THESIS

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR HOCKEY OFFICIALS

Submitted by

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ABSTRACT

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR HOCKEY OFFICIALS

Noise in the workplace is a common occurrence. These sounds can have various characteristics that can affect each individual. Many people around the world subject themselves to loud noises at recreational activities including concerts, monster truck rallies, and sporting events. Some individuals also work these events as security employees, referees, and concession workers. Depending on the arena and the sport, games may take place one to four days a week at a particular venue. The National Institute for Occupational Safety and Health (NIOSH) identifies exposure to noise as one of the most common hazards associated with workplaces.[2]

According to the National USA Hockey League, there are over 20,000 registered officials (referee/linesman) regulating hockey in the United States.[6] The identified hockey official population could be at risk of developing noise induced hearing loss (NIHL) because of the noise exposure at hockey games. For this study, personal noise dosimeters and a sound level meter were used to record noise exposures during hockey games for the 2014 season to ascertain if hockey referees were at increased risk of NIHL. A total of 30 personal noise samples and 20 area noise samples were collected. The study was completed in December 2014. The noise dosimetry results were compared to the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL), OSHA Action Level (AL), and American Conference for Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV).

Noise dose was calculated for each official per game to determine if noise controls were warranted at this specific venue. No referees or linesmen were overexposed to noise when

compared to the OSHA PEL. However, twenty-five referees and linesmen (89%) were overexposed to noise according to the ACGIH recommendations (85 dBA, 3 dB exchange rate), and two officials (7%) were exposed above the OSHA Action Level (85 dBA, 5 dB exchange rate). An average equivalent sound-pressure level (Leq) range of 79 dBA to 90 dBA was measured using a sound level meter at four locations in the arena over five games.

In addition to area and personal monitoring, the number of whistle blows by the officials was counted during the first period of four games, and the average number of whistle blows per game for referees and linesmen was 60. According to previous researchers, whistle blows are one of the loudest and closest noise sources to referees. Some whistles reach sound levels as high as 116 dBA.[17]

Based on the results, it is recommended that this venue take preventative action in reducing noise exposure for hockey referees. Future research should continue sampling at sports arenas and focus on implementing control measures in hockey arenas.

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DEDICATION

For my family and friends who have been there for me with patience, support, and guidance.

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AL	Action Level
ACHA	American Collegiate Hockey Association
ASHA	American Speech-Language-Hearing Association
CDC	Centers for Disease Control and Prevention
CSU	Colorado State University
dB	Decibel
dBA	Decibel, A-weighted
HCP	Hearing Protection Program
Hz	Hertz
Leq	Equivalent Continuous Sound Pressure Level
NHL	National Hockey League
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NIDCD	National Institute on Deafness and Other Communication Disorders
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPE	Personal Protective Equipment
SLM	Sound Level Meter
SPL	Sound Pressure Level

TLV	Threshold Limit Value
TWA	Time Weighted Average
WHO	World Health Organization
WSHL	Western States Hockey League

CHAPTER 1 : INTRODUCTION

Noise is often referred to as a sound – often loud and/or unwanted. One of the most common sources of noise exposure is in the workplace. More than 30 million workers in the United States (US) are exposed to hazardous noise levels that pose a risk of hearing loss.[1] The National Institute for Occupational Safety and Health (NIOSH) identifies exposure to noise as one of the most common hazards associated with workplaces.[2] Overexposure to noise can lead to permanent noise-induced hearing loss (NIHL). Currently, more than10 million US workers have permanent noise induced hearing loss.[1] Noise induced hearing loss can be reduced and essentially prevented by using hearing conservation programs which include the use of noise exposure monitoring.[2] Losing one's hearing does not just happen in the workplace. Many people enjoy recreational activities after work that can add to their noise exposure including attending concerts, shooting rounds at the gun range, or attending sporting events.[3] Individuals may experience the sensation of temporary hearing loss when they leave a loud concert or sporting event. For example, their ears may feel "full" or normal noises sound muffled.[3] Repeated exposures to these sounds for too long or if too loud can decrease the sensitivity of hearing over time.[3]

In order to reduce the risk of noise induced hearing loss in the workplace, the Occupational Safety and Health Administration (OSHA) published noise exposure standards that specified workplaces must implement or face penalties.[4] The OSHA noise exposure standard is referred to as the permissible exposure limit (PEL), which is an 8-hour time weighted average (TWA) of 90 dB as measured on the A-weighted scale (dBA) with a 5 dB exchange rate (ER).[4] OSHA requires employers to enroll employees in a hearing conservation program (HCP) if the employees are above the Action Level (AL), which is an 8-hour TWA of 85 dB with a 5 dB exchange rate.[5] The American Conference for Governmental Industrial Hygienist (ACGIH) established noise exposure guidelines that are more conservative than OSHA standards.[5] The ACGIH guideline is referred to as the Threshold Limit Value (TLV), which is an 8-hour TWA of 85 dB with a 3 dB exchange rate.[5] These three standards and guidelines were used to assess noise exposures in this study.

In recent years, researchers have started to focus on specialized workplaces that include sporting events and indoor arenas. According to the National USA Hockey League, there are over 20,000 registered officials regulating hockey in the United States.[6] The identified hockey official population could be at risk of developing noise induced hearing loss (NIHL) due to noise exposure at games. The current study focused on measuring personal noise exposure of officials (referees and linesmen) during ice hockey games to determine if the officials were overexposed to noise according to the OSHA PEL, OSHA AL, and ACGIH TLV. Personal noise dosimeters and a sound level meter were used to record noise exposures during hockey games for the 2014 season. The noise dosimetry results were compared to the OSHA PEL, OSHA AL, and ACGIH TLV for each official at each game to determine if there is a need for noise controls at this specific venue. The SLM results were used to monitor arena acoustics and whether area samples exceeded an equivalent sound pressure level (Leq) of 85 dB. The number of whistle blows per game was counted to estimate the average total whistles blown.

CHAPTER 2 : LITERATURE REVIEW

Noise Induced Hearing Loss

Noise is measured in decibels resulting from the sound pressure from the noise source. Exposure to noise that is too loud or too long can cause a decrease in the ability to hear sound. Noise is damaging to the ears because sound pressure waves are collected in the ear and the pressure may cause damage to the delicate structures in the ear. Specifically, noise-induced hearing loss (NIHL) is caused by damage to sensitive structures in the *inner* ear when the ear is exposed to noise that is harmful.[7] Noise induced hearing loss may be manifested as temporary, permanent, immediate, or delayed; and in one or both ears.[7] NIHL can affect individuals regardless of race, age, and gender. According to the National Institute of Health (NIH), "15 percent of Americans between the ages of 20 and 69 – or 29 million Americans – have hearing loss that may have been caused by exposure to work or in leisure activities".[7] Excessive noise exposure to induce hearing loss can range from a single impulse sound to continuous sounds throughout a work shift.[7] Work-related hearing loss remains a top priority for health and safety professionals as more individuals are reporting hearing loss at work. In order to maintain employee hearing through their lifetimes and reduce or eliminate noise-induced hearing loss, the Occupational Safety and Health Administration (OSHA) developed standards to protect workers from noise exposure. These occupational standards are required for specified work places.

Noise Exposure Standards and Guidelines

Many organizations have been involved with establishing noise exposure limits that can be implemented in every work place. OSHA is under the Department of Labor and has the responsibility to enforce health and safety standards.[8] OSHA developed its noise standards in the early 1980s. Other organizations such as the American Conference for Governmental Industrial Hygienists (ACGIH) and the National Institute for Occupational Safety and Health (NIOSH) have published more conservative noise exposure guidelines that are widely used in research. NIOSH is within the Centers for Disease Control and Prevention (CDC) and its purpose is to conduct research and provide recommendations for workplaces.[2] For this study, the OSHA PEL, OSHA AL, and ACGIH TLV were used to assess overexposure to noise.

Permissible Exposure Limit

OSHA published noise exposure standards that specified workplaces must implement or face penalties. OSHA's noise standard can be found in the Code of Federal Regulations, Title 29, Chapter XVII, Part 1910, Subpart G.[9] It is written in the OSHA standard that all employees must have a time-weight average (TWA) of 90 decibels or lower on the A-weighted scale (dBA) over an 8-hour work shift.[4] The TWA value is adjusted based on an exchange rate (ER) with increments of 5 decibels.[4] For every increase in 5 decibels, the allowable exposure time is reduced by half.[4] For example, at 95 dBA the allowable time is 4 hours. The OSHA 90 dBA limit is referred to as the permissible exposure limit (PEL). The PEL represents a 100 percent noise dose. OSHA also established a maximum decibel for impulse noise of 140 dB for peak sound pressure level.[8] The OSHA occupational noise exposure standards used for this study are listed in Table 2.1.

Action level

In 1981, OSHA implemented requirements for employers to establish a hearing conservation program (HCP) when the TWA is 85 dBA or the dose is 50%, referred to as the Action Level (AL).[10] The HCP is used to educate and train employees about noise and how to protect themselves.[10] Audiometric testing and annual monitoring is required for all employees enrolled in a HCP. For this study, the action level was one method used to assess whether officials were overexposed during each game. The researcher determined whether enrollment in a hearing conservation program was required and/or if noise controls should be implemented.

Threshold Limit Value

ACGIH developed a similar guideline to OSHA, but supported a more conservative value.[5] ACGIH has a guideline that employee exposure to noise must be at or below 85 decibels for an 8-hour work shift with a 3 decibel exchange rate.[5] For example, at 88 dBA the allowable exposure time is 4 hours. The ACGIH 85 dBA limit is referred to as the Threshold Limit Value (TLV). The ACGIH occupational noise exposure recommendations used for this study are listed in Table 2.1.

Table 2.1: OSHA, ACGIH/NIOSH Noise Exposure Limits

Noise Exposure Limits and Guidelines		
Duration (hours per day)	Decibels (dBA)	
	OSHA	ACGIH
8	90	85
4	95	88
2	100	91
1	105	94
½	110	97
¼	115	100
Peak	140	140

Recommended Exposure Limit

NIOSH also recommends an 8-hour TWA limit of 85 dBA with 3 dBA exchange rate. NIOSH refers to this limit at a Recommended Exposure Limit (REL).[2] NIOSH recommends a noise exposure assessment when employees are exposed at or above the REL. NIOSH designed the REL to prevent hearing impairments greater than 25 dB in roughly 10 percent of the population.[2] The NIOSH occupational noise exposure has a threshold of 75 dBA which is lower than the ACGIH threshold of 80 dBA. The NIOSH occupational noise exposure recommendations were not used for this study.

Other Guidelines and Recommendations

According to the National Institute on Deafness and Other Communication Disorders (NIDCD), exposure to "long or repeated exposures to sound at or above 85 decibels can cause hearing loss".[7] This organization determined that loud noise exposure can cause ringing, buzzing, and roaring in the ears or head. NIDCD states that exposure to loud noises can cause a temporary hearing loss that will subside after some time (up to 48 hours); however, there may be some residual long-term damage.[7] The NIDCD recommends knowing which noise sources can cause damage, wearing personal protective equipment (PPE), moving away from noise sources, and having one's hearing tested.[7]

A similar statement was made by the American Speech-Language-Hearing Association which states that any sounds louder than 85 decibels can cause permanent hearing loss whether from a short blast or repeated exposures.[11] Physical changes in the body including raised blood pressure, increased heart rate, disruption of development of baby before birth, upset stomach, and difficultly sleeping can be caused by loud noises.[11] The American Speech-Language-Hearing Association lists recreational activities that can be damaging including hunting/shooting, snowmobiling, attending rock concerts, and personal music devices.[11]

Each organization has established a set of standards or guidelines which are deemed appropriate to prevent noise induced hearing loss in the workplace. In order to assess whether companies are meeting OSHA standards, personal and area noise measurements are conducted according to OSHA requirements.

Noise Exposure Assessment Equipment

Sound Level Meter

A sound level meter (SLM)/octave band analyzer (OBA) is an instrument that is used to assess how loud an environment is by measuring the overall sound pressure level (SPL) and the SPL for distinct frequencies. A SLM/OBA can be used to spot check dosimeters, identify noise sources, and determine peak noise levels. The SLM/OBA is also used to determine if hazardous noise levels are present and can determine if personal noise dosimetry is warranted. The basic components of a SLM/OBA include a transducer (microphone), an electronic amplifier, a frequency analyzer, and an indicator display. Types of sound level meters include type 0, 1, 2, and 3 or S.[12] For this study, a type 2 SLM/OBA was used which is suitable for general field applications. The frequency analyzer ranges from 10 Hertz (Hz) to 20,000 Hz.[12] The SLM/OBA was used in the A-weighting scale to represent the human hearing response. The SLM/OBA used in the C-weight emphasizes the lower frequencies and is often used to assess loudness of machinery.[13]

Noise Dosimeter

A noise dosimeter is an instrument that is used to assess the amount of noise to which an individual is exposed to during a work shift.[14] A noise dosimeter also measures the sound pressure levels like an SLM/OBA. Unlike the SLM/OBA, dosimeters are used to assess personal employee exposure to noise. A noise dosimeter is worn by attaching the microphone to the employee within in the hearing zone. OSHA defines the hearing zone as "a sphere within a two foot diameter surrounding the head".[15] This area is located near the ear between the head and shoulder. A noise dosimeter can be used to determine if an employee exceeds occupational noise exposure limits (e.g., the OSHA PEL, ACGIH TLV, or OSHA AL). Noise dosimeters will calculate the employee's TWA for an 8-hour work shift and/or an adjusted TWA for a work shift less than 8 hours. If a noise sample is less than 8 hours, the dosimeter assumes 0 dBA exposure for the time remaining in 8 hours. Other noise measurements calculated by noise dosimeters include percent dose, Leq, Lmax, Lmin, and Peak results.[16] Lmax is the maximum sound level during the sampling period. Lmin is the minimum sound level during the sampling period. Peak sound level is the maximum instantaneous level of sound during the time interval.

Relevant Studies

Five studies and one pilot study have been conducted in and around sports arenas examining noise exposures. Noise exposures for sporting events have been studied; however, few researchers have focused on prolonged exposures for employees who work at sporting events such as concession workers, fans, and security guards. Only one pilot study examined noise exposure of hockey officials.

Flamme and Williams researched the characteristics of different whistles used by sports officials during games as well as self-reported hearing status.[17] The objectives of Flamme and Williams were to "examine the prevalence of hearing loss in a sample of sports officials and estimate the duration of whistle use required to reach a permissible exposure limit".[17] The researchers tested different types of whistles and it was determined that each whistle model resulted in a SPL greater than 90 decibels.[17] Sports officials were asked to complete an online survey regarding their exposures to whistle noise as well as hearing loss.[17] Whistle sound levels ranged from 104 to 116 dBA as recorded in an empty gymnasium. Based on the conclusions made by the researchers, officials could only be exposed to whistle sounds for 30 seconds until 100% noise dose was reached using NIOSH recommendations. According to Flamme and Williams, officials are exposed to a variety of sounds including "crowd noise, marching bands, whistles, etc".[17] In order to assess exposure to noise, Flamme and Williams used the NIOSH REL.[17] The researchers recommended future studies assess different types of sporting events, level of competition, and number of events requiring use of a whistle.[17]

Cranston et al., characterized indoor hockey arenas at two locations. Occupational noise exposure at hockey arenas was deemed an issue by Cranston et al. because employees are encouraged to be loud and are in close quarters to cheering fans. The design of the arena was also considered. Cranston et al. sampled employees and fans at two venues which included collegiate and semi-professional hockey leagues.[18] In order to assess employee and fan exposure to noise, Cranston et al. used the OSHA PEL and the ACGIH TLV. Based on area and personal noise measurements, Cranston et al. determined that no workers or fans were overexposed based on OSHA standards.[18] However, the researchers concluded that 50 percent of all workers and fans sampled were above the ACGIH TLV. In addition, they found that there was no significant difference in noise exposure between the fans and workers using a two-way ANOVA (for both OSHA and ACGIH standards). Cranston et al. also used guidelines developed by the World Health Organization (WHO) for the general population which suggests noise exposures up to 70 dB over a 24 hour period. Based on the recommendation from the WHO, Cranston et al. determined that some fans were overexposed to noise.[18] The researchers urged for continued research in louder stadiums to determine if arena design plays an important role in worker noise exposure.[18]

Engard et al. assessed noise exposure at three outdoor football stadiums using personal and area sampling methods. In order to determine if workers and fans were overexposed to noise, the researchers used OSHA, ACGIH, and WHO standards, guidelines, and recommendations. A total of 27 workers between three stadiums were measured. Engard et al. determined that football stadium workers' noise exposures did not exceed the OSHA PEL, but exceeded the ACGIH TLV and the OSHA AL. Further, Engard et al. found that 96% of workers sampled were above ACGIH standards.[19] The researchers also found that 39% of workers' noise doses exceeded the OSHA action level, requiring enrollment in a hearing conservation program. No significant difference was found between personal noise exposures at the stadiums even though there was a significant noise level variability between games in each stadium. Engard et al. did conclude that there was overexposure to noise in football stadiums and recommended future research focus on the differences in arena composition. Fan guides, pamphlets, websites, and communication tools about noise exposure were recommended by the researchers to inform sporting enthusiasts about overexposure to noise.[19]

England and Larsen[20] published findings regarding noise levels of spectators at intercollegiate basketball events. The purpose of the study was to document the intensity of noise levels and assess the impact of the noise. England and Larsen used a sound level meter/dosimeter and audiometric testing to determine impact of noise exposure on fans during one basketball season. A total of 20 participants over ten games were used to assess noise at basketball games.[20] The researchers used audiometric testing to determine if fans experienced a temporary threshold shift with repeated exposures to loud noises. As stated by the researchers, repeated exposures to noise can lead to permanent threshold shifts. The noise exposures at the basketball games were compared to the NIOSH REL. The researchers mentioned that the REL does not directly apply to basketball games; it is a workplace standard and games do not last eight hours. The noise dose for participants ranged between 23.1% and 115% with an average of 59.7%.[20] Based on the audiometric testing and results from the sound level meter/dosimeter, England and Larsen recommended that Utah State University warn fans of the dangers of intense noise and potential for hearing loss.[20] The researchers determined that the average noise intensities did not exceed workplace standards. England and Larsen recommended continuing research to study noise levels at loud sporting events and to raise awareness of noise exposure to fans at these events.[20]

Hodgetts and Liu of the Department of Speech Pathology and Audiology from University of Alberta conducted personal noise measurements on themselves during Stanley Cup playoff games in 2006.[21] Liu wore a dosimeter during three games between the Edmonton Oilers and Carolina Hurricanes. The average sound pressure levels were 104.1, 100.7, and 103.1 dB[21]. The researchers discussed magnitude of noise exposure in leisure activities and the size of the population. The researchers determined that the average sound exposure levels were above the recommended standards of 85 dB with a 3 dB exchange rate. During game 3, individuals attending the game would reach their respective noise dose exposures in just six minutes.[21] The researchers conducted audiometric testing to determine if participants were experiencing a temporary threshold shift. Both subjects experienced a threshold shift between five and ten decibels. One subject experienced a severe shift of 20 decibels. The researchers noted that employees working these venues and large events should be sampled as they are at a higher risk of hearing loss.[21] Hodgetts and Liu concluded that there is a need to expand awareness about the need for hearing protection at work and during leisure activities.[21]

In 2014, Langley et al. conducted a pilot study to assess noise exposures to hockey referees to determine if officials were potentially overexposed to noise and if a larger study was warranted (Langley, unpublished master's thesis). The researchers measured personal noise exposures of 23 hockey referees and linesmen at two relatively small ice hockey arenas located in northern Colorado.[22] Similar to Cranston et al. and Engard et al., Langley et al. determined no overexposure according to OSHA PEL but found that 70% of officials were overexposed according to ACGIH guidelines.[22] In addition, the researchers found that all officials had a Leq greater than 85 dBA and that 83% of linesmen and 55% of referees were overexposed according to ACGIH TLV criteria.[22] The sample size in this study was not sufficient to determine if the linesmen's and referees' noise exposures were significantly different. Langley et al. recommended hearing protection with filters to reduce noise exposure and allow officials to communicate on the ice. In conclusion, the researchers determined that hockey officials were overexposed to noise, recommended implementation of controls, and to continue hockey official noise exposure research in a larger arena.

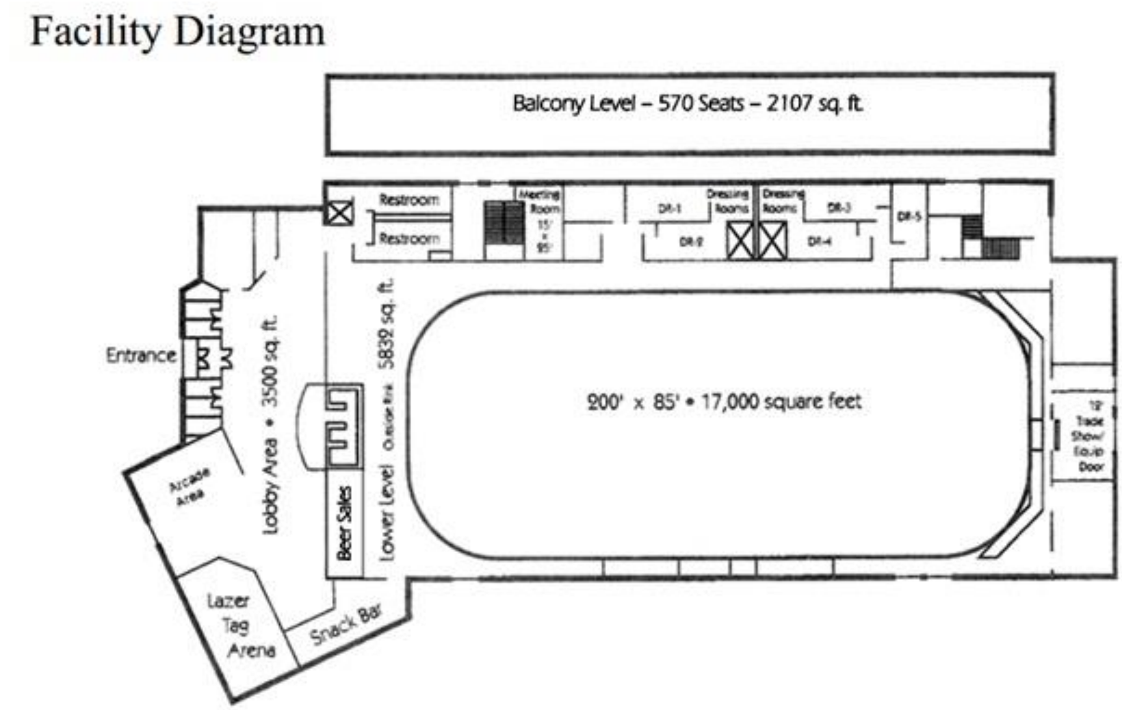
The current study expands on the Langley et al. study by: (1) increasing the personal noise monitoring sample size in a larger, and postulated, louder arena; (2) characterizing the arena noise using a sound level meter; and (3) estimating the number of whistle blows by the officials. This study was conducted simultaneously with another study that involved audiometric testing of those hockey officials that were monitored for noise exposure.

Ice Hockey Background

For this study, a three-official system (one referee and two linesmen) was used at each game. Hockey officials enforce rules and maintain the order of the game. Referees are identified by wearing orange or red arm bands and have the authority to issue penalties.[6] A referee's job includes conducting faceoffs to start the game and after every goal is scored. Linesmen are primarily responsible for breaking up fights or altercations during the game and are responsible for issuing violations on the center and blue line such as offsides.[6] The arena used for this study was for a USA Hockey sanctioned Tier III junior team competing in the Western States Hockey

League (WSHL). The total arena is 35,000 square feet with a 2,000 seat capacity. An illustration of the arena is shown below.[23]

Figure 1: Facility Diagram



CHAPTER 3 : PURPOSE AND SCOPE

Purpose

The purpose of this study was threefold: (1) to determine the noise exposure of referees and linesmen working at Facility 1 during ice hockey games; (2) to measure the average noise sound pressure levels in the arena using a sound-level meter; and (3) to estimate the number of whistle blows per game. Personal noise exposures and area noise samples were collected and compared to the OSHA and ACGIH noise criteria. Noise dosimeters were used to measure hockey officials' noise exposures for the duration of one hockey game. This assessment allowed researchers to determine if ice hockey referees and linesmen were overexposed to noise according to OSHA standards and ACGIH guidelines. Area noise measurements were taken to provide a range of sound pressure levels for the arena at four locations around the arena. Future subjects will benefit from the results of this study in determining the need for training, new product development, and hearing protection requirements for hockey officials.

Research Questions

The characterization of noise exposure in hockey officials was used to answer the following:

1. Are referees and/or linesmen overexposed according to the OSHA PEL, OSHA AL, and ACGIH TLV?
2. Is there a difference in referee and linesmen exposures?
3. Are background arena levels (crowd noise, public address system, and buzzer) greater than 85 decibels as measured on the A-weighted scale?

Scope

This research was conducted in October, November, and December 2014 during the first part of the hockey season at an arena located in southern Wyoming. Personal noise dosimeters were used at every game on one referee and two linesmen. Area measurements were taken at the first five games using a sound level meter and recorded randomly every five minutes at four pre-determined locations. Whistle blows were counted at four games during the first period for referees and linesmen. Participants were selected at training for the Western States Hockey League (WSHL) and American Collegiate Hockey Association (ACHA) officials in Cheyenne, Wyoming in September 2014. Another study conducted simultaneously by Adams et al. will use the noise dosimetry data from this study to examine the relationship between audiometric testing results and personal noise exposures. The investigator explained all sampling methods to all participants using a pre-written script. A total of 30 participants (10 referees, 20 linesmen) were sampled for this study. General area samples at positions equidistant from the wall of the ice rink at random intervals were collected during ice hockey games during the second period of the game.

CHAPTER 4 : METHODS AND MATERIALS

Recruitment

All research was conducted according to the protocols established by the Institutional Review Board for Human Subjects at Colorado State University (CSU). A verbal written approved script was read to all participants of the study. The recruitment of subjects for the study occurred at a training session for the Western States Hockey League (WSHL) and American Collegiate Hockey Association (ACHA) officials in Cheyenne, Wyoming in September 2014. The study participants were an excellent representation of all officials at this particular arena since a majority of participants completed two or three games over the sampling duration. All study participants were voluntary and not randomized.

Sample size was calculated based on the Adams et al. study of temporary threshold shifts (TTS) as well as previous literature. Upon consultation with a statistician, it was determined that the researchers use a conjectured proportion of 50% suffering a TTS with n=30 officials, the 95% margin of error (ME) for the proportion overexposed would be 18%. The researchers planned to collect as many samples as feasible to decrease the amount of sampling error. For this study, a total of 30 officials (referee/linesman) participated in this study. The researcher provided each worker a consent form and explained their role in this research project. A consent form was signed for each participant in the study.

Personal Noise Monitoring

Personal noise exposures were collected using Larson Davis Personal Noise Dosimeters, Models 706RC and 703+ (Provo, Utah) provided by the CSU OSHA Consultation Program. Dosimeters were placed on each respective referee or lineman for every game on the dominant side as per the OSHA Technical Manual.[15] Officials hold their whistles in their non-dominant hand and the dosimeter was placed on the opposite side. Each dosimeter was set with the same four settings as determined by the OSHA Technical Manual.[15] These four settings include threshold rate, criterion level, exchange rate, and criterion duration. The dosimeters were mistakenly set with a threshold of 80 dB instead of 90 dB for Dose 1. The criterion level was set at 90 dB with an exchange rate of 5 dB. A threshold of 80 dB incorporates all noise levels greater than 80 dB into the dose estimate. Dose 2 was used to calculate a TWA using the ACGIH criteria with a threshold of 80 dB, criterion level of 85 dB, and exchange rate of 3 dB.[5] Dose 3 was used to calculate a TWA using the OSHA AL with a threshold of 80 dB, criterion level of 85 dB, and exchange rate of 5 dB.[12] Dose 4 was used to calculate total noise exposure with a threshold of 0 dB, criterion level of 80 dB, and exchange rate of 5 dB which is used in international noise exposure sampling. The dosimeters are accurate within plus or minus two decibels. The correct dosimeter settings to compare to OSHA standards and ACGIH guidelines are listed in Table 4.1.

Table 4.1: Larson Davis Noise Dosimeter Settings

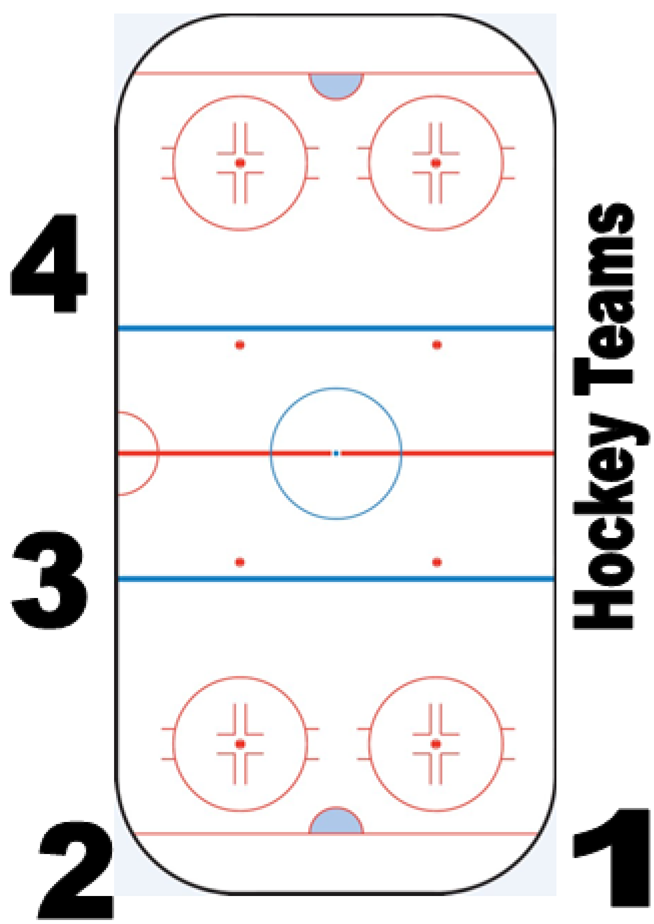
Settings	OSHA AL	OSHA PEL	ACGIH TLV
Exchange Rate (dB)	5	5	3
Threshold Rate (dB)	80	90	80
Criterion Level (dB)	85	90	85
Criterion Duration (hours)	8	8	8
RMS Weight		A Weight	
Peak Weight		Unweighted	
Detector Setting		Slow	
Sample Interval		1 second	
Gain (dB)		0	
Battery Type		Alkaline	

Each dosimeter was calibrated before and after each game using Larson Davis Blaze software package to assure that the dosimeter maintained calibration. Dosimeters were calibrated using a precision acoustic calibrator (Model CAL 150) at 94 dB and 114 dB. All calibration results were recorded on a field sheet with changes noted between pre- and post-calibration. Noise sampling procedures were adapted from the OSHA Technical Manual (OTM), Section II, Chapter 5, TED 1-0.15A.[15] The dosimeters were attached by affixing the dosimeter to the referee/linesmen belt guard, running the cord underneath his/her jersey, and clipping the microphone to the shirt seam near the collar. The placement of the microphone was as close as possible to the official's hearing zone. The microphone was placed on the dominant side as per the OSHA Technical Manual.[15] The researcher checked the placement of the microphone and encouraged the officials to let the researcher know if the microphone cord was restricted. Officials were informed not to blow, tap, or yell directly into the microphone before each game. Officials were also informed that the microphone was merely recording sound levels and not recording actual speech to assure comfort and confidentiality. Observation notes were made during the sampling period to verify the microphone position and any issues with the dosimeters during the games. The researcher checked on officials and dosimeter placements during three period breaks and adjusted the microphone placement if needed. Once sampling was completed, the dosimeters were post-calibrated using Larson Davis Blaze software.[16] Calibration results were recorded on a field sheet and any changes in decibel level were noted. An example field sheet used for sampling for this study can be found in Appendix B.

Area Noise Monitoring

Area noise measurements were collected using a Larson Davis System 824 sound level meter and octave band analyzer (SLM/OBA) (Provo, Utah). The SLM/OBA was pre-calibrated using a precision acoustic calibrator (Model CAL 200) at 94 dB and 114 dB. Calibration results and time of calibration were recorded. Measurements were taken at four pre-determined locations in the arena as depicted in Figure 2. The pre-determined locations were sampled using a random number generator to determine sampling order for each game. Area measurements were collected in the second period of the first five games to acquire a range of background noise during the games. Noise sources during the sampling period included buzzers from score goals, music, public address system, number of people in attendance, etc. Noise area sampling methods were derived from the OSHA TED 1-0.15A.[15] The SLM/OBA was held one meter away from the researcher during sampling as close to ear level as possible. Once sampling was completed, the SLM was post-calibrated at 94 dB and 114 dB to determine if calibration was adequate. Calibration data were recorded on the field notebook and any changes were noted.

Figure 2: SLM Measurement Points in Arena (Numbers 1-4)[24]



Whistle Blows

The number of whistle blows during the first period was recorded for the first five games to estimate the number of whistles blows during each game. The researcher sat in the fan section located on the East side of the arena and whistle blows were tallied on field sampling sheets (Appendix C). Characteristics of whistle blows such as length, penalties, etc were also noted on field sampling sheets. Once data collection of whistle blows was completed over five games, an average was calculated.

Data Analysis

Personal noise dosimetry data were downloaded using the Larson Davis Blaze software.[16] For each referee and linesman, the following measurements were documented: equivalent sound pressure level (Leq), peak sound pressure level (Lpeak), OSHA AL and ACGIH percent dose, time weighted average (TWA), 8-hour TWA. OSHA PEL percent dose and 8-hour TWA were calculated separately. Summary statistics including mean and standard deviation were calculated for referees and linesmen exposure and total official exposure.

With a threshold value of 80 dB, the dosimeter will integrate all noise above 80 dB. With a threshold value of 90 dB, the dosimeter will integrate all noise above 90 dB. For this study, the dosimeters were mistakenly set at with a threshold of 80 dB instead of 90 dB. Since a threshold value of 80 dB was used for all samples for Dose 1 setting, the dose calculated will be an estimated 10% higher than a dosimeter using a threshold value of 90 dB. In order to compare the data to OSHA PEL, data points were exported to excel and Dose 1 data were modified to exclude noise levels below 90 dB. Once data points below 90 dB were excluded, an OSHA PEL percent dose and OSHA PEL 8-hour TWA were calculated. In order to compare the results taken during the sampling time, the OSHA PEL percent dose was calculated using the equation:

Equation 4.1: Noise Dose Calculation[16]

$$Dose = (100/T_C)\int_{T1}^{T2} 10^{\left[\frac{L_{as}-L_C}{q}\right]} dt$$

where,

L_{as}= frequency (A) and exponential-time (SLOW) weighted sound level in dB

L_c=criterion level in dB

T_c= Criterion duration in hours

q= exchange rate constant (if exchange rate=5, q=16.61)

Each one second sample with an Lmax greater than 90 dB was used to calculated dose in that one second. This process was completed for all samples. Total OSHA PEL percent dose was calculated by adding all the one second doses during the sample time. Once OSHA PEL dose was calculated, OSHA PEL 8-hour TWA was calculated using the equation:

Equation 4.2: Time Weighted Average Calculation[16]

$$TWA = q * log_{10}[1/T \int_{T1}^{T2} 10^{\frac{L_{as}}{q}} dt]$$

where,

L_{as}= frequency (A) and exponential-time (SLOW) weighted sound level in dB

T=measurement period (Run Time)

q= exchange rate constant (if exchange rate=5, q=16.61)

Area noise measurements from the Larson Davis SLM were downloaded using the Larson Davis 824 utility software. For each game and location, the following measurements were documented: Leq, Max, and Min. Summary statistics including mean and standard deviations were calculated over the span of five games.

The number of people in attendance at each game was determined based on ticket sales and collected after the second period. The number in attendance does not include those that entered the game after the second period because tickets were not required. Mean and standard deviations for each arena location and total arena sound levels were calculated.

CHAPTER 5 : RESULTS

Personal Noise Dosimetry

Thirty personal noise dosimetry samples were taken on indoor hockey officials during ten regular-season hockey games to determine if their noise exposures exceeded ACGIH and OSHA criteria. One dosimeter malfunctioned during sampling on the October 17, 2014 game and was not used for analysis. Another dosimeter fell off of a referee during a game on November 7, 2014 and a partial noise sample was collected. This sample was not used for analysis but reported in Appendix A to show exposure. The remaining 28 samples were averaged together over the total of ten games. The summary statistics of noise exposure for officials over the sampling time is shown in Table 5.1 with ACGIH and OSHA criteria. Individual noise exposure for each referee and linesman are reported in Appendix A. Time weighted averages were rounded to the nearest decibel. As shown in Table 5.1, the mean ACGIH TWA for all officials during the sampling time was 92 dB. The mean $OSHA_{AL}$ TWA during the sampling time was 89 dB.

Table 5.1: Summary Statistics of Personal Noise Monitoring

	$ACGIH_{TLV}$ TWA (dBA)	ACGIH Dose (%)	$OSHA_{AL}$ TWA (dBA)	$OSHA_{AL}$ Dose (%)	$OSHA_{PEL}$ Dose (%)
Mean	92	181.6	89	27.3	17.7
SD	2.2	94.6	1.7	7.0	6.3

The descriptive statistics for each game including the number of people in attendance, Leq, Max, and Peak values are shown in Table 5.2. The attendance numbers were collected after the second period when ticket sales ended. The Leq, Max, and Peak results were taken from each dosimeter worn by the officials. The Leq, Max, and Peak values were rounded up to the next decibel for a conservative noise exposure measurement. The mean Leq for all officials over the sampling time was 93 dB, which is above the recommended Leq of 85 dB. The mean Peak noise level was 134 dB, which is below the OSHA maximum impulse noise level of 140 dB. Individual descriptive statistics for hockey games are reported in Appendix A.

Table 5.2: Descriptive Summary Statistics for Hockey Games

	Attendance	Leq (dBA)	Max (dBA)	Peak (dBA)
Mean	446	93	116	134
SD	117.8	2.2	2.8	5.0

OSHA standards and ACGIH guidelines are based on a TWA noise exposure of 8 hours. Shown in Table 5.3 are the 8-hour TWAs according to the ACGIH TLV, OSHA AL, and OSHA PEL based on the dosimeter settings. Hockey officials were not exposed for 8 hours. The average exposure time was 2 hours and 48 minutes. The average ACGIH 8-hour TWA was 88 dBA with a standard deviation of 2.1 dBA, which exceeded the recommended TLV of 85 dBA. The mean OSHA 8-hour TWA using AL criteria was 81 dBA, which is below the recommended AL of 85 dBA. The OSHA 8-hour TWA using the occupational PEL standard was 78 dBA with a standard deviation of 2.5 dBA, which is below the occupational limit of 90 dBA. Individual 8-Hour TWA exposures are reported in Appendix A.

Table 5.3: Official 8-Hour Time Weighted Averages (n=28)

	ACGIH 8-Hour TWA (dBA)	$OSHA_{AL}$ 8-Hour TWA (dBA)	$OSHA_{PEL}$ 8-Hour TWA (dBA)
Mean	88	81	78
SD	2.1	1.7	2.5

Shown in Table 5.4 are the average noise exposures for referees over ten hockey games. The mean noise exposure using the OSHA PEL criteria for a time weighted average (TWA) was 78 dBA, which is below the occupational exposure 8-hour limit of 90 dBA. The mean noise exposure using ACGIH criteria for a TWA was 88 dBA, which exceeded the 8-hour threshold limit value of 85 dBA. The average $OSHA_{AL}$ TWA was 81 dBA, which is below the 8-hour action level of 85 dB. The average Leq for referees was 92 dBA, which exceeded the NIDCD recommendation of 85 dBA.[7] Individual referee noise exposure results are reported in Appendix A.

Table 5.4: Average Referee Noise Exposure (n=9)

	ACGIH		$OSHA_{AL}$		$OSHA_{PEL}$	
	Mean	SD	Mean	SD	Mean	SD
Leq (dBA)	92	1.8	92	1.8	92	1.8
8-Hour TWA (dBA)	88	1.7	81	1.4	78	1.9
Dose (%)	160.5	62.6	26.0	5.5	17.5	4.7

Shown in Table 5.5 are the average noise exposures for linesmen over ten hockey games. The mean noise exposure using OSHA criteria for a TWA was 78 dBA ,which is below the 8-hour OSHA PEL. Using ACGIH criteria, the average TWA was 88 dBA, which is above the 8-hour ACGIH TLV of 85 dB. The average $OSHA_{AL}$ TWA was 82 dBA, which is below the 8-hour action level of 85 dBA. Similar to the referees, average linesman Leq was 93 dBA, which are above NIDCD recommendation of 85 dBA.[7] Individual lineman noise exposure results are reported in Appendix A.

Table 5.5: Average Linesmen Noise Exposure (n=19)

	ACGIH		$OSHA_{AL}$		$OSHA_{PEL}$	
	Mean	SD	Mean	SD	Mean	SD
Leq (dBA)	93	2.4	93	2.4	93	2.4
8-Hour TWA (dBA)	88	2.3	82	1.8	78	2.8
Dose (%)	191.7	106.5	27.9	7.6	19.0	7.8

Based on the average noise exposures for referees and linesmen shown in Tables 5.4 and 5.5, the number and respective percentage of officials that were overexposed based on the OSHA and ACGIH eight-hour criteria are reported in Table 5.6. No referees or linesmen were overexposed to noise according to the OSHA PEL. Twenty-five of twenty-eight (89%) referees and linesmen were overexposed according to the ACGIH TLV recommendations. Two of nineteen (11%) linesmen were over the OSHA AL of 85 dBA. Twenty-eight of twenty-eight officials (100%) had sound equivalent pressure levels (Leq) greater than 85 dBA.[7]

Table 5.6: Number and Percentage of Referees and Linesmen

Exceeding OSHA and ACGIH Criteria

	Leq>85 (dBA)	$OSHA_{AL}$ (dBA)	$OSHA_{PEL}$ (dBA)	$ACGIH_{TLV}$ (dBA)
Referees (n=9)	(9/9) 100%	(0/9) 0%	(0/9) 0%	(8/9) 89%
Linesmen (n=19)	(19/19) 100%	(2/19) 11%	(0/19) 0%	(17/19) 89%
All	(28/28) 100%	(2/28) 7%	(0/28) 0%	(25/28) 89%

Area Monitoring Results

Sound level meter (SLM) measurements were taken during the second period of each game. Individual one minute measurements were taken at four points around the indoor ice arena. The SLM measurements were used to determine general arena acoustics and an average of sound pressure levels within the arena. Area monitoring results including Leq, Max, Min, and Peak are shown in Table 5.7. The average Leq was 82 dBA, which is below the recommended action level of 85 dBA; however, area sampling cannot conclude total sound levels over the game because only a one minute sample was taken at random intervals. A total of four out of twenty samples were above the recommended 85 dBA.[2] The highest peak value was 113 dBA, which was when the home team scored. The area noise measurements were affected by crowd noise, background music, goals scored, whistles, and the PA system. The results of area noise sampling were used to conclude that the arena acoustics at various positions can lead to different noise levels.

Table 5.7: Summary Statistics for Area Sampling Noise Measurements

	Leq (dBA)	Min (dBA)	Max (dBA)	Peak (dBA)
Mean	82	72	90	107
SD	4.2	2.2	5.0	3.6

Whistle Blowing Results

Previous researchers have focused on the sound levels of whistles and how long it would take for officials to reach their daily dose of noise using NIOSH standards.[17] For this study, the number of whistle blows for each official was counted by the researcher to determine the average number of whistles per period. In order to obtain an estimate of total whistles blown in a game, the average number of whistles per period was multiplied by three (i.e. three periods per game). Shown in Table 5.8 is the average number of whistle blows counted during four hockey game periods. At this particular venue, referees averaged an estimated total of 72 whistle blows per game and linesmen averaged an estimated total of 57 whistle blows. The number of whistle blows during a hockey game depends on the number of penalties, goals scored, fouls, and timeouts. The range of whistle blows per game can vary depending on level of experience, rivalries, fan interferences, and levels of hockey play. Individual whistle blow results are reported in Appendix A.

Table 5.8: Average Number of Whistle Blows Per Period

	Referee	Linesmen
Mean Per Period	24	19
SD	6.7	2.4
Estimated Mean Per Game	72	57
SD	20.0	7.2

CHAPTER 6 : DISCUSSION

The purpose of this study was threefold: (1) to determine the noise exposure of referees and linesmen working at Facility 1 during ice hockey games; (2) to measure the average noise sound pressure levels in the arena using a sound-level meter; and (3) to estimate the number of whistle blows per game. Based on the literature review, only a handful of researchers have examined noise exposure in sporting arenas.[18,19,20,21] In addition, Langley et al. examined noise exposures for hockey officials in a pilot study and the researcher recommended future noise assessments of larger hockey venues.[22]

Personal Noise Dosimetry

Based on the results of the personal noise sampling in this study, the author concluded that a majority of referees and officials were overexposed to noise according to ACGIH guidelines during the duration of single hockey games. Noise samples were collected for an average of 2 hours and 48 minutes for each game. During this time, a referee or linesman received an estimated 20% of their daily noise dose according to OSHA PEL criteria. The OSHA and ACGIH standard is based on noise exposure for an 8-hour period.[4,5] In order to compare the noise samples to occupational exposure limits, the 8-hour TWA was calculated for each official. In order to calculate the 8-hour TWA for this study, the sample calculation included approximately five hours of 0 dB exposure, since the games lasted roughly three hours. Eighty-nine percent of referees' and linesmen's noise exposures exceeded the 8-hour ACGIH TLV for the duration of the game. Some games took place Friday night after the officials had left their day jobs. The noise dose received at the game should be considered an additional occupational noise exposure supplemental to the officials' daily noise dose from their daytime jobs. If an official were exposed to a TWA of 88 dBA at work and then officiated a hockey game, his/her noise exposure could exceed the occupational noise standards and guidelines. However, the officials' job information was not collected for this study. It is important to note that the noise samples collected in this study are considered secondary occupational noise exposures since officials are paid for their time.

Cranston et al. found that 40% of hockey concession workers at Venue 1 and 57% of hockey concession workers at Venue 2 exceeded the ACGIH TLV.[18] In comparison, the current researchers found that 89% of officials exceeded the ACGIH TLV and OSHA AL. Cranston et al. also found that no hockey concession workers exceeded the OSHA AL and the current researchers found that two workers exceeded the OSHA AL.[18] For both studies, none of the employees exceeded the OSHA PEL. The differences in results can be attributed to: venue size, "rowdiness" of the crowd, type of game (regular versus playoff), noise sources, number of people in attendance, and population sampled (i.e., concession workers versus hockey officials).

Engard et al. found that 96% of football stadium workers were overexposed to noise in football stadiums according to the ACGIH TLV guideline.[19] Football stadiums and ice hockey arenas differ in design but do have several similar qualities. Both have fans that get involved with the game by cheering, have referees/linesmen to control the dynamics of the game, and use whistles to signal. With the exception of indoor football stadiums, most football stadiums are open and larger than traditional ice hockey arenas. Engard et al. examined three different arenas, where the current researchers focused on one arena. The typical duration of sampling in Engard et al's study was three and a half to four hours and the current sampling duration was less than three hours. Engard et al. measured noise exposures for concession and security workers as well as fans. In the current study, the researchers measured noise exposures for referees and linesmen.

In the United States, football is a more popular, well-attended sport than ice hockey. It is with these differences in mind that the current study and Engard et al. study have different overexposure percentages.

Collegiate basketball personal noise measurements were collected by England and Larsen.[20] A Larson Davis 710 (type 2 sound level meter/noise dosimeter) was used during 10 games during the 2009-2010 Utah State University basketball season. The researchers found that the noise levels exceeded the action level (85 dB) of the NIOSH standard (in 6 out of 10 games). The average maximum sound level was 135 dBA. For the current study, the average maximum sound level was 116 dBA. England and Larsen set up their dosimeters with a threshold of 75 dB and exchange rate of 3 dB, which was more conservative that the dosimeter settings used in the current study.[20] The average Leq over 10 games was 84.64 dBA with a range of 78.7 to 90.1 dBA.[20] The current study's researcher found a higher average Leq of 93 over the course of 10 hockey games. England and Larsen calculated an average noise dose of 59.7%.[20] This is higher than the noise dose calculated for the current study. One difference in the results was likely due to the threshold value set used for noise dosimeters. For England and Larsen's dosimeters, the integration to calculate TWA and noise dose was set at 75 dBA. For the current study, integration to calculate TWA and noise dose was set 80 dBA for ACGIH TLV, 80 dBA for OSHA AL, and 90 dBA for OSHA PEL. England and Larsen also hand calculated noise doses using the NIOSH standard to acquire a 2-hour noise dose. The current study compared results to ACGIH and OSHA guidelines and compared the 8-hour TWA without any adjustments.

In the study conducted by Hodgetts and Liu, the researchers found a range of sound exposure levels between 100 and 105 dB.[21] These results were quite a bit higher than the 75-90 dB area sample ranges in the current study. The discrepancy in the noise levels was likely due to the venue size, number of people in attendance, popularity of the National Hockey League (NHL), and how area samples were collected. Although the current study was conducted at a smaller arena below the professional and semi-professional level, 89% of officials were still overexposed to noise according to the ACGIH standard. It can be postulated that larger venues could pose a higher noise level and a greater probability of overexposure to noise for employees and patrons. It is recommended that future studies focus on continuing noise measurements at larger arenas.

Langley et al. followed similar sampling methods as in the current study but included two ice hockey venues rather than one arena. Similar to the current study, the researchers found that no officials' noise exposures exceeded the OSHA PEL. Unlike the current study, Langley et al. determined that officials' noise exposures did not exceed the OSHA AL and were not required to be in a hearing conservation program. In the current study, 7% of officials were above the OSHA AL.[22] Among all officials that participated in the Langley et al. study, 70% were overexposed to noise according to ACGIH standards. In the current study, 89% of participants were above the ACGIH TLV.[22] The current researchers used Langley's sampling methods but at a larger arena, which could have contributed to the higher noise exposure among all hockey officials. Results from the Langley et al. study and the current study warrant the need for noise control, mitigation, and hearing protection in ice hockey arenas.

Area Sampling

The results of area noise sampling led the researchers to conclude that the arena acoustics at various positions result in different noise levels. Noise samples taken near the spectator section (locations 2 and 3) generally had higher sound pressure levels than locations 1 and 4. Since random interval samples were taken during each game, isolating noise sources was difficult. For example, a sample at location 1 was taken in the third minute with no goals scored (79 dBA) and a sample at location 3 was taken in the seventh minute with two goals scored (90 dBA). Most one minute samples included music from the PA system, whistle blows, hockey pucks hitting the wall, and cheering fans. The speaker locations for this arena were located on the ceiling facing downward and up in the stands near the corners. The music played was at the discretion of the master of ceremonies for each game. This arena had a rotation of masters of ceremonies and thus music loudness depended on who was controlling the speaker volume. The exact sound level of each noise source could not be determined based on the sampling method used. The sounds at each arena sampling position can change rapidly depending on the action of the game. For this arena, the equivalent sound pressure level ranged from 75 dB to 90 dB for the one minute samples.

Cranston et al. conducted area noise measurements in indoor hockey arenas similar to the current study. The researcher concluded that the mean Leq over three games was 81 dBA to 96 dBA and the peak SPL was 105 dBA to 124 dBA.[18] For the current study, the mean Leq over ten hockey games was 82 dBA and the peak SPL was 107 dBA. The respective range for Leq was 76 dBA to 90 dBA and for peak SPL was 99 dBA to 113 dBA.[18] Similar sampling methods were used in both studies. Cranston et al. found a consistently higher SPL in the south end of the arena which was not found in the current study. The researcher was also able to sample at each directional location which was not possible in the current study. Cranston et al.'s results were higher in both the mean Leq and peak SPL. This difference in mean Leq and peak SPL could be due to the sampling methods (two minute versus one minute samples), noise sources at each location, and/or venue size.

Engard et al. used area sampling as a means to double check the dosimeter reading in football stadiums and to examine crowd sound level changes. Engard et al. reported that the average sound level when the team was on offense was 79 dB and when on defense was 91 dB.[19] The researchers attributed this increase in crowd noise to fans encouraging their team to win. In the current study, change in crowd noise was not monitored; however, the average sound levels per game were comparable. This could suggest similarities in the acoustics between hockey and football arenas, but would need to be studied further. The researchers were able to quantify specific noise sources at each venue using the sound level meter. Impulse noises from the cannon fired at the home games in the Engard et al. study averaged over 110 dB,[19] well above any measured area sample in the current study. Engard et al. also focused on fan and worker noise exposure. This was beyond the scope of the current study, but could be included in future studies.

Limitations

Although the minimum sample size was achieved, the sample size was not large enough to determine a significant difference between referee and linesmen exposure. Another limitation is that this study included sampling at one arena during one half of a season which may not be representative of all hockey arenas, attendance, and game dynamics. Since this facility used a three official system, only one referee exposure could be assessed at each game. A larger study population could have helped the researchers examine the statically significant differences between referee and linesmen exposure to noise and number of whistle blows.

Another limitation of this study was the randomization of area noise sampling. Because the noise samples were randomized, it was difficult to capture each individual noise source such as a single whistle blow, public address system announcement, music, crowd noise, or goals scored. During each one minute area sample, noise sources that contributed to the overall sound level were noted on field sampling sheets (Appendix C). If more resources and equipment were available, total stationary noise samples for the duration of the game could have been utilized. For future studies, individual controlled samples of public address systems, crowd noises, and goals scored should be measured to acquire a more accurate representation of arena noise exposure for fans and officials. These updated area samples can provide vital information for implementing noise controls at specific venues.

A final limitation involved the active and physical nature of hockey officials. These characteristics made it difficult to maintain the microphone in the hearing zone as referees and linesmen would skate quickly around the rink, break up fights, and call penalties using arm motions. It is possible that some of the dosimeter microphones could have been bumped during sampling which could have increased noise exposure or overloaded the microphone. The microphones were repositioned for each referee during period breaks to provide optimal comfort for the officials and maintain appropriate microphone position. One noise sample was lost in this study due to a fall on the ice. One referee was contacted by a player and fell on the dosimeter. For future studies, it is recommended that researchers use smaller dosimeters that clip to the official's collar to prevent loss of samples.

CHAPTER 7 : CONCLUSION AND FUTURE WORK

Results of Original Research Questions

The noise exposure assessment of indoor hockey officials was used to answer the following questions:

1. Are referees and linesmen overexposed according to the OSHA PEL, OSHA AL, and ACGIH TLV?

   Yes, according to ACGIH criteria, 89% of referees and linesmen were overexposed to noise. According to the OSHA PEL, referees and linesmen were not overexposed to noise. Although no officials were overexposed to the OSHA PEL, 7% of officials exceeded the OSHA action level of 85 dB. All officials exceeded a Leq of 85 dB.

2. Is there a difference in referee and linesmen exposures?

   No, there was relatively no difference between referee and linesmen noise exposure. The difference in referee percent dose (i.e. 160.5%) compared to linesman percent dose (191.7%) is attributed to the log scale component when calculating time weighted averages. All other variables (TWA, Leq, etc) were within plus or minus 2 decibels. Due to sample size limitations, there were not enough samples to determine a significant difference between referee and linesman noise exposure. Because the facility used a three official system, twice the number of samples collected represented linesmen exposures. In order to compare referees to linesmen, this study would need to collect similar and large sample sizes. Based on the whistle results, the referees had a higher average number of whistle blows, but a significant difference was not determined. Based on observations made during each hockey game, the referee and two linesmen remained close to the outside wall whenever possible. Many times during the game, the referee and linesman would be in close proximity to each other corresponding to similar noise exposures.

3. Are background arena levels (crowd noise, public address system, and buzzer) greater than 85 decibels on the A-weighted scale?

   Yes, background levels due to crowd noise, public address system, and buzzer were greater than 85 decibels on the A-weighted scale at some points during each game. The average maximum noise level was 90 dBA and average peak level was 107 dBA. Due to the random sampling method used, it was difficult to determine how each individual component of the arena contributed to overall noise exposure. When area sampling was taking place, high impact noise from the puck hitting the side of the rink registered at over 110 dBA. Although arena sampling was not officially conducted before the game, loud impulse noises were noted during the warm up period. Based on sampling results, it was determined that there were several other noise factors that should be examined in future research including fights, missed goals, and rivalry games.

<u>Recommendations</u>

Referees and Linesmen

A majority of officials (referees and linesmen) exceeded the 8-hour TWA of 85 dBA for the ACGIH TLV. It is highly encouraged that hockey officials are proactive with hearing protection. Since hockey games do not last 8-hours, many of the standards cannot be applied to determine true overexposure to noise; however, officials were overexposed during the duration of each game. For future research, job details and other noise exposures should be collected to determine true occupational noise exposure per day.

Spectators

Although fans were not sampled in the current study, it is recommended that signage be posted to raise awareness of high noise levels during hockey games. It is also recommended that when fans participate in these sporting events, they wear hearing protection and sit further away from the speakers whenever possible to reduce their noise exposure.

Future Work

The researchers in this study focused on noise exposures to hockey officials at one venue and it was determined that 89% of officials were overexposed to noise according to established guidelines from ACGIH. Future studies should focus on larger, well-attended venues.

More research is needed to study hearing loss in hockey officials as well as other sporting officiates and employees. The hockey arena in this study was larger in comparison to the Langley et al. study (2,000 person capacity versus 900 person capacity), but was still below the arena size of semi-professional and professional hockey games (up to 20,000 spectators).

In addition to personal noise sampling, it is also recommended that future studies focus on attaining an accurate number of whistles blown during each game. Based on previous studies, whistles are the majority of impulse noise exposure to hockey officials. It is possible that the number of whistle blows for each game is related to the amount of noise exposure for officials based on raw data in this study. Another possible impulse noise exposure is the hockey pucks hitting the glass. The researchers in the current study observed sound pressure levels well above 100 dB when pucks hit the glass or side wall.

Researchers should continue to examine arena acoustics to study the individual noise factors as well as appropriate controls to reduce noise exposures to officials, fans, and workers in hockey arenas. Individual measurements of each noise source including PA system, whistle noise, and crowd noise should be collected and analyze to determine what contributes most to overall noise exposure. Speaker location and orientation should be noted to determine if it affects overall noise exposures.

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APPENDIX A

Individual Sampling Results
Personal Noise Monitoring (over sampling period)

Official	Referee/ Linesman	ACGIH TWA (dBA)	ACGIH Dose (%)	$OSHA_{AL}$ TWA (dBA)	$OSHA_{AL}$ Dose (%)	$OSHA_{PEL}$ Dose (%)	Notes
1	Linesman	95	342.0	91	44.6	34.9	
2	Linesman						Sample lost
3	Referee	93	252.7	90	37	26.2	
4	Referee	91	137.7	88	24.3	14.9	
5	Linesman	96	346.0	91	36.0	28.0	
6	Linesman	93	207.3	89	27.8	19.4	
7	Referee	91	129.7	87	22.4	13.5	
8	Linesman	90	107.5	87	21.1	12.5	
9	Linesman	90	110.1	87	22.7	13.7	
10	Linesman	94	269.5	90	31.3	23.0	
11	Linesman	94	255.9	89	28.9	20.6	
12	Referee	92	175.1	88	26.2	17.9	
13	Referee	90	103.3	87	22.6	16.8	
14	Linesman	91	146.0	87	24.5	17.8	
15	Linesman	93	193.2	88	25.7	14.2	
16	Referee	92	101.6	88	17.1	11.2	Partial sample
17	Linesman	91	132.9	88	25.7	16.7	
18	Linesman	91	130.9	88	26.0	17.3	
19	Referee	91	132.7	88	25.2	18.5	
20	Linesman	92	146.6	89	27.5	22.3	
21	Linesman	93	195.0	90	30.6	16.1	
22	Linesman	89	80.7	87	19.5	9.6	
23	Linesman	97	476.0	93	46.0	37.8	
24	Referee	94	236.2	89	27.5	18.2	
25	Linesman	88	71.9	86	19.1	9.6	
26	Linesman	92	170.1	89	28.5	19.8	
27	Referee	93	210.7	89	30.8	21.4	
28	Referee	88	66.2	86	17.7	9.8	
29	Linesman	93	187.6	88	26.0	18.2	
30	Linesman	89	72.4	86	17.9	9.2	
Totals							
Mean	N/A	92	181.6	89	27.3	17.7	N/A
SD	N/A	2.2	94.6	1.7	7.0	6.3	N/A

Descriptive Statistics for Hockey Games

Date	Attendance	Leq	Max	Peak
17-Oct	501	95	117	133
		93	117	136
18-Oct	377	93	118	129
		91	121	131
		96	119	133
24-Oct	332	93	114	131
		91	114	132
		90	115	137
25-Oct	344	90	118	135
		94	119	132
		94	115	132
26-Oct	237	92	121	132
		90	116	127
		91	112	143
7-Nov	516	93	116	136
		92	117	136
		91	115	136
8-Nov	587	91	115	129
		91	115	130
		92	115	136
14-Nov	515	93	113	133
		89	121	136
		97	118	134
21-Nov	589	94	110	127
		88	115.0	132
		92	115.0	152
13-Dec	457	93	113	134
		88	119	138
		93	113	136
Mean	446	93	116	134
SD	117.8	2.2	2.8	5.0

Referee and Linesmen 8-Hour Time Weighted Averages (n=30)

Official	$ACGIH_{TLV}$ 8-Hour TWA (dBA)	$OSHA_{AL}$ 8-Hour TWA (dBA)	$OSHA_{PEL}$ 8-Hour TWA (dBA)
1	91	85	83
2	N/A	N/A	N/A
3	89	83	81
4	87	80	77
5	91	83	81
6	89	81	79
7	86	80	76
8	86	79	75
9	86	80	76
10	90	82	80
11	90	81	79
12	88	81	78
13	86	80	78
14	87	80	78
15	86	80	76
16	86	78	75
17	87	81	78
18	87	81	78
19	87	81	78
20	87	81	80
21	88	82	77
22	85	79	74
23	92	85	83
24	89	81	78
25	84	79	74
26	88	81	79
27	89	82	79
28	84	78	74
29	88	81	78
30	84	78	73
Totals			
Mean	88	81	78
SD	2.1	1.7	2.5

Average Area Sampling Noise Measurements

		Position 1 (dBA)	Position 2 (dBA)	Position 3 (dBA)	Position 4 (dBA)
Game 1	Leq	79	82	89	82
	Min	71	75	71	72
	Max	85	91	97	91
	Peak	102	106	109	106
Game 2	Leq	89	79	82	82
	Min	71	71	72	75
	Max	97	85	91	91
	Peak	109	102	106	106
Game 3	Leq	79	81	81	81
	Min	72	71	72	70
	Max	88	88	88	93
	Peak	112	106	103	106
Game 4	Leq	75	85	84	83
	Min	69	72	74	69
	Max	80	92	92	92
	Peak	103	105	108	106
Game 5	Leq	77	76	90	78
	Min	67	67	73	69
	Max	83	86	98	82
	Peak	99	113	112	104

Totals		Leq	Min	Max	Peak
	Mean	82	72	90	107
	SD	4.2	2.2	5.0	3.6

Referee and Linesmen Whistle Blows Per Period

	Referee	Linesman 1	Linesman 2
	14	17	19
	29	23	18
	27	18	17
	23	15	20
Mean	24	19	
SD	6.7	2.4	
Per Game	72	57	

APPENDIX B

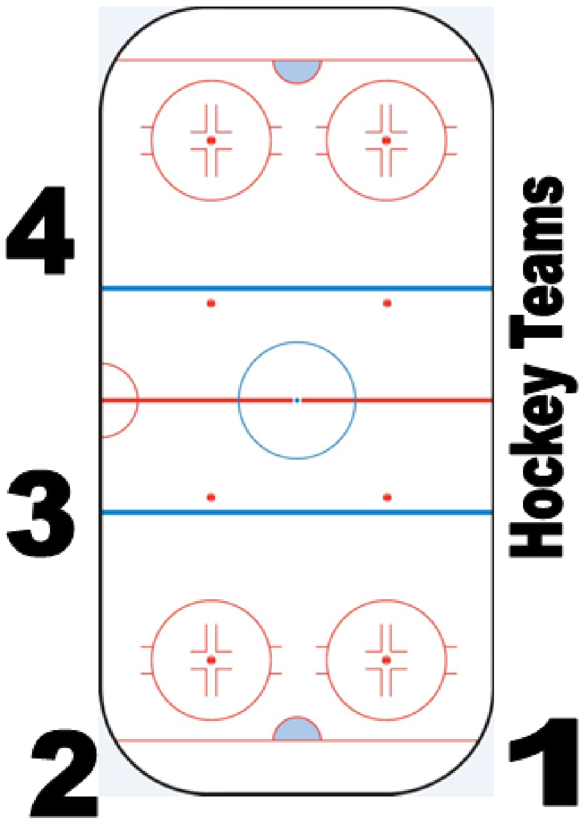
Noise Dosimeter Calibration Sheet

Dosimeter Number		
Subject ID		
Position	Referee	Linesman
Date		
Game/Opponent		
Attendance		

Pre-calibration	
Date:	
Time:	
Calibration Deviation 1: 94 dB	
Calibration Deviation 2: 114 dB	
Time On:	
Time Off:	
Whistle Blows:	
Notes:	
Post-Calibration	
Date:	
Time:	
Calibration Deviation 1: 94 dB	
Calibration Deviation 2: 114 dB	

APPENDIX C

Sound Level Meter Sampling Sheet



Position	Time	File Number

Samples taken 6 feet from wall of the rink

Use random number generator to pick samples

Take one sample every five minutes

Record noise sources

Noise Sources