THESIS

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR SPORTING EVENTS

Submitted by

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ABSTRACT

NOISE CHARACTERIZATION AND EXPOSURE OF INDOOR SPORTING EVENTS

Noise, as a hazard in the work place, has long been recognized as an issue facing workers. The National Institute for Occupational Safety and Health (NIOSH) recognizes that control of noise is a critical issue facing today's employers and employees. Occupational hearing loss was identified as one of the 21 priority areas for research in the next century. A report from the EPA in 1981 estimates that over 9 million Americans are exposed to occupational noise greater than 85 decibels (dB) and more recent estimates from NIOSH indicate excessive noise exposures upwards of 30 million.

Occupational and recreational noise exposures were evaluated at a two sporting arenas hosting hockey games at the collegiate and semi-professional level. Between the two facilities studied, a total of 54 personal noise dosimetry samples were taken over the course of seven home hockey games, three at Venue 1 and four at Venue 2. This included 15 worker personal noise samples and nine fan personal noise samples at Venue 1; and 19 worker personal noise samples and 11 fan personal noise samples at Venue 2.

Extensive area monitoring was conducted at each venue to further characterize the stadium noise on a location by location basis. These data are useful in characterizing occupational exposure of indoor arena support staff and may also provide a foundation for future research

No workers or fans from either venue were exposed to noise in excess of the Occupational Safety and Health Administration (OSHA) permissible exposure limit of an eight-hour time-weighted average (TWA) of 90 A-weighted decibels (dBA) or the eight-hour TWA action limit of 85 dBA. However, six of 15 (40%) workers and three of nine (33%) fans sampled at Venue 1 were exposed to noise in excess of the American Conference of Governmental Industrial Hygienists (ACGIH) recommended threshold limit value (TLV) of 85dBA.. In addition, eleven of 19 (57%) workers and ten of 11 (90%) fans sampled at Venue 2 were exposed to noise in excess of the ACGIH noise TLV.

A two-way analysis of variance (ANOVA) was conducted on the personal noise dosimetry data from workers and fans to determine if there were significant differences between noise exposures to workers and fans within and between the venues investigated. At a 95% confidence level, it was determined that there were significant noise exposure differences between nearly all groups in evaluating both OSHA and ACGIH criteria. However, no significant noise exposure differences were detected between workers at the different venues.

ACKNOWLEDGEMENTS

I would like to give thanks to my committee members, Dr. Robert Gotshall, Delvin Sandfort and Dr. William Brazile for their ongoing support and encouragement in this project. This research could not have been possible without the Mountains and Plains Education Research Center as it supported me in nearly all of my research and graduate coursework.

DEDICATION

For my family and friends; the ones who matter most in this world.

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of Variance
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
HP	Hearing Protection
Hz	Hertz
Leq	Equivalent Continuous Sound Pressure Level
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
TTS	Temporary Threshold Shift
TWA	Time Weighted Average
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

The human ear is a remarkable organ; its ability to process and interpret different sounds is astonishing. From the sound of pin a dropping to that of a jet engine, the human ear can interpret and distinguish with ease. It is able to differentiate many different sounds at many different levels of intensity. It is truly an impressive organ and is often taken for granted by many people every day. Noise and sound are an integral part of humanity in this world; it provides the foundation for communication between humans within society. Before the modern age, the ability to identify and differentiate the sounds of friend and foe were essential to survival and ultimately determined if one was allowed to contribute to the gene pool.

It is fundamental to consider the differences between noise and sound. Sound is commonly defined as vibrations that move the though air or other mediums to be perceived by humans or other animals.(1) This definition provides the elementary basis upon which hearing, noise, and sound are based. Noise, however, is defined as sounds, especially ones that are loud, unpleasant, or those that cause disturbances. (1) Therefore, by definition, noise can interfere with or pollute the ability to perceive other more important sounds. Moreover, whether the noise source is occupational or of leisure origin, society has become a much louder place as the human race has evolved. It has been well documented over time that excessive noise is associated with hearing loss in those who are exposed to it. Bernadino Ramazzini, considered the father of Industrial Medicine, made observations associating church bell ringers with hearing loss in his famous work “De Morbis Artificum Diatraba”.(2)

Noise, as a hazard in the work place, has long been recognized as an issue facing workers. The National Institute for Occupational Safety and Health (NIOSH) recognizes that control of noise is a critical issue facing today's employers and employees. Occupational hearing loss was identified as one of the 21 priority areas for research in the next century.[3] The authors of an Environmental Protection Agency report from 1981 estimated that over 9 million Americans were exposed to occupational noise greater than 85 decibels (dB); [4] more recent estimates from NIOSH indicated occupational exposures exceeding 85 dB to more than 30 million workers. Occupational authorities contend that noise is the most ubiquitous of industrial pollutants; many can be said to be more dangerous, but no others can be considered to be so wide spread. [5]

Occupational noise is a noteworthy exposure because noise-induced hearing loss (NIHL) is not only permanent and irreversible, but it is also 100 percent preventable. [6] Despite being 100 percent preventable, NIHL remains one of the most common occupational injuries or illnesses and is the second most self-reported occupational illness or injury in workers in the United States. [3] Although hearing loss is a common occupational injury or illness, its significance and relevance is often underrated because of the absence of pain or visual effects in exposed workers. [4] The progression of NIHL is slow and is often disregarded by affected workers. Damage can often go unnoticed in affected individuals and can result in difficulty interacting with others in both occupational and leisure-based settings. Severe NIHL can significantly decrease the quality of life in those workers who are afflicted.

In addition to contributing to the potential for decreased quality of life, exposure to excessive levels of noise is also associated with increased risk for cardiovascular disease, accidents resulting in work-time lost, absenteeism at work, stress, and decreases in productivity. [4, 7]

Although noise exposure in occupational settings has long been recognized as damaging to worker hearing, it was not until 1948 that the first hearing conservation program was implemented.[4, 8] This program was intended to protect workers in the Air Force from hazardous noise exposures while on the job. The year, 1971, marked the passage of the Occupational Safety and Health Act and the creation of the Occupational Safety and Health Administration. Most Americans are covered in occupational settings by the rules and regulations of OSHA. [4] Even with the development of OSHA, and its regulation of occupational noise exposure, noise induced hearing loss due to occupational exposures is too often overlooked. A population often underserved in typical occupational noise evaluation is arena and stadium workers. Exposure to these workers is important; in most cases they are the first to arrive, and the last to leave.

As identified in a study conducted by Engard *et al.* [9] stadium and arena personnel and other event support staff are often underserved with regard to the regulation of the occupational noise. Many different types of support staff are required to successfully host a sports event. Engard *et al.* focused on exposure to personnel and fans at outdoor stadiums. The focus of this paper was to evaluate and characterize noise exposure to personnel and fans during hockey games at indoor arenas.

CHAPTER 2: LITERATURE REVIEW

Sound is the transmission of energy in the form of a pressure wave through an elastic medium. The characteristics of a wave determine the pitch and the intensity of the pressure wave. Frequency, which determines the pitch of the sound, is measured in Hertz (Hz) and is a function of cycles per second. Amplitude of the wave relates its pressure to that of the atmosphere and is how loud a sound is perceived. The range of these pressures, 20 micropascals to 200 Pascals, covers several orders of magnitude. Therefore sound is measured on a logarithmic scale and sound pressure level is conveyed in units of decibels (dB).[4, 7]

Sound may be measured using three different weighting scales: A, B, and C. These weighting scales were developed on the basis of human perception of loudness at variable frequencies [4, 7]. The human ear is capable of detecting sounds spanning a wide range of frequencies; however, it is not equally proficient at detecting all of them to the same degree. A-weighting is used to most closely match the characteristics of human hearing. A-weighting emphasizes measurements at high frequencies and deemphasizes those at low frequencies. B-weighting has similar characteristics to that of A, but is rarely used. C-weighting is most often used in the presence of impulse and blast type noises characterized by rapid rise and fall in sound pressure. It can also be used in conjunction with A-weighting as a comparative value for detecting low frequency noise. [4, 7] The relative responses for the different weighting scales are presented in Table 1.

Table 1: Relative Response for A, B and C-Weighting [4]

Nominal Frequency (Hz)	A-Weighting dB	B-Weighting dB	C-weighting dB
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.2	-8.5
20	-50.5	-24.2	-6.2
25	-44.7	-20.4	-4.4
31.5	-39.4	-17.1	-3
40	-34.8	-14.2	-2
50	-30.2	-11.6	-1.3
63	-26.2	-9.3	-0.8
80	-22.5	-7.4	-0.5
100	-19.1	-5.6	-0.3
125	-16.1	-4.2	-0.2
160	-13.4	-3	-0.1
200	-10.9	-2	0
250	-8.6	-1.3	0
315	-6.6	-0.8	0
400	-4.8	-0.5	0
500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1000	0	0	0
1250	0.6	0	0
1600	1	0	-0.1
200	1.2	-0.1	-0.2
2500	1.3	-0.2	-0.3
3150	1.2	-0.4	-0.5
4000	1	-0.7	-0.08
5000	0.5	-1.2	-1.3
6300	-0.1	-1.9	-2
8000	-1.1	-2.9	-3
10000	-2.5	-4.3	-4.4
12500	-4.3	-6.1	-6.2
16000	-6.6	-8.4	-8.5
20000	-9.3	-11.1	-11.2

Physiology of the Ear

Human hearing is quite remarkable. An individual with normal hearing can hear noise at frequencies as low as 20 Hz and as high as 20,000 Hz.[4] Hearing is ultimately the translation of a pressure wave through air to a nerve impulse interpreted by the brain. The authorities on hearing and noise have divided the human ear into three regions, each of which is responsible for important aspects of hearing.[4, 7] The structures of the human ear can be found in Figures 1 and 2 below

Outer Ear

Sound is gathered and modified beginning at the outer ear. The outer ear includes the pinna and auditory canal which leads to the tympanic membrane. Because of the shape and dimensions of the outer ear, sounds of some frequencies are amplified and others are attenuated. As the pressure waves enter the ear, sounds at frequencies between 2000 and 4000 Hz are amplified by approximately 10-15 dB. This amplification of noise between 2000 and 4000 Hz contributes to increased risk for noise induced hearing loss (NIHL).[3,4]

Middle Ear

The middle ear is composed of the tympanic membrane, the ossicle bones (malleus, incus and stapes), tensor tympani, stapedius, and the eustachian tube. After the pressure wave traveling through air has reached the eardrum or tympanic membrane, it causes vibration of the tympanic membrane. This vibration of the eardrum is translated into the movement of the ossicle bones which are connected to the tympanic membrane. As the pressure wave travels from the outer ear to the middle ear, the wave amplifies the force as it moves to the inner ear and cochlea. The function of the middle ear is to efficiently transform motion of the tympanic membrane in air to motion of the ossicles in the fluid filled inner ear.

One important feature of the middle ear is its ability to provide partial protection to sustained loud noise. This protection is accomplished through the tightening of the tensor tympani and stapedius muscles, which results in the tightening of the tympanic membrane. As a result the tympanic membrane is less able to transfer acoustic energy to the inner ear. These muscles provide some protection but can fatigue quickly and should not be relied on for consistent protection.

The eustachian tubes are channels that travel the distance between the middle ear and the nasal breathing ways. These channels allow for the equalization of middle ear and outside pressure. If a differential in pressure begins to build, the tympanic membrane may become displaced and hearing may become affected. [3,4]

Inner Ear

The inner ear is composed of the cochlea, organ of corti, and stereocilia. The final step in human hearing is the translation of the mechanical wave created by the ossicles and eardrum to nerve impulses to be interpreted by the brain. The cochlea is located in the inner ear and plays an important role in this step of the process. It is a snail-shaped spiraled organ and is fluid filled with two membranes that run the distance of the organ. These membranes are reissner’s membrane and the basilar membrane. This arrangement of membranes creates a three chambered orientation within the cochlea. Approximately 25,000 hair cells called stereocilia are located atop the Basilar membrane. A third membrane sits atop the basilar membrane and is called the tectorial membrane. With this orientation, initiation of neural impulses occurs when the Basilar Membrane moves up or down resulting in the creation of a shearing force. The shearing force that is produced results in the bending of the stereocilia.[3,4]

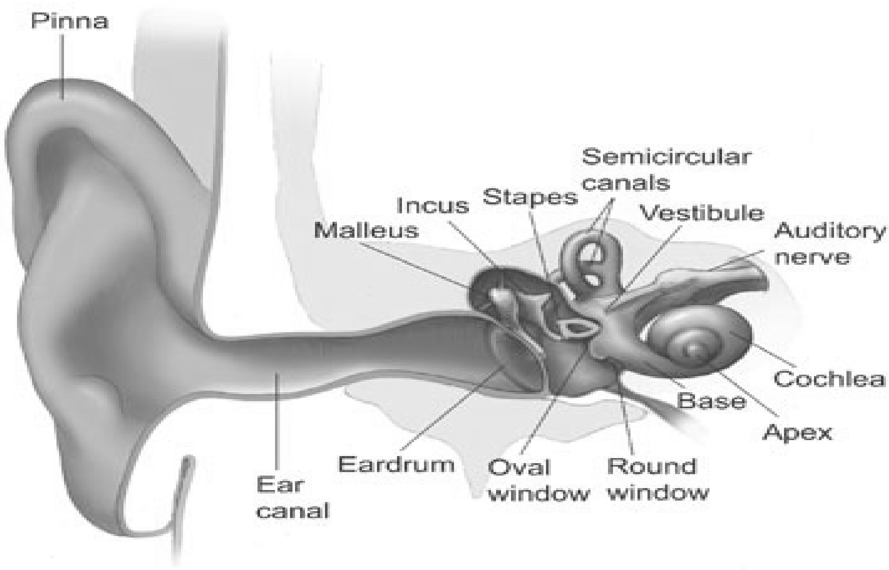

Figure 1: Structures of the Human ear (NIDCD 2008)

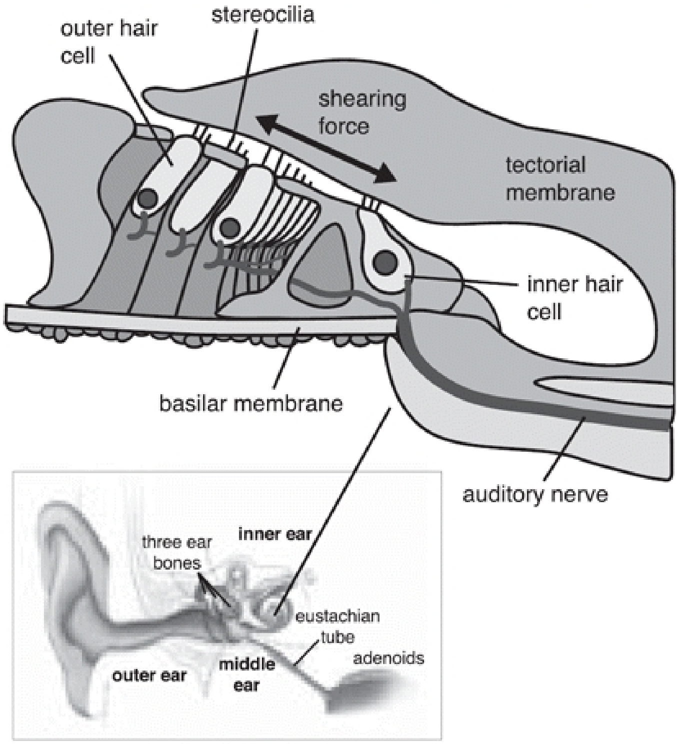

Figure 2: Structure of Inner-ear and the Interaction Between Tectorial Membrane and Stereocilia (National Institutes of Health 2007)

<u>Sound and Effect on Hearing</u>

Noise induced hearing loss has long since been a problem observed in society. Specifically, one of the very first documented case studies evaluated hearing loss observed in blacksmiths in the 1800's. Scientist and physician John Fosbroke observed deafness in blacksmiths and was one of the first to note the progression of noise induced hearing loss. Noise remains one of the most pervasive industrial contaminants in the workplace. One of the first notable applications of occupational epidemiology was conducted by physician and researcher Thomas Barr in 1886 who evaluated the presence of deafness in boilermakers using rudimentary audiometric testing. [5] He concluded that none of the boilermakers had normal hearing.

Three physical characteristics of sound determine its effect on human hearing. They are: amplitude, frequency, and duration. Amplitude determines how loud one perceives the sound to be. Frequency determines the pitch of the sound received, and duration is how long the sound lasts over time. Depending on the specific characteristics of the noise, hearing can be damaged in two ways. The first way is called acoustic trauma. In this case, the sound is so loud that tissue is damaged by the pressure of the sound. Acoustic damage generally takes place when the sound pressure level exceeds 140 dB. Acoustic trauma results in conductive hearing loss. Conductive hearing loss results when conduction of the pressure wave is physically stopped. In many cases, conductive hearing loss can be reversed by surgical or other interventions. [4, 11]

The second form of hearing loss is called noise induced hearing loss (NIHL) and is the result of cumulative trauma to the stereocilia located in the cochlea of the inner ear. All three characteristics of noise (amplitude, frequency, and duration) play a role in the development of NIHL. This cumulative trauma results in swelling of the stereocilia and overall decreased sensitivity to sounds. [11] Temporary damage to stereocilia in the cochlea is referred to as a temporary threshold shift (TTS). A TTS is characterized by a temporary decrease in sensitivity to sound, thus hearing is muffled.

[4, 12] This condition can take hours, or even days until the stereocilia display normal function. Repeated exposure to noise that causes a TTS will result in permanent hearing loss. [13] A TTS always precedes permanent hearing loss. Permanent hearing loss is characterized by damage to stereocilia in the cochlea is called sensorineural hearing loss. With time, the stereocilia will die and be replaced by non-responsive scar tissue. Permanent damage to the stereocilia will result in a standard threshold shift. As defined by OSHA, a standard threshold shift is a change in hearing threshold relative to a baseline audiogram of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either ear. [14]

Noise Exposure Standards

With regard to occupational noise exposure in general industry, workers are covered by OSHA's Occupational Noise Exposure Standard found in Title 29 Code of Federal Regulations (CFR), 1910.95. [14] The standard stipulates a permissible exposure limit of 90dBA as an eight-hour time weighted average (TWA) based on a 5 dB exchange rate. Additionally, employees must be enrolled in a hearing conservation program if exposed to 85 dBA as an eight-hour TWA or a noise dose of 50% as measured by a personal noise dosimeter (defined as the "action level").

Occupational Noise Exposure in construction is covered by 29 CFR 1926.52. [15] This standard also specifies a PEL of 90 dBA as an eight-hour TWA using a 5 dB exchange rate but does not specify an action level (e.g., 85 dBA or 50% dose) for enrollment into a hearing conservation program. However, if employees are exposed to noise greater than the PEL, they are required to be enrolled in a hearing conservation program.

The standard stipulates:

Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in this section when measured on the A-scale of a standard sound level meter at slow response. When employees are subjected to sound levels exceeding those referenced in the regulations, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of the table, personal protective equipment as required in Subpart E, shall be provided and used to reduce sound levels within the levels of the table.

OSHA stipulates that workers are to be enrolled in a hearing conservation program (HCP) when it is documented that their exposures to noise are greater than the action level of 85 dBA for an eight-hour time weighted average (TWA), or greater than a 50% dose as measured by a personal noise dosimeter. The OSHA Standards use a 5 dB exchange rate. Typical hearing conservation programs include personal noise dosimetry, annual audiometric testing, and proper record keeping. [14, 15] Additionally, employees who are enrolled in an HCP should be trained and educated on proper use of hearing protection and the risks of hearing loss. Participation in an HCP shall be provided to employees at no cost. Compliance with the OSHA noise PEL is enforceable by law. Fines and other penalties can be levied by OSHA compliance officers if the noise PEL is exceeded.

The American Conference of Governmental Industrial Hygienists (ACGIH) has developed recommendations for occupational noise exposure. In general, ACGIH standards are more conservative and are considered to be more protective to worker health. They are widely considered best practice in industry and are utilized in many developed countries throughout the world. The standards for noise exposure set by the ACGIH are not enforceable by law. The ACGIH Threshold Limit Values (TLV) writes that an eight-hour TWA of noise exposure shall not exceed 85 dBA with a threshold of 80 dBA. [16]

The primary difference between the OSHA and ACGIH standards are the allowable eight-hour TWAs and the exchange rates used by each organization. The ACGIH stipulates that workers may be exposed to 85 dBA TWA in an eight-hour day with a 3 dB exchange rate. The OSHA standard stipulates that workers can be exposed to 90 dBA TWA over an eight-hour day with a five dB exchange rate. The exchange rate describes the relationship between an increase in sound pressure level (SPL) and the decrease in allowable time. When an increase in SPL equal to the exchange rate occurs, the maximum allowable time for exposure is halved.

The three dB exchange rate is considered to be more conservative because an increase or decrease of three dB in SPL represents a doubling or halving of acoustic energy. Thus, this relationship is referred to as the equal-energy rule (See Table 2). For example, an eight-hour TWA of 85 dBA is equivalent to an exposure of four hours at 88 dBA.

The 5 dB exchange rate, as adopted by OSHA, is widely accepted to be less protective than the three dB exchange rate. The five dB exchange rate was designed to account for occupational environments in which exposure to noise is intermittent in nature. This would allow for some recovery of the ears. However, most noisy environments do not provide enough time for adequate recovery between exposures.

Table 2: OSHA and ACGIH Noise Exposure Limits

Permissible Noise Exposures		
Allowable Exposure (min)	Sound Pressure Level (dBA)	
	OSHA	ACGIH
480	90	85
240	95	88
120	100	91
60	105	94
30	110	97
≤ 15	115	100

The World Health Organization (WHO) has developed recommended guidelines for noise exposure for the general population to include leisure-based activities. The WHO recommended guidelines for noise exposure suggest up to 70 dB over a 24 hour period can be considered safe to human hearing and the risk for hearing impairment to be negligible. To avoid hearing impairment, the peak SPL of impulse noise for adults and children shall not exceed 140 dB and 120 dB respectively. [17]

Relevant Studies

There are currently no published in-depth studies which evaluate sound levels in arenas during hockey games. However, there was a preliminary investigation which evaluated sound levels during Stanley Cup playoff games. Additionally, there are studies which evaluate concerts and other events held inside arenas.

NIOSH conducted a Health Hazard Evaluation of workers and fans in arenas during motocross and monster truck events. The investigators found that seven of eight employees had exposures which exceeded the OSHA Action Limit of 85 dBA. Additionally, The NIOSH Recommended Exposure Limit and the ACGIH Threshold

Limit Value were exceeded in every subject sampled. Fan noise was documented using three and five dB exchange rates; average exposures ranged from 97-100 dBA and 92-95 dBA respectively.

Hodgetts and Liu [18] conducted noise dosimetry and audiometric testing during three National Hockey League (NHL) Stanley Cup playoff games. Hodgetts and Liu observed equivalent continuous sound levels (Leq) of 104, 101 and 103 dBA over periods exceeding three hours. Subjects who participated reported muffled hearing and mild ringing tinnitus after the events. Additionally the authors reported that the hearing thresholds of the subjects deteriorated by 5 to 10 dB for most frequencies, with the most substantial threshold shifts occurring in the 4000 Hz range. [18] This is concerning because human hearing is known to be most susceptible to damage in the 4000 Hz range.

Notable research regarding noise exposure during sporting events was also conducted by Axelsson and Clark. [19] A personal noise dosimeter was worn at one hockey game. The average sound pressure level was observed to be 100 dBA with a peak value of 120 dBA. This is equivalent to 117% of the OSHA PEL. Personal dosimetry was also conducted at game six of the 1987 World Series. The average SPL was 97 dBA, which is equivalent to 90.4% of the OSHA PEL. The researchers suggested that fans and attendees should be included in hearing conservation programs.

William Clark [20] conducted a review of noise exposures of leisure activities and calculated a geometric mean of 103.4 dBA from 16 studies which evaluated exposures at discotheques and rock concerts. Clark concluded that occasional exposure to noise exceeding 100 dBA a few hours per week or month represented little risk for hearing loss. However, he also concluded that those individuals who regularly attend such events, such as artists or workers at the venue, may be at elevated risk for noise induced hearing loss. Sadhra *et al.*, found TTS and permanent hearing loss in student employees working at university venues. Observed sound pressure levels of the work environment exceeded 90 dBA. Of those that participated, 29% showed a permanent threshold shift 30 dB or greater.

Engard *et al.*, conducted personal noise dosimetry and area sampling in three different outdoor football venues and found that 96% of workers sampled were overexposed by ACGIH standards. [(9)] Further, Engard *et al.*, also found 39% of workers sampled to be exposed to sound exceeding the OSHA action limit of 85 dBA with a 5 dB exchange rate and 100% of workers sampled to be exposed to sound exceeding the ACGIH threshold limit value of 85 dBA with a three dB exchange rate. The investigators emphasized that they believed implementation of hearing conservation programs to be necessary at the sampled facilities.

CHAPTER 3: PURPOSE AND SCOPE

Purpose:

In order to successfully host an event at an indoor arena, namely hockey, any number of support staff may be required to address unique needs. Support staff at hockey games can include: mobile concessions workers, concession booth workers, event security, ushers, technical support staff and others. These staff members are usually at the arena well before and after the event or game. Occupational noise exposure at indoor sporting events is of concern for three reasons. First, these employees are required to work in close quarters with fans that are encouraged to be as loud as possible. Close quarters of the fans in an enclosed area may enhance reverberant conditions and increase occupational and recreational noise exposure. Second, the public address (PA) system is often set to a level that is as loud as or louder than the fan noise so that patrons can hear the announcer. Finally, arena design may also contribute to the noise of the environment. This interaction between the fans, the PA system, and arena design merit an investigation to characterize and document this exposure. The purpose of this study is to characterize and evaluate the exposure to employees and fans in attendance at hockey games at venues where collegiate and semi-professional hockey games are hosted.

The following research questions are used in the context of this thesis to address exposure to fans and employees

(1) Are workers at professional, semi-professional, and collegiate hockey games overexposed to noise based on currently accepted exposure limits?

(2) Do the observed data indicate differences between workers and fans within and between the different venues?

(3) What are the potential implications for NIHL in employees and fans due to occupational and leisure noise exposure in working or attending the hockey games?

Scope:

Employees and fans from Venue 1 and Venue 2 were solicited for participation in the study. Unfortunately, a third venue declined to participate in any capacity and thus is not included in the remainder of this thesis. Sound surveys were conducted during three and four home games at Venue 1 and 2 respectively. Venues were chosen based on size and level of play the venue supported. Initial design incorporated three arenas with different fan capacities, due to resistance from management at the professional level; the scope of the project was significantly revised to include exposure only at the collegiate and semi-professional levels. Sampling visits were chosen based on the scheduling both of the investigator and of the venue being sampled.

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CHAPTER 4: MATERIALS AND METHODS

Recruitment

Facility managers from three venues which host hockey games were contacted for participation in the research study. This was accomplished formally through use of a written verbal script. As previously mentioned, management at the third venue declined any participation in this study. Therefore, only two venues agreed to participate in the study. Managers at both of the two venues agreed to aid the primary investigator in identifying potential candidates for participation in the study. Ushers were identified for participation at both venues. These individuals help patrons to seating and oversee crowd conduct. Fans were identified for participation prior to game time and were recruited using a written verbal script and were chosen at random, due to shortage of time before games fans were not always equally distributed throughout the arena. All research conducted for this project was done so in accordance with all rules and regulations imposed by the Institutional Review Board at Colorado State University to ensure protection of all human subjects who were involved with this research.

Employees and fans were formally recruited into the research study using a written verbal script. Subjects that were recruited for participation in the study were informed of their roles or responsibilities as fans and workers in participation. Before any participation by any subjects took place, all subjects provided informed consent for participation in the study. All research and activities affiliated with this project were conducted according to the protocol approved by the Research Integrity and Compliance Review Office at Colorado State University.

Personal Noise Monitoring

Personal noise dosimetry was conducted using equipment from the Colorado State University Occupational Safety and Health Administration (OSHA) Consultation Program. Dosimetry samples were collected using Larson Davis Personal Noise Dosimeters models 706RC and 703+ manufactured in Provo, Utah. The Larson Davis dosimeters can measure noise using up to four configurations (e.g., exchange rates, thresholds, and criterion levels) simultaneously; two configurations were utilized for noise measurement in this project based on OSHA and the American Conference of Industrial Hygienists (ACGIH) criteria as indicated in Table 3 below.

Table 3: Dosimeter Settings

Setting	ACGIH	OSHA
Exchange Rate (dB)	3	5
Threshold (dBA)	80	90
Criterion Level (dBA)	85	90
Criterion Duration (min)	480	
Weighting	A-Weighting	
Detector setting	Slow	
Gain (dB)	0	

All dosimeters were pre- and post-calibrated according to manufacturer's specifications to ensure accuracy and consistent readings during measurement. Dosimeters were calibrated to 94 and 114 dB. All calibration data were recorded and changes were noted and percent deviation was calculated where applicable. Fans and employees were instructed go about business as usual, but were informed not to tap, blow, or yell directly into the microphones. One dosimeter per subject was clipped to subject's belt and the microphone was attached to the shirt as close to the hearing zone as possible. Dosimetry was conducted with guidance from Berger *et al.* [4] and the OSHA Technical Manual. [21]

Area Noise Monitoring

A Larson Davis System 824 Sound Level Meter (SLM)/ Octave Band Analyzer (OBA) manufactured in Provo, Utah, was used to conduct all area noise monitoring during sampling events. Two-minute area samples were taken on all sides in the middle of the respective section. For example, samples were taken on the North end at the level of the glass, portal to the section, and at the very top of the section. Figures for both arenas illustrating area sampling locations can be found in the results section of this thesis. To ensure reliability, accuracy and validity, the SLM/OBA was pre- and post-calibrated according to manufacturer specifications. The Larson Davis Sound Level Meter was calibrated to both 94 and 114 dB. All calibration data were recorded and if applicable, percent deviation was calculated and recorded. All area monitoring was conducted with guidance from Berger *et al.* [4] and the OSHA Technical Manual. [21]

Data Management and Statistical Analysis

Prior to data collection, the statistical laboratory at Colorado State University was consulted to determine the appropriate number of required number of samples. Professional statistical consultants conducted a power analysis based on previous studies. The total number of samples acquired reflects the input received from CSU statistical laboratory.

Data from the Larson Davis dosimeters were downloaded and analyzed using the Larson Davis Blaze software. Dosimetry data were examined on the basis of: OSHA eight-hour time weighted averages (TWA), OSHA % dose, ACGIH eight-hour TWA, and ACGIH % dose. Percent dose data were log transformed prior to statistical analysis due to the high variation of the dose data. A two-factor Analysis of Variance (ANOVA) with two venues and two job classifications (i.e., worker or fan), was conducted on the personal dosimetry data obtained from sampling events. To account for date, a random effect was nested within venue. An interaction between job and date within venue was included in this analysis. Individual job by venue means were compared by pairwise contrasts.

Data obtained from the Larson Davis model 824 during area sound monitoring were downloaded to a computer using the Larson Davis 824 software. Data were analyzed on the basis of: equivalent continuous sound pressure level (Leq), and peak sound pressure level (SPL). Octave band data were recorded for Leq at each measurement location during sampling events. Both 1/3 and full-octave bands were recorded. However, only some of the full octave bands are included in the in the results below to illustrate how the data were used. Data from the SLM was analyzed and graphed using Microsoft Excel.

CHAPTER 5: RESULTS AND DISCUSSION

Personal Dosimetry

Venue 1

A total of 23 personal dosimetry samples (14 workers and nine fans) were taken during three home games at Venue 1. Tables 4 and 5 contain summary statistics of worker and fan noise exposures, respectively. Mean OSHA and ACGIH eight-hour TWAs and % doses for workers and fans are presented in the tables. Table 6 contains the proportion of workers sampled who were exposed to noise exceeding published occupational exposure limits. Six of fifteen (40%) workers sampled were overexposed to American Conference of Governmental Industrial Hygienists (ACGIH) standards for occupational noise exposure. No workers sampled exceeded the OSHA permissible exposure limit or the OSHA action limit. Three of nine (33%) fans sampled over the three home games were overexposed to ACGIH standards for occupational noise exposure. No exposure to fans exceeded the OSHA permissible exposure limit or the OSHA action limit. Table 7 contains the proportion of fans sampled at Venue 1 who were exposed to noise exceeding published occupational exposure limits.

Table 4: Mean Worker Noise Dosimetry Results at Venue 1

				ACGIH		OSHA	
Date	# Sampled	Attendance		% Dose	8- hour TWA	% Dose	8- hour TWA
2/18/11	5	5625	Mean	70.74	82	7.94	69
			SD	63.83	3.08	9.46	7.04
2/19/11	5	6146	Mean	88.8	84	10.62	73
			SD	27.21	1.41	4.64	3.49
3/5/11	4	5569	Mean	99.58	84	12.05	74
			SD	43.97	1.78	5.4	3.44

Table 5: Mean Fan Noise Dosimetry Results at Venue 1

				ACGIH		OSHA	
Date	# Sampled	Attendance		% Dose	8- hour TWA	% Dose	8- hour TWA
2/18/11	3	5625	Mean	27.23	79	1.9	61
			SD	5.82	0.87	0.78	2.87
2/19/11	3	6146	Mean	62.5	83	5.53	68
			SD	32.66	2.52	3.56	4.85
3/5/11	3	5569	Mean	87.53	84	8.07	71
			SD	43.63	2.77	4.42	5.26

Table 6: Proportion of Workers Sampled at Venue 1 Exceeding Occupational Exposure Limits

OSHA PEL	OSHA Action Limit	ACGIH TLV
0%	0%	(6/15) 40%

Table 7: Proportion of Fans Sampled at Venue 1 Exceeding Occupational Exposure Limits

OSHA PEL	OSHA Action Limit	ACGIH TLV
0%	0%	(3/9) 33%

Venue 2

A total of 30 personal noise dosimetry samples (19 workers and 11 fans) were taken during four home games. Tables 8 and 9 contain summary statistics for worker and fan noise exposures, respectively. Mean OSHA and ACGIH eight hour TWAs and % doses for workers and fans are presented in the tables. Eleven of 19 workers sampled at Venue 2 were overexposed to ACGIH standards for occupational noise exposure. No workers sampled were exposed to noise exceeding the OSHA permissible exposure limit or the OSHA action limit. Table 10 contains the proportion of workers sampled who were exposed to noise exceeding published occupational exposure limits. Ten of 11 (91%) fans sampled over 4 home games at Venue 2 were overexposed to ACGIH standards for occupational noise exposure. No exposure to fans exceeded the OSHA permissible exposure limit or OSHA action limit. Table 11 contains the proportion of fans sampled at Venue 2 who were exposed to noise exceeding published occupational exposure limits.

Table 8: Mean Worker Noise Dosimetry Results at Venue 2

				ACGIH		OSHA	
Date	# Sampled	Attendance		% Dose	8-hour TWA	% Dose	8-hour TWA
2/23/11	5	5289	Mean	111.28	85	14.06	76
			SD	22.96	1	2.77	1.6
2/26/11	5	5289	Mean	85.82	84	10.74	74
			SD	21.56	1.17	2.79	1.97
3/4/11	5	5289	Mean	88.56	84	11.1	74
			SD	13.74	0.69	1.72	1.14
3/16/11	4	5289	Mean	119.15	86	15.58	77
			SD	12.3	0.45	1.25	0.59

Table 9: Mean Fan Noise Dosimetry Results at Venue 2

				ACGIH		OSHA	
Date	# Sampled	Attendance		% Dose	8-hour TWA	% Dose	8-hour TWA
2/23/11	3	5289	Mean	162.93	87	18.6	78
			SD	49.18	1.46	5.46	2.37
2/26/11	3	5289	Mean	119.63	81	12.2	65
			SD	103.3	11.21	10.54	21.9
3/4/11	3	5289	Mean	387.6	89	27.5	80
			SD	391.51	4.15	15.81	3.87
3/16/11	2	5289	Mean	510.75	90	31	81
			SD	531.53	5.8	20.22	5.09

Table 10: Proportion of Workers Sampled at Venue 2 Exceeding Occupational Exposure Limits

OSHA PEL	OSHA Action Limit	ACGIH TLV
0%	0%	(11/19) 57%

Table 11: Proportion of Fans Sampled at Venue 2 Exceeding Occupational Exposure Limits

OSHA PEL	OSHA Action Limit	ACGIH TLV
0%	0%	(10/11) 91%

Table 12: Proportion of Fans and Workers Exceeding Occupational Exposure Limits by Venue

	ACGIH		OSHA	
	Venue 1	Venue 2	Venue 1	Venue 2
Workers	(6/15) 40%	(11/19) 57%	0%	0%
Fans	(3/9) 33%	(10/11) 91%	0%	0%

Area Monitoring

Venue 1

An SLM was used to measure peak SPLs and Leqs at numerous locations throughout the arena. Additionally, octave band analysis was conducted at all locations. Locations where area noise monitoring took place are seen below in Figure 3. As displayed in figure 4, the mean Leq for all three games ranged from 81 dBA to 96 dBA; and the peak SPL for all three games ranged from 105 dBA to 124 dBA.. Octave band analysis data from one sampling event on 18 February 2011 are presented in Figures 5, 6 and 7 and are examples of the data obtained from octave band analysis during area monitoring. As illustrated below in Figures 5, 6, and 7, the highest Leq values by octave were consistently in the south end of the arena. Additionally, the highest three-game mean peak SPL and Leq were measured in the south end of the arena. Based on preliminary analysis the loudest frequency spectrum of the noise in the arena during the sampling even on February 18, 2011 was centered between 500 and 2000 Hz.

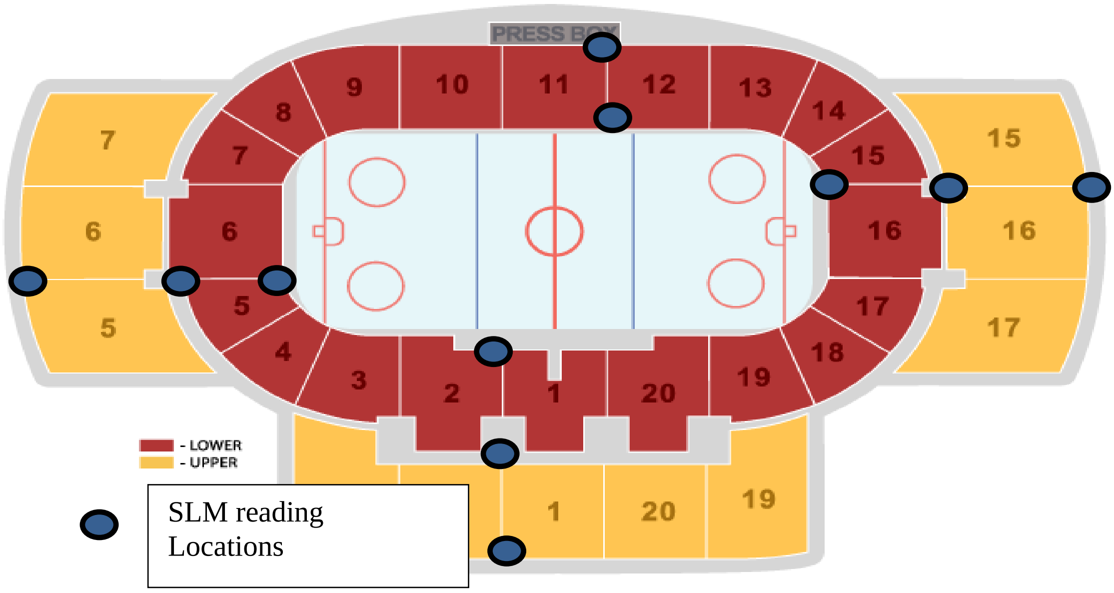

Figure 3: Measurement Locations at Venue 1

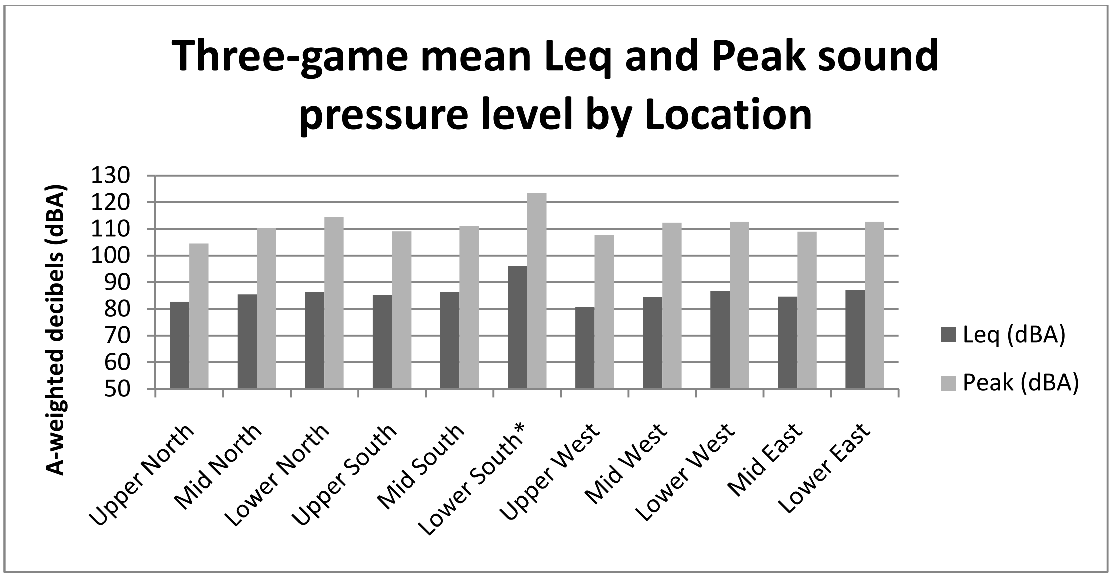

Figure 4: Three-game Mean and Peak SPL by Location and Level in the Arena

Figure 4 notes: * - Student Section. The highest peak SPL and Leq values were observed in the student section during sampling.

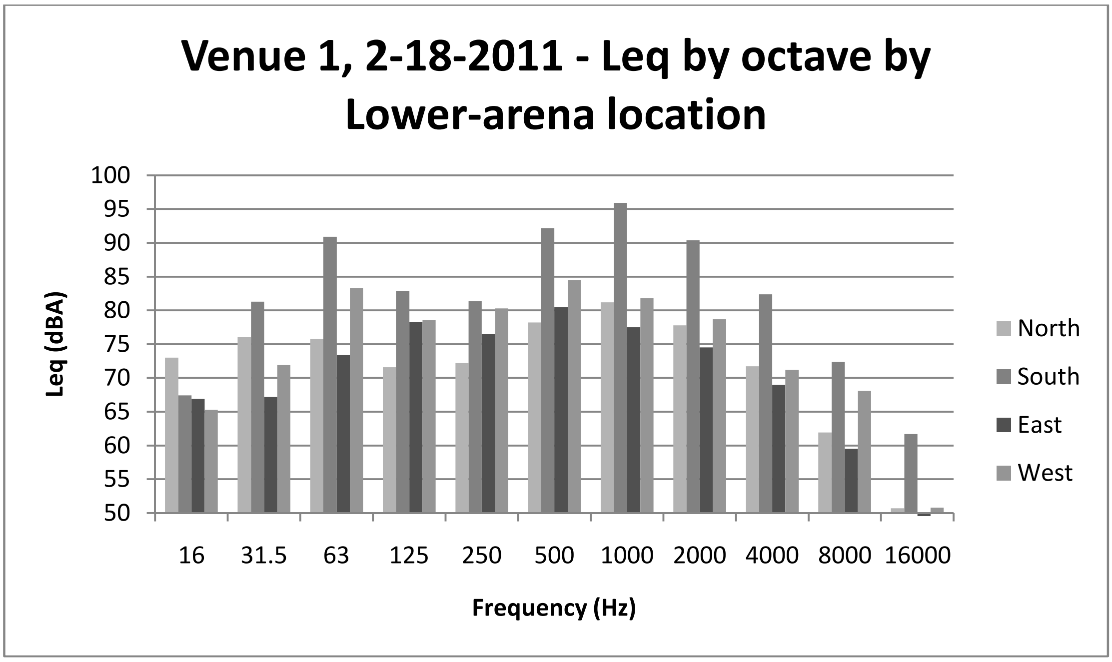

Figure 5: Leq by Octave in Lower Arena Locations as Measured on February 18, 2011

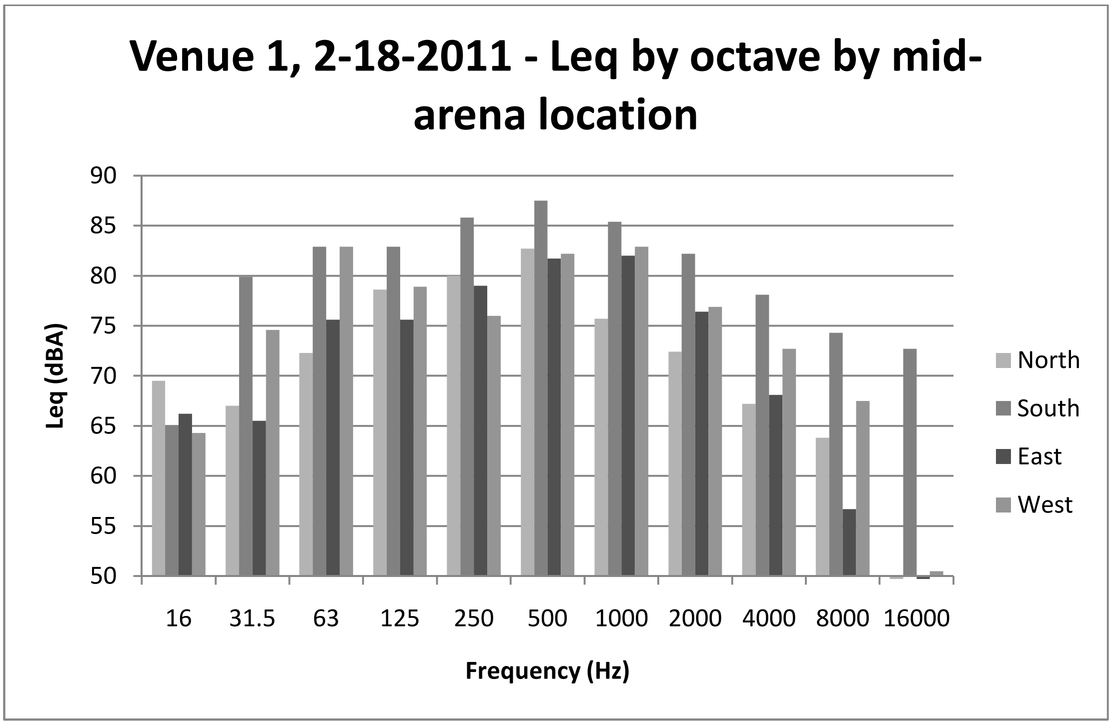

Figure 6: Leq by Octave in Mid Arena Locations as Measured on February 18, 2011

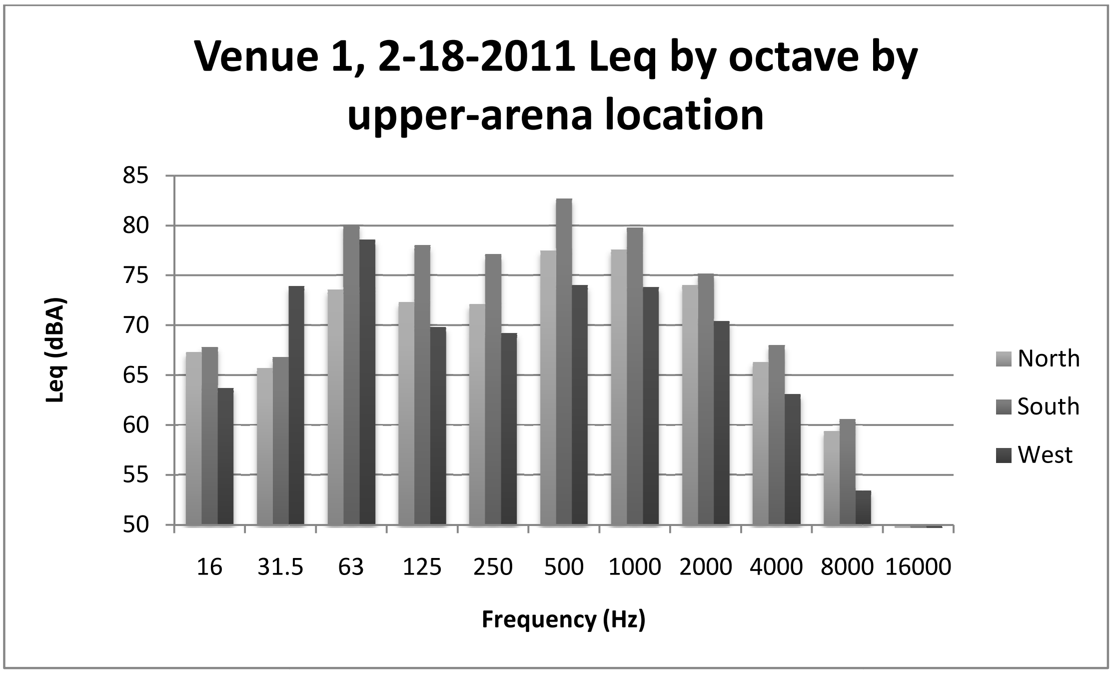

Figure 7: Leq by Octave in Upper Arena Locations as Measured on February 18, 2011

Venue 2

An SLM was used to measure peak SPLs and Leqs at numerous locations throughout the arena. Additionally, octave band analysis was conducted at all locations. Locations where area noise monitoring took place are seen below in Figure 8. As displayed in figure 9, the mean Leq for all four games ranged from 85 dBA to 97 dBA; and the peak SPL for all three games ranged from 110 dBA to 117 dBA.. The mean Leq and peak SPL for all four games are displayed graphically in Figure 9. On average, the Leq and peak data obtained from area monitoring the distribution appears to be relatively uniform in most cases, with slight deviations in the lower-south and upper-east locations of the arena. Octave band analysis data from one sampling event on February 23, 2011 is contained in Figures 10, 11 and 12. Based on preliminary analysis, the loudest frequency spectrum of the noise in the arena during the sampling even on February 23, 2011 was centered between 500 and 2000 Hz.

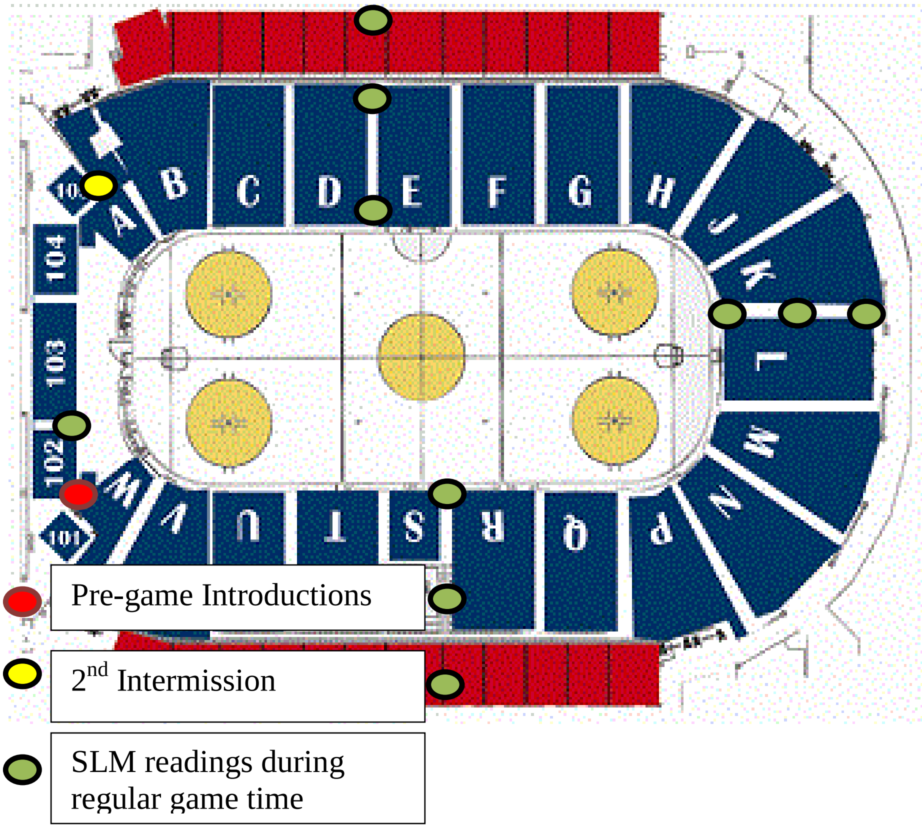

Figure 8: Measurement Locations at Venue 2

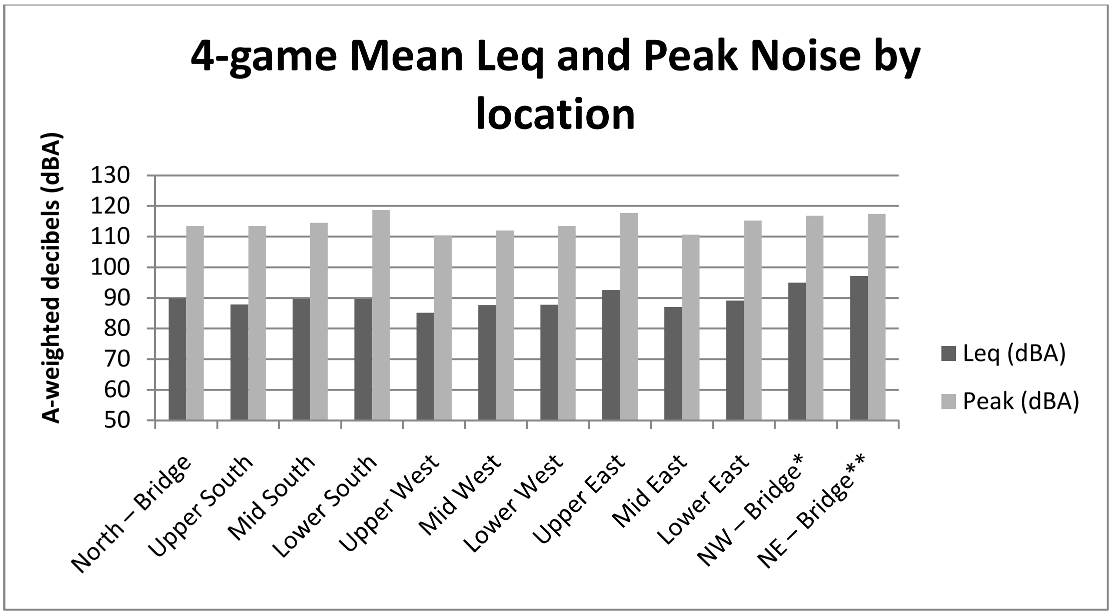

Figure 9: Four-game Mean Leq and Peak Sound Pressure Level by Location and Level in the Arena

Figure 9 notes: * = Pregame introductions, **= 2nd Intermission

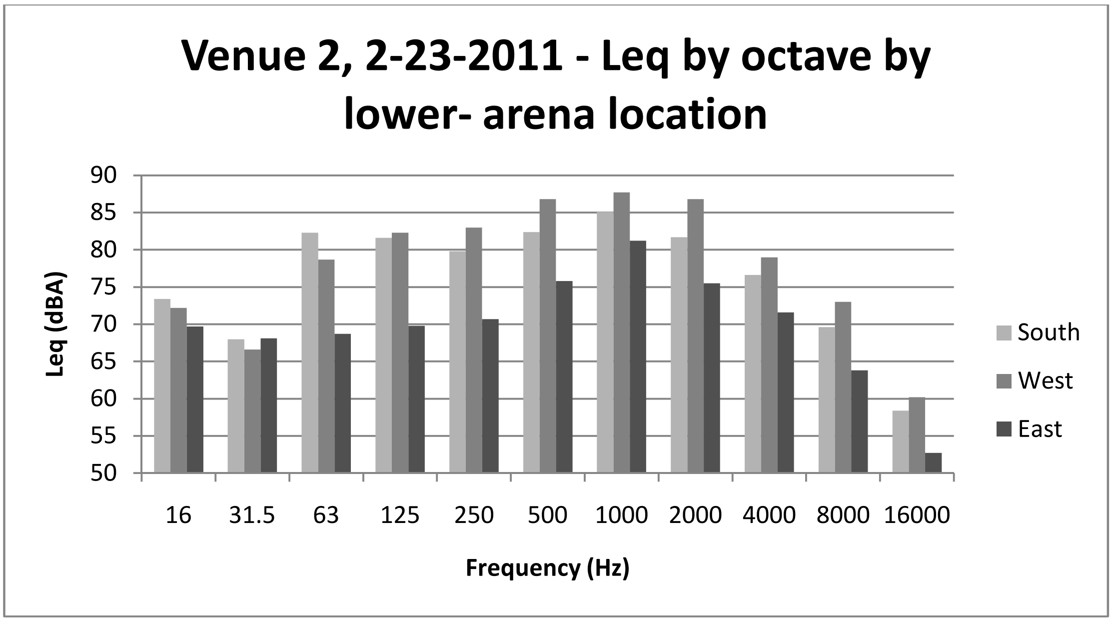

Figure 10: Leq by Octave in Lower Arena Locations as Measured on February 23, 2011

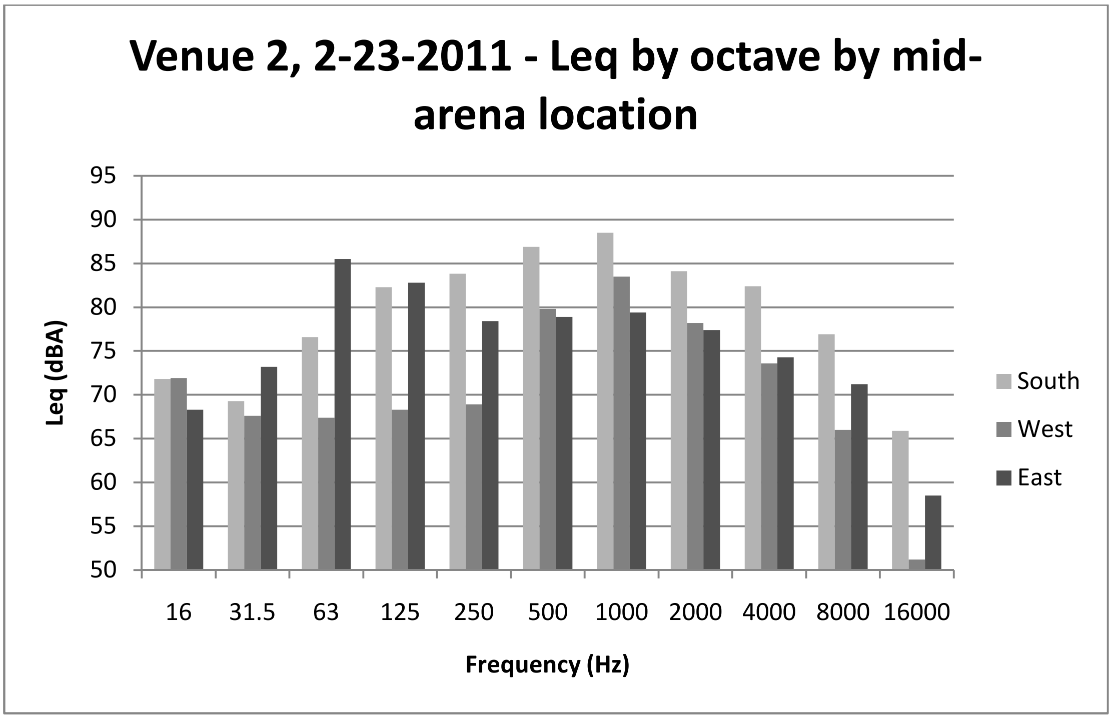

Figure 11: Leq by Octave in Mid Arena Locations as Measured on February 23, 2011

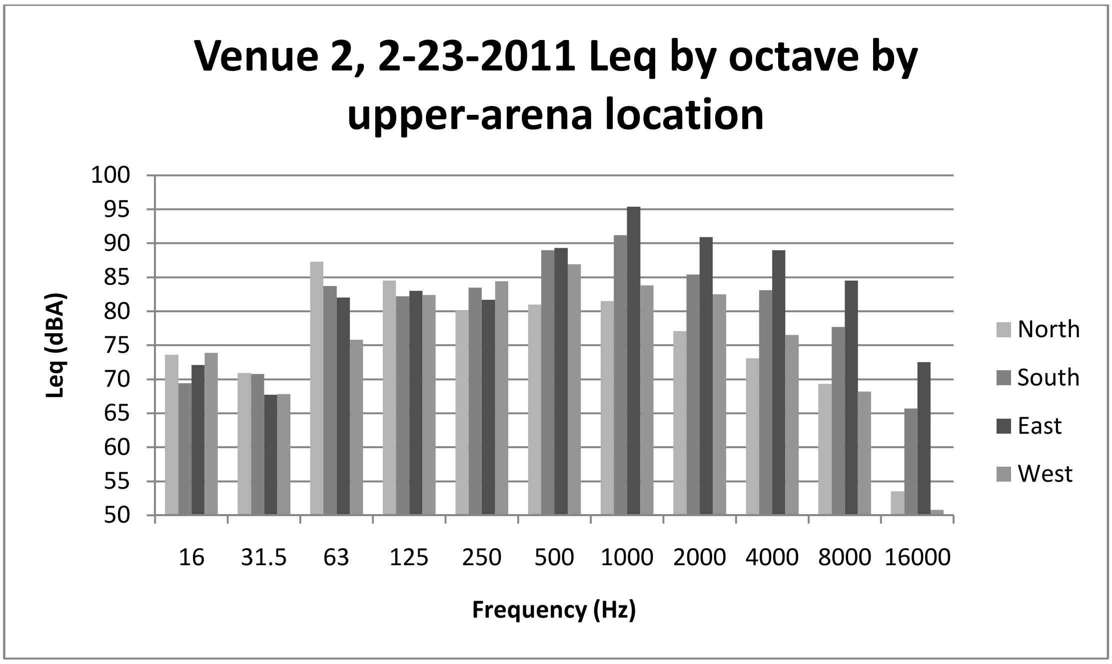

Figure 12: Leq by Octave in Upper Arena Locations as Measured on February 23, 2011

<u>Statistical Analysis</u>

To ensure statistical validity, noise dosimetry data were tested for normal distribution; assumptions of normality were met. To compare results obtained from noise dosimetry at both venues, a two-factor analysis of variance (ANOVA) with two venues and two classifications, worker or fan, was conducted. To account for event date, a random effect was nested within venue. An interaction between job and date within venue was included in this analysis. Individual job by venue means were compared by pairwise contrasts. All statistical comparisons were made with 95% confidence limits ($\alpha = 0.05$). Pairwise comparisons of workers and fans included: OSHA eight-hour TWA, log transformed OSHA % dose, ACGIH eight-hour TWA and log transformed ACGIH % dose. Data from the pairwise comparisons are contained in Tables 12, 13, 14 and 15. These data are displayed graphically in Figures 13, 14, 15, and 16.

The results of the two-way ANOVA indicate significant differences ($p < 0.05$) in comparing the groups studied on the basis of: OSHA eight-hour TWA, log transformed OSHA % dose, ACGIH eight-hour TWA, and log transformed ACGIH % dose. Significant interactions were found between fans and workers at within venues, between fans by venue, and between fans and workers at different venues. Specific significant interactions found for each variable are listed below in the following paragraphs.

Mean OSHA eight-hour TWA

In evaluating difference of least square means of the OSHA eight-hour TWA, significant differences ($p <0.05$) were found for most pairwise comparisons. Fans and workers at Venue 1 were found to have significantly different OSHA eight-hour TWA values. Fans between venues were found to have significantly different OSHA eight-hour TWA values. Fans at Venue 1 were found to be significantly different from workers at Venue 2. Workers at Venue 1 were found to have significantly different OSHA eight-hour TWAs compared to fans at Venue 2. Finally, exposures of fans at Venue 2 were found to be significantly different from workers at Venue 2. No significant difference was found in workers between venues. Significant differences indicated the following:

- Exposure to fans at Venue 1 were significantly less than workers at Venue 1
- Exposure to Fans at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 1 was significantly less than workers at Venue 2
- Exposure to workers at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 2 was significantly greater than workers at Venue 2

Mean Log transformed OSHA % dose

In evaluating difference of least square means of mean log transformed OSHA % dose, significant differences ($p < 0.05$) were found for most pairwise comparisons. Fans and workers at Venue 1 were found to have significantly different OSHA % dose. Fans between venues were found to have significantly different OSHA % dose. Fans at Venue 1 were found to be significantly different from workers at Venue 2. Workers at Venue 1 were found to have significantly different OSHA eight-hour TWAs compared to fans at Venue 2. Finally, exposures of fans at Venue 2 were found to be significantly different from workers at Venue 2. No significant difference was found in workers between venues. Significant differences indicated the following

- Exposure to fans at Venue 1 were significantly less than workers at Venue 1.
- Exposure to fans at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 1 was significantly less than workers at Venue 2
- Exposure to workers at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 2 was significantly greater than workers at Venue 2

Mean ACGIH eight-hour TWA

In evaluating differences of least square means of the ACGIH eight-hour TWA, significant differences ($p < 0.05$) were found for most pairwise comparisons. Fans between venues were found to have significantly different ACGIH eight-hour TWAs. Fans at Venue 1 were found to have significantly different ACGIH TWAs compared to workers at Venue 2. Workers at Venue 1 were found to have significantly different ACGIH eight-hour TWAs compared to fans at Venue 2. Finally, exposures of fans at Venue 2 were found to be significantly different from workers at Venue 2. Fans and workers at Venue 1 were found to have no significant differences in ACGIH eight-hour TWA. No significant differences were found in workers between venues. Significant differences indicated the following:

- Exposure to fans at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 1 was significantly less than workers at Venue 2
- Exposure to workers at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 2 was significantly greater than workers at Venue 2

Mean Log transformed ACGIH % dose

In evaluating differences of least square means of the log transformed ACGIH % dose, significant differences ($p < 0.05$) were found for most pairwise comparisons. Fans between venues were found to have significantly different log transformed ACGIH % dose. Fans at Venue 1 were found to have significantly different log transformed ACGIH % dose compared to workers at Venue 2. Workers at Venue 1 were found to have significantly different log transformed ACGIH % dose compared to fans at Venue 2. Finally, log transformed ACGIH % dose of fans at Venue 2 were found to be significantly different from workers at Venue 2. Fans and workers at Venue 1 were found to have no significant differences in log transformed ACGIH % dose. No significant differences were observed in workers between venues. Significant differences indicated the following:

- Exposure to fans at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 1 was significantly less than workers at Venue 2
- Exposure to workers at Venue 1 was significantly less than fans at Venue 2
- Exposure to fans at Venue 2 was significantly greater than workers at Venue 2

Table 13: Difference of Least Square Means: OSHA 8 hr TWA

Comparison	Estimate	DF	t-value	P-value	Alpha
f(1)w(1)	-5.369	43.1	-3.57	0.0048*	0.05
f(1)f(2)	-12.4034	9.88	-5.24	<0.0001*	0.05
f(1)w(2)	-8.4148	8	-3.76	0.0027*	0.05
w(1)f(2)	-7.0343	8.32	-3.11	0.0168*	0.05
w(1)w(2)	-3.0457	6.55	-1.43	0.486	0.05
f(2)w(2)	3.9887	43.2	2.89	0.0292*	0.05

Table key:
* = significan differences, $p < 0.05$
1= Venue 1
2= Venue 2
f= Fans
w= workers

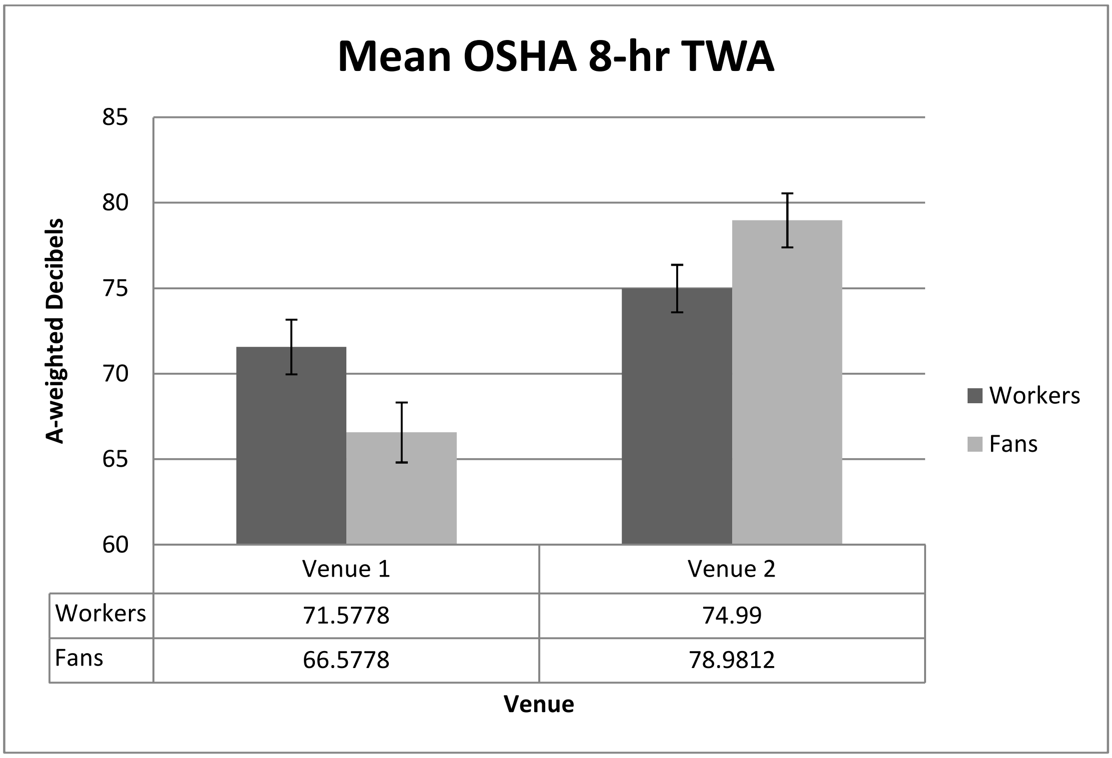

Figure 13: Mean OSHA 8 Hour TWA

Table 14: Difference of Least Square Means: Log Transformed OSHA dose

Comparison	Estimate	DF	t-value	P-value	Alpha
f(1)w(1)	-0.3218	43.1	-3.55	0.0009*	0.05
f(1)f(2)	-0.7441	9.95	-5.25	0.0004*	0.05
f(1w(2)	-0.5041	8.04	-3.77	0.0054*	0.05
w(1)f(2)	-0.4223	8.36	-3.12	0.0135*	0.05
w(1)w(2)	-0.1823	6.57	-1.43	0.1974	0.05
f(2)w(2)	0.24	43.2	2.89	0.0059*	0.05

Table key:
* = $p < 0.05$
1= Venue 1
2= Venue 2
f= Fans
w= workers

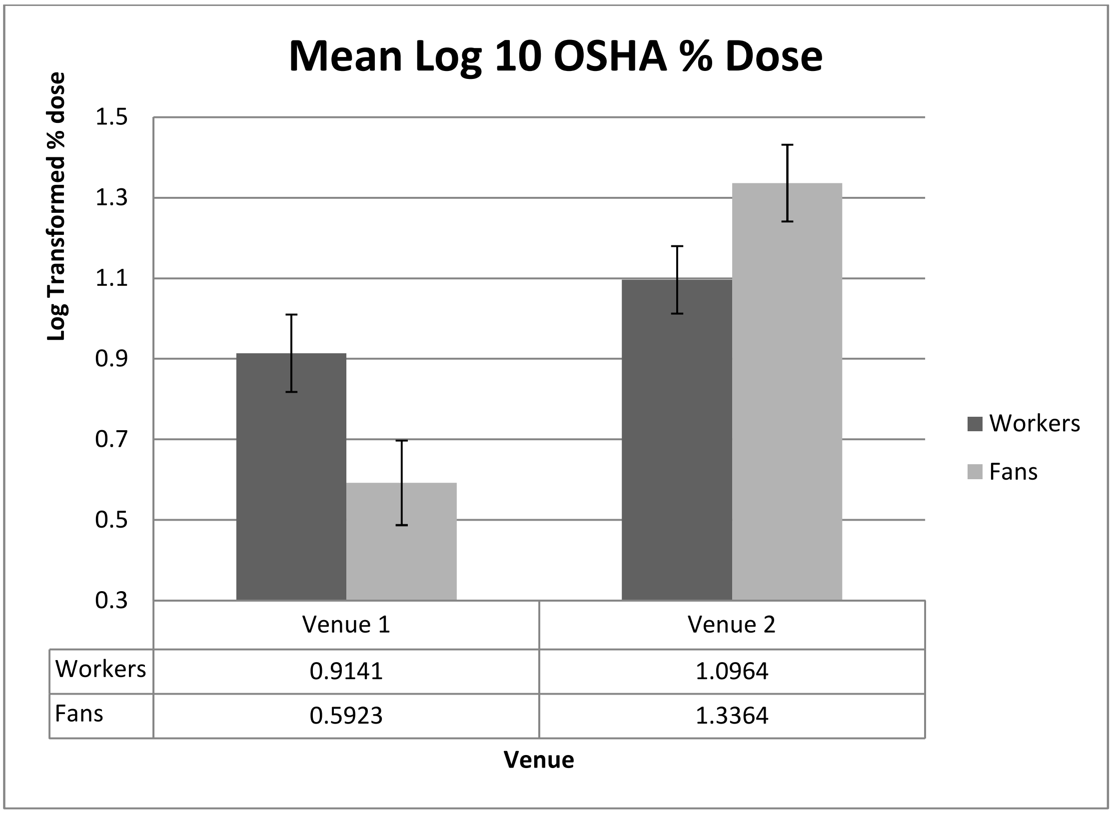

Figure 14: Mean Log Transformed OSHA % Dose

Table 15: Difference of Least Square Means: ACGIH 8 hr TWA

Comparison	Estimate	DF	t-value	P-value	Alpha
f(1)w(1)	-1.9775	43.1	-2.22	0.1346	0.05
f(1)f(2)	-6.6179	12.5	-5.41	<0.0001*	0.05
f(1w(2)	-3.0407	9.56	-2.68	0.0492*	0.05
w(1)f(2)	-4.6404	10	-4.03	0.0012*	0.05
w(1)w(2)	-1.0632	7.27	-1.01	0.747	0.05
f(2)w(2)	3.5772	43.2	4.38	0.0004*	0.05

Table key:
* = $p < 0.05$
1= Venue 1
2= Venue 2
f= Fans
w= workers

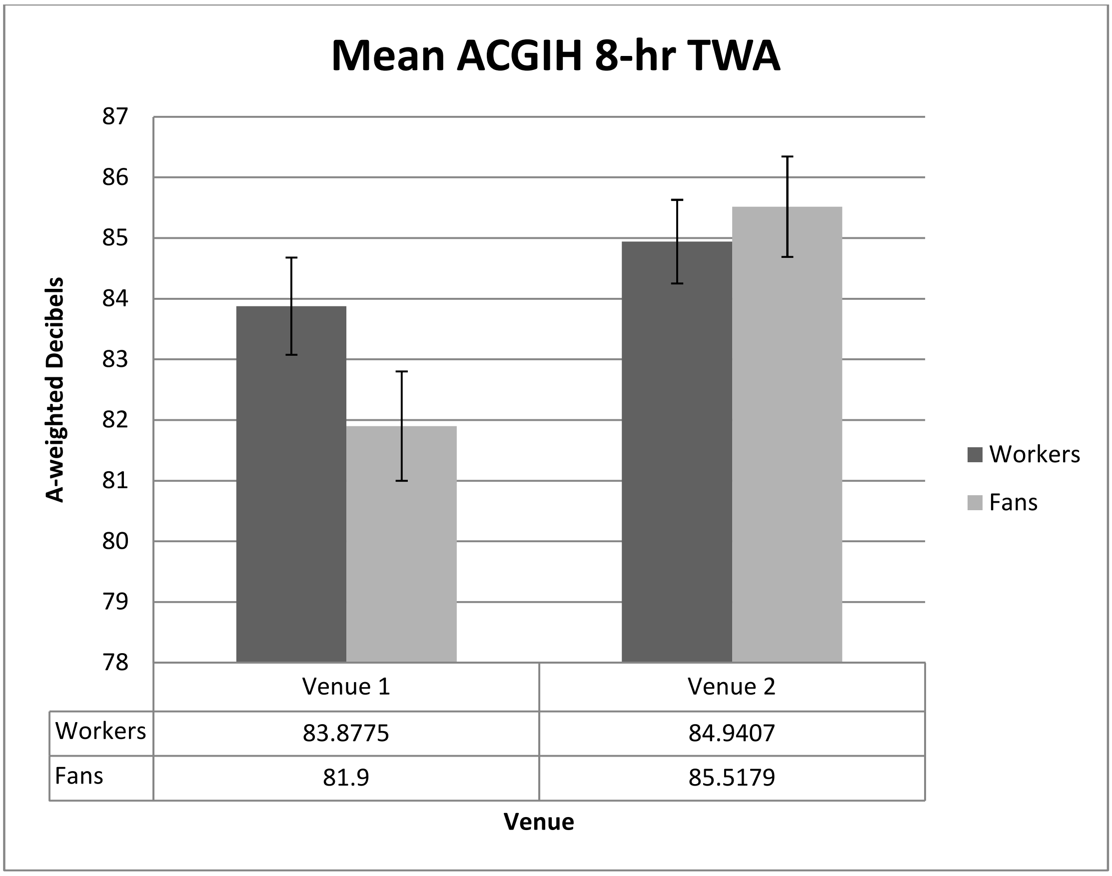

Figure 15: Mean ACGIH 8 Hour TWA

Table 16: Difference of Least Square Means: ACGIH Log Transformed ACGIH dose

Comparison	Estimate	DF	t-value	P-value	Alpha
f(1)w(1)	-0.1978	43.1	-2.21	0.1356	0.05
f(1)f(2)	-0.6617	12.6	-5.4	<0.0001*	0.05
f(1w(2)	-0.3031	9.58	-2.57	0.0505*	0.05
w(1)f(2)	-0.4639	10.1	-4.02	0.0013*	0.05
w(1)w(2)	-0.1058	7.28	-1	0.7529	0.05
f(2)w(2)	0.3587	43.2	4.38	0.0004*	0.05

Table key:
* = p < 0.05
1= Venue 1
2= Venue 2
f= Fans
w= workers

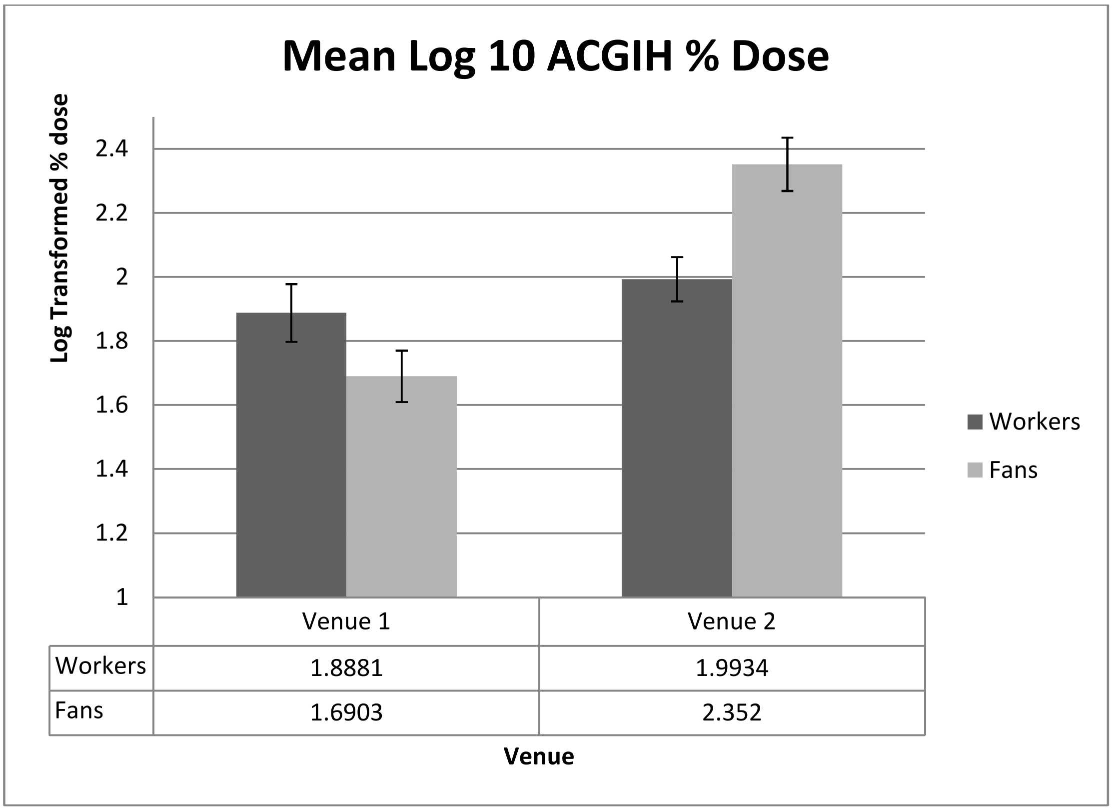

Figure 16: Mean log transformed ACGIH % dose

Discussion:

Significant differences were found in all variables analyzed between fans and workers within and between venues after analyzing data acquired from personal dosimetry at the respective venues. The only exception however, was that no significant differences were detected in comparing workers between venues for any variable. Additionally, no significant differences in means were detected between fans and workers at Venue 1 in evaluating mean ACGIH eight-hour TWAs and mean log transformed ACGIH % dose. Based on SLM and personal dosimetry data, Venue 2 was louder than Venue 1. Also noteworthy is the fact that exposures to workers sampled at Venue 1 were significantly less than exposure to fans at Venue 1while the reverse is true for Venue 2. In general the fans at Venue 2 were found to have the greatest exposure of all of the groups evaluated; this was also found to be statistically true.

Significant differences between fans and workers between and within venue may be attributed to the location of the worker or fan. That is, ushers who stood in the portal to the seating area may have been protected from the crowd noise because of the location of the post. Work is not usually conducted in close proximity to the fans. Ushers at both venues conducted work in similar fashion; they would report to the assigned post and remain there until intermissions. During intermissions, ushers reported to the outer concourse to supervise fan activity.   Fans on which personal dosimetry was conducted, most often remained seated for the duration of the game and therefore were in close-proximity to other noise producing fans which may contribute to an increased overall dose to the fans.

The significantly increased exposure in fans at Venue 2 compared to those at Venue 1 may be attributed to a number of factors. Venue 2 is widely known to have a loyal fan base and at the time had a streak of more than 300 sold out home games. The fans of Venue 2 may have been more intense or more "die-hard" than those in attendance at the Venue 1. Venue 2 has been coined as the loudest arena in region. This may result in a noticeable difference in attitude and behavior of fans at Venue 2 to produce more noise. It is also be helpful to evaluate the capacity and level of attendance of the games sampled. Venue 1 has a higher seating capacity for hockey games compared to the Venue 2, but attendance was not substantially increased compared to Venue 1. This means there were more empty seats, and on average there may have been more distance between fans which may have contributed to the observed decreased dose of sampled fans compared to those at Venue 2.

Among workers sampled during the home games at Venue 1 and Venue 2, 40% and 57% were exposed to noise that exceeded ACGIH standards for occupational noise exposure. None of the workers sampled had exposure above the OSHA Permissible Exposure Limit or the OSHA Action Limit. Even though results of the personal dosimetry indicated no legal implications, a combined 50% of all workers sampled between the two venues exceeded the recommendations for exposure to occupational noise published by the ACGIH.

The study conducted by Engard *et al.*[(9)] found that 96% of workers sampled were exposed to noise levels exceeding the ACGIH TLV and 39% exceeded the OSHA action limit. Engard *et al.* [9] also highlighted that 96% of fans sampled exceeded the ACGIH TLV.. The current study found that only 40% of workers sampled at Venue 1 and 57% at Venue 2 exceeded the ACGIH TLV. This study also found that 33% and 91% of fans exceeded the ACGIH TLV. Additionally no workers or fans sampled in the current study exceeded the OSHA action limit. The differences observed between the two studies may be attributed a number of factors including:

attendance of the event, specific game environments, and popularity of the sporting event.

Data collected during NHL playoff hockey by Hodgetts and Liu [18] indicated that the Leq ranged from 101 to 104 dBA. This noise level range was greater than the noise-level ranges observed in the current study. Hodgetts and Liu documented a very popular sporting event during post season professional playoff hockey and is not a typical game environment. Additionally, Axelsson and Clark [19], who conducted similar preliminary investigations at professional hockey games also found exposures to be in excess of 100 dBA. These studies represent atypical exposure at indoor sporting events.

Limitations

The primary limitation of this study is the lack of a third venue for comparison. Capacity of the proposed third venue was substantially larger than the two included in the study. Comparing the studied populations to a third venue would increase the relevance of the research to occupational and recreational noise exposure.

A second limitation to this study addresses randomness of the samples taken at the each game. Efforts were taken to ensure a representative and random sample of the workers and fans in attendance at each game. But due to lack of time, financial and human resources the samples taken were not completely at random. Some workers were sampled over multiple games while others were not. Due to resistance of random fans to participate in the study, some fans were sampled at more than one event.

Another limitation that needs to be addressed is the nature of the sound level meter data. Two minute measurements were taken at every location during every game. However, the timing of the measurements at each location is not the same for each reading. For example, a reading at the lower south end of an arena may have taken place in minute three of the second period; the readings in the lower north, west and east ends are compared directly even though the time elapsed in the game of the measurements is not the same. Averaging all of the measurements from the games could potentially balance the distribution of the noisy periods sampled events. If more resources were available, more comprehensive surveys could be conducted and accurate time comparisons between locations could occur.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Evaluation of worker and fan exposure to occupational and recreational noise was conducted in this study to address the following research questions:

(1) Are workers at professional, semi-professional, and collegiate hockey games overexposed to noise based on currently accepted exposure limits?

Sampling data indicated that 40% of workers sampled at Venue 1 and 57% of workers sampled at Venue 2 were overexposed to occupational noise according to ACGIH recommendations. No workers or fans at Venue 1 or Venue 2 approached the OSHA action limit (i.e., 85 dBA) for enrollment into a hearing conservation program; therefore no workers were exposed to noise in excess of the OSHA PEL.

Fifty percent of all workers sampled between the two venues were exposed to noise exceeding the ACGIH TLV.

(2) *Do the observed data indicate differences between workers and fans within and between the different venues?*

Results from a two-way ANOVA indicated that there were several significant differences in personal noise exposure of workers and fans within and between the venues studied. A two-way analysis of variance was conducted on OSHA eight-hour time weighted averages, log transformed OSHA % dose, ACGIH eight-hour time weighted averages, and log transformed ACGIH % dose. Results from the statistical analyses indicated that Venue 2 was significantly louder than Venue 1 in nearly all pairwise comparisons for all variables of interest. Noise exposure to fans at Venue 2 was significantly greater than Venue 1in all variables statistically analyzed.

The two-way ANOVA indicated that noise exposure to workers between venues were never significantly different regardless of the variable being analyzed ($p>0.05$). Additionally, fans and workers from Venue 1 were not significantly different in evaluating ACGIH eight-hour TWA and log transformed ACGIH % dose ($p > 0.05$). Conversely the same comparison was significantly different in evaluating OSHA eight-hour TWA and log transformed OSHA % dose.

(3) What are the potential implications for NIHL in employees and fans due to occupational and recreational noise exposure in working or attending the hockey games?

In evaluating the data obtained from the personal noise dosimetry conducted on workers and fans, 33% and 91% of fans and 40% and 57% of workers at Venues 1 and 2 respectively were overexposed to the recommended ACGIH noise exposure limits. It is well documented that exposure to hazardous occupational noise (> 85 dB) contributes to increased risk for development of noise induced hearing loss.[4] The WHO recommendation to assess noise exposure to patrons of entertainment venues by occupational exposure limits [22] is applied to this study; therefore, it can be concluded that many of the fans were overexposed to noise.

This study represents only one aspect of occupational exposure for these types of workers. Event support staff observed in this study may work many different events at multiple venues in the area.

Recommendations

Workers

Noise levels within both arenas were well below the OSHA action limit of 85 dBA TWA or 50% dose, therefore no formal hearing conservation program is recommended for these facilities for compliance with OSHA standards. However, if managers want to assure that employees are not overexposed to the recommended ACGIH criteria (8 hour TWA of 85 dBA) it is recommended that a hearing conservation program be implemented for both venues. Prior to the beginning of the study, both venues provided hearing protectors to workers to use on a voluntary basis. However, it is unknown whether employees were trained on how to properly use hearing protection.

Fans

Prior to the study, there were reports from fans that noise in certain sections of Venue 2 was excessive. In response, management at Venue 2 began offering hearing protection to fans who were concerned about excessive noise exposure. However, it was not observed that the facility was actively advertising the availability of hearing protectors. It was noted by the investigator that different sections were located closer or farther away from the public address system speakers. This may play a role in how loud a patron or worker perceived the event to be. It is recommended that Venue 2 continue to offer hearing protection to patrons and that Venue 1 begin offering hearing protectors to those who seek it.

Future Research

This study has illustrated the potential for overexposure to ACGIH criteria. This study only characterized one event of noise exposure relevant to the workers at these facilities. Depending on the staffing agency, workers may work many different venues and many different types of events. Therefore, further research could be conducted to characterize occupational noise exposure of event support staff as they work different venues and different types of events. Future research could also incorporate pre- and post-audiograms to detect the presence of TTS in workers at these venues. Future research to further characterize occupational exposure to noise at indoor arenas should incorporate a third venue with a more substantial difference in fan capacity.

Research should also be undertaken to determine if certain locations within the stadium are louder than others and to determine if speaker location within the arena has a significant effect on noise exposure at certain locations within the arena.

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