THESIS

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR HOCKEY OFFICIALS

Submitted by

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ABSTRACT

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR HOCKEY OFFICIALS

Researchers have recently associated self-reported hearing loss in sports officials who use whistles. However, the actual noise exposures or degree of hearing loss to sports officials have not been determined to date. Researchers have shown that frequent noise exposures to equivalent sound pressure levels that exceed 85 dB may not only contribute to hearing loss, but also incidence of hypertension. Therefore, a pilot study was conducted to assess hockey official noise exposures at two sporting arenas that host junior and collegiate hockey games. The purpose of this study was threefold: (1) to measure the noise to which hockey officials are exposed; (2) to determine if hockey officials are at increased risk of hearing damage from officiating games; and (3) to determine if hearing protection is warranted. This pilot study will help determine if a more comprehensive study, including audiometric testing, at louder, larger sports arenas is necessary.

A total of 23 hockey official noise exposure samples were taken over the course of six hockey games. The hockey official noise exposure samples were collected while they were officiating games using Larson Davis personal noise dosimeters Models 706 and 703+. Each game was approximately three hours in duration. The dosimeters were pre-calibrated and attached to the officials with the microphone positioned within a one-foot radius of their heads on their dominant sides. The dosimeters were post-calibrated and the data were downloaded using the Larson Davis Blaze® Software. Analysis of the noise data included descriptive statistics such as the time-weighted average, eight-hour time-weighted average, noise dose percent, the equivalent sound pressure level, and the predicted 8-hour noise dose percent.

Although the hockey games were only approximately three hours in duration, 15 of 23 (65%) of the officials were overexposed to noise based on the American Conference of Governmental Industrial Hygienists recommended threshold limit value of 85 dBA as an eight-hour time-weighted average (3 dB exchange rate). Furthermore, all officials sampled had equivalent continuous sound pressure levels that exceeded 85 dBA. None of the hockey officials were exposed to noise levels in excess of the Occupational Safety and Health Administration (OSHA) permissible exposure limit of 90 dBA as an eight-hour TWA (5 dB exchange rate) or the OSHA action limit of 85 dBA (5 dB exchange rate).

Based on the results of this pilot study, hockey officials are overexposed to hazardous levels of noise that can likely contribute to hearing loss. Therefore, recommendations that include training and the use of earplugs were provided to reduce hockey official noise exposure and reduce the risk of developing noise-induced hearing loss in this population of workers. However, to determine if temporary hearing loss occurs from hockey game noise, future research using audiometric testing pre- and post-game exposure should be performed.

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DEDICATION

For my family and friends who have guided and supported me throughout this entire process. Your love, affection, and encouragement made all of this possible.

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LIST OF KEYWORDS

ACGIH	American Conference of Governmental Industrial Hygienists
AL	Action Limit
CFR	Code of Federal Regulations
CSU	Colorado State University
dB	Decibel
dBA	Decibel, A-weighted
dBB	Decibel, B-weighted
dBC	Decibel, C-weighted
HCP	Hearing Conservation Program
HHE	Health Hazard Evaluation
HP	Hearing Protection
Hz	Hertz
IRB	Institutional Review Board
kHz	Kilohertz
Leq	Equivalent Continuous Sound Pressure Level
Lmax	Max Level
Lpeak	Peak Level
MSHA	Mine Safety and Health Administration
NCAA	National Collegiate Athletics Association
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health

NIPTS	Noise-Induced Permanent Threshold Shift
NITTS	Noise-Induced Temporary Threshold Shift
NHL	National Hockey League
OSHA	Occupational Safety and Health Administration
PEL®	Permissible Exposure Limit
PPE	Personal Protective Equipment
RICRO	Research Integrity and Compliance Review Board
REL®	Recommended Exposure Limit
SD	Standard Deviation
SLM	Sound Level Meter
SPL	Sound Pressure Level
TLV®	Threshold Limit Value
TTS	Temporary Threshold Shift
TWA	Time Weighted Average
TWA (8)	Eight-Hour Time Weighted Average
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

The formal definition of noise, defined by the Merriam-Webster Dictionary is, "any sound that is undesired or interferes with one's hearing of something" (Merriam-Webster, 2013). Excessive exposure to intolerable levels of noise can produce a variety of health effects in the human body that can include temporary and permanent threshold shifts in a person's ability to hear. Introduction to noise levels that exceed 85 decibels (dB) may not only contribute to hearing loss but also incidence of hypertension (Berger et al., 2003).

Noise-related hearing loss has been reported as one of the most prevalent occupational health concerns for over twenty-five years (Occupational Safety and Health Administration, 2013). The National Institute of Occupational Safety and Health Administration (NIOSH) estimated as many as 30 million workers are exposed to hazardous noise in the United States (OSHA, 2013). Since the exposure to hazardous noise is such a prevalent occurrence in the workplace, it is important to mitigate and control the effects of excessive noise exposure in the workplace. The noise occupational exposure limits introduced in this study originate from OSHA and the American Conference of Governmental Industrial Hygienists (ACGIH).

The primary focus of this research was to determine if officials were exposed to that level of noise, which could potentially cause NIHL. Larson Davis Spark® personal noise dosimeters were used to determine the level of intensity and duration of noise exposure to examine the potential of NIHL to hockey officials during hockey games. NIHL results in the irreversible damage of the nerve cells of the inner ear. Although this damage occurs over time, continuous exposure to high frequency noise (3000 hertz to 6000 hertz) and high sound pressure levels (greater than 85 dB) can vastly increase one's risk in developing NIHL. However, with the proper administrative and engineering controls in addition to the proper hearing protection, the risk of developing NIHL can be reduced in the workplace.

This study focused on the measurement of hockey official personal noise exposures throughout the course of sporting events at two hockey venues to determine whether or not officials require hearing protection during games. The hockey officials that were sampled represent the northern Colorado hockey official associations responsible for officiating junior and collegiate hockey games throughout northern Colorado. During the course of a hockey game, officials were exposed to a variety of different noise sources. Noise sources included the music from the public address system, the whistles used by the officials, and shouting from the stadium occupants.

The noise exposure assessment of hockey officials of junior and collegiate hockey games provided a critical examination into whether or not officials are exposed to noise levels that exceed the ACGIH or OSHA criteria. The ACGIH threshold limit value (TLV) is 85 A-weighted decibels (dBA) as an 8-hour time-weighted average (TWA) with a 3 dB exchange rate. The OSHA permissible exposure limit (PEL) is 90 dBA as an 8-hour TWA with a 5 dB exchange rate. In addition, the assessment allowed the researchers to determine if officials should enroll in a hearing conservation program (HCP), if the OSHA action limit of 85 dBA was exceeded. Because the officials follow OSHA PELs, individuals exposed to noise levels at or above 85 dB with a five dB exchange rate scaled for an 8-hour workday must be enrolled in a HCP.

CHAPTER 2: LITERATURE REVIEW

The Human Ear and Sound

The human ear is a miraculous organ that converts pressure waves in the air into electrical signals that are decoded by the brain as sound. The human ear consists of three parts: the outer ear, the middle ear, and the inner ear. The function of the outer ear is to gather sound. The outer ear is comprised of the pinna (or auricle), the external auditory canal (or meatus), and the tympanic membrane (or eardrum). The outer ear gathers and conducts sound waves into the external auditory canal and transfers them to the tympanic membrane. In this region of the ear, sound wave transmission is provided a constant environment in the meatus to resonate at select frequencies to enhance sound transmission. Because the meatus resonates at or near 3000 hertz (Hz), this results in good sound conduction in the frequency range from 600-6000 Hz as it travels to the middle ear. Because the meatus resonates at a select frequency of 3000 Hz, this region is the most hazardous to hearing. As sound waves are gathered by the pinna and pass through the external auditory canal, they reach the tympanic membrane and into the middle ear (Berger et al., 2003).

The function of the middle ear is to transmit sound. The middle ear consists of the tympanic membrane, the ossicles (malleus, stapes, incus), the tensor tympani, the oval window, and the round window. The middle ear converts pressure waves in the air into mechanical forces that are delivered to the inner ear. The ossicles allow for pressure waves to be transformed into mechanical forces. The lever created by the ossicles allows for the force of the waves to be amplified 1.3 times compared to its original size. The oval and round windows act as portals where these forces are transferred into the inner ear (Berger et al., 2003). An illustration of the outer, middle, and inner ear is depicted in Figure 2.1.

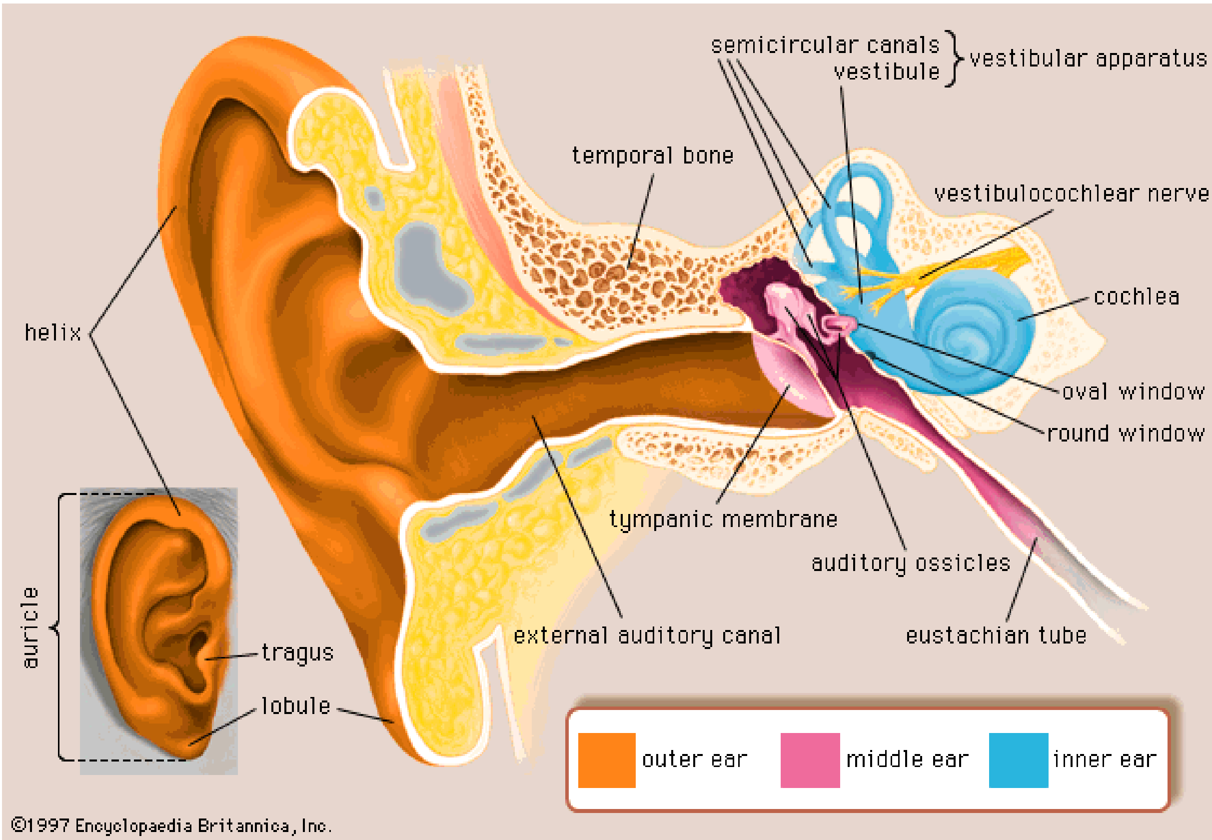

Figure 2.1: Anatomy of the Human Ear (Encyclopedia Britannica, 1997)

The primary function of the inner ear is to perceive sound. The inner ear is comprised of three components: the cochlea, the organ of corti, and the basilar membrane. The cochlea, the primary structure of the inner ear, is divided into three parts: the scala vestibuli, the scala media, and the scala tympani. It is rooted in the temporal bone and filled with endolymph fluid. When the oval window is pushed into the scala vestibuli, the round window will bulge outward and vice versa. "This involves the actual movement of fluid from scala vestibuli to scala tympani, so there is a corresponding force tending to deflect the basilar membrane toward scala tympani. This force allows for a wave of movement that begins near the oval window (at the basal end of the cochlea) and travels away from it (towards the apex of the cochlea, or apically)" (Berger et al., 2003).

The organ of corti, the primary organ in the inner ear to perceive sound, lies on the basilar membrane within the cochlea. The cochlea houses approximately 4,000 inner hair cells and 12,000 outer hair cells used to initiate neural impulses in the auditory nerve. These neural impulses occur as the basilar membrane, which causes the stereocilia of the hair cells to bend. The vibration of the basilar membrane allows for a pull, or shearing force of the cells against the tectoral membrane. The constant bending of hair cells activates the neural endings to allow for sound to be transformed into an electrical response. This response travels through the vestibulocochlear nerve and the brain interprets the signal as sound (Berger et al., 2003). The sound wave frequency detection as waves travel through the basilar membrane is depicted in Figure 2.2.

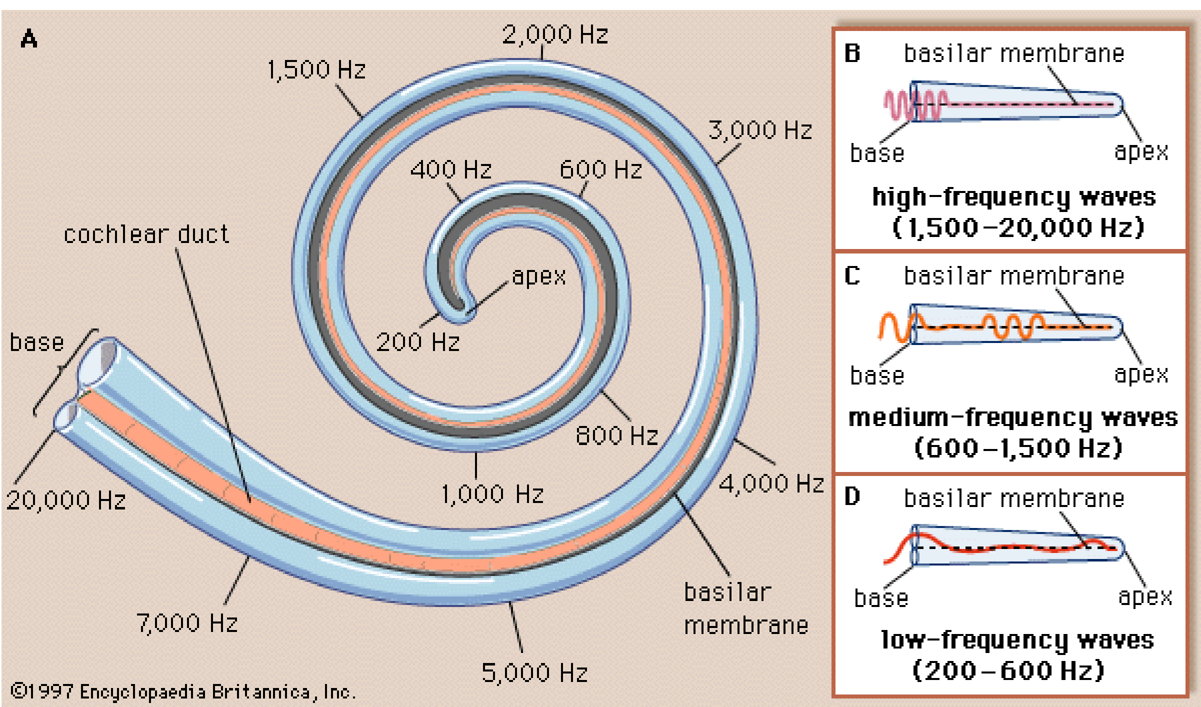

Figure 2.2: Frequencies of the Basilar Membrane (Encyclopedia Britannica, 2011).

Noise-Induced Hearing Loss

Noise-induced hearing loss affects 10 to 20 million workers in the United States. It is important to note that the introduction to noise levels that exceed 85 decibels (dB) may not only contribute to hearing loss but also incidence of hypertension (Berger et al., 2003). Therefore, it is important there is not an introduction of equivalent continuous sound pressure levels (Leq) greater than 85 dB in the workplace. A Leq is defined as a single decibel value that takes into account the total sound energy over a period of time (Gracey & Associates, 2014). If workers are exposed to excessive levels of noise for each workday throughout their working lifetime without proper hearing protection, they can develop permanent, irreversible hearing loss (Anna, 2011).

Exposure to noise can cause a noise-induced temporary threshold shift (NITTS), noise-induced permanent threshold shift (NIPTS), tinnitus, and/or acoustic trauma. NITTS refers to a temporary, reversible loss in hearing sensitivity. This loss can be as a result of short-term exposure to noise or simply neural fatigue in the inner ear. With NITTS, an individual's hearing sensitivity will return to the pre-exposed level in a matter of hours or days, without continued excessive exposure (Anna, 2011).

NIPTS is a permanent, irreversible loss in hearing sensitivity due to the destruction of sensory cells in the inner ear. This damage is typically seen through long-term exposure to noise or acoustic trauma (Anna, 2011).

Tinnitus is used to describe the condition in which individuals complain about sounds in the ear(s) without the actual presence of sounds around them. The sound is frequently described as a hum, buzz, ring, roar, or whistle. This sound is produced by the inner ear or the nervous system. It can be caused by a non-acoustical event, such as a blow to the head or the prolonged use of aspirin. However, the primary cause of tinnitus is exposure to high sound levels, though it can be caused by short-term exposure to high sound levels, such as firecrackers and gunshots. If tinnitus occurs immediately after a noise exposure, there is a high probability the event was damaging to hearing. If the event was experienced repeatedly, it will likely result in permanent hearing loss (Anna, 2011).

Acoustic trauma refers to a temporary or permanent hearing loss due to a sudden intense acoustical event, such as an explosion. The result of acoustic trauma can be a conductive or sensorineural hearing loss. An example of conductive hearing loss is when the event causes a perforated eardrum or damage to the middle ear ossicles. An example of sensorineural hearing loss is when the event causes temporary or permanent damage to the hair cells in the cochlea (Anna, 2011).

Weighting Filters

A number of different acoustical measuring instruments utilize selective weighting filters. For acoustical measuring instruments, there are three weighting filters: A, B, and C. These filters derive their characteristics from the perception of loudness of pure tones by human hearing. Other instruments contain bandpass filters (e.g., octave band) to analyze the spectral content of sound waveforms. From a functional standpoint, these weighting filters (A and C) can be seen as “tone controls”. This can be demonstrated with sound level meters (SLM), which have a provision for connecting earphones in the amplifier chain following the filters. However, when bandpass filters are switched from one to another, interesting observations can be made regarding the frequency components in the perceived sound. These observations can include speech with high noise frequencies being filtered out (Berger et al., 2003).

The A- or C-weighting filters are not used to determine loudness of complex sound waveforms. Instruments for these purposes exist and are used to evaluate sound characteristics, in addition to other uses. These instruments use specific complex filtering and signal processing. Thus the use of C (or possibly A) weighting would have to be based on professional judgment (Berger et al., 2003).

The C-weighting filter is recommended in the processing measurement of true impulse sound. Impulses that have significant frequency components only above several hundred hertz will not produce significantly different readings between A and C weightings. Therefore, OSHA recommends unweighted measurements for impulse sounds (Berger et al., 2003).

The A-weighting curve is an approximation of equal loudness perception characteristics of human hearing for pure tones relative to a reference of 40 dB sound pressure level (SPL) at 1 kHz. "Its application to the measurement of noise exposure for hearing protection and other purposes is only remotely, if at all related to equal loudness perception". The empirically derived measures using A-weighting give a better estimation of the threat to hearing by given noise waveforms than the other weightings. Because of the simplicity and substantiated results, the A-weighting filter continues to receive wide acceptance (Berger et al., 2003). The Larson Davis Spark® personal noise dosimeters used in this study were programmed with the A-weighting filter. The A-, B-, and C-weighting filters based on relative response (dB) and frequency (Hz) is described in Figure 2.3.

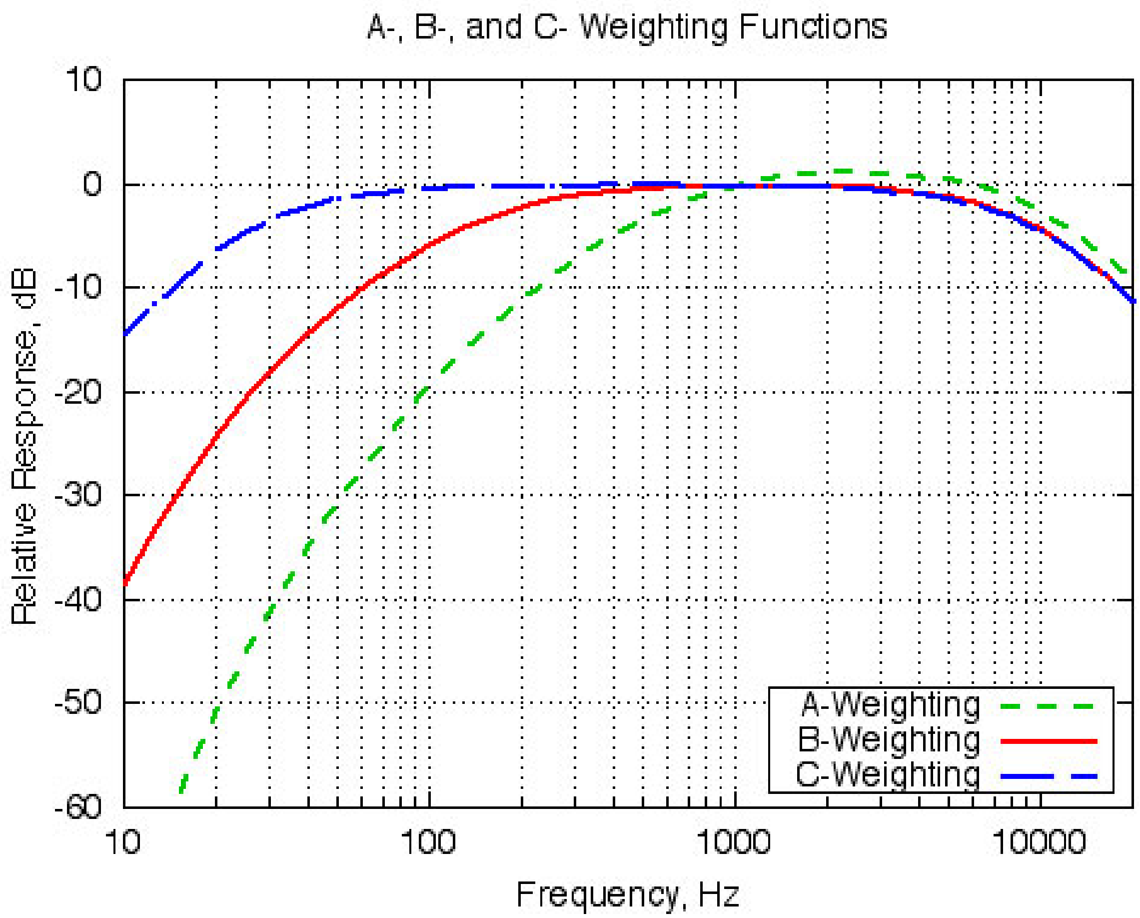

Figure 2.3: A-, B-, and C-Weighting Filters (Castle Group, 2014).

<u>Threshold Limit Values</u>

The members of the ACGIH set threshold limit values (TLVs) and biological exposure indices for a number of physical and chemical agents in the workplace. Although their recommendations do not directly affect the government standards set by OSHA and the Mine Safety and Health Administration (MSHA), they carry considerable weight in the scientific and technical communities. In 1994, the ACGIH revised its standards for noise by changing from the 5-dB to the 3-dB exchange rate. The ACGIH currently recommends a TLV of 85 dBA over an eight-hour period and specifies TLVs for 24 hours at 80 dBA down to 0.11 seconds at 139 dBA (Berger et al., 2003). The ACGIH TLV for noise is described in Table 2.1.

Table 2.1: ACGIH TLV for Noise.

	Duration Per Day	Sound Level (dBA)
Hours	8	85
	4	88
Minutes	30	97
	15	100
Seconds	1.76	127
	0.88	130
	0.44	133
	0.22	136
	0.11	139

Hearing Conservation Program

The PEL mandated by OSHA is in place to ensure that employees do not exceed noise exposures of 90 dBA with an exchange rate of five dB for an eight-hour TWA. However, OSHA has mandated the use of hearing conservation programs designed to reduce employee exposures to excessive noise. OSHA mandates the use of hearing conservation programs (HCP) to prevent initial occupational hearing loss and protect the hearing of employees through the introduction of hearing protection or engineering controls (OSHA, 2014). According to OSHA, an effective HCP requires "employers to monitor noise exposure levels in a way that properly identifies employees exposed to noise at or above 85 dBA averaged over an 8-hour TWA." If noise exposures in the work place are above 85 dBA, employers are required to monitor all employees who are likely exposed to excessive noise (OSHA, 2002).

In addition, employers must provide an audiometric testing program to employees at no cost to workers who are exposed to an action level at or above 85 dBA, measured as an 8-hour TWA. The aim of the audiometric testing program is to determine if the employer's hearing conservation program prevents hearing loss. Audiometric testing is performed by a certified audiologist and includes baseline and annual audiometric testing (OSHA, 2002).

Furthermore, employers must provide employees with at least two different types of hearing protection (e.g., earplugs and ear muffs). Employers are required to demonstrate how employees should utilize their hearing protection and ensure they can effectively protect workers from excessive noise. The OSHA action limit (AL) is where employers take the initiative once workplace exposures meet or exceed an 8-hour TWA of 85 dBA with a 5 dB exchange rate, or at a noise dose of 50% (OSHA, 2002). The OSHA PEL is set at 90 dBA with an 8-hour TWA, using a 5 dB exchange rate. The OSHA PEL for noise exposure criteria is described in Table 2.2.

Table 2.2: OSHA PEL for Noise.

	Duration Per Day	Sound Level (dBA)
Hours	8	90
	4	95
Minutes	30	110
	15	115
Seconds	1.76	160
	0.88	165
	0.44	170
	0.22	175
	0.11	180

Personal Noise Dosimeters

A personal noise dosimeter is a type of instrument that detects sound-level measurements within an individual's hearing zone. The hearing zone is referred to as a hypothetical sphere with a 30-centimeter (about one foot) radius that encircles the head. The microphone of the personal noise dosimeter is placed within an individual's hearing zone in order to detect personal sound-level measurements. A personal noise dosimeter is worn on the body and serves two functions. The first function is that the microphone senses the acoustic pressure and converts it into an electrical signal for subsequent processing. The second function of the dosimeter is that the personal noise dosimeter component integrates and computes the desired noise measurements. These instruments are battery powered and are derived directly from SLMs in order to simplify measurement and computational procedures (Berger et al., 2003).

In order to assure these devices work properly, a pre- and post-calibration must be performed to determine the accuracy of the reading. This calibration is done through the emission of a specified SPL and frequency into the dosimeter microphone. Dosimeters are equipped with different threshold levels, exchange rates, and weighing criteria. The threshold levels of dosimeters represent the level below at which noise will not be detected by the instrument and vary based on the criteria (OSHA PEL, OSHA AL, ACGIH TLV) that is being assessed. The dosimeters can be designed to compute data for the OSHA PEL, the OSHA AL, and the ACGIH TLV. The OSHA PEL requires employee noise exposure to be less than 90 dB with a five dB exchange rate, whereas the OSHA AL requires that actions be taken once employee noise exposures exceed 85 dBA or a dose greater than or equal to 50% (Berger et al., 2003). If employee noise exposures exceed 85 dBA or a dose greater than or equal to 50%, employees are required to be enrolled in a HCP. For the purpose of this study, the members of OSHA require entrance into a HCP if the hockey officials exceed the OSHA AL of 85 dBA with an 8-hour TWA using a 5 dB exchange rate.

Relevant Studies

No studies have been published to date that characterize the noise exposure levels of sports officials using noise measurement equipment. However, studies have been conducted where sports officials self-described their levels of hearing loss reported on online questionnaires (Flamme and Williams, 2013). Research has been performed on sports stadium employees and fans to assess their noise exposures during indoor and outdoor athletic events (Engard et al., 2010, Cranston et al., 2013, and England and Larsen, 2014).

Noise Exposure, Characterization, and Comparison of Three Football Stadiums

Researchers at Colorado State University (CSU) conducted a study in 2010 that examined noise exposure at three football stadiums. The researchers determined the noise exposure of workers and fans during football games at uncovered National Football League (NFL), large-sized college, and medium-sized college football stadiums (76,000, 54,000, and 34,000 seating capacities respectively) in Northern Colorado (Engard et al., 2010).

Engard et al. found that of the 28 workers sampled who attended football games (medium college and large college), none were overexposed to noise based on the OSHA PEL. However, 27 of 28 (96%) workers were overexposed according to ACGIH criteria. In addition, 11 of 28 (39%) workers were over the OSHA action level of 85 dBA, which requires enrollment in a HCP (Engard et al., 2010).

The researchers noted that of the 25 fans who attended football games, five (20%) were overexposed to noise based on the OSHA PEL criteria. Furthermore, 17 of 25 (68%) fans exceeded the OSHA action level of 85 dBA. In addition, 24 of 25 (96%) fans were subjected to noise exposures that exceeded the ACGIH TLV of 85 dBA (Engard et al., 2010).

The investigators recommended that the stadium management present at the two universities implement an HCP and provide hearing protective equipment, in compliance with the National Institute for Occupational Safety and Health (NIOSH) recommendations for arena monster truck/motocross shows. In addition, the researchers recommended that stadium management include noise warnings in fan guides and pamphlets to increase public awareness of excessive noise exposure. The investigators also encouraged fans to wear hearing protective equipment at sporting events to prevent tinnitus and NIHL (Engard et al., 2010).

Occupational and Recreational Noise Exposure from Indoor Arena Hockey Games

Researchers at CSU examined occupational and recreational noise exposure from indoor arena hockey games. Two hockey venues were selected for research – Venue One (15 workers and 9 fans) and Venue Two (19 workers and 11 fans) with workers and fans selected to participate in the study.

Cranston et al. discovered at Venue One, 6 of 15 (40%) workers exceeded the ACGIH 8-hour TWA TLV of 85 dBA. No employees exceeded the OSHA 8-hour TWA PEL of 90 dBA or the OSHA 8-hour TWA action limit of 85 dBA. Furthermore, 3 of 9 (33%) fans exceeded the ACGIH noise criteria, but none of the fans surpassed the OSHA noise criteria. The mean equivalent continuous sound pressure levels (Leq) for all three games at Venue One ranged from 81 to 96 dBA, and the peak SPL for all three games ranged from 105 to 124 dBA (Cranston et al., 2013).

The investigators observed that 11 of 19 (58%) workers at Venue Two exceeded the ACGIH 8-hour TWA TLV of 85 dBA. However, none of the workers' exposures exceeded the OSHA noise standards. The 10 of 11 (91%) fans sampled surpassed the ACGIH noise exposure criteria, but none exceeded the OSHA PEL or the OSHA action limit. The mean Leq for all four games at Venue Two ranged from 85 to 97 dBA. The peak SPL for all four games ranged from 110 dBA to 117 dBA (Cranston et al., 2013).

Cranston et al. recommended workers from both venues enroll in a HCP since 50% of the workers sampled exceeded the ACGIH noise criteria (Cranston et al., 2013). Engard et al.

discovered that 96% of workers sampled were exposed to noise levels that exceed the ACGIH criteria and 39% of workers exceeded the OSHA action limit. Engard et al. also highlighted that 96% of fans sampled were exposed to noise levels that exceeded the ACGIH TLV. Cranston and colleagues discovered that at Venues One and Two, 40% and 57% of workers and 33% and 91% were overexposed to ACGIH criteria, respectively (Cranston et al., 2013).

Furthermore, Cranston et al. suggested that the personal noise dosimetry results of workers sampled at Venue One and Venue Two were not significantly different, since the workers were not seated among the patrons. The worker mean noise exposures of ACGIH percent dose at Venue One and Venue Two were 86% and 101%, respectively. The researchers concluded that these results were not significant due to the high standard deviations associated with the means (Venue One standard deviation at 15 and Venue Two standard deviation at 16). The investigators demonstrated that workers and fans that attend indoor hockey games could be overexposed to noise based on ACGIH criteria (Cranston et al., 2013).

Noise Levels Among Spectators at an Intercollegiate Sporting Event

Researchers at Utah State University conducted a study in 2009 and 2010 that examined the intensity of noise levels at intercollegiate basketball games. Ten intercollegiate basketball games were selected for research with 20 fans solicited to participate in the study. Personal noise dosimeters were used to measure the participants' game-induced noise exposures. Audiometric testing and distortion product otoacoustic emissions tests were performed to assess the hearing sensitivity of participants (England and Larsen, 2014).

England and Larsen (2014) discovered that the average maximum sound level across the 10 games sampled was 135 dBA. The mean equivalent sound level for the 10 intercollegiate basketball games sampled was 85 dBA, with a range of 79 dBA to 90 dBA. The researchers used the NIOSH recommended exposure limit (REL) criteria of 85 dBA over an 8-hour TWA with a 3 dB exchange to determine the percent noise dose of fans who attended intercollegiate basketball games. The mean percent noise dose of the fans that attended the 10 basketball games was 59.7%, with a range of 23.1% to 115% (England and Larsen, 2014).

Using audiometric testing, the researchers observed the mean hearing thresholds of fans across frequencies (1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz) in both ears (left and right) decreased by 4 dB from threshold measured before attendance at the basketball game. The average decrease in distortion product otoacoustic emissions intensity in participants across frequencies (1000 Hz, 1400 Hz, 2000 Hz, 2800 Hz, 4000 Hz, 6000 Hz, 8000 Hz) in both (left and right) ears was 2 dB (England and Larsen, 2014).

The researchers demonstrated that temporary threshold shifts in hearing occurred in fans during the 10 intercollegiate basketball games sampled using audiometric testing and distortion product otoacoustic emissions testing. England and Larsen (2014) recommended that fans and employees present at Utah State University basketball games should be warned about the dangers of noise exposures from attending intercollegiate basketball games. The researchers also suggested that crowd participants and arena employees are provided with hearing protection to reduce exposures to hazardous noise during intercollegiate basketball games (England and Larsen, 2014).

Can Hockey Playoffs Harm Your Hearing?

William Hodgetts and Richard Liu conducted noise dosimetry and audiometric testing during three National Hockey League (NHL) Stanley Cup playoff games. Liu was equipped with a personal noise dosimeter and his exposure was monitored throughout the course of the three hockey games. In addition, pre-game and post-game audiometric testing was performed on Liu and another participant to determine if a temporary threshold shift in hearing occurred during the three hockey games (Hodgetts and Liu, 2006).

The Leqs experienced during each game (> 3 hours) was 104.1, 100.1, and 103.1 dB respectively. Individuals who participated in the study reported muffled hearing and tinnitus after the events. In addition, the authors reported that the hearing thresholds of both subjects deteriorated by 5 to 10 dB for most frequencies, with the most significant change occurring at 4000 Hz. This is especially concerning because hearing is most susceptible to damage in this range (Hodgetts and Liu, 2006).

Sports Officials' Hearing Status: Whistle Use As a Factor Contributing To Hearing Trouble

Researchers at Western Michigan University conducted research on sports officials. The researchers examined the prevalence of hearing loss in sports officials with regards to whistle use. Flamme and Williams (2013) surveyed a group of Michigan sports officials using a web-based questionnaire. The questionnaire was designed to determine the types of whistles used by officials and report any symptoms of hearing loss and tinnitus experienced. The acoustic characteristics of whistles were also investigated to determine the use required to reach a 100% noise dose (Flamme and Williams, 2013).

Flamme and Williams (2013) discovered that 50% of surveyed sports officials experienced tinnitus after sporting events, and approximately 13% of officials reported almost always experiencing tinnitus after sporting events. Moreover, an additional 11% reported post-game tinnitus more than once a week or once a month. (Flamme and Williams, 2013).

In order to determine the percent noise dose of whistles, the researchers transformed sound levels to the total signal time to reach a 100% noise dose. The researchers used the NIOSH REL criteria of 85 dBA over an 8-hour TWA using a 3 dB exchange rate to determine the percent noise dose of whistles. The total signal times of the 26 whistles used to achieve a 100% noise dose ranged between 5 and 90 seconds, with a mean of 34 seconds (Flamme and Williams, 2013).

Furthermore, the researchers also investigated the acoustic characteristics of whistles. The researchers wanted to determine if whistle use contributed to a sports official's noise exposure profile. Twenty-six whistles were used during the study. Each whistle was signaled five times one meter away from a microphone and the field equivalent at the ear (43 millimeters from the entrance of the right ear canal) (Flamme and Williams, 2013).

The researchers discovered that the mean output levels across the five signals of the 26 whistles sampled from a distance of one meter were between 104 dBA and 109 dBA. The mean output levels across the five signals of the 26 whistles sampled from a distance of the field equivalent at the ear were between 104 dBA and 115 dBA (Flamme and Williams, 2013).

Flamme and Williams (2013) suggested that sports officials have a greater probability to develop hearing impairment sooner and burdened by their effects longer than the general population. In addition the sounds produced by the whistles were high enough to be a part of the sports official's risk profile. However, whistles are probably not the only component that contributes to sports officials' noise exposure profile. Additional factors that contribute to sports officials' noise exposure include crowd noise and the public address system (Flamme and Williams, 2013).

Noise Exposure At a Monster Truck and Motocross Show

The researchers for NIOSH conducted a Health Hazard Evaluation (HHE) during monster truck and motocross events (Morley et al., 1998). Investigators conducted personal noise dosimetry on ushers and security personnel during each show. Noise monitoring was performed to determine the crowd output of noise during the four-hour events. The investigators found that three of four employees exceeded the OSHA Action limit of 85 dBA. The NIOSH recommended exposure limit (REL) and the ACGIH TLV were exceeded for all employees. In addition, spectators present at the event were exposed to noise levels that ranged from 95 to 100 dBA. The researchers concluded that employees and fans present at additional large events (rock concerts, hockey games, etc.) might be exposed to high levels of noise from the crowd (Morley et al., 1998).

Hearing Conservation Programs for Nonserved Occupations and Populations

Axelsson and Clark (1995) conducted additional research regarding noise exposure during sporting events. A personal noise dosimeter was worn at one hockey game, with an average SPL and peak value of 100 dBA and 120 dBA respectively. Furthermore, personal dosimetry was conducted during game six of the 1987 Major League Baseball World Series. The average SPL from game six of the World Series was 97 dBA, exceeding the OSHA PEL. The researchers suggested both fans and workers at these sporting events be included in a hearing conservation program.

Noise Exposure from Leisure Activities

William Clark (1991) conducted a review of noise exposure in leisure activities of young individuals. Considered the most common sources of noise included: exposures to live music, personal listening devices, noise around the house, and firearm activities. The review compared 16 studies that evaluated exposures from sources considered to be the most common to noise exposure.

A geometric mean of 103.4 dBA was calculated from the 16 studies that were considered frequent sources of elevated noise exposures. Clark concluded that infrequent exposure to noise levels that exceeded 100 dBA a few hours a week or month represent little risk for hearing loss. However, individuals who often attend these events, such as performers or employees at the venue may have an elevated risk for noise-induced hearing loss.

CHAPTER 3: PURPOSE AND SCOPE

Purpose

The purpose of this study was to determine the game-induced noise exposures of hockey officials employed to officiate collegiate and junior hockey games in northern Colorado using personal noise dosimeters. Personal noise dosimetry measurements were measured on the A-weighted scale. Dosimeters were used to measure hockey official noise exposure for the duration of the hockey game to determine if occupational exposure limits were exceeded. Personal noise exposures from the officials were collected and compared to the OSHA PEL and the ACGIH TLV criteria. The hockey official organizations that perform junior and collegiate hockey officiating in northern Colorado are required to enroll officials into a hearing conservation program if the OSHA AL is met. This research provides the officials of junior and collegiate hockey in northern Colorado their average noise exposures during collegiate and junior hockey games. With this research, the management of these organizations can make informed decisions about noise mitigation that can lead to reduced noise exposures of officials. Future participants will benefit from the results of this study by suggesting methods for training, hearing protection, and means to reduce excessive noise exposure.

Hypothesis and Research Question

The null hypothesis for this research is that hockey officials are not exposed to hazardous levels of noise while officiating junior and collegiate hockey games. The hypothesis for this study was that hockey officials who were exposed to noise exposures during the course of junior and collegiate hockey games would exceed the ACGIH TLV TWA of 85 dB with a 3 dB exchange rate during an eight-hour work shift. It was also hypothesized that the game-induced noise exposures of hockey officials during junior and collegiate hockey games would increase their risk of developing NIHL.

The evaluation of the hockey officials' personal noise dosimetry measurements was used to answer the following:

1. What is the average noise TWA, eight-hour time-weighted average (TWA (8)), and Leq for OSHA PEL, OSHA AL, and ACGIH TLV criteria for hockey officials?
2. Do junior and collegiate hockey official noise exposures exceed the ACGIH TLV, OSHA PEL, and OSHA AL occupational criteria for noise?
3. Are hockey officials at an increased risk of hearing damage from officiating games without hearing protection?

Scope

The research for this study was conducted in January and February, 2014, during northern Colorado junior and collegiate hockey games. The hockey official noise evaluations were conducted in two facilities that host junior and collegiate indoor hockey events in northern Colorado. Over the course of six hockey games (two at Venue One, four at Venue Two), a total of 23 personal noise dosimetry samples were collected. Permission was obtained to only solicit hockey officials authorized by the hockey league associations present in northern Colorado to officiate junior and collegiate indoor hockey games. Hockey official noise exposures were measured using Larson Davis Models 706 and 703+ personal noise dosimeters during the course of each hockey game. Participants in the study were all consenting adults, employed by the hockey official organizations present in northern Colorado. The study population was not limited to gender or race, however all participants in the research were over the age of 18. Hockey officials who participated in the study did not wear hearing protection during the junior and collegiate hockey games hosted in northern Colorado.

CHAPTER 4: METHODS AND MATERIALS

Site Selection

The supervisor for the junior and collegiate hockey official organizations in northern Colorado was contacted for the solicitation of officials in this study. The nature of this study limited noise measurements to the duration of the game and not for a full eight hours.

Hockey Official Recruitment

Hockey officials who officiate junior and collegiate hockey events in northern Colorado were contacted to determine their availability for participation. Communication with hockey officials was made in accordance with the Institutional Review Board (IRB) and Research Integrity and Compliance Review Board (RICRO). This included a description of the research sampling methods and procedures used. Individuals who participated in the study were assured that any personal identifiable research records would remain confidential to the extent allowed by law. The supervisor for the junior and collegiate hockey official organizations in northern Colorado was notified of the results of the study. Hockey officials who participated in the study signed and dated their consent to perform in the research study.

Description of Hockey Arenas

Venue One

Venue One is an indoor ice-skating recreational arena located in northern Colorado. The arena hosts ice-skating sessions that are open to the general public, in addition to activities and leagues. Activities hosted at Venue One include junior and collegiate hockey games, figure skating, hockey clinics, and skating lessons. Leagues hosted at Venue One include adult hockey, tournaments, and youth hockey leagues. The Venue also hosts collegiate hockey events for colleges and universities throughout the state of Colorado. Venue One holds a stadium capacity of 500 patrons. However, the estimated crowd attendance at the games sampled ranged from 200 to 370 patrons.

Venue Two

Venue Two is an indoor ice-skating recreational arena located in northern Colorado. The arena hosts ice-skating sessions that are open to the general public, in addition to leagues and activities offered to adults and children. Venue Two hosts activities that include curling, speed skating, adult drop-in hockey, collegiate hockey, fitness skating, and skating lessons. The venue also hosts junior and collegiate hockey events with teams throughout Colorado. Venue Two houses a stadium capacity of 400 patrons. However, the estimated crowd attendance at the games sampled ranged from 120 to 200 patrons.

Descriptions of Hockey Leagues

The junior hockey league is a collection of traveling teams comprised of individuals who are between 16 and 20 years old. The junior hockey league hosts hockey games in the state of Colorado and also competes with other teams across the United States. The collegiate hockey leagues are comprised of National Collegiate Athletics Association (NCAA) Division II and Division III hockey teams throughout the United States. These leagues compete with other colleges and universities that comprise the Mountain West Conference across the United States. The junior and collegiate hockey leagues host regular season games that span from November to

March. Therefore, data collection occurred from January to February of 2014 while hockey season was in session.

Description of Hockey Official Positions

In ice hockey, officials maintain the order and enforce the rules of the game. Therefore, there are two categories of officials: referees and linesmen. Referees and linesmen perform their jobs inside the hockey rink. They are traditionally dressed in a black hockey helmet, black trousers, a black-and-white striped shirt, hockey skates, and a whistle. Their protective equipment includes a cup supporter and shin pads (Hockey Referee HQ, 2014). Some officials would have their last name printed on the back of their uniform for identification purposes, but this was seen as optional during the games sampled.

The task of the referees is to maintain the general supervision of the game and can be identified by their red or orange armbands. The referee is the only official with the authority to enforce penalties for violations of the rules. The referee also coordinates the opening faceoff at the beginning of each period and after each goal is scored in the game. These faceoffs are performed at the center ice dot in the hockey rink (Hockey Referee HQ, 2014).

Linesmen are primarily responsible for watching the violations that involve the center and blue lines. These violations include icing and offside infractions, after which the linesmen conduct faceoffs.   They are also expected to break up fights, scuffles, and any additional altercations that may occur during the game (Hockey Referee HQ, 2014).

On-Ice Officiating Systems

Depending on the hockey league, there are officiating systems designed to coordinate the gameplay of a hockey event. For the collegiate games (NCAA Division II and III) that were surveyed, a four-official system was utilized. A four-official system uses two linesmen and two referees throughout the course of the hockey game. In this system, each referee and linesman works either the lead or the rear position of the gameplay. As the game continues to transition from one side of the ice to the other, the lead becomes the rear and vice-versa. Along with collegiate hockey games, this system is also incorporated in the National Hockey League (NHL) (Hockey Referee HQ, 2014).

For junior hockey games (ages 16 to 20 years), a three-official system was used. The three-official system incorporates two linesmen and one referee during the course of the hockey game. This system is also known as a two-one system, where there are two linesmen at the front and one referee in the back, or vice-versa. This system is also commonly used in Division III NCAA indoor ice hockey (Hockey Referee HQ, 2014). A description of a hockey rink is presented in Figure 4.1.

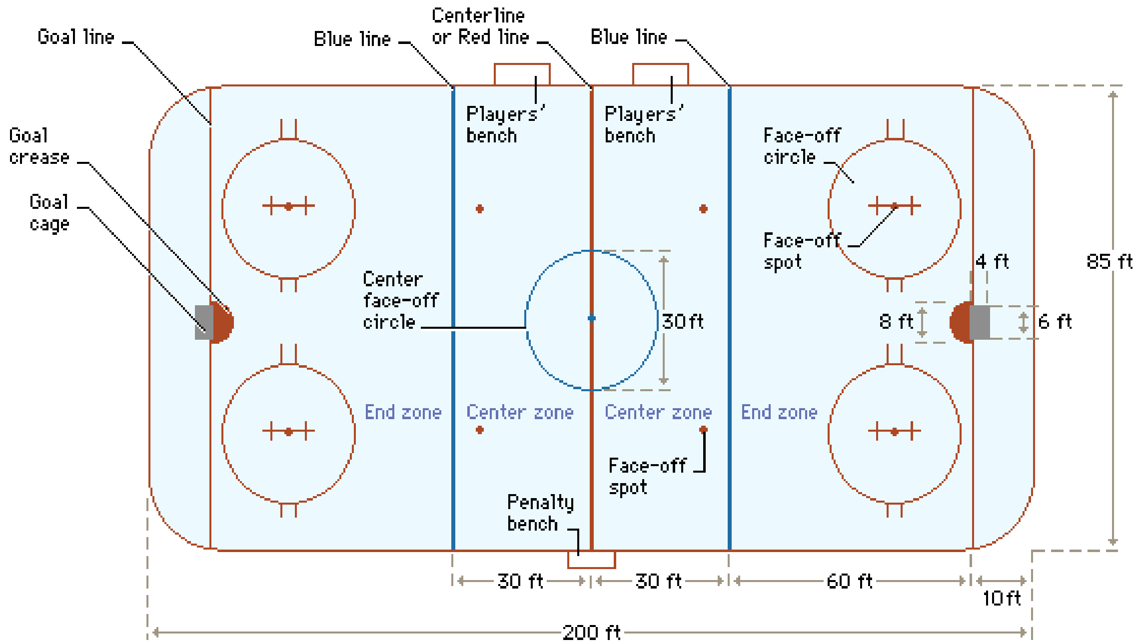

Figure 4.1: Description of a hockey rink (Mybackyardicerink.com, 2008).

Personal Noise Monitoring

Personal noise exposures were measured using Larson Davis Spark® Models 706 and 703+ (Provo, UT) personal noise dosimeters to determine the hockey official's noise exposure during indoor junior and collegiate hockey games. The dosimeters were pre-calibrated to assure the integrity and accuracy of the data based on the manufacture's standards. Before data collection, a one-sample t-test was performed using data from a previous study (Cranston et al., 2010) that measured worker and fan noise exposure at two indoor hockey venues. The one-sample t-test was used to determine that a sample size between 20 and 32 individuals would be sufficient to obtain 90% probability of rejecting the null hypothesis. Noise sampling procedures were followed using the OSHA Technical Manual, TEDI-0.15A, Section III, Chapter 5. The dosimeters were programmed with the set parameters shown in Table 4.1 to allow for the results to be compared to the ACGIH TLV, the OSHA PEL, and the OSHA AL noise criteria. The thresholds for the ACGIH TLV, the OSHA PEL, and OSHA AL are also included in Table 4.1.

Table 4.1: Larson Davis Spark® Dosimeter Measuring Parameters

	ACGIH TLV	OSHA PEL	OSHA AL
Weighting	A	A	A
Range	70 – 140 dB	70 – 140 dB	70 – 140 dB
Response	SLOW	SLOW	SLOW
Exchange Rate	3 dB	5 dB	5 dB
Threshold	80 dB	90 dB	80 dB
Criterion Level	85 dB	90 dB	85 dB
Criterion Time	8	8	8
Upper Limit	115 dB	115 dB	115 dB

Prior to the hockey game, the dosimeter microphone was placed upright between the neck and shoulder of the hockey official, as close as possible to the individual's hearing zone. The hockey officials were encouraged to resume their normal activities during the course of each game and not yell or blow their whistles directly into the microphones. During each intermission, the officials were monitored to check their microphones and dosimeters and ensure they were comfortable with the equipment. A sampling log was also maintained for officials that described their position, sampling start time, sampling stop time, sample location, pre-calibration, post-calibration, intermission equipment checks, and crowd attendance. An example of this log can be found in Appendix A. Collected data during the study included the sampling dates, the hockey official positions (referee or linesman), the number of officials at each game, crowd attendance, and any additional activity that would interfere with the data collection (e.g., disturbance of the microphone). The dosimeter remained operational throughout the game, including the intermissions between periods. After the conclusion of the game, the dosimeter was removed from the hockey officials and taken to a laboratory to be post-calibrated. The post-calibration was performed to determine if the calibration of the dosimeters remained unvaried during sampling. Hockey official TWAs and Leqs were calculated by the dosimeters for the time of their use and also adjusted for an eight-hour sampling period.

Statistical Analysis

The data collected from the dosimeters was downloaded and analyzed using Larson Davis Blaze® software (Part Number: SWW_Blaze; Date: September 14, 1999). The dosimetry data were examined on the basis of OSHA and ACGIH: projected dose, percent dose, equivalent level steady-state sound pressure level (Leq), TWA, TWA (8), the peak level (Lpeak), and the max level (Lmax). The Lpeak is referred to as the peak level of the sound pressure with no time constant applied. The Lmax is referred to the maximum sound level with a time constant applied (Fast or Slow) and is very different to the Lpeak (NoiseMeters Limited, 2014). The dosimetry data means and standard deviations (SD) were calculated based on overall hockey official noise exposure, linesman noise exposure, and referee noise exposure.

CHAPTER 5: RESULTS

A total of 23 personal noise dosimetry samples were collected at six hockey games hosted at Venues One (2 games) and Two (4 games). Each game was on average two hours and 42 minutes in duration. Although the purpose of this study was to determine the game-induced noise exposures of hockey officials employed to officiate collegiate and junior hockey games in northern Colorado using personal noise dosimeters, there were some discrepancies in the results of linesmen and referees. The purpose of this study was not to compare hockey venues or the types of hockey officials (linesmen and referees). However, the personal noise dosimetry data of the linesmen and referees who hosted the six hockey games at Venues One and Two were included in the results.

Hockey Official Personal Noise Exposures at Venues One and Two (All Games)

The OSHA PEL (n = 14), OSHA AL (n = 23), and ACGIH TLV (n = 23) mean percent noise dose for all hockey officials (n = 23) was 11.2, 19.2, and 119.9 percent, respectively. The mean percent noise dose for the OSHA PEL and OSHA AL criteria was not exceeded by any of the hockey officials sampled. However, with a mean hockey official percent noise dose of 119.9%, the hockey officials sampled exceeded the ACGIH TLV criteria for noise. The OSHA PEL, OSHA AL, and ACGIH TLV mean projected noise dose percent for both classes of hockey officials was 33.2, 57.4, and 354.9 percent, respectively. The mean Leq for linesmen and referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 90 dBA.

The OSHA PEL, OSHA AL, and ACGIH TLV mean TWA for linesmen and referees was 82, 86, and 90 dBA, respectively. The mean TWA (8) for referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 74, 78, and 85 dBA, respectively. The mean TWA (8) for the OSHA PEL and OSHA AL criteria was not exceeded by any of the hockey officials sampled. However, with a mean TWA (8) of 85 dBA, the hockey officials sampled exceeded the ACGIH TLV criteria for noise.

The average Lmax for linesmen and referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 115 dBA. The OSHA PEL, OSHA AL, and ACGIH TLV mean Lpeak for all hockey officials was 133 dB. Impulse noises measured for linesmen and referees did not exceed 140 dB. The mean linesmen and referee noise dosimetry results for Venues One and Two are displayed in Table 5.1. The individual hockey official Leq noise exposures are presented in Figure 5.1. The individual hockey official TWA and TWA (8) results for the ACGIH TLV, OSHA AL, and OSHA PEL criteria are shown in Figures 5.2, 5.3, and 5.4, respectively.

Table 5.1: Mean Hockey Official Noise Dosimetry Results for Venues One and Two

Mean Hockey Official Dosimetry Results for Venues One and Two (n = 23)						
	OSHA PEL (n = 14)		**OSHA AL (n = 23)**		**ACGIH TLV (n = 23)**	
	Results	SD	Results	SD	Results	SD
Dose (%)	11.2	5.74	19.2	5.63	119.9	96.3
Projected Dose (%)	33.2	16.2	57.4	16.0	354.9	271.8
Leq (dBA)	90	2.13	90	2.13	90	2.13
TWA (dBA)	82	2.71	86	1.78	90	2.16
TWA (8) (dBA)	74	2.70	78	1.83	85	2.21
Lmax (dBA)	115	4.50	115	4.50	115	4.50
Lpeak (max) (dB)	133	5.49	133	5.49	133	5.49

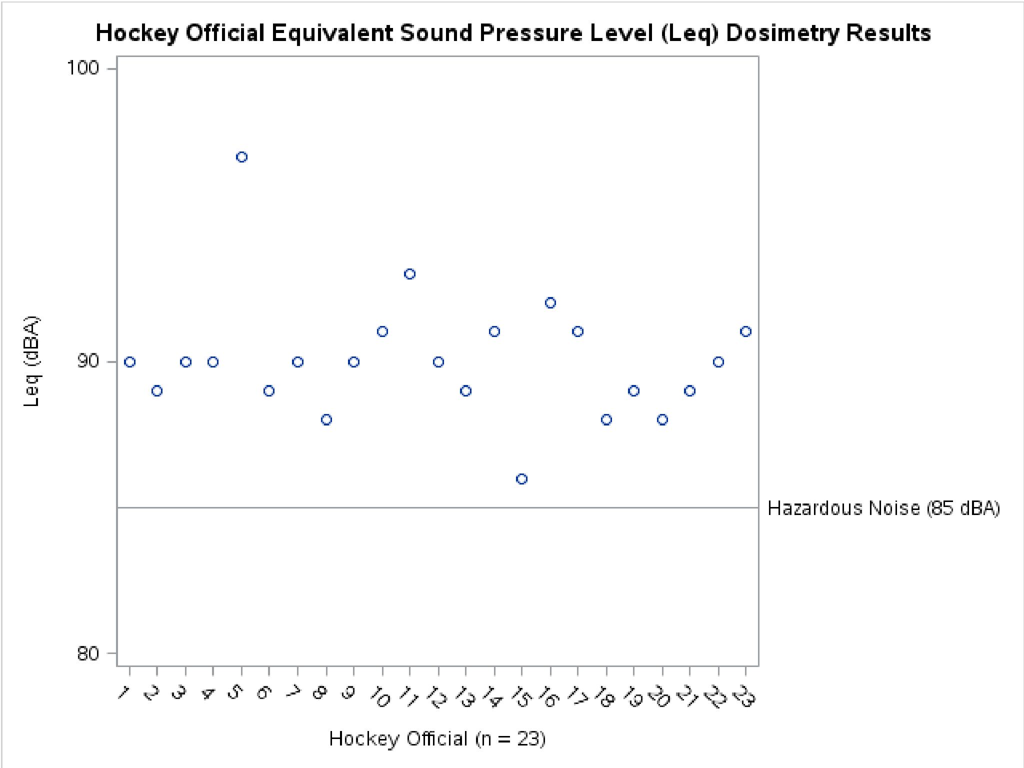

Figure 5.1: Hockey Official Equivalent Sound Pressure Level (Leq) Dosimetry Results

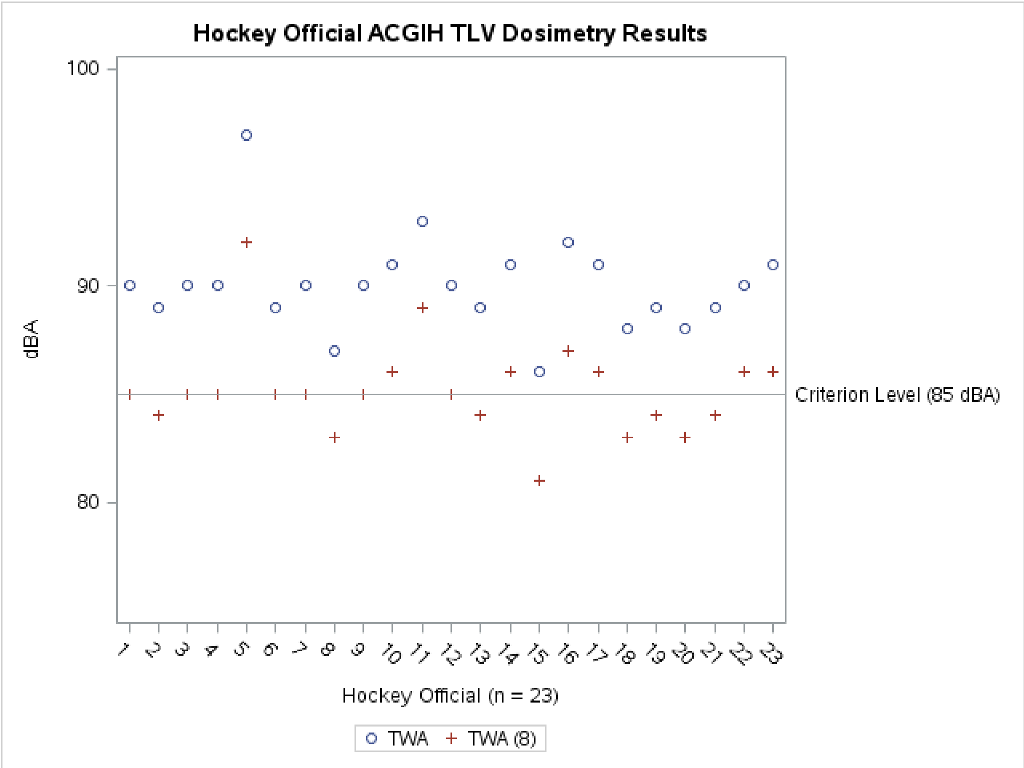

Figure 5.2: Hockey Official ACGIH TLV Dosimetry Results

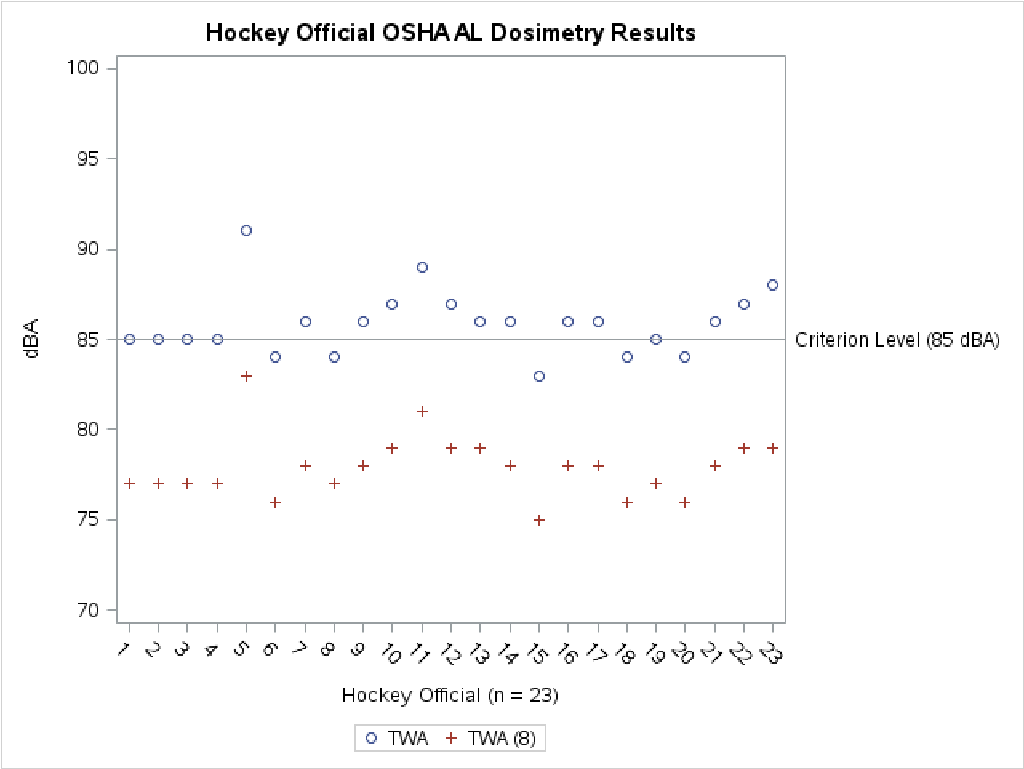

Figure 5.3: Hockey Official OSHA AL Dosimetry Results

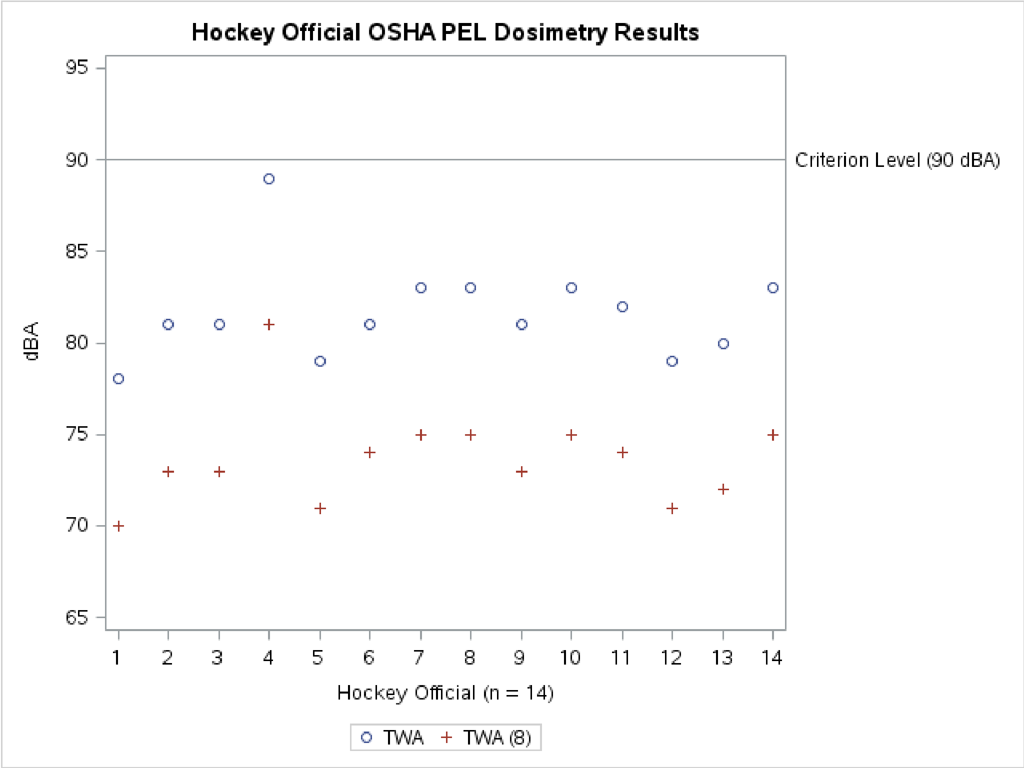

Figure 5.4: Hockey Official OSHA PEL Dosimetry Results

Linesmen Personal Noise Exposures at Venues One and Two (All Games)

The OSHA PEL (n = 8), OSHA AL (n = 12), and ACGIH TLV (n = 12) mean percent noise dose for linesmen (n = 12) was 12.2, 20.6, and 143.3 percent, respectively. The mean percent noise dose for linesmen did not exceed the OSHA PEL or the OSHA AL criteria. However, with a linesmen mean percent noise dose of 143.3%, the linesmen sampled exceeded the ACGIH TLV criteria for noise. The OSHA PEL, OSHA AL, and ACGIH TLV mean projected noise dose percent for linesmen was 36.0, 61.0, and 421.1 percent, respectively. The mean Leq for linesmen based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 90 dBA.

The OSHA PEL, OSHA AL, and ACGIH TLV mean TWA for linesmen was 82, 86, and 90 dBA, respectively. The mean TWA (8) for linesmen based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 74, 78, and 86 dBA, respectively. The mean TWA (8) for linesmen was not exceeded for the OSHA PEL or OSHA AL criteria. However, with a mean TWA (8) of 86 dBA, the linesmen sampled exceeded the ACGIH TLV criteria for noise.

The average Lmax for linesmen based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 116 dBA. The OSHA PEL, OSHA AL, and ACGIH TLV mean Lpeak for linesmen was 134 dB. Impulse noises for linesmen did not exceed 140 dB. The mean linesmen noise dosimetry results for Venues One and Two are displayed in Table 5.2. The individual linesmen official Leq noise exposures are presented in Figure 5.5. The individual linesmen TWA and TWA (8) results for the ACGIH TLV, OSHA AL, and OSHA PEL criteria are shown in Figures 5.6, 5.7, and 5.8, respectively.

Table 5.2: Mean Linesmen Noise Dosimetry Results for Venues One and Two

Mean Linesmen Dosimetry Results for Venues One and Two (n = 12)						
	OSHA PEL (n = 7)		**OSHA AL (n = 12)**		**ACGIH TLV (n = 12)**	
	Results	SD	Results	SD	Results	SD
Dose (%)	12.2	7.42	20.6	7.04	143.3	127.5
Projected Dose (%)	36.0	20.8	61.0	19.9	421.1	358.7
Leq (dBA)	90	2.41	90	2.41	90	2.41
TWA (dBA)	82	3.32	86	2.07	90	2.42
TWA (8) (dBA)	74	3.33	78	2.10	86	2.48
Lmax (dBA)	116	4.78	116	4.78	116	4.78
Lpeak (max) (dB)	134	7.19	134	7.19	134	7.19

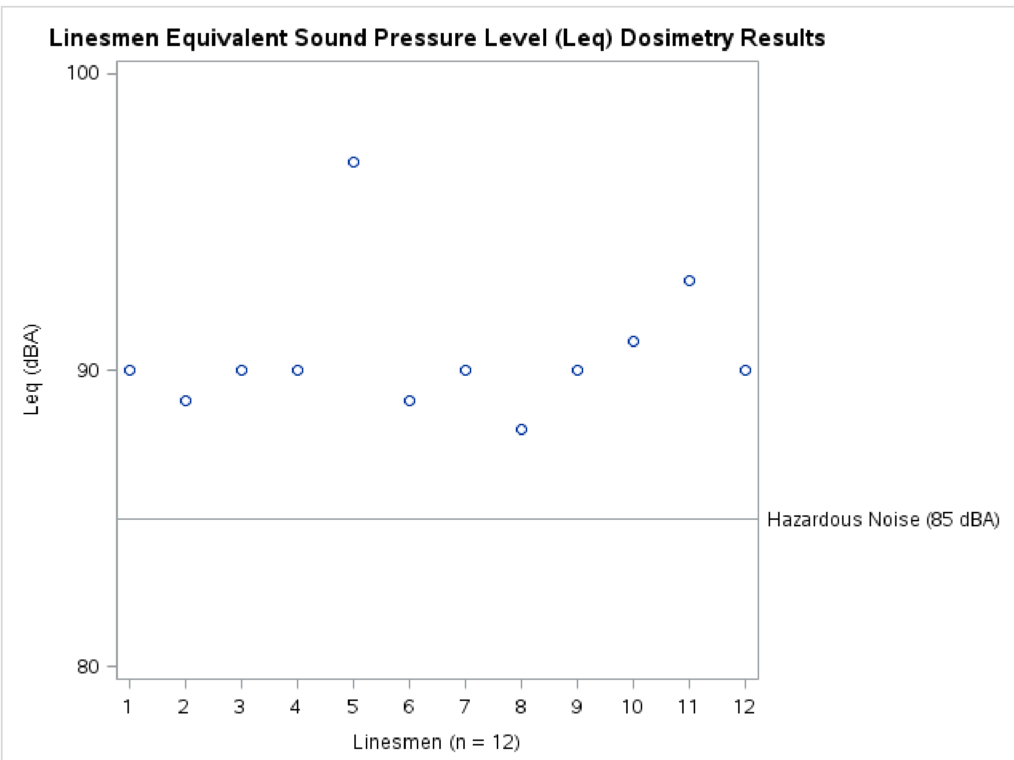

Figure 5.5: Linesmen Equivalent Sound Pressure Level (Leq) Dosimetry Results

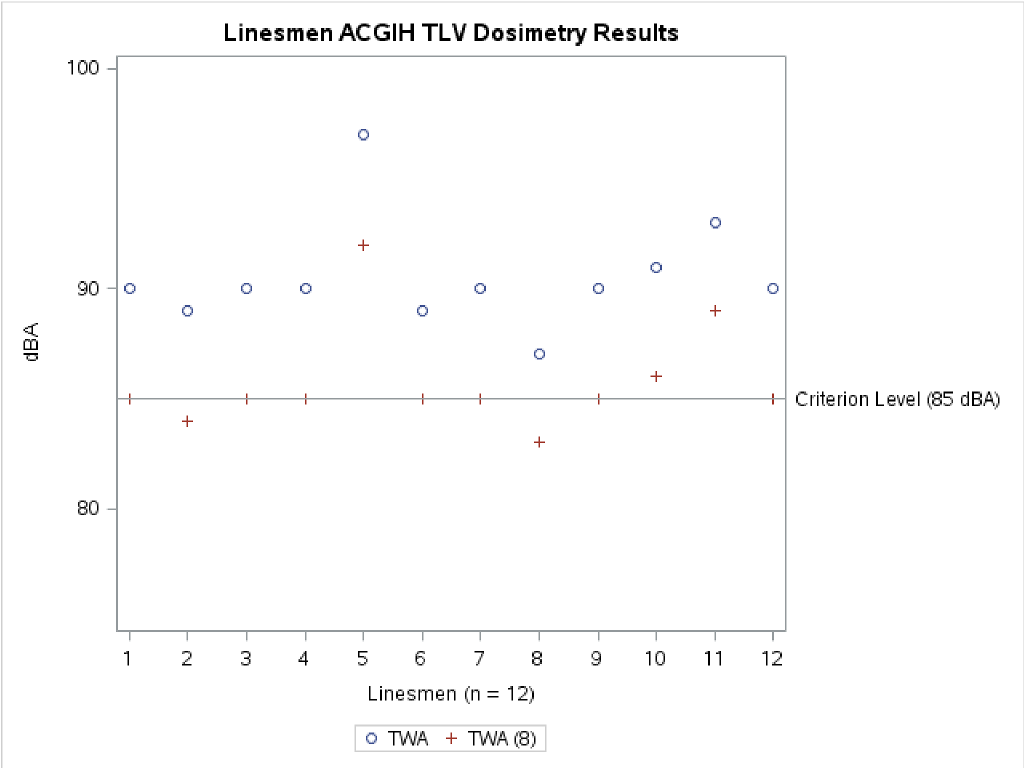

Figure 5.6: Linesmen ACGIH TLV Dosimeter Results

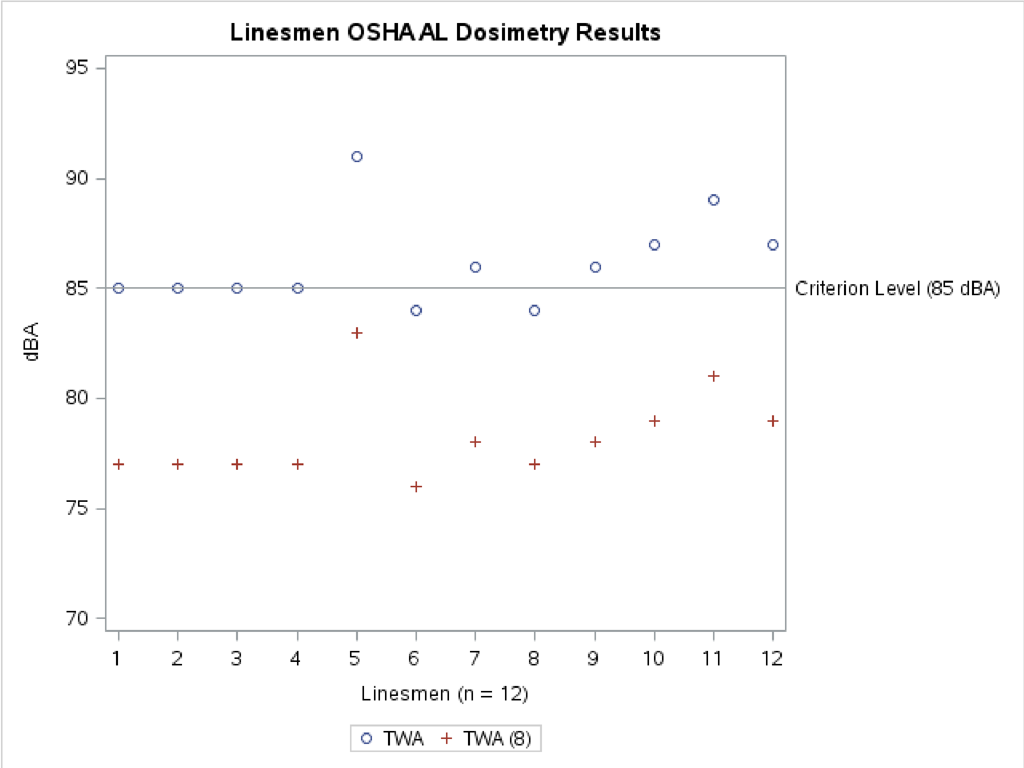

Figure 5.7: Linesmen OSHA AL Dosimetry Results

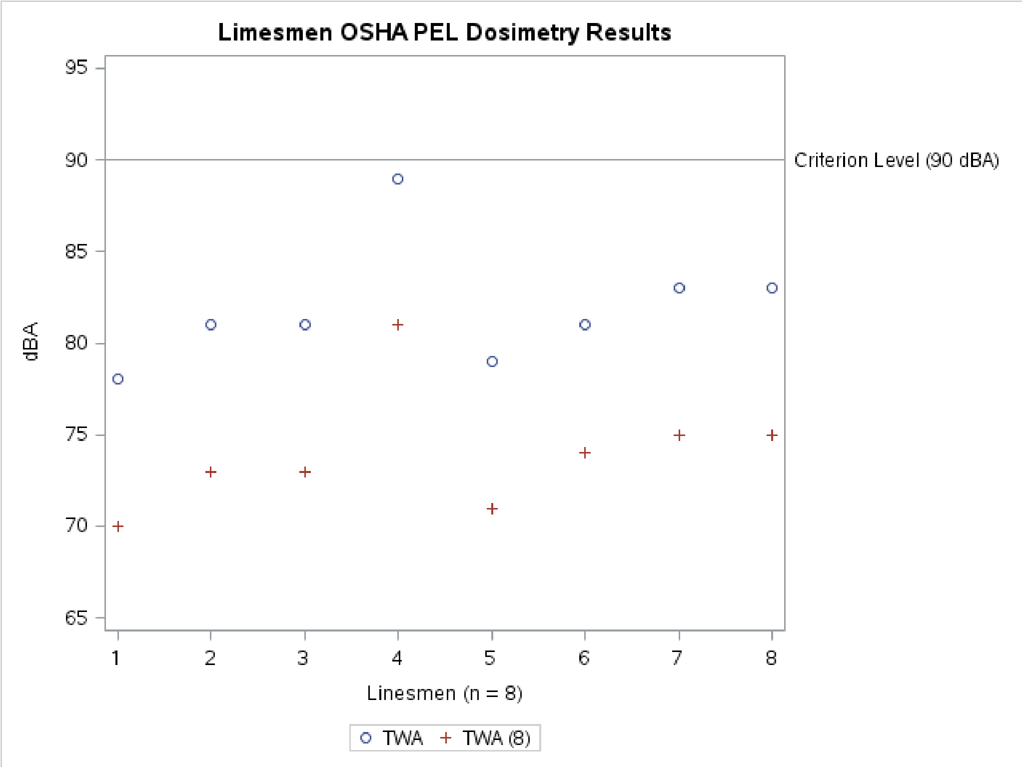

Figure 5.8: Linesmen OSHA PEL Dosimetry Results

Referee Personal Noise Exposures at Venues One and Two (All Games)

The OSHA PEL (n = 6), OSHA AL (n = 11), and ACGIH TLV (n = 11) mean percent noise dose for referees (n = 11) was 9.8, 17.8, and 94.5 percent respectively. The mean percent noise dose for the referees did not exceed the OSHA PEL, OSHA AL, or the ACGIH TLV criteria for noise. The OSHA PEL, OSHA AL, and ACGIH TLV mean projected noise dose percent for referees was 29.6, 53.5, and 282.7 percent, respectively. The mean Leq for referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 89 dBA.

The OSHA PEL, OSHA AL, and ACGIH TLV mean TWA for referees was 81, 85, and 89 dBA, respectively. The mean TWA (8) for referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 73, 77, and 84 dBA, respectively. The mean TWA (8) for the referees did not exceed the OSHA PEL, OSHA AL, or the ACGIH TLV criteria for noise.

The average Lmax for referees based on OSHA PEL, OSHA AL, and ACGIH TLV criteria was 114 dBA. The OSHA PEL, OSHA AL, and ACGIH TLV mean Lpeak for referees was 133 dB. Impulse noises for referees did not exceed 140 dB. The mean referee noise dosimetry results for Venues One and Two are displayed in Table 5.3. The individual referee Leq noise exposures are presented in Figure 5.9. The individual referee TWA and TWA (8) results for the ACGIH TLV, OSHA AL, and OSHA PEL criteria are shown in Figures 5.10, 5.11 and 5.12, respectively.

Table 5.3: Mean Referee Noise Dosimetry Results for Venues One and Two

Mean Referee Dosimetry Results for Venues One and Two (n = 11)						
	OSHA PEL (n = 6)		**OSHA AL (n = 11)**		**ACGIH TLV (n = 11)**	
	Results	SD	Results	SD	Results	SD
Dose (%)	9.8	2.16	17.8	3.29	94.5	33.9
Projected Dose (%)	29.6	7.05	53.5	9.92	282.7	99.9
Leq (dBA)	89	1.68	89	1.68	89	1.68
TWA (dBA)	81	1.80	85	1.38	89	1.72
TWA (8) (dBA)	73	1.69	77	1.45	84	1.76
Lmax (dBA)	114	4.27	114	4.27	114	4.27
Lpeak (max) (dB)	133	2.87	133	2.87	133	2.86

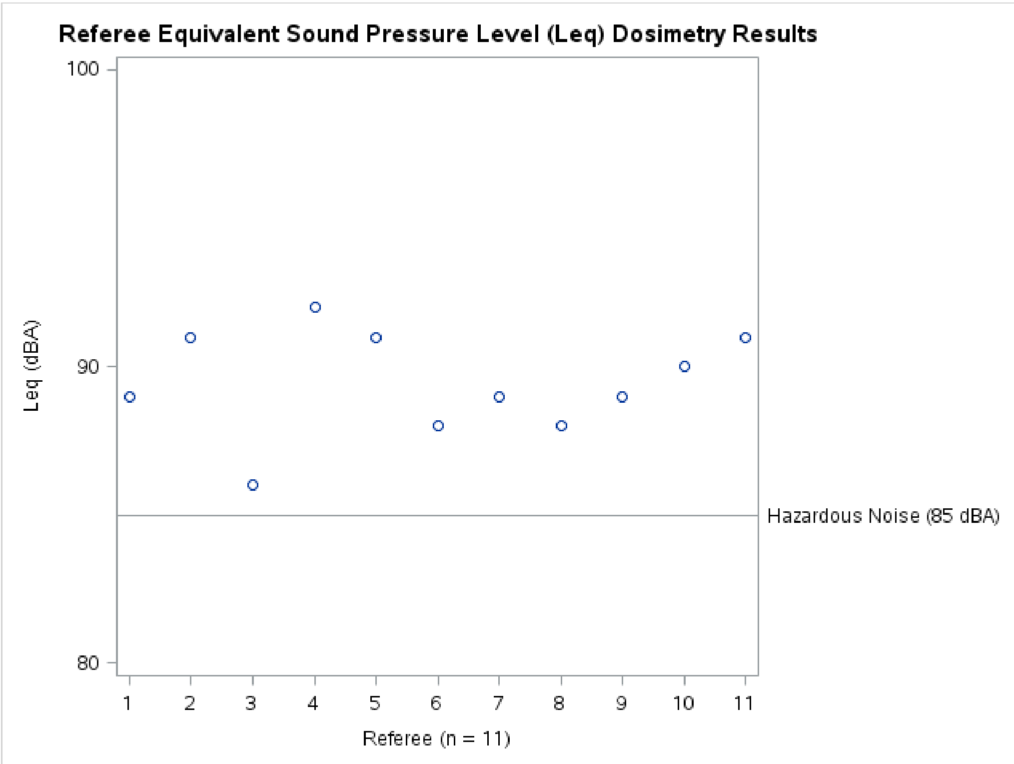

Figure 5.10: Referee Equivalent Sound Pressure Level (Leq) Dosimetry Results

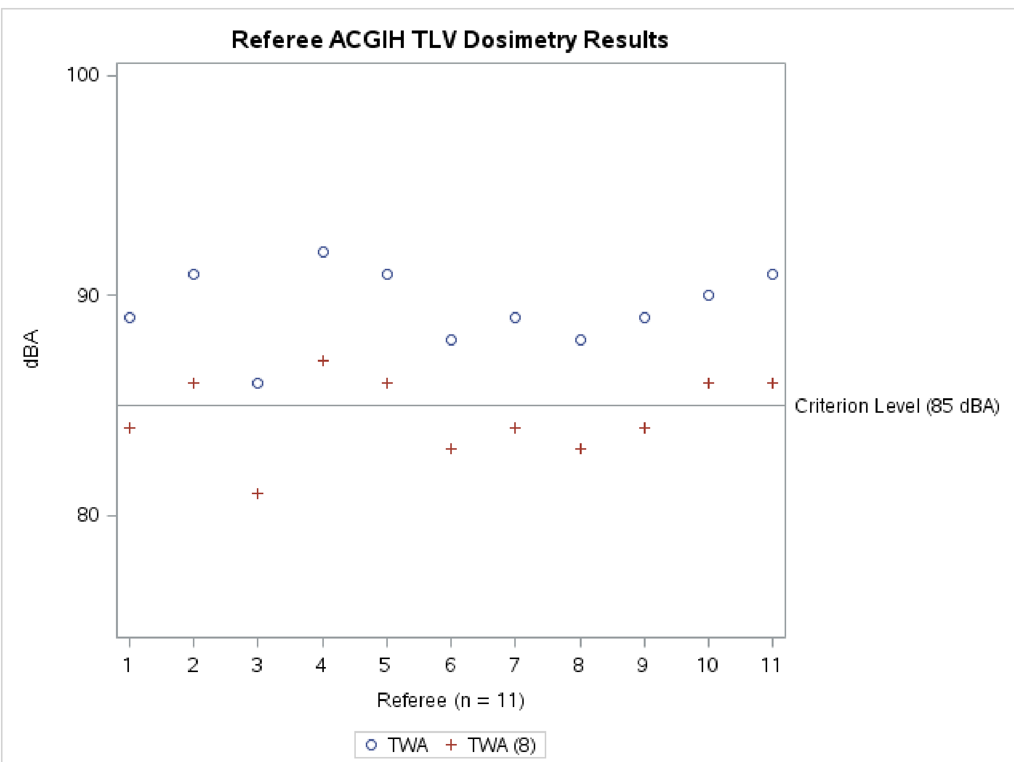

Figure 5.10: Referee ACGIH TLV Dosimetry Results

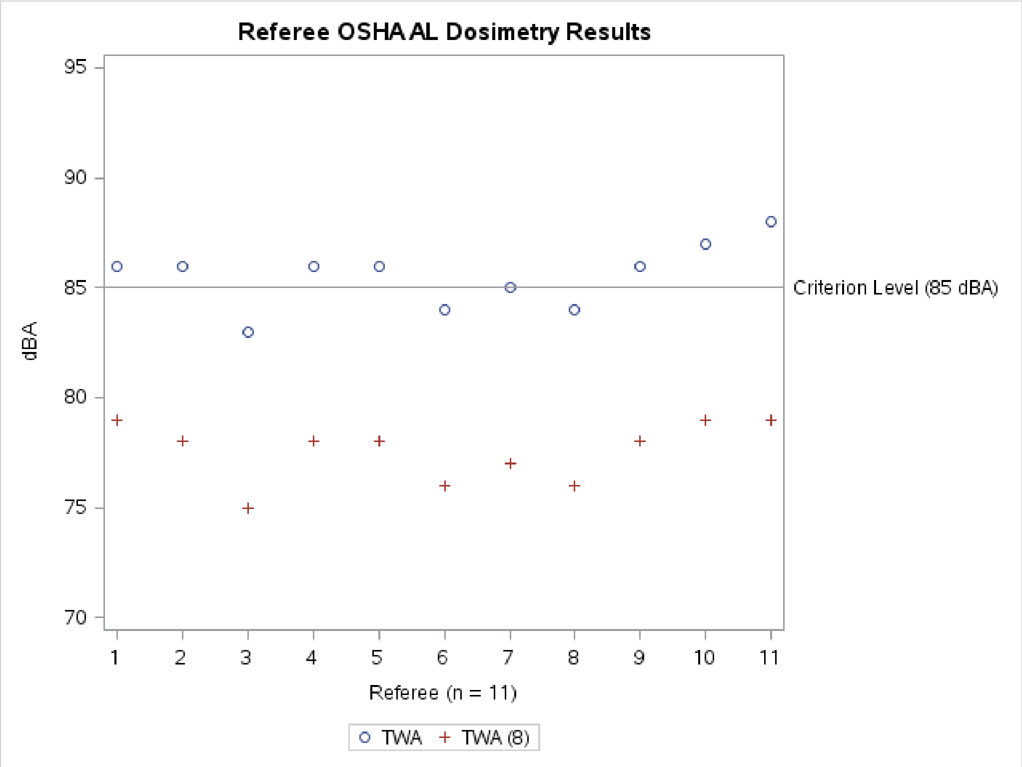

Figure 5.11: Referee OSHA AL Dosimetry Results

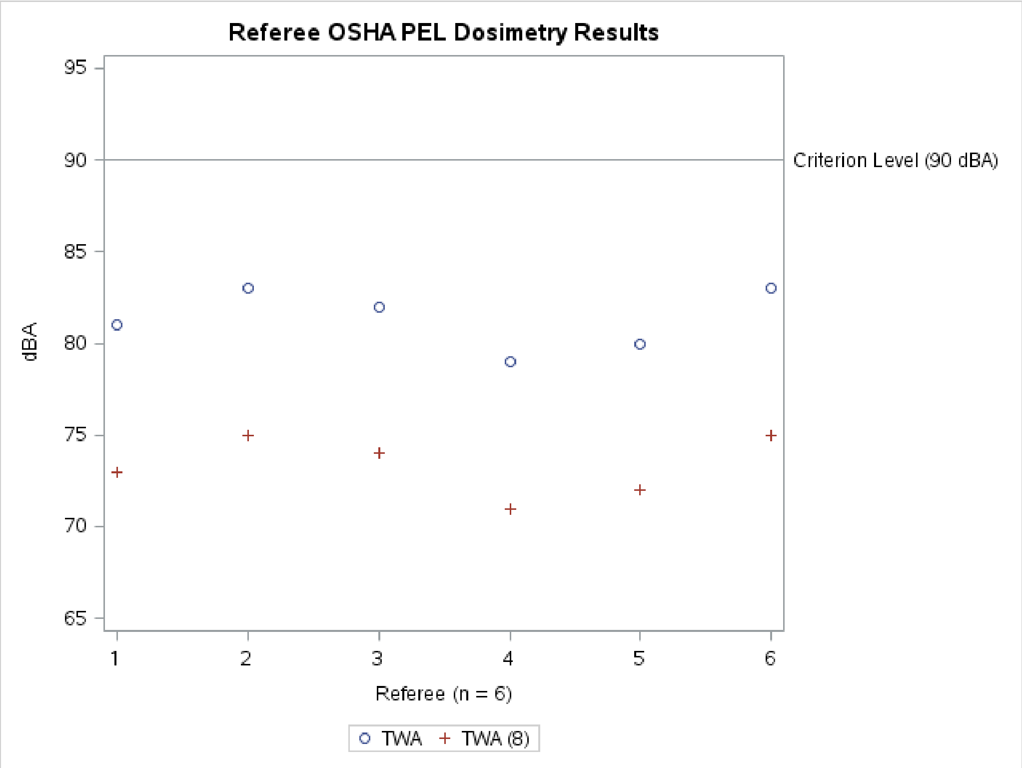

Figure 5.12: Referee OSHA PEL Dosimetry Results

Exceedance of Occupational Exposure Limits at Venues One and Two (All Games)

It is noted that at both venues, the linesmen and referees were all exposed to a Leq greater than 85 dBA. In addition, none of the linesmen or referees were overexposed to noise based on the OSHA PEL or OSHA AL criteria. Ten of 12 (83%) linesmen sampled were overexposed to noise based on the ACGIH TLV criteria. Five of 11 (45%) referees sampled were overexposed to noise based on the ACGIH TLV criteria. In total, 15 of 23 (65%) of officials were overexposed to noise at Venues One and Two based on the ACGIH TLV criteria. The exceedance of occupational exposure limits for linesmen, referees, and all hockey officials who participated in sampling are displayed in Table 5.4.

Table 5.4: Exceedance of Occupational Exposure Limits for Linesmen, Referees, and Linesmen and Referees at Venues One and Two

Exceedance of Occupational Exposure Limits at Venues One and Two				
	Leq > 85 dBA	OSHA PEL (8-hour TWA)	OSHA AL (8-hour TWA)	ACGIH TLV (8-hour TWA)
Linesmen (n = 12)	(12/12) 100%	(0/8) 0%	(0/12) 0%	(10/12) 83%
Referees (n = 11)	(11/11) 100%	(0/6) 0%	(0/11) 0%	(5/11) 45%
All (n = 23)	(23/23) 100%	(0/14) 0%	(0/23) 0%	(15/23) 65%

CHAPTER 6: DISCUSSION

The purpose of this study was threefold: (1) to measure the noise to which hockey officials are exposed; (2) to determine if hockey officials are at increased risk of hearing damage from officiating games; and (3) to determine if hearing protection is warranted. Therefore, the null hypothesis for this study was that hockey officials are not exposed to hazardous levels of noise. Based on the results of this study, 65% of hockey officials (83% linesmen; 45% referees) exceeded the ACGIH TLV for noise exposure. However, none of the officials sampled exceeded the OSHA PEL or OSHA action limit, nor were they exposed to impulse noise levels greater than 140 dBA. In addition, all officials who participated in this study had Leqs that were greater than 85 dBA. Therefore, the noise to which the sampled officials were exposed places them at an increased risk of developing NIHL. In this case, recommendations will be provided to reduce hockey official noise exposure during games.

Personal Noise Dosimetry

Although 20 to 32 samples were required to achieve statistical power, a total of 23 personal noise dosimetry samples were collected from the hockey officials. The OSHA AL criteria dose percentage from Table 5.1 was calculated at 19.2%. Since none of the hockey officials sampled exceeded the OSHA AL criteria, the hockey officials are not required to enroll in a HCP. However, the eight-hour TWA accounts for nearly five hours and twenty minutes of no noise exposure, as the average time for each hockey game was two hours and 42 minutes. However, it is unlikely the officials do not receive any noise exposure during the remainder of the day. Some of the hockey officials that participated in this study would officiate junior and collegiate hockey games as a part-time income, which could suggest they have other occupations. In addition, the officials may partake in hobbies and activities that expose them to excessive noise. Thus, it is possible that the hockey officials are engaged in other activities that may expose them to hazardous noise. These activities may include occupations, hobbies (e.g. firearm activities, musical instruments), and events (e.g. music festivals).

Cranston et al. at found that 40% of hockey game workers sampled at one venue and 57% of employees at another exceeded the ACGIH TLV (Cranston et al, 2013). The researchers also found that 33% and 91% of fans exceeded the ACGIH TLV (Cranston et al., 2013). In addition, the study performed by Engard et al. at football arenas found that 96% and 36% of workers sampled exceeded the ACGIH TLV and OSHA action limit respectively (Engard et al., 2010). In the current study, 65% of hockey officials (83% linesman; 45% referees) exceeded the ACGIH TLV. In addition, all of the officials sampled were exposed to an equivalent continuous sound pressure level greater than 85 dBA. None of the officials sampled in the current study exceeded the OSHA PEL or the OSHA action limit. The differences observed between the three studies may be attributed to the following: event attendance, game environment, popularity of the sporting event, open arenas versus closed arenas, hockey official arena location versus hockey fan arena location, and hockey official arena location versus hockey arena employee location.

During NHL playoff hockey games, Hodgetts and Liu indicated a Leq range from 101 to 104 dBA (Hodgetts and Liu, 2006). The noise levels observed here were much greater than the Leq ranges produced in the current study (86 to 97 dBA). The estimated crowd capacity in the current study ranged from 120 to 370 participants. Hodgetts and Liu documented a very popular event during the NHL playoff season and may not be representative of a regular season game. Therefore, Hodgetts's study represents atypical noise exposure at indoor hockey events.

The researchers in the present study suggested that hockey officials are overexposed to noise during indoor junior and collegiate hockey games. During data collection, all the officials sampled exceeded a Leq of 85 dBA. Researchers have noted that frequent exposure to noise levels over 85 dBA not only contributes to hearing loss but also incidence of hypertension (Berger et al., 2003).

Factors That Likely Contributed to Noise Exposure

During the course of the hockey event, there were a number of factors that contributed to the hockey officials' noise exposure. A personal communication from a hockey official suggested the public address (PA) system within each venue contributed to hockey game noise exposures. During each contest, it was observed that the public address system was used to frequently play music and shout out antics to excite the crowd and the players during the game. The PA system would often be active prior to each puck drop and during time-outs throughout the game. Therefore, the loud music from the PA system likely increased the noise exposure to which the officials were exposed.

An additional factor that contributes to excessive noise exposure is the use of whistles during games. A study conducted by Flamme and Williams (2013) surveyed sports officials regarding their whistle use and symptoms of hearing loss during games. The questionnaires revealed that sports officials reported symptoms of hearing damage higher than the general United States population. In addition, the researchers found that sound levels produced by whistles ranged between 104 to 116 dBA, which corresponds to maximum exposure times of 90 to 5 seconds, respectively. Flamme and Williams concluded that whistle use could potentially contribute to hearing loss among officials. The researchers in the present study observed that certain peaks in the time history graphs of the dosimetry data were within the range of 104 to 116 dBA. An example of a time history graph from the personal noise dosimetry data is illustrated in Figure 6.1. These peaks could have been attributed to whistle use from the officials. Therefore, the use of whistles may place hockey officials at risk of developing NIHL.

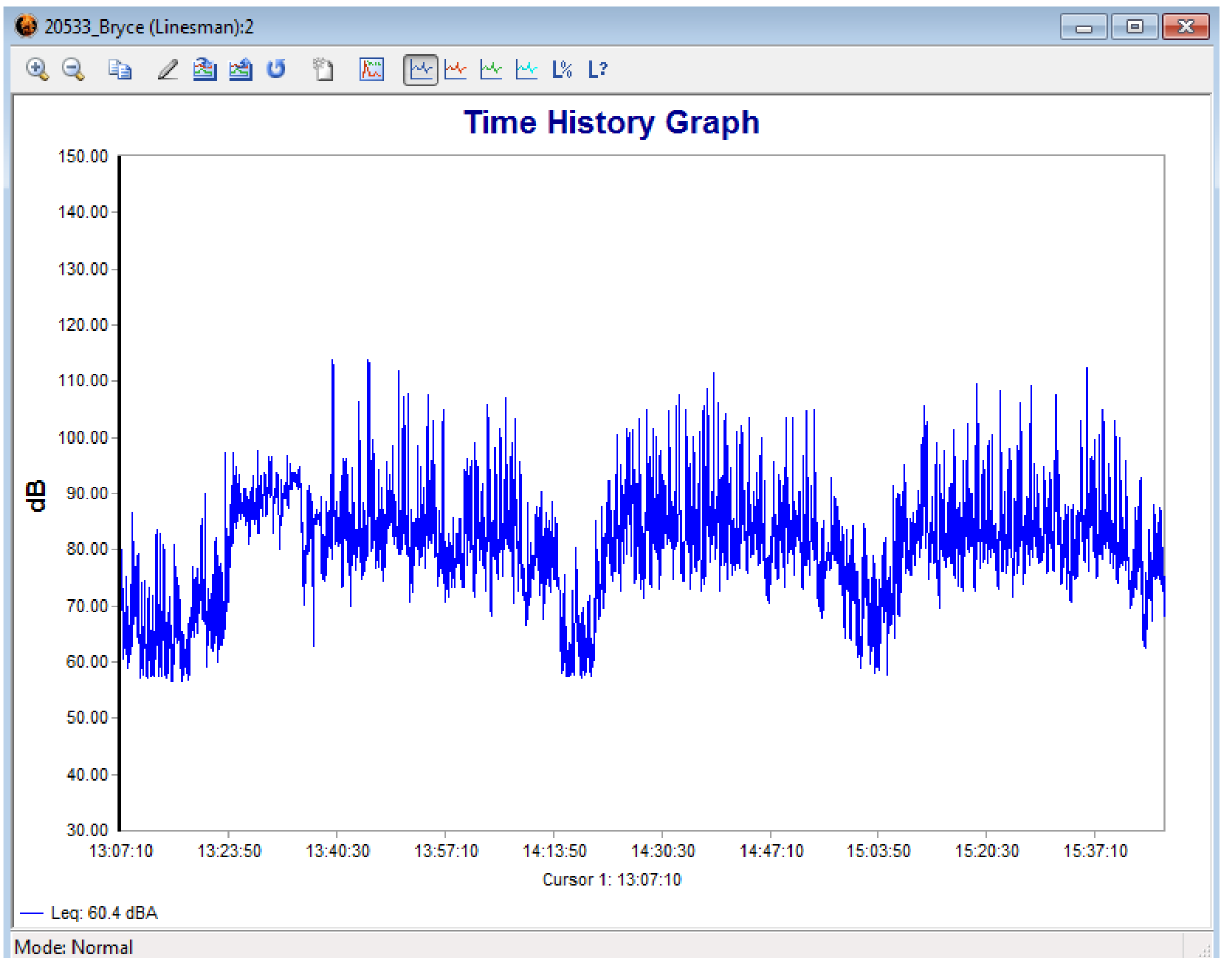

Figure 6.1: Example of Personal Noise Dosimetry Time History Graph

Chants from the crowd are an additional factor that can contribute to hockey official noise exposure. During the course of a hockey game, the crowd is vocally engaged in the hockey game, chanting praises and jeers at the players and the officials. Although the games that were attended were small in number (estimated 120 to 370 patrons per game), the noise emitted from the crowd contributed to the noise exposure during hockey games.

Interactions between the officials and the players are an additional factor that could have attributed to noise exposure. Throughout the course of a hockey game, officials frequently interact with the players to make calls, break up scuffles, and appoint in-game violations. These constant interactions and word exchanges among players and coaches could potentially increase the noise exposure to which hockey officials are exposed.

Discrepancy Between Linesmen and Referees

During data collection, it was observed that a higher percentage of linesmen (83%) had exceeded the ACGIH TLV criteria than referees (45%). It was found that 10 of 12 (83%) linesmen sampled exceeded the ACGIH TLV, whereas five of 11 (45%) referees sampled exceeded the ACGIH TLV, despite the officials having the same on-ice time. Factors that could have contributed to this include the on-ice positioning and different job tasks between linesmen and referees.

The type of official system used during each game (three-official system or four-official system) could have dictated how close each official was to the in-game action. The lead and rear position changes of the referees and linesmen in each system could have placed them either closer or further away from in-game action. These position changes in each official could have caused the discrepancy in noise exposure between referees and linesmen.

The different job tasks between linesmen and referees could have led to the discrepancy in noise exposure. During the course of a game, linesmen and referees each perform different job tasks. Referees enforce the rules and maintain the natural order of the game. Referees are the only officials during games able to grant penalties for the violations of the rules. Linesmen are primarily responsible for watching the violations that involve the center and blue line. These violations include icing and offside infractions, after which the linesmen conduct faceoffs. They are also expected to break up fights, scuffles, and any additional altercations that may occur during the game. It is possible the differences in player interactions between linesmen and referees could play a role in the different noise exposures between the two official classes.

Study Limitations

The primary limitation was that the current research was a field study and the noise levels of hockey officials may vary greatly for each junior and collegiate hockey game in estimating the true mean noise exposure. The scope of this research only examined two venues in northern Colorado, collecting a total of 23 personal noise dosimetry samples. However, the hockey officials sampled during this research also officiate a number of junior and collegiate hockey games in various venues throughout Wyoming and Colorado. Therefore, the noise levels of hockey officials can vary greatly in estimating the true mean noise exposure of hockey officials.

A second limitation would be the determination of the actual number of crowd participants at each junior and collegiate hockey game. During data collection, some of the collegiate hockey games did not account for the number of patrons who attended each game. Therefore, the true number of crowd attendance was estimated for some of the hockey games sampled. Fortunately, some of the hockey games used for sampling did account for the number of fans present at the game. Thus, the researchers in the present study estimated a range (120 to 370 patrons) of the participants present at each game using the venues that did account for crowd attendance. The actual number of crowd attendance at each junior and collegiate game used for sampling would have allowed for a more accurate representation of participants present at each venue.

Another limitation of the research would be the inconsistencies in the Larson Davis Spark® personal noise dosimeter settings. The personal noise dosimeters used in the present study measured hockey official noise exposures for OSHA PEL, OSHA AL, and ACGIH TLV criteria for noise exposure. However, during data collection, some of the personal noise dosimeters were unable to measure the OSHA PEL criteria for noise exposure. It appeared that some of the Larson Davis Spark® personal noise dosimeters were not programmed to measure the OSHA PEL criteria. As a result, only 14 (8 linesmen; 6 referees) hockey official personal noise exposures were collected for the OSHA PEL criteria. If all of the personal noise dosimeters were programmed to measure the OSHA PEL criteria, it would have allowed for a more accurate representation of the hockey official OSHA PEL results.

An additional limitation of the research was the lack of sound level meter data within each venue. The researchers in the present study only measured the amount of hockey official noise dose exposure during junior and collegiate hockey games. However, the researchers were unable to determine the actual sources of noise exposure during hockey games. Using sound level meters, researchers could determine which potential sources of noise (e.g. crowd, public address system) provide the highest levels of noise during junior and collegiate hockey games.

CHAPTER 7: CONCLUSION, RECOMMENDATIONS, AND FUTURE WORK

The evaluation of hockey official exposure to noise during indoor junior and collegiate hockey games was used to answer the following questions:

1) *What is the average noise TWA, TWA (8) and Leq for the OSHA PEL, OSHA AL, and ACGIH TLV criteria for hockey officials?*

   The mean OSHA PEL TWA, TWA (8), and Leq for linesmen and referees were 82, 74, 90 dBA, respectively. The mean OSHA AL TWA, TWA (8), and Leq for linesmen and referees were 86, 78, and 90 dBA, respectively. The mean ACGIH TLV TWA, TWA (8), and Leq for linesmen and referees were 90, 85, and 90 dBA, respectively.

2) *Do junior and collegiate hockey official noise exposures exceed the ACGIH TLV, OSHA PEL, and OSHA AL occupational criteria for noise?*

   Sixty-five percent of hockey officials (83% linesmen; 45% referees) were overexposed to occupational noise based on ACGIH recommendations. However, none of the officials sampled exceed the OSHA AL or the OSHA PEL for noise exposure. Based on these results, hockey officials are not required by OSHA to enroll into a hearing conservation program, but since the ACGIH TLV was exceeded for 65% of officials, hearing protection is recommended, because they are exposed to hazardous levels of noise.

3) *Are hockey officials at an increased risk of hearing damage from officiating games without hearing protection?*

Without the use of hearing protection, hockey officials are at an increased risk of hearing damage. The hockey officials sampled all had equivalent continuous sound pressure levels that exceeded 85 dBA, which places them at an increased risk for hearing damage. It has been well documented that exposures to hazardous occupational noise greater than 85 dBA contributes to an increased risk for developing NIHL (Berger et al, 2003).

Recommendations

The noise levels within each venue were well below the OSHA action limit of 85 dBA, or 50% noise dose, therefore no formal hearing conservation program is required for facilities in compliance with OSHA standards. However, if hockey official supervisors want to ensure that their employees are not overexposed to noise based on ACGIH criteria (eight-hour TWA of 85 dBA, 3 dB exchange rate), it is recommended that hockey officials be trained about hearing loss and the use of hearing protection.

The researchers in the present study observed that 65% of the hockey officials sampled exceeded the ACGIH TLV criteria for noise. In addition, all of the hockey officials sampled had equivalent sound levels that exceeded 85 dBA. Therefore, it is important that the hockey officials are trained about hearing loss and the value of hearing conservation. This training should emphasize that the environment to which hockey officials are exposed places them at an increased risk of developing NIHL. The hockey officials should know that NIHL is a permanent, irreversible form of hearing loss and its primary cause is from frequent exposures to noise levels greater than 85 dBA. Hockey officials should also be trained on the importance and proper use hearing protection to reduce noise exposures and decrease the risk of developing NIHL.

The use of earplugs would provide adequate protection from unwanted noise exposure during hockey games. In addition, earplugs designed to offer variable noise reduction to reduce exposure to unwanted frequencies of noise would be a great means of protection for officials. These earplugs allow for individuals to still hear normal conversations without the removal of earplugs. This would be a more acceptable solution for hockey officials, as they have to interact with the players, coaches, and each other during games. A representation of the style of earplugs that are recommended for hockey officials is displayed in Figure 7.1.

Figure 7.1: QuietEar Reusable Ear Plugs (Earplug Superstore, 2014).

The earplugs displayed in Figure 7.1 contain a built-in acoustic filter in the form of a precisely designed vent. As the volume of noise increases at the ear, these earplugs provide increased noise reduction, which results in greater nose protection at higher noise levels. This means at lower noise levels, one can still hear voices without the removal of earplugs. These earplugs offer different noise attenuation at high and low frequencies, which means the sounds in the frequency range of the human voice are less attenuated than the higher, more dangerous frequencies (Earplug Superstore, 2014). A table that displays the attenuation levels of the earplugs at varying frequencies is displayed in Figure 7.2.

Frequencies Hz	125	250	500	1k	2K	4K	6K	8K
Attenuation db	9	10.5	14.2	16.7	22.5	32.2	36.1	36.6
		Low to Moderate Noise Reduction in Normal Speech Range				Highest Noise Reduction in the Dangerous Frequency Range		
Std Deviation db	3.9	4.2	4.3	5.1	5.5	5.0	7.0	7.7
Tested according to U.S. Standards ANSI S12.6 - 1997.								

Figure 7.2: Attenuation chart for the recommended earplugs (Earplug Superstore, 2014).

The use of hockey helmet ear protectors during games may provide some degree of hearing protection for officials. However, it is unknown whether or not the use of helmet ear protectors can provide sufficient hearing protection. Throughout sampling, it was observed that some hockey officials removed the ear protectors on their helmets. It was not required by officials to wear their helmet ear protectors during games. Personal communication from hockey officials stated that the helmet ear protectors were removed to increase helmet comfort during games. Future research can determine whether or not the incorporation of hockey helmet ear protectors can provide adequate hearing protection during games. An illustration of hockey helmet ear protectors is displayed in Figure 7.3.

Figure 7.3: Hockey helmet ear protectors (Ice Warehouse, 2014).

Future Work

This study addressed the potential for noise overexposure of hockey officials based on ACGIH and OSHA criteria. The noise exposure of hockey officials that participate in junior and collegiate indoor hockey games were characterized in this study. Depending on the type of hockey league (NCAA, NHL, etc.) and the sporting event (football, basketball, etc.), officials may work different venues and perform different tasks during the event. Therefore, it is likely that larger venues with higher stadium capacities may have higher noise levels due to the elevated crowd capacity. In addition, audiometric testing to determine temporary threshold shifts in hearing will be a critical component to determine if hearing loss could occur for sporting officials. Therefore, future research would incorporate the use of audiometric testing before and after each hockey game, in addition to noise characterization with the use of personal noise dosimetry during games. The use of audiometric testing will allow researchers to determine if hockey officials experience temporary hearing loss during hockey games. This will provide additional empirical data to determine if hockey officials are at risk for developing noise-induced hearing loss.

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APPENDIX A

Noise Monitoring Data Checksheet

Dosimeter Serial Number	
Pre-calibration (date and dB)	
Post calibration (date and dB)	
Sample Date	
Sample Location	
Job Title	
Dosimeter secured to waistband/belt	
Cord secured to back of shirt with tape	
Microphone in middle of shoulder	
Microphone upright	
Microphone secured with tape	
Time Dosimeter On	
Intermission 1 Microphone Check/Notes	
Intermission 2 Microphone Check/Notes	
Time Dosimeter Off	
Notes	
Crowd Attendance	