers who did not report severe tinnitus. This was consistent with the literature, which also indicated hearing status tended to be worse in those with tinnitus than those without. Rubak et al. (2008) found 43% of study participants with tinnitus also had hearing loss, while only 22% of participants without tinnitus also had hearing loss. Ukaegbe et al. (2016) found participants with tinnitus had a greater mean pure tone average than those without tinnitus: 14.8 ± 9.0 for tinnitus participants and 11.2 ± 6.0 for participants without tinnitus. This study and the literature indicated these hearing thresholds were worse in those with tinnitus, especially in frequencies at and above 2000 Hz. Frequencies in this region were more susceptible to noise-related damage (Bohne & Harding, 2000; Mehrparvar et al., 2011; Nandi & Dhatrak, 2008).

Comparison of Standard Threshold Shift Criteria in Workers Reporting Tinnitus

The OSTS criterion identified the greatest number of shifts in hearing threshold (*n* = 2,194), while the OSTS-A identified the fewest shifts in hearing threshold (*n* = 1,499). The NSTS identified the second most shifts (*n* = 2,045). Some of these findings were similar to results indicated by Masterson et al. (2014) in which the prevalence of OSTS was greater than the prevalence of OSTS-A. However, Masterson et al. found the opposite to be true with regard to the NSTS and OSTS—the NSTS criteria had a greater prevalence than OSTS. Similarly, Royster (1992) found the NSTS (*n* = 1,056) identified more shifts than the OSTS did (*n* = 958). Daniell et al. (2003) also indicated that NSTS identified a greater number of shifts than the OSTS with the former identifying 656 shifts and the latter identifying 434. The 4kMax criteria were created for the purposes of Griest and Bishop (1998) and were not compared to other STS criteria in that study.

Temporal Relationship Between Standard Threshold Shift and Tinnitus Self-Report

This capstone project expanded upon the study by Griest and Bishop (1998). The findings of that study indicated 74% of workers self-reported tinnitus prior to an STS. Based on these results, the researchers suggested the presence of a self-report of tinnitus on a worker's health history questionnaire could be a useful early indicator of noise-induced hearing loss. The results of this current study indicated the opposite: 99% of the workers self-reported tinnitus after the identification of an STS. The same STS criteria used in Griest and Bishop, the 4kMax criteria, were used to compare results.

Analyzing the results among male participants and specifically results found using the 4kMax STS criterion was important for a more direct comparison with the results of Griest and Bishop (1998), which included only males and used only 4kMax STS criteria. In the current study, mean lag time of self-reported severe tinnitus for males was -6.0 years, which indicated severe tinnitus was self-reported prior to the identification of an STS and followed more closely with Griest and Bishop in which self-reported tinnitus also occurred prior to a 4kMax shift. It was unknown if the temporal onset or progression of tinnitus differed between males and females.

One possible explanation for why the current findings differed from what was found in Griest and Bishop (1998) was the method of self-report of tinnitus was different between the two studies. While both included a yes or no question about tinnitus on the workers' hearing health questionnaire, the current study asked specifically about "severe" tinnitus. It might take longer for tinnitus to progress to a "severe" degree, which meant workers could take longer to report it than for workers to report the occurrence of tinnitus in general. Another difference between studies was the sample size. Griest and Bishop used a sample of 81 noise-exposed male workers from one worksite with 15 years of data. Only males were included in the sample. The sample size of the full data set for this current study was 165,023 workers from 264 different worksites with 50 years of data. A larger sample size allowed for more statistical power and a larger sample could more accurately represent the whole population. Both males and females were included in the current study sample. The larger sample size and the inclusion of both males and females over an extended period of time allowed for a more thorough examination of the temporal link between tinnitus and STS.

Implications for Hearing Conservation Programs

The results of this current study had some important implications for hearing conservation programs. Neither OSHA (1983) nor MSHA (1999) currently lay out any obligations for employers regarding tinnitus. These organizations also do not currently require medical histories, which means they are not designed to detect or prevent tinnitus among workers. Thus, even though the participants in this current study were already enrolled in an HCP, the current HCP regulations might fail to address the importance of tinnitus maintenance. This is important as the current results indicated self-reported, severe tinnitus followed noise-exposure and hearing loss. The lag times found in this current study suggested workers with an STS are at risk of developing tinnitus. Thus, by preventing NIHL, HCPs might have an opportunity to prevent tinnitus as well. The earlier that workers with an STS are given information about how to protect their hearing and how to manage tinnitus symptoms should these occur, the more likely early intervention could benefit these workers. Thus, HCPs should include tinnitus-based prevention strategies, intervention, and management for workers. Hearing conservation programs should also implement a question regarding the presence of tinnitus as part of the audiometric monitoring program. To help with this, further studies should examine the different ways of asking about tinnitus to determine what might be the most useful question(s) to implement. Another important factor was the workers in this present study each reported “severe” tinnitus. It is necessary for workers who report severe tinnitus to be given referral for further intervention and examination to rule out any medical issues that might be contributing to their symptoms.

Tinnitus and NIHL could affect workers negatively such as increased difficulty in localizing sound sources, increased difficulty with verbal communication, increased headaches and increased levels of frustration, anger, irritability, and depression (Hétu et al., 1995; Steinmetz et al., 2008). Worker's compensation claims are high for those with tinnitus and hearing loss as well (NIOSH, 2014; U. S. Department of Veterans Affairs, 2018). The potential for tinnitus-related worker compensation claims is high among industrial workers with noise-induced hearing loss. Therefore, there is a great need for risk management by employers to help reduce the impact and reduce the prevalence of tinnitus and NIHL among workers.

Study Limitations

The current study was based upon the otologic history questionnaire each worker filled out at the time of their annual audiometric testing; there was only one question regarding tinnitus. The tinnitus questionnaire was limited to asking about the presence of "severe ringing in the ears" with a space for the worker to select either "Yes" or "No." Only the "Yes" responses were recorded in the database and, thus, there was no way to determine how many workers selected "No" versus how many left the answer blank. One limitation of this simple question was there was no way to determine when the workers first noticed the onset of their tinnitus. Therefore, no absolute timeline was available. In this study, the date of audiological testing was used for the date of tinnitus onset when tinnitus might have occurred months prior to the date of the audiogram. A more thorough questionnaire should allow for a worker to report the date when the tinnitus started; this would be beneficial as it could provide a more accurate timeline of tinnitus onset to shift in hearing thresholds. Furthermore, there were no data to show whether workers were routinely administered the question regarding tinnitus at each audiometric testing time. It was possible this question was not administered consistently or every time; thus, there was the potential there could have been workers with tinnitus who were not identified in the current study.

There was the lack of differentiation as a function of the TWA noise of the workers. There was no collection of specific noise-exposure related data for the workers and thus, no inferences could be made about the severity of the noise exposure and how variations in noise exposure in the TWA might influence the lag timelines between STS and self-report of tinnitus. This requires further study and analysis. This study was also limited in that inferential statistics were not used. Age and sex are correlates of tinnitus and should be controlled for use in inferential statistics, which was beyond the scope of this research project.

Another limitation of this tinnitus self-report was a worker's ability to accurately answer the question involved the worker's understanding of what constitutes "severe" tinnitus. Severity of tinnitus is subjective and thus a worker who has tinnitus but does not consider it to be severe might not self-report. Furthermore, one worker might self-report having severe tinnitus only if he or she has had tinnitus ongoing for some time, while another might self-report simply if he or she had experienced a moment of severe ringing once in the previous month. Without a detailed questionnaire that defined tinnitus, asked more specific questions such as how frequently a worker experienced these symptoms, and clarified the severity classifications for the worker, there might be a wide range of interpretations that would vary a worker's decision on whether to report having "severe" tinnitus.

Strengths

The data set analyzed in this study had a large sample size and had a wide range of demographic information such as age and sex. The sample size analyzed for this study was 146,792 workers, which provided sufficient statistical power for a preliminary analysis.

However, there is a need to further explore the age and sex correlates of self-reported "severe" tinnitus using inferential statistics. The age of workers in this sample was broad and ranged from 20 years old to 69 years old. Other studies such as Griest and Bishop (1998) only had male subjects, while this study included both male and female subjects. The data set analyzed in this study also had a large sample of types of worksites. The data set was comprised of workers from 41 employers and 264 plants, which included 33 North American Industry Classification System codes and provided an opportunity to characterize tinnitus and STS criteria across a large number of industries and jobs. Another strength of this study was four STS methods were used on the same data set, which provided a more thorough examination of significant threshold shifts.

Future Research Directions

Future research should include more precise methods of tinnitus reporting and using more thorough tinnitus questionnaires. This could help get a more accurate date of tinnitus onset, which would provide a more accurate portrait of lag time between tinnitus and STS. Future research should also incorporate a Tinnitus Handicap Inventory or other tinnitus measures to examine more specifically how tinnitus affects workers. Future studies should also examine how differences in TWA noise exposures relate to lag times between STS and tinnitus self-reporting. Future studies should also examine how the presence of tinnitus is asked about and compare different methods.

Summary

Workers with severe tinnitus were identified to have an STS the most with the OSTS criteria (2,194 tests), followed by the NSTS (2,045 tests), and the 4kMax (1,591). The OSTS-A criterion identified the fewest STS among workers with tinnitus (1,499 tests). The temporal relationship indicated the self-report of severe tinnitus followed the identification of an STS for all four criteria. Statistical analysis indicated significant findings (p = .00001) that 99% of the time, the self-reporting of severe tinnitus occurred after the identification of an STS for all four criteria. The mean lag time was OSTS: 1.6 years, OSTS-A: 2.3 years, NSTS: 2.1 years, and 4kMax: 1.1 years. For the OSTS, OSTS-A, and NSTS criteria, the lag time decreased by approximately one year for each age group decade. These results underscored the existence of a temporal relationship between the development of NIHL and the onset of severe tinnitus. The high prevalence of tinnitus in noise-exposed workers indicated a need for more tinnitus focused prevention and management in hearing conservation programs.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

DATE:	December 20, 2019
TO:	Brennen Karl, BA
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[1538104-1] Tinnitus as an Early Warning Sign of Noise-Induced Hearing Loss in Industrial Workers
SUBMISSION TYPE:	New Project
ACTION:	APPROVAL/VERIFICATION OF EXEMPT STATUS
DECISION DATE:	December 20, 2019
EXPIRATION DATE:	December 20, 2023

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB approves this project and verifies its status as EXEMPT according to federal IRB regulations.

We will retain a copy of this correspondence within our records for a duration of 4 years.

If you have any questions, please contact Nicole Morse at 970-351-1910 or nicole.morse@unco.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Northern Colorado (UNCO) IRB's records.

APPENDIX B

DATA LOGIC

Data Set key:

Original Baseline Left: Under Field Name "StsL", where the data says "FIRST"

Original Baseline Right: Under Field Name "StsR", where the data says "FIRST"

Left thresholds: L5, L1, L2, L3, L4, L6, L8

Right thresholds: R5, R1, R2, R3, R4, R6, R8

Other relevant data information: Test Date, Birth Date
Tinnitus "Yes" Dates

QUALITY CONTROL – INCLUSION/EXCLUSION CRITERIA IN SEQUENCE

1. All records are assumed to be noise exposed and enrolled in the hearing conservation program according to the professional responsible for the data source.
2. Tinnitus Status: Yes
   a. If an employee marked "yes" for tinnitus, it is stated as "yes"
   b. If an employee marked "no" or left the question unanswered, then the "tinnitus" response is blank and will be excluded from analysis.
   c. Employees who marked yes on at least one test date will be included in the analysis.
   d. The dates of tinnitus reported as "yes" will be recorded
   e. Prevalence of tinnitus in the data set will need to be calculated
3. A worker's hearing threshold data will be excluded from analysis if fewer than three audiometric tests were performed within a 3-year period in one or both ears.
   a. Examine the data set for each listed "Employee" number and check for at least 3 consecutive years of "Test Date" in the data set, if this exists, then the data can be used for analysis.
4. Audiometric records must contain hearing thresholds for 500, 1000, 2000, 3000, 4000, and 6000 Hz in both the right and left ear.
   a. If any test frequency has a "no response" code "NR" or no threshold code "NT", this test will be excluded from the data set for that ear.
5. Demographic descriptors of the data set will need to be collated.

OSTS Twice (OSHA, 1983):
Greater than or equal to 10 dB average shift from baseline at 2000, 3000, and 4000 Hz in either ear and persistent on next annual audiogram.

1. Separate ear analysis to look for an STS in **EITHER** ear.
2. Find FIRST test for each ear to serve as first baseline reference and record test dates
   a. OSHABaseDateL1 and OSHABaseDateR1 in the data
3. For OSHABaseDateL1 and OSHABaseDateR1:
   a. Calculate OSTS average of left and right using thresholds for 2000, 3000, and 4000 Hz: (L2, L3, L4, R2, R3, R4)
   b. Compute Average OSHABaseDateL1: L2, L3 and L4 = OSHASTSAvgL1, and R2, R3 and R4 = OSHASTSAvgR1
4. For each subsequent annual test calculate the OSHASTS Average for the left and right ears and number them sequentially
   a. E.g. the second test in the series would label the average as OSHASTSAvgL2 and OSHASTSAvgR2, then OSHASTSAvgL3 and OSHASTSAvgR3 etc. in sequence until the last test date in the series.
5. Next calculate OSHASTSL1 and OSHASTSR1 using the formulae: (looking for a ≥10 dB difference on each sequential test until the first OSTS is identified for each ear) WITHOUT AGE CORRECTIONS
   a. Subtract OSHASTSAvgL2 – OSHASTSAvgL1
   b. Subtract OSHASTSAvgR2-OSHASTSAvgR1……………………
   c. E.g. Subtract OSHASTSAvgR3-OSHASTSAvgR1 if no STS on test #2 etc.
   d. When OSTS ≥10 dB average shift is identified, record the date and label as OSHASTSDateL1 and/or OSHASTSDateR1
6. Next determine if the OSTS is persistent (twice) e.g. "confirmed" on the subsequent annual test.
   a. Evaluate for existence of tests conducted within 12-24 months of the OSHASTSDateL1 and OSHASTSDateR1, if YES
   b. Re-calculate OSHASTSL1Retest and OSHASTSR1Retest for each of the dates in the 11-23- month period using the calculation in #5 above and substituting the STS average for each of the retest dates. Label as OSHASTSL1RetestL1 and OSHASTSR1RetestR1 etc. for each of the subsequent retests in the timeframe.
   c. If ≥10 dB average shift is identified on any OSHASTSL1Retest and/or OSHASTSR1Retest dates in the timeframe, record the date and label as OSHASTSDateL1Conf and/or OSHASTSDateR1Conf
   d. Any STS test not labeled as "confirmed" will be an unconfirmed STS for data interpretation.
7. Ultimately the output would have a list of initial and confirmed OSHA STS dates for each ear in employees that reported the presence of tinnitus on at least one exam.

OSTS-A (Age Correction):

Repeat the OSTS algorithm above but use OSHA 1910.95 App F - Calculations and application of age corrections to all audiograms. This would occur prior to step #5 above and age corrections would be applied to all tests analyzed in the data set.

Occupational Safety and Health Association. *Calculations and application of age corrections to audiograms* (Standard No. 1910.95 App F). Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95AppF

Determine from Tables F-1 or F-2 the age correction values for each subject (employee) as a function of sex (male or female)

a. Find **most recent** (Test Date) – (Birth Date)
b. Find corresponding age correction values at 2000, 3000 and 4000 Hz separately.
c. Find the age at Baseline: (FirstOSHABaseL Test Date – Birth Date) or (FirstOSHABaseR – Birth Date)
d. Find corresponding age correction values at 2000, 3000 and 4000 Hz
e. Take values from step (d.) and subtract from values found in step (b.)
f. Values found in step (e.) represent portion of hearing shift that may be caused due to aging at each test frequency.

If Male employee:

1. Most Recent Test Date – Birth Date = (Age)
2. F1(Age): Test Frequencies 1000, 2000, 3000, 4000, 6000 for corresponding values of age correction a. Call these F1(1000), F1(2000), F1(3000), F1(4000), F1(6000)
3. Baseline Test Date: FirstOSHABase – Birth Date = (AgeBase)
4. F1(AgeBase): Test Frequencies 1000, 2000, 3000, 4000, 6000 for corresponding values
5. F1(Age) Test Frequencies – F1(AgeBase) Test Frequencies = represented that portion of the change in hearing that may be due to aging.

F1(Age)(2000)-F1(AgeBase)(2000) = Threshold Difference F1(Age)(3000)-F1(AgeBase)(3000) = Threshold Difference F1(Age)(4000)-F1(AgeBase)(4000) = Threshold Difference

6. Take the test frequency threshold that shifted and subtract the Threshold Difference Test Date (L2) – Threshold Difference = Age Corrected Threshold for L2 Test Date (L3) – Threshold Difference = Age Corrected Threshold for L3 Test Date (L4) – Threshold Difference = Age Corrected Threshold for L4

If Female employee:

1. Most Recent Test Date – Birth Date = (Age)
2. F2(Age): Test Frequencies 1000, 2000, 3000, 4000, 6000 for corresponding values ofage correction a. Call these F2(1000), F2(2000), F2(3000), F2(4000), F2(6000)
3. Baseline Test Date: FirstOSHABase – Birth Date = (AgeBase)
4. F2(AgeBase): Test Frequencies 1000, 2000, 3000, 4000, 6000 for corresponding values
5. F2(Age) Test Frequencies – F2(AgeBase) Test Frequencies = represented that portion of the change in hearing that may be due to aging.

F2(Age)(2000)-F2(AgeBase)(2000) = Threshold

Difference F2(Age)(3000)-F2(AgeBase)(3000) =

Threshold Difference F2(Age)(4000)-F2(AgeBase)(4000)

= Threshold Difference

Take the test frequency threshold that shifted and subtract the Threshold Difference

Test Date (R2) – Threshold Difference = Age Corrected Threshold for R2

Test Date (R3) – Threshold Difference = Age Corrected Threshold for R3

Test Date (R4) – Threshold Difference = Age Corrected Threshold for R4

TABLE F-1 - AGE CORRECTION VALUES IN DECIBELS FOR MALES

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

TABLE F-2 - AGE CORRECTION VALUES IN DECIBELS FOR FEMALES

Years	Audiometric Test Frequency (Hz)				
	1000	2000	3000	4000	6000
20 or younger..........	7	4	3	3	6

21	7	4	4	3	6
22	7	4	4	4	6
23	7	5	4	4	7
24	7	5	4	4	7
25	8	5	4	4	7
26	8	5	5	4	8
27	8	5	5	5	8
28	8	5	5	5	8
29	8	5	5	5	9
30	8	6	5	5	9
31	8	6	6	5	9
32	9	6	6	6	10
33	9	6	6	6	10
34	9	6	6	6	10
35	9	6	7	7	11
36	9	7	7	7	11
37	9	7	7	7	12
38	10	7	7	7	12
39	10	7	8	8	12
40	10	7	8	8	13
41	10	8	8	8	13
42	10	8	9	9	13
43	11	8	9	9	14
44	11	8	9	9	14
45	11	8	10	10	15
46	11	9	10	10	15
47	11	9	10	11	16
48	12	9	11	11	16

49	12	9	11	11	16
50	12	10	11	12	17
51	12	10	12	12	17
52	12	10	12	13	18
53	13	10	13	13	18
54	13	11	13	14	19
55	13	11	14	14	19
56	13	11	14	15	20
57	13	11	15	15	20
58	14	12	15	16	21
59	14	12	16	16	21
60 or older	14	12	16	17	22

NSTS (NIOSH, 1998): Greater than or equal to 15 dB shift from baseline at any frequency (500, 1000, 2000, 3000, 4000, or 6000Hz), confirmed with follow up test

1. Separate ear analysis to look for an STS in **EITHER** ear.
2. Find FIRST test for each ear to serve as first baseline then

   label as NSTSBaseL1 and NSTSBaseR1

3. Find left and right thresholds for 500, 1000, 2000, 3000, 4000, 6000

   Hz (L5, L1, L2, L3, L4, L6, R5, R1, R2, R3, R4, R6)

4. Find shifts from baseline ≥ 15dB at any frequency (500, 1000, 2000, 3000, 4000, 5000, 6000 in each ear.

(L5 at Each Subsequent Date) >or= (FirstNSTSBaseL +15)] and/or

(L1) >or= (FirstNSTSBaseL +15) and/or

(L2) >or= (FirstNSTSBaseL +15) and/or (L3)

>or= (FirstNSTSBaseL +15) and/or (L4) >or=

(FirstNSTSBaseL +15) and/or (L5) >or=

(FirstNSTSBaseL +15) and/or (L6) >or=

(FirstNSTSBaseL +15) and/or (R5) >or=

(FirstNSTSBaseLR+15) and/or (R1) >or=

(FirstNSTSBaseR +15) and/or (R2) >or=

(FirstNSTSBaseR +15) and/or (R3) >or=

(FirstNSTSBaseR +15) and/or (R4) >or=

(FirstNSTSBaseR +15) and/or (R5) >or=

(FirstNSTSBaseR +15) and/or (R6) >or=

(FirstNSTSBaseR +15)

5. Find confirmation of shift on retest

Retest: Next Test Date within 1 year following (Test Date) with STS where STS is confirmed Exclude [Test Date] following [Test Date] where STS is not confirmed

Griest & Bishop Maximum Threshold Shift

Threshold shift: a change relative to the baseline of at least 10 dB in the average hearing threshold at 2000, 3000, and 4000 Hz, in either ear. Maximum threshold shift: the greatest threshold shift that occurred during the study period at 4000 Hz in the left ear.

1. Separate ear analysis to look for an STS in **<u>EITHER</u>** ear.
2. Find FIRST test for each ear to serve as first baseline then

   label as GBSTSBaseL1 and GBSTSTBaseR1

3. Find left and right thresholds for 2000, 3000, 4000

   Hz (L2, L3, L4, R2, R3, R4)

1. Find average shifts from baseline greater than or equal to10

   dB (L2+L3+L4)/3) >or= (FirstGBSTSBaseL+10)

and/or

((R2+R3+R4)/3) >or= (FirstGBSTSBaseR+10)

2. Find Griest and Bishop Maximum threshold shift

(L4) >or= (FirstGBSTSL+10) : Now find the greatest shift from this