THESIS

NOISE EXPOSURE, CHARACTERIZATION, AND COMPARISON OF THREE FOOTBALL STADIUMS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY DEREK ENGARD ENTITLED NOISE EXPOSURE, CHARACTERIZATION, AND COMPARISON OF THREE FOOTBALL STADIUMS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

NOISE EXPOSURE, CHARACTERIZATION, AND COMPARISON OF THREE FOOTBALL STADIUMS

The National Institute for Occupational Safety and Health and the occupational safety and health community named hearing loss as one of the 21 priority areas for research in the next century and maintains that work-related hearing loss continues to be a critical workplace safety and health issue. An overlooked group of employees are those that work in stadiums and arenas. Not only are the workers potentially exposed to high levels of hazardous noise, but the spectators attending these events may also be exposed.

Five personal noise-exposure samples were collected from workers at Hughes Stadium (Fort Collins, CO) and Folsom Field (Boulder, CO) during three home football games for a total of 30 personal noise exposures. Five personal noise-exposure samples were collected from fans at Invesco Field (Denver, CO) and two samples from fans at Hughes Stadium and Folsom Field during three home football games for a total of 27 personal noise-exposure samples.

None of the workers' noise doses were above the Occupational Safety and Health Administration permissible exposure limit of 90 dBA. However, 11 of 28 (39%) workers' noise doses exceeded the Occupational Safety and Health Administration action level of 85 dBA which would require enrollment into a hearing conservation program. Following the American Conference of Governmental Industrial Hygienists recommendations for noise exposure limits, 27 of 28 (96%) workers would be considered

overexposed. In addition, 24 of 25 fans (96%) were also overexposed according to the American Conference of Governmental Industrial Hygienists and the World Health Organization recommendations. Data were not collected for two fans and two workers.

At the 95% confidence level, workers' and fans' noise exposures were not significantly different among the three stadiums. However, there was significant noise-level variability between the games in each individual stadium. The peak sound pressure level was found to be significantly higher at Hughes Stadium than the other stadiums due to the firing of the Army cannon. Flat peak sound pressure levels of over 140 decibels were recorded on the field and in the stands.

All employees that work inside the stadiums should be included in a hearing conservation program, which would include audiometric testing, continued exposure monitoring, hearing protection, training, and record keeping. The program should also include all other possible occupational-noise sources.

The facility managers should include a warning of possible loud-noise exposure during any sporting events held at the stadiums in fan guides, pamphlets, websites, or other appropriate communication tools. This information should include the health effects of loud noise exposure, namely noise-induced hearing loss.

The information should also be specifically targeted to parents of young children, including a strong recommendation that hearing protection should be worn by all children during the sporting event. “Hearing Protection Required” signs should be placed around the Army cannon at Hughes Stadium.

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists’
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
CFR	Code of Federal Regulations
CSU	Colorado State University
CU	University of Colorado
dB	Decibel
dBA	Decibel, A-weighted
dBC	Decibel, C-weighted
HCP	Hearing Conservation Program
HPD	Hearing Protection Device
Hz	Hertz
ISO	International Organization for Standardization
kHz	Kilohertz
Leq	Equivalent Continuous Sound Pressure Level
NFL	National Football League
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NRR	Noise Reduction Rating

OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PTS	Permanent Threshold Shift
SD	Standard Deviation
SLM	Sound Level Meter
SPL	Sound Pressure Level
TLV	Threshold Limit Value
TD	Touchdown
TTS	Temporary Threshold Shift
TWA	Time Weighted Average
U.S.	United States
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

What is noise? The Merriam-Webster Dictionary defines noise as sound that lacks musical quality or is noticeably unpleasant.[(1)] Some noise is in the eye of the beholder, but it is hard to refute that most people today live in a world that is nosier than 150 years ago. The industrial revolution marked the beginning of a steady growth in noise to which the average person is exposed. The increase in mechanization, including transportation and manufacturing, has greatly influenced our daily lives, but has also amplified the noise problem. Planes, trains, and automobiles have been in our world for more than 100 years now, and most people would characterize them as "noisy." Ask anyone who lives near an airport, next to railroad tracks, or near a busy street and you will receive complaints of noise. The coming of the electronic age has not decreased the noise problem. Televisions, personal music players, loudspeakers, and radios all pose a threat to our hearing if the sound levels are excessive.

The relationship between exposure to high levels of noise and subsequent hearing loss has been known for centuries. Church bell-ringers, blacksmiths, and coppersmiths were all documented as having hearing loss when compared to the general population.[(2)] Ramazzini, who many consider the father of occupational medicine, wrote about coppersmiths in 1713, "…the ears are injured by that perpetual din, and in fact the whole head, inevitably, so that workers of this class become hard of hearing and, if they grow old at this work, completely deaf."[3] However, with the increase of noise in our industrial society, people continue to suffer from hearing damage and/or loss. The World Health Organization (WHO) estimated in 1995 that there were 120 million people with disabling hearing difficulties worldwide.[4] The authors that conducted the most recent occupational hearing loss surveys in the United States (U.S.) in the 1980's concluded that approximately 30 million American workers were exposed to hazardous noise levels alone or in combination with other ototraumatic agents that are potentially damaging to their hearing.[5, 6]

The National Institute for Occupational Safety and Health (NIOSH) and the occupational safety and health community identified hearing loss as one of the 21 priority areas for research in the next century and maintains that work-related hearing loss continues to be a critical workplace safety and health issue. Noise-induced hearing loss (NIHL) is one of the most common occupational diseases and the second most self-reported occupational illness or injury.[5] Many occupational health and safety authorities contend that noise is the most ubiquitous of industrial pollutants; there are others more dangerous but none so widespread.[2] NIHL is 100 percent preventable but once acquired, it is permanent and irreversible.

The loss of hearing is indisputably a quality of life issue that affects not only the individual but family, friends, and co-workers as well. People who have poor hearing experience listening and communication difficulties almost on a daily basis. This leads to restricted social participation, isolation, reduced autonomy, negative self-image, and diminished quality of life.[7] Researchers of hearing impairment among the elderly found significant results in social inactivity and isolation, which can lead to an increase in poor health and mortality.[8, 9] Exposure to high levels of noise can also increase the risk of cardiovascular disease, lost-time accidents, absenteeism, stress and lower productivity.[10, 11]

In 1948, the United States Air Force was the first organization in the U.S. to mandate a hearing conservation program to protect workers from hearing damage.[11, 12] It was not until 1971 when the newly-created Occupational Safety and Health Administration (OSHA) promulgated a noise standard that covered most American workers.[11] However, due to manpower and budget constraints OSHA usually only has time to monitor high-hazard industries. This fact, coupled with a lack of good hearing conservation education in this country, causes many workers potentially exposed to hazardous noise to be overlooked.

An underserved group of employees are those that work in stadiums and arenas. These employees can include anyone from referees, grounds crew, food service employees, athletic trainers, equipment and security personnel; all working to host sporting events, concerts, motor sports, etc. Not only are the workers potentially exposed to high levels of hazardous noise, but the spectators attending these events could also be exposed. The primary focus of this study was to evaluate personal noise exposures and to characterize the noise in outdoor stadiums during football games.

CHAPTER 2: LITERATURE REVIEW

Sound is energy transmitted through an elastic medium, such as air, in the form of a pressure wave. The frequency of the wave determines the pitch of a sound and is measured in Hertz (Hz). The amplitude of the sound pressures, relative to atmospheric pressure, can range from 20 micropascals to 200 pascals, a range of 1-10 million. Therefore, the logarithm of sound pressure is used as a basis for sound measurement that is reported in decibels (dB).[10, 11]

The response of the human ear is not equally sensitive to sounds of different frequencies. Noise-exposure measurements are normally conducted using the A-weighting scale. Sound pressures are measured in the flat frequency spectrum and then modified with the A-weighting scale to quantify the noise in a way comparable to that of human hearing. The dB measurements are emphasized in the higher frequencies and deemphasized in the lower frequencies to give an approximation of equal loudness perception that closely matches human hearing. The C-weighting scale is mostly used in applications to measure impulse or blast-type sounds, and does not deemphasize the lower frequencies as much as the A-weighting scale.

Table 2.1 provides the correction factors used for the weighting filters at the reference frequency of 1000 Hz. The A-weighted measurements are reported as the sound pressure level (SPL) in decibels dBA, and the C-weighted measurements are reported as dBC.[10, 11] See Table 2.2 for some common sound pressure levels.

Table 2.1: Relative Response for A and C Weighting[11]

Frequency (Hz)	**A-Weighting (dB)**	**C-Weighting (dB)**
16	-56.7	-8.5
31.5	-39.4	-3.0
63	-26.2	-0.8
125	-16.1	-0.2
250	-8.6	0.0
500	-3.2	0.0
1000	0.0	0.0
2000	1.2	-0.2
4000	1.0	-0.8
8000	-1.1	-3.0
16000	-6.6	-8.5

Table 2.2: Common Sound Pressure Levels[13]

Noise Source	A-Weighted Sound Level in Decibels	Noise Environments	Subjective Evaluations
Near Jet Engine	140	Deafening	128 times as loud
Civil Defense Siren	130	Threshold of Pain	64 times as loud
Hard Rock Band	120	Threshold of Feeling	32 times as loud
Accelerating Motorcycle a few feet away	110	Very Loud	16 times as loud
Noisy Urban Street/Heavy City Traffic	100	Very Loud	8 times as loud
Ambulance Siren; Food Blender	95	Very Loud	
Garbage Disposal	90	Very Loud	4 times as loud
Freight Cars; Living Room Music	85	Loud	
Pneumatic Drill; Vacuum Cleaner	80	Loud	2 times as loud
Busy Restaurant	75	Moderately Loud	
Near Freeway Auto Traffic	70	Moderately Loud	Reference Level
Average Office	60	Moderate	1/2 as loud
Suburban Street	55	Moderate	
Light Traffic; Soft Radio Music	50	Quiet	1/4 as loud
Large Transformer	45	Quiet	
Residence Without Stereo Playing	40	Faint	1/8 as loud
Soft Whisper	30	Faint	
Rustling Leaves	20	Very Faint	
Human Breathing	10	Very Faint	Threshold of Hearing

Physiology of the Ear

The human ear is a remarkable organ that enables man to sense the acoustic pressure waves, convert them into a mechanical vibration, and finally into electrical signals that are interpreted by the brain. A normal healthy human ear can hear sounds from a low pitch of 20 Hz to a relatively high-pitched sound of 20,000 Hz.[10, 11] Berger, et al.[11] have divided human hearing into three major steps of action:

1. Modification of the acoustic wave by the outer ear (the pinna and earcanal leading up to the tympanic membrane, or eardrum). Sound waves enter the outer ear and travel through the external auditory canal (ear canal), which leads to the tympanic membrane (see Figure 2.1). Sound waves in the 2-4 kHz region are amplified by 10 to 15 decibels due to the combined action of the pinna, ear canal, and head.

This greatly increases the risk of hearing damage in these frequencies which will be discussed later.

2. Conversion of the modified acoustic wave to a mechanical force that is transmitted through the middle ear to the inner ear. The sound waves cause the eardrum to vibrate which transmits these vibrations to three small bones in the middle ear; the malleus, incus, and stapes. These bones (ossicles) amplify, or increase, the force and send the vibrations to the cochlea, or inner ear.
3. Transformation of the resulting mechanical wave into nerve impulses in the inner ear. The cochlea is a fluid-filled organ with an elastic membrane that runs down its length. This membrane is called the basilar membrane because it serves as the base on which key hearing structures sit. The organ of Corti rests on the basilar membrane and contains two types of hair (sensory) cells, the inner hair cells and the outer hair cells. These cells have hair-like structures extending from the top called stereocilia (see Figure 2.2). The vibrations from the ossicles induce a fluid wave inside the cochlea which moves the basilar membrane causing the stereocilia on top of the hair cells to bump up against an overlying membrane and deflect. The deflections of the stereocilia generate neural impulses. The auditory nerve carries the signal to the brain, which translates the signal into a “sound” that we can recognize and understand.[5, 11]

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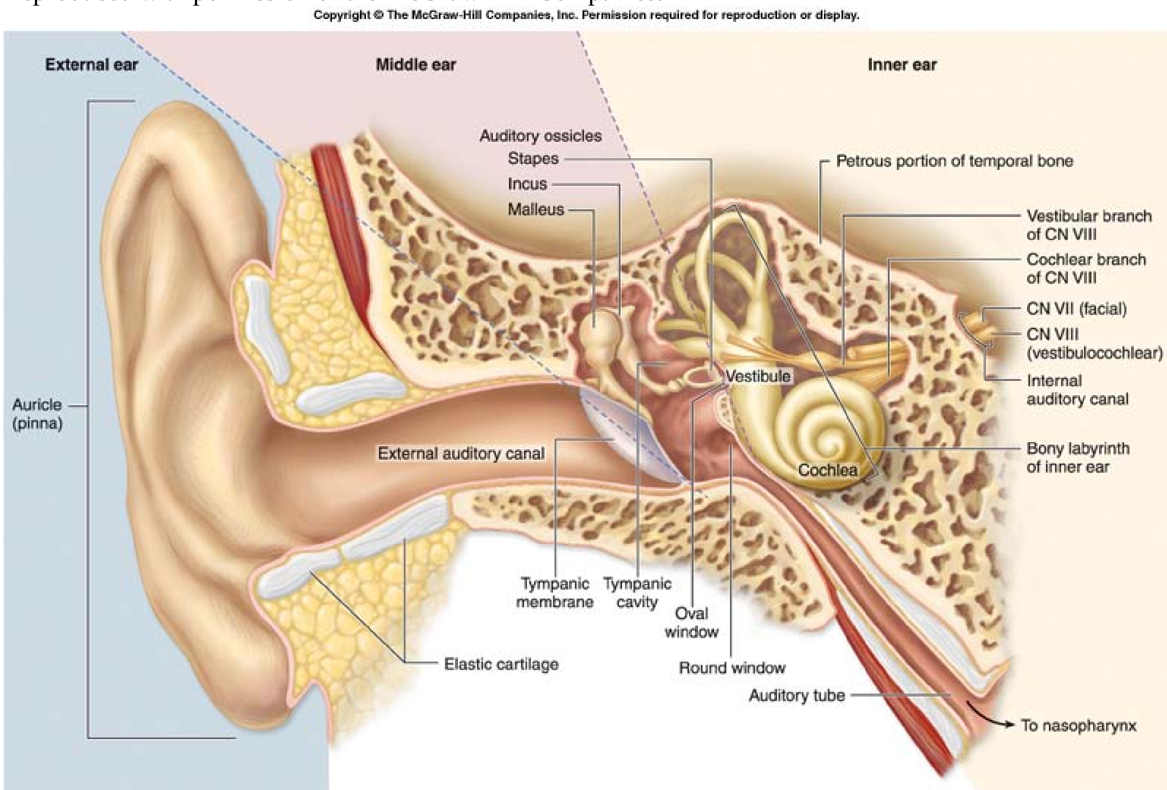

Figure 2.1: Structures of the Human Ear[14]

<u>Noise-Induced Hearing Loss</u>

During the industrial revolution when the workforce was changing from an agricultural basis to one of manufacturing, more workers than ever before were exposed to loud noise. This trend produced some of the first modern scientific studies of noise exposure and hearing loss. British physician John Fosbroke wrote in 1831, “The blacksmiths’ deafness is a consequence of their employment; it creeps on them gradually, in general at about forty or fifty years of age. At first the patient is insensible of weak impressions of sound; the deafness increases with a ringing and noise in the ears, slight vertigo, and pain in the cranial bones, periodical or otherwise, and often violent.”[15] Two American physicians, Roosa and Holt, examined boilermakers in Portland, Maine and concluded after a period of time essentially all workers in this industry became deaf, marking the use of the term "boiler-maker's deafness." One of the most well known early applications of occupational epidemiology regarding noise was by British physician Thomas Barr in 1886. He measured the hearing ability of one hundred boilermakers and three other groups by their ability to detect the ticking of a watch at various distances. He concluded none of the boilermakers had normal hearing.(2)

The outcome of hearing loss was clearly identified, but the mechanism was poorly understood. Adequate prevention measures were also not well known, with Holt reporting that men inserted cotton wool in their ears but derived no benefit; he had no alternative suggestions.(11) Many fundamental concepts now firmly associated with NIHL came from many studies following World War I. For example, the newly invented electronic audiometer was used to evaluate many veterans of the war which verified and measured the initial loss of hearing acuity at the higher frequency ranges. It was also during this period that ear plugs providing some level of protection were developed.(2)

The effects of sound on a person depend upon three physical characteristics of sound: amplitude, frequency, and duration. Exposure to noise can damage the ear in two distinct circumstances with respect to the three characteristics of sound. If the instantaneous peak sound pressure level exceeds 140 dB, the acoustic energy can stretch the delicate inner ear tissues beyond their elastic limits and rip or tear them apart. This type of damage is called acoustic trauma. It occurs instantaneously and results in an immediate hearing loss that is often permanent. The damage to the ear is mechanical in nature and only depends upon the amplitude of the sound pressure level and not duration or frequency.(11, 16)

NIHL on the other hand depends upon all three characteristics of sound, most importantly duration and SPL. Exposure to noise between 85 and 140 dBA can damage the cochlea metabolically rather than mechanically. This type of damage is cumulative and subtle; growing slowly over years of exposure.[16] Moderate exposure may initially cause temporary hearing loss called a temporary threshold shift (TTS). A TTS can effect intercellular changes in the hair cells and swelling of the auditory nerve endings. There is also evidence of a regional decrease in stiffness of the stereocilia, which may lead to a decrease in the coupling of sound energy to the hair cells, altering hearing sensitivity (see Figure 2.2).[17] A TTS can give the impression of fullness in the ears and sounds appear to be muffled. Recovery from a TTS can take a few hours to days depending upon both the duration and the intensity of the noise exposure.[18, 11]

Repeated exposure to sounds that cause a TTS may gradually cause a permanent threshold shift (PTS) resulting in NIHL. This type of damage normally occurs in three stages over a number of years. In the fist stage, damage to the stereocilia is often the first change. The stereocilia can become bent, broken, fused, or totally destroyed (see Figure 2.2). This leads to the death of the hair cells which are replaced by scar tissue. These hair cells do not regenerate and the losses are cumulative and subtle (see Figure 2.2). Hearing losses can be detected audiometrically beginning in the second stage, which can start after a few weeks to a few years of exposure, depending upon the SPL. However, due to the physiology of the ear discussed earlier, these losses usually occur around 4000 Hz. These losses usually do not affect speech understanding significantly; consequently they are seldom detected unless the hearing is tested by audiometry. This stage continues to see destruction of hair cells which can lead to degeneration of the cochlear nerve fibers. Finally, with continued noise exposure, losses continue to accumulate at 4000 Hz and they spread to the lower frequencies, which are important for speech understanding. It is at this point the patient becomes aware of a problem, but unfortunately much of the damage has already been done.[11, 16, 17]

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Healthy Stereocilia   Moderately Damaged   Severely Damaged

Figure 2.2: Morphological changes to stereocilia.

<u>Relevant Noise Exposure Standards/Recommendations</u>

The current federal regulation that covers most workers in general industry is the OSHA Occupational Noise Exposure Standard 29 Code of Federal Regulation (CFR) 1910.95. The standard states:

> Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table 2.3 when measured on the A scale of a standard sound level meter at slow response. When employees are subjected to sound exceeding those listed in Table 2.3, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of Table 2.3, personal protective equipment shall be provided and used to reduce sound levels within the levels of table. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.[20]

Noise exposure of construction workers is covered in OSHA 29 CFR 1926.52.

An important aspect of this standard is the hearing conservation program. The employer must administer a continuing, effective hearing conservation program whenever employee noise exposures equal or exceed an eight-hour time-weighted average (TWA) sound level of 85 dBA, or a dose of fifty percent using a five dB exchange rate. Briefly, the requirements of a hearing conservation program include noise exposure monitoring, audiometric testing, hearing protection, training, and record keeping.[20]

The American Conference of Governmental Industrial Hygienists' (ACGIH) and NIOSH have also established occupational noise exposure limits which are listed in Table 2.3. In addition, no exposures of an unprotected ear in excess of a C-weighted peak sound pressure level of 140 dBC should be permitted.[21,22] These limits are not legally enforceable; however they are widely accepted in the scientific, and safety and health community as being more protective than the OSHA limits. Virtually all other developed countries, including the International Organization for Standardization (ISO) follow similar guidance as ACGIH and NIOSH.[11]

Table 2.3: OSHA, ACGIH, and NIOSH Noise Exposure Limits*

Permissible Noise Exposures		
Duration per day, hours	Sound level dBA, slow response	
	OSHA	ACGIH/NIOSH
8	90	85
4	95	88
2	100	91
1	105	94
0.5	110	97
.25 or less	115	100

*Adapted from references 20, 21, and 22.

The two primary differences between the OSHA and ACGIH/NIOSH exposure limits are the allowable eight-hour TWA exposure limit (criterion level) and the exchange rate. OSHA has established a criterion level of 90 dBA with an exchange rate of five dB.[20] ACGIH and NIOSH have adopted a criterion level of 85 dBA with an exchange rate of three dB.[21,22] The exchange rate is the trade-off relationship between an increase/decrease in sound level and the corresponding change in allowed exposure duration.[11] As seen in Table 2.3 for ACGIH/NIOSH, 85 dBA is allowed for eight hours, but with an increase in three dB, the exposure time is decreased by half to four hours. Under the OSHA standard, 90 dBA is allowed for eight hours, but with an increase in five dB the exposure time is decreased by half to four hours.

The three decibel exchange rate is also known as the equal-energy rule because a three dB increase or decrease represents a doubling or halving of the sound energy. This approach makes the assumption that hearing damage depends only on the daily amount of A-weighted sound energy, so an 85 dBA noise exposure of eight hours produces the same amount of potential damage as exposure to 88 dBA at four hours. The three dB exchange rate has been firmly supported by scientific evidence for assessing hearing damage as a function of noise level and duration.[21, 11]

The five dB exchange rate mandated by OSHA is less protective than the equal energy hypothesis. The five dB exchange rate is used to account for possible interruptions in noise exposures that can occur during the workday. This presumes that some recovery from the noise exposure occurs during these breaks and the hearing loss would not be as great as it would be if the noise were continuous. However, the recommendation to use a five dB exchange rate was postulated in the 1960’s and subsequent scientific studies have validated the use of a three dB exchange rate. The three dB exchange rate may be conservative in truly intermittent noise exposures, but the five dB exchange rate will be under protective in most others.[21, 11]

The WHO has issued guidelines and recommendations for noise exposure regarding the general population, including entertainment events. They consider a daily average sound exposure of 70 dBA over 24 hours to be safe for the ear. The WHO recommends noise exposure for employees of entertainment venues should be controlled by established occupational standards; and at the very least, the same standards should apply to the patrons of these events. To avoid acute hearing impairment the maximum SPL should always be below 110 dBA, and the peak SPLs should never exceed 140 dB for adults and 120 dB for children. They also recommend patrons should not be exposed to sound levels greater than 100 dBA during a four-hour period more than four times per year.[4]

Relevant Studies

Currently there are no published, relevant studies evaluating the sound levels inside a football stadium during a football game. However, there are studies involving music concerts held in stadiums and other events held inside arenas.

In Clark's[23] review of noise exposure from leisure activities he calculated a geometric mean of 103 dBA from the reported sound levels of many studies regarding discotheques and rock concerts. He went on to write that although it is recognized that while a 100 dBA exposure for a few hours weekly or monthly presents little risk to the attendee, it may represent significant risk of NIHL to employees who are exposed on a daily basis.[23]

NIOSH conducted a health hazard evaluation of the noise exposure of workers and fans inside an arena during a monster truck and motocross show. The investigators found that the OSHA eight-hour TWA noise permissible exposure limit (PEL) of 90 dBA was not exceeded for any employee, except in one case. However, the NIOSH recommended exposure limit (REL) and the ACGIH threshold limit value (TLV) of 85 dBA were always exceeded for these workers. The investigators did not calculate the TWA for the fans, but reported the average noise exposures during the show. The fans were exposed to 92 to 95 dBA, and from 97 to 100 dBA, when calculated according to a five dB and three dB exchange rates, respectively. The maximum dBA, slow-response (the average of the SPL during one second) measurements exceeded 120 dBA for both the workers and fans.[24]

The OSHA action level for a hearing conservation program was exceeded for all employees, except in one case. The investigators noted the unusual work situations of these employees. The arena did not have monster truck shows five days a week, 52 weeks a year, nor did they work a full eight-hour shift. This makes the comparison to a normal working situation difficult in this case. However, there were other events held in the arena that could potentially expose the employees to excessive noise, such as music concerts, hockey games, etc. The NIOSH investigators recommended that the arena management implement a HCP including hearing protection devices (HPD) for its employees.[24]

Hodgetts and Liu[25] conducted a brief study of potential noise exposure during the National Hockey League Stanley Cup playoffs in 2006. One dosimeter was worn for games three, four and six at the home games of the Edmonton Oilers. The authors reported average exposure levels for each game as 104, 101 and 103 dBA respectively. Pure-tone audiometry and otoacoustic emissions tests were performed on one of the authors and his wife pre- and post-game. Audiometric data indicated that the hearing threshold of both subjects deteriorated by five to 10 dB for most frequencies. However, the largest changes were seen at 4000 Hz, where subject 2 experienced a TTS in one ear of 20 dB. The otoacoustic test revealed that subject 1 experienced a decrease in the strength of the outer hair cell responses. The authors noted that the risk of hearing loss for those who attend hockey games frequently, such as arena workers, warranted serious consideration.[25]

Two cursory studies were conducted by Axelsson and Clark.[26] A Larsen-Davis noise dosimeter was worn to one hockey game for more than three hours of exposure data. They recorded an average SPL of 100 dBA with maximum values up to 120 dBA. They calculated a noise dose of 117% per OSHA standards. In 1987 they recorded noise data from game six of the Major League Baseball World Series in the Hubert H. Humphrey Metrodome. The average SPL was 97 dBA and the calculated OSHA noise dose was 90%. The researchers noted that the data suggested that attendees at professional sporting events were exposed at levels and durations that exceed most federal guidelines. In closing they wrote: "…assuming that players and other employees are exposed to the same noise as spectators, these individuals undoubtedly should be included in a hearing conservation program."[26]

CHAPTER 3: PURPOSE AND SCOPE

Purpose

Many workers are involved in the successful operation of National Football League (NFL) and college football games. These workers are on the job well before kickoff and remain working after the game has ended. One component of any football game is crowd noise. The crowd in almost any game is encouraged to make loud noise while the visiting team is on offense; in theory increasing the home-team advantage (see Figure 3.1). This crowd noise, including noise from the public address system and team bands, concentrated in one area is significant enough to warrant investigation of noise exposure to people inside the stadium. Workers and fans are exposed to this crowd noise for the duration of the game and possibly longer while fans enter and exit the stadium. The purpose of this study was to determine the noise exposure of workers and fans during football games at a NFL, large college, and medium college football stadium. The total number of fans in attendance, personal noise exposures, and area sound levels were collected and compared within each stadium and between the three stadiums.

Figure 3.1: Folsom Field Public Address System

<u>Research Questions</u>

The evaluation of the different football stadiums was used to answer the following three research questions:

1. Are NFL, large-sized college, and medium-sized college football stadium workers and/or fans overexposed to noise?
2. Are the personal noise exposures different when using the OSHA PELs and the ACGIH TLVs?
3. Are noise levels at NFL, large-sized college, and medium-sized college football stadiums significantly different?

Scope

Workers and fans from Hughes Stadium (Fort Collins, CO), Folsom Field (Boulder, CO), and Invesco Field (Denver, CO) were solicited for participation in this study. These stadiums were selected due to their difference in typical fan capacity and adjacent geographical location. Three home football games of the Colorado State University (CSU) Rams, University of Colorado (CU) Buffaloes, and Denver Broncos were monitored in their respective stadiums. The football games selected for exposure monitoring were based on time constraints imposed by the volunteer research subjects and the availability of the investigator (see Table 3.1).

Table 3.1: Stadium Monitoring Schedule and Opponents

Date	**Hughes Stadium**	**Folsom Field**	**Invesco Field**
9/6/2008		Eastern Washington	
9/14/2008			Chargers
9/18/2008		West Virginia	
9/20/2008	Houston		
9/21/2008			Saints
10/4/2008		Texas	
10/5/2008			Buccaneers
11/1/2008	BYU		
11/15/2008	New Mexico		

CHAPTER 4: MATERIALS AND METHODS

Recruitment

The facility managers were contacted at Colorado State University, the University of Colorado, and Invesco Field to solicit participation in this research. This led the researcher to further contacts within the respective schools' athletics departments to find willing managers or employees interested in participating in the study who work on the field during football games or supervise those that do. Whether the researcher spoke with the manager or employee on the phone or in person; the purpose, benefits, and their voluntary participation was explained in accordance with the verbal script approved by the Human Subjects Office of CSU.

A total of ten workers, five at each university, volunteered to participate in the study. This included members of the football equipment team at CSU and the athletics department facilities and grounds crew at CU. The manager at Invesco Field declined participation in this study.

The researcher contacted friends, family, and colleagues to solicit volunteers to wear personal noise dosimeters as fans during the games at all three stadiums. Again, the approved verbal script was used when speaking with possible fans either by telephone or in person. A total of nine fans agreed to participate in the study; two at Hughes Stadium, two at Folsom Field, and five at Invesco Field.

All research was conducted according to the protocols established by the Human Subjects Office of CSU. The researcher provided each worker and fan a consent form and again explained their role in the research. The form was signed by both parties before conducting the research.

Personal Noise Monitoring

All noise sampling equipment was provided by the CSU OSHA Consultation Program. Personal noise exposures were collected using Larson Davis Personal Noise Dosimeters, Models 706RC and 703+, on field workers and fans during each game. The dosimeters are a type two instrument with an accuracy of plus or minus two decibels and were set according to the parameters shown in Table 4.1.

Table 4.1: Larson Davis Noise Dosimeter Settings

Settings	**OSHA**	**ACGIH**
Exchange Rate (dB)	5	3
Threshold (dBA)	80	80
Criterion Level (dBA)	90	85
Criterion Duration (hours)	8	8
SPL Weight	A Weighting	
Peak Weight	Unweighted	
Detector	Slow	
Gain (dB)	0	

The personal noise dosimeters were pre-calibrated using the Larson Davis Blaze software package to assure sampling accuracy. Noise sampling procedures followed the guidance in OSHA Technical Manual, TED 1-0.15A, Section III, Chapter 5,[27] as well as the guidance by Berger, et al.[11]. The noise dosimeters were attached to the selected workers and fans, and the microphone was clipped to the worker's or fan's shirt lapel, as close as possible to the person's hearing zone. The workers and fans were instructed to not blow or yell directly into the microphone and to continue their normal tasks/activities as usual. After sampling completion, the dosimeters were post-calibrated to determine if the dosimeter calibration changed and, if appropriate, the extent of change. All samples were annotated with a specific number traceable to the worker and fan monitored. The investigator assured anonymity of the subjects by following the CSU human research approved subject protocol.

Area Noise Monitoring

A Larson Davis System 824 sound level meter (SLM)/octave band analyzer was used to measure the stadium noise and characterize the noise frequency spectrum. The SLM was pre-calibrated to assure sampling accuracy. The investigator followed the guidance in OSHA TED 1-0.15A,(27) as well as the guidance by Berger, et al.(11) for area noise survey monitoring. The microphone was held at a height close to ear level approximately one meter from the researcher. Numerous sampling measurements were recorded throughout each game. After sampling completion, the SLM was post-calibrated to determine if the SLM calibration changed and, if appropriate, the extent of change.

Data Analysis

The data from the Larson Davis personal noise dosimeters were downloaded for analysis using the Larson Davis Blaze software package. An examination of the data included descriptive statistics of the equivalent continuous sound pressure level (Leq), maximum (Max) SPL, minimum (Min) SPL, peak SPL, OSHA percent dose, OSHA eight-hour TWA, ACGIH percent dose, and ACGIH eight-hour TWA. These data were further analyzed using the statistical software MINITAB to determine if there were any statistically significant findings according to the original research questions. Due to the large variation in the OSHA and ACGIH percent dose data, the data were log-transformed before analysis. This transformation was necessary because the results spanned several orders of magnitude. The OSHA percent dose had a range of 9-132% and the ACGIH percent dose ranged from 32-2484%. Statistical tests performed included: one-way Analysis of Variance (ANOVA), Tukey's 95% confidence pair-wise comparison, and two-sample T-test.

The data from the Larson Davis SLM were downloaded for analysis using the Larson Davis 824 software. An examination of the data included the Leq, Max, Min, and peak sound pressure levels with A, C, and flat weighting. The flat frequency spectrum data were also analyzed from 125 to 8000 Hz. The data were analyzed and graphed with Microsoft Excel.

CHAPTER 5: RESULTS AND DISCUSSION

Hughes Stadium

Worker Personal Noise Dosimeter Results

A total of 14 personal noise-exposure samples were taken on workers at three football games on the field at Hughes Stadium during the study period (see Figure 5.1). One noise dosimeter was left inside the locker room by the worker during the November 1st football game and consequently was not used for analysis. The 13 remaining samples were averaged together for each game to produce the descriptive statistics shown in Table 5.1. One of the more alarming measurements in Table 5.1 is the mean peak SPL for the workers at each game. Workers at all three games had peak exposures greater than 140 dB, which exceeded the OSHA limit of 140 dB.

Table 5.1: Descriptive Statistics for Hughes Stadium Workers

						OSHA		ACGIH	
Date	**Attendance**		**Leq**	**Max**	**Peak**	**% Dose**	**8-hour TWA**	**% Dose**	**8-hour TWA**
20-Sep	21,539	Mean	92	117	144	38	83	200	88
		SD	2	4	3	7	2	76	2
1-Nov	20,222	Mean	94	116	145	50	85	316	90
		SD	2	2	2	16	2	159	2
15-Nov	17,401	Mean	89	112	148	25	80	100	85
		SD	2	2	4	9	3	56	3
Total									
Mean	**19,721**		**91**	**114**	**146**	**33**	**82**	**200**	**88**
SD	**2,114**		**3**	**4**	**3**	**16**	**3**	**144**	**3**

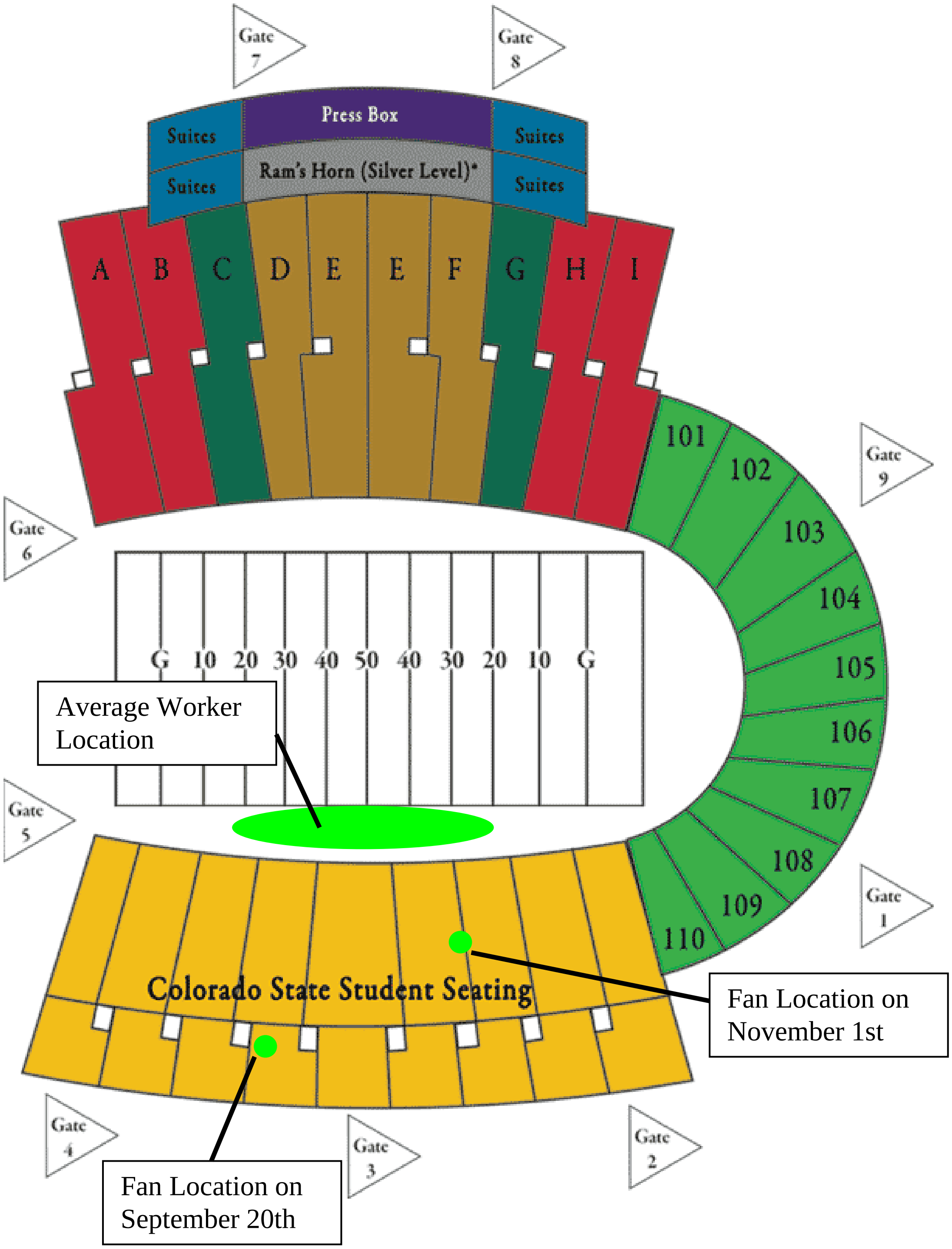

Figure 5.1: Worker and Fan Locations at Hughes Stadium

Shown in Table 5.2 are the number of workers that were overexposed and the percentage of overexposures based on OSHA and ACGIH eight-hour TWA criteria. None of the workers were overexposed according to OSHA criteria; however 93% of the workers were overexposed following ACGIH recommendations. In addition, 21% of the workers had exposures equal to or greater than the action level of 85 dBA.

Table 5.2: Number of Workers Exceeding OSHA and ACGIH 8-Hour TWA Criteria

		OSHA Criteria				**ACGIH Criteria**	
Date	Number of Workers Sampled	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA	Number of Workers ≥ 90 dBA	Percent of Workers ≥ 90 dBA	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA
20-Sep	5	0	0%	0	0%	5	100%
1-Nov	4	3	75%	0	0%	4	100%
15-Nov	5	0	0%	0	0%	4	80%
Total	14	3	21%	0	0%	13	93%

A one-way Analysis of Variance (ANOVA) was performed on the OSHA and ACGIH eight-hour TWAs and their respective percent dose among the three football games measured to determine if the variation among the games was statistically significant. The overall variation among the three games was found to be slightly significant. The OSHA TWA ANOVA F statistic was 5.67 (p-value of 0.02) and the ACGIH TWA ANOVA F statistic was 6.44 (p-value of 0.014). The OSHA percent dose ANOVA F statistic was 8.53 (p-value of 0.006) and the ACGIH percent dose ANOVA F statistic was 8.51 (p-value of 0.006). A pair-wise multiple-comparison of the mean TWAs and percent dose was also conducted to further examine which games may be statistically different from the others. According to the Tukey 95% confidence pair-wise comparison, the games on November 1st and 15th were considered significantly different for both the OSHA and ACGIH TWAs and their respective dose. This variation can be seen in Figure 5.2.

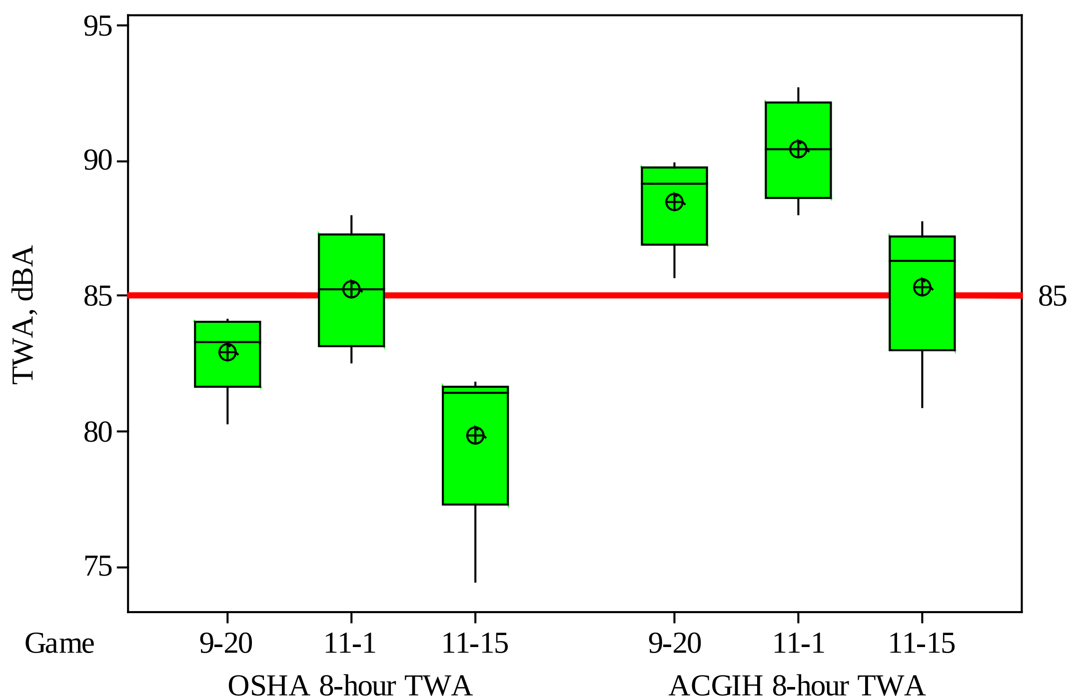

Figure 5.2: Boxplot of OSHA and ACGIH Workers 8-Hour TWA at Hughes Stadium

Fan Personal Noise Dosimeter Results

Two fans for each of the three games (for a total of six samples) at Hughes Stadium were solicited for participation. However, the two fans targeted for the November 15th game did not show-up for data collection. Therefore, a total of four samples were taken at two games during the study period of fans inside Hughes Stadium (see Figure 5.1). The remaining four samples for the two games were averaged together to produce the descriptive statistics shown in Table 5.3.

Table 5.3: Descriptive Statistics for Hughes Stadium Fans

						OSHA		ACGIH	
Date	**Attendance**		**Leq**	**Max**	**Peak**	**% Dose**	**8-hour TWA**	**% Dose**	**8-hour TWA**
20-Sep	21,539	Mean	92	118	139	25	80	159	87
		SD	1	8	0	4	1	24	1
1-Nov	20,222	Mean	99	121	145	100	90	1259	96
		SD	2	2	11	37	3	667	2
15-Nov	17,401	Mean							
		SD							
Total									
Mean	**19,721**		**95**	**120**	**142**	**50**	**85**	**501**	**92**
SD	**2,114**		**5**	**5**	**7**	**53**	**6**	**761**	**5**

The WHO recommendation of applying the same occupational standards to fans of entertainment events was used. Therefore, the more scientifically sound ACGIH criteria were used to determine if fans were potentially overexposed to noise during football games. Shown in Table 5.4 are the number of fans that were overexposed and the percentage of overexposure based on ACGIH eight-hour TWA criteria. All four fans were overexposed according to ACGIH recommendations. In addition, all of the fans were over the WHO limits regarding the Max SPL of 110 dBA, and 50% had peak SPLs over 140 dB.

Table 5.4: Number of Fans Exceeding ACGIH 8-Hour TWA Criteria

		ACGIH Criteria	
Date	Number of Fans Sampled	Number of Fans ≥ 85 dBA	Percent of Fans ≥ 85 dBA
20-Sep	2	2	100%
1-Nov	2	2	100%
15-Nov	0	0	0%
Total	4	4	100%

A one-way ANOVA was performed on the ACGIH eight-hour TWAs and percent dose among the two football games measured to determine if the variation among the games was statistically significant. The overall variation between the two games was found to be significant. The ACGIH TWA ANOVA F statistic was 24.7 (p-value of 0.038) and the percent dose was 25.37 (p-value of 0.038). This variation can be seen in Figure 5.3.

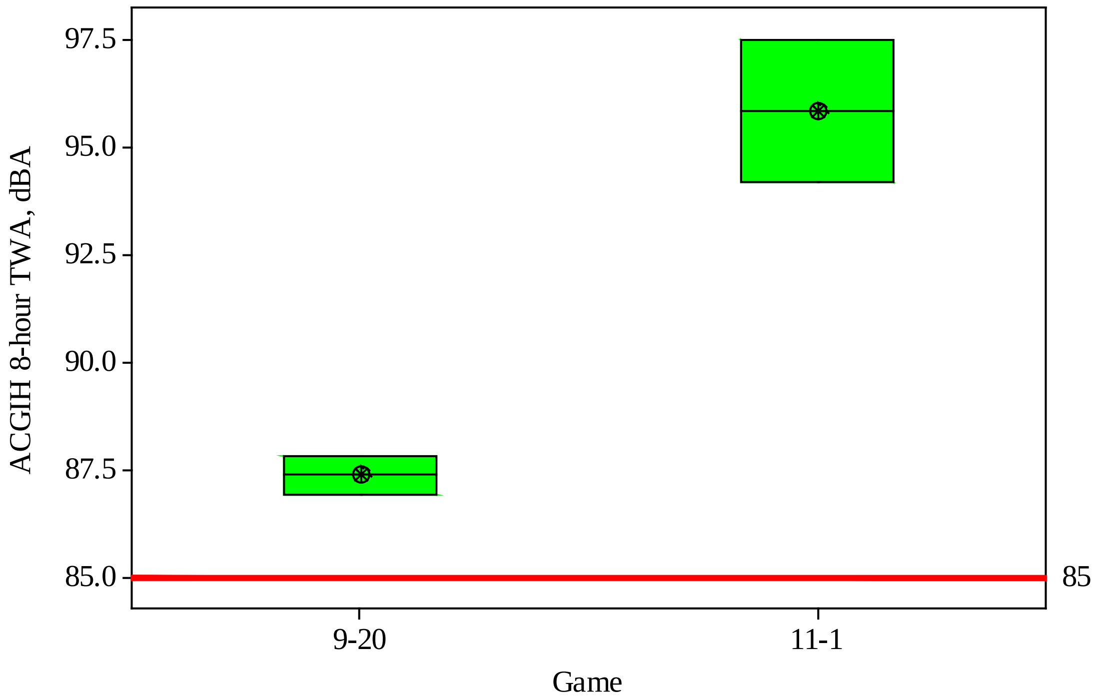

Figure 5.3: Boxplot of ACGIH Fans 8-Hour TWA at Hughes Stadium

Sound Level Meter Results

Numerous SLM measurements were taken at each game and at various times throughout the individual games. The measurements were taken on the field at various locations within the stadium. The SLM measurements were used as a back-up to verify the data from the personal noise dosimeters was correct and to determine the frequency spectrum of the crowd noise. Figure 5.4 is one example of the measurements taken during the game on November 15th.

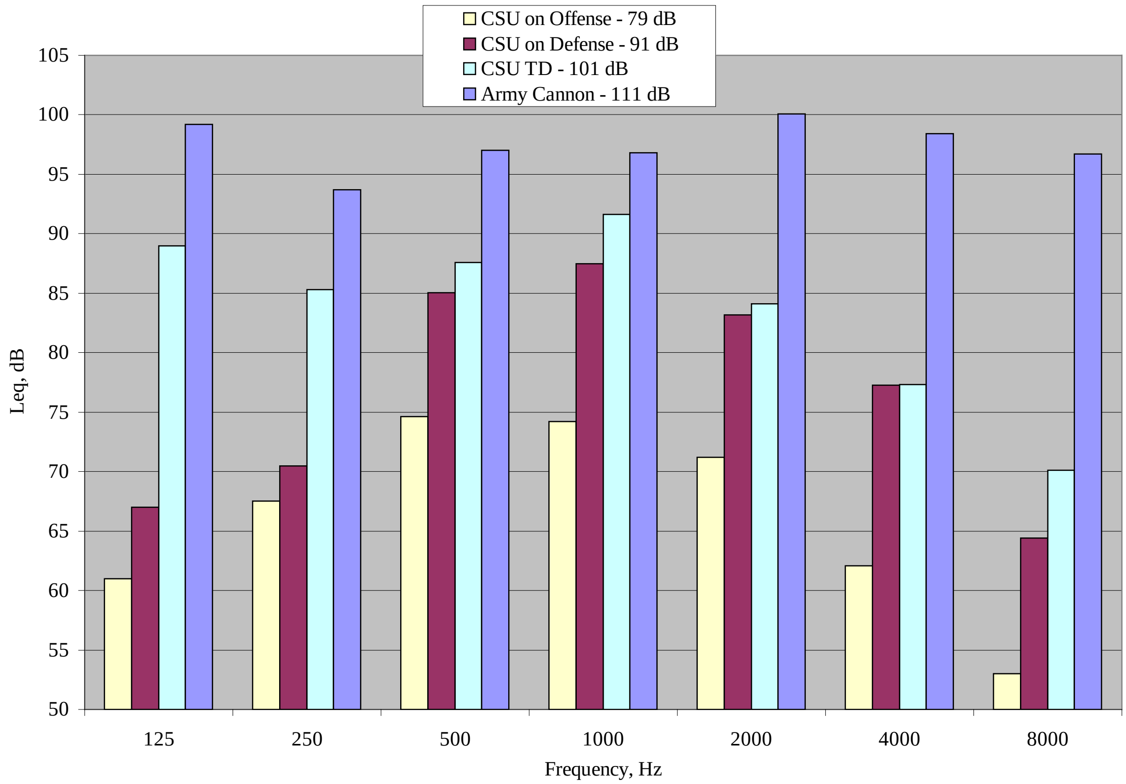

Figure 5.4: November 15th Hughes Stadium Octave Band Analysis and Overall Leq

As shown in Figure 5.4, the noise was much louder while the home team (CSU) was on defense. The average crowd noise while CSU was on offense was 79 dB, and it increased by 12 dB when CSU was on defense. The loudest frequency spectrum of the crowd noise was centered between 500-2000 Hz. The Army Reserve Officer Training Corps (ROTC) fired a cannon before and after the game, during halftime, and then after each CSU touchdown (TD) or field goal. The measurements shown in Figure 5.4 of the Army cannon were taken about six meters away. The firing of the cannon was a true impulsive sound lasting less than one second. The peak SPL of this measurement was 151 dBA and dBC, well above all published standards or recommendations.

Folsom Field

Worker Personal Noise Dosimeter Results

A total of 15 personal noise exposure samples were taken on workers at three football games on the field at Folsom Field during the study period (see Figure 5.5). One noise dosimeter did not record data on the October 1st football game and consequently was not used for analysis. The 14 remaining samples were averaged together for each game to produce the descriptive statistics shown in Table 5.5.

Table 5.5: Descriptive Statistics for Folsom Field Workers

						OSHA		ACGIH	
Date	**Attendance**		**Leq**	**Max**	**Peak**	**% Dose**	**8-hour TWA**	**% Dose**	**8-hour TWA**
6-Sep	46,417	Mean	92	113	130	38	83	251	89
		SD	1	2	1	7	1	53	1
18-Sep	51,883	Mean	94	114	133	66	87	398	91
		SD	1	2	9	5	0	54	1
4-Oct	53,927	Mean	87	110	129	33	82	159	87
		SD	1	2	3	6	2	32	1
Total									
Mean	**50,742**		**91**	**112**	**131**	**44**	**84**	**251**	**89**
SD	**3,883**		**3**	**2**	**5**	**21**	**3**	**137**	**2**

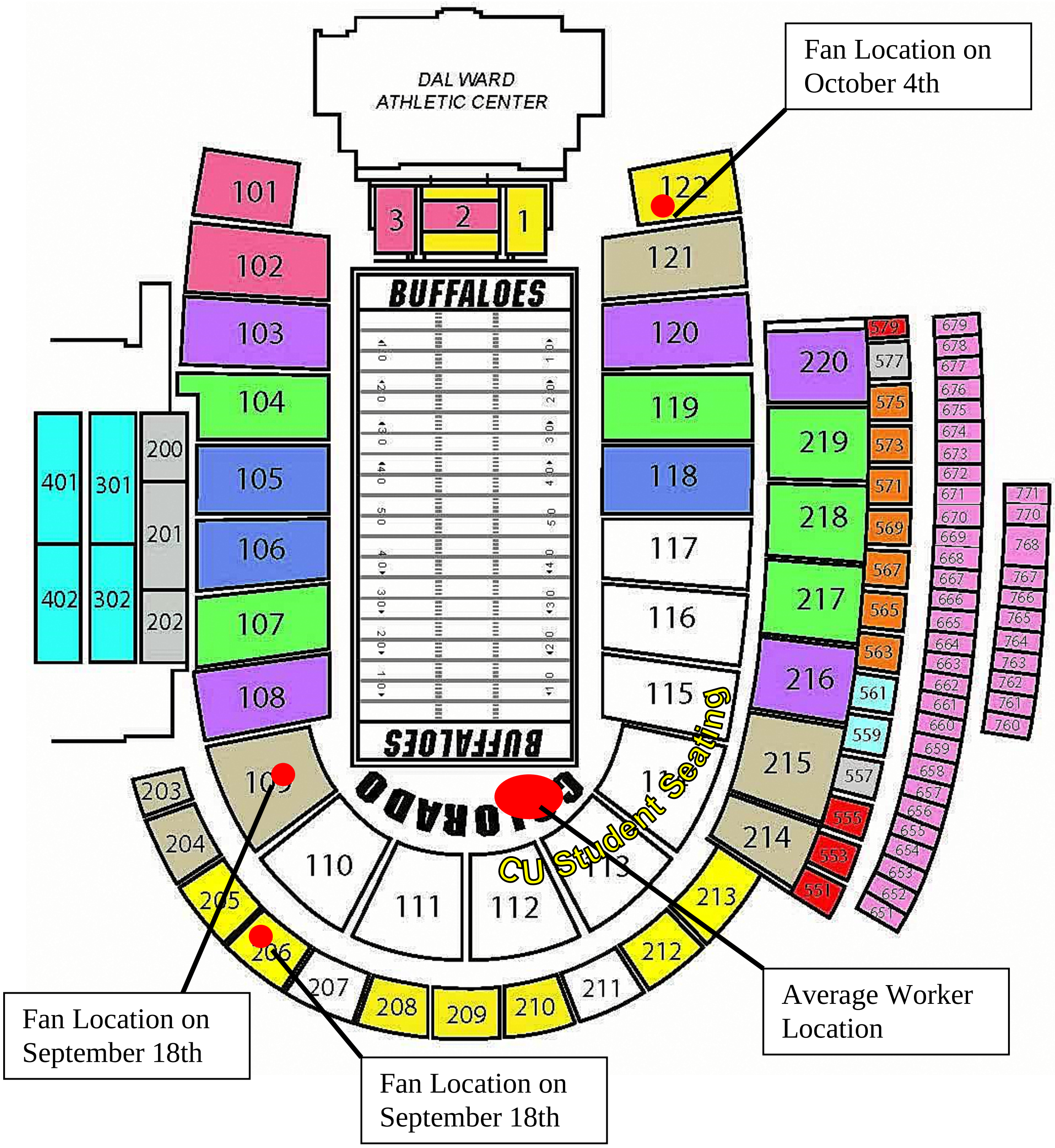

Figure 5.5: Worker and Fan Locations at Folsom Field

Shown in Table 5.6 are the number of workers that were overexposed and the percentage of overexposures based on OSHA and ACGIH eight-hour TWA criteria. None of the workers were overexposed according to OSHA criteria; however 100% of the workers were overexposed following ACGIH recommendations. In addition, 57% of the workers had exposures equal to or greater than the action level of 85 dBA.

Table 5.6: Number of Workers Exceeding OSHA and ACGIH 8-Hour TWA Criteria

		OSHA Criteria				**ACGIH Criteria**	
Date	Number of Workers Sampled	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA	Number of Workers ≥ 90 dBA	Percent of Workers ≥ 90 dBA	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA
6-Sep	5	2	40%	0	0%	5	100%
18-Sep	5	5	100%	0	0%	5	100%
4-Oct	4	1	25%	0	0%	4	100%
Total	14	8	57%	0	0%	14	100%

A one-way ANOVA was performed on the OSHA and ACGIH eight-hour TWAs and their respective percent dose among the three football games measured to determine if the variation among the games was statistically significant. The overall variation among the three games was found to be highly significant. The OSHA TWA ANOVA F statistic was 18.66 (p-value less than 0.0001) and the ACGIH TWA ANOVA F statistic was 20.54 (p-value less than 0.0001). The OSHA percent dose ANOVA F statistic was 68.46 (p-value less than 0.0001) and the ACGIH percent dose ANOVA F statistic was 48.33 (p-value less than 0.0001). A pair-wise multiple-comparison of the mean TWAs and percent dose was also conducted to further examine which games may be statistically different from the others. According to the Tukey 95% confidence pair-wise comparison, all of the games were considered significantly different for both the OSHA and ACGIH

TWAs and their respective dose, with one exception. The OSHA eight-hour TWA was not significantly different between the games on September 6th and October 4th. This variation can be seen in Figure 5.6.

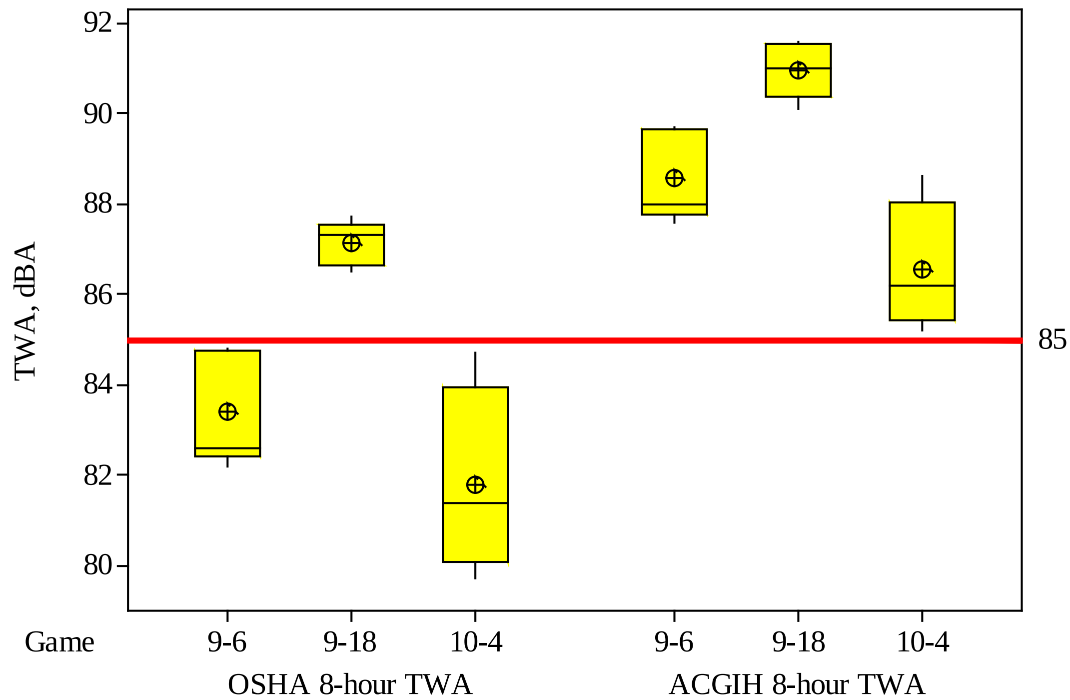

Figure 5.6: Boxplot of OSHA and ACGIH Workers 8-Hour TWA at Folsom Field

Fan Personal Noise Dosimeter Results

A total of six personal noise exposure samples were taken on fans at three football games inside Folsom Field during the study period (see Figure 5.5). The samples for the three games were averaged together to produce the descriptive statistics shown in Table 5.7.

Table 5.7: Descriptive Statistics for Folsom Field Fans

						OSHA		ACGIH	
Date	**Attendance**		**Leq**	**Max**	**Peak**	**% Dose**	**8-hour TWA**	**% Dose**	**8-hour TWA**
6-Sep	46,417	Mean	96	123	133	76	88	631	93
		SD	2	5	6	14	1	361	2
18-Sep	51,883	Mean	93	114	127	66	87	398	91
		SD	0	4	0	2	0	9	0
4-Oct	53,927	Mean	90	111	129	38	83	159	87
		SD	0	0	2	1	0	5	0
Total									
Mean	**50,742**		**93**	**116**	**130**	**57**	**86**	**316**	**90**
SD	**3,883**		**3**	**6**	**4**	**18**	**2**	**296**	**3**

The WHO recommendation of applying the same occupational standards to fans of entertainment events was used. Therefore, the more scientifically sound ACGIH criteria were used to determine if fans were potentially overexposed to noise during football games. Shown in Table 5.8 are the number of fans that were overexposed and the percentage of overexposure based on ACGIH eight-hour TWA criteria. All six fans were overexposed according to ACGIH recommendations. In addition, all of the fans were over the WHO limits regarding the Max SPL of 110 dBA, however none of the fans had peak SPLs over 140 dB.

Table 5.8: Number of Fans Exceeding ACGIH 8-Hour TWA Criteria

		ACGIH Criteria	
Date	Number of Fans Sampled	Number of Fans ≥ 85 dBA	Percent of Fans ≥ 85 dBA
6-Sep	2	2	100%
18-Sep	2	2	100%
4-Oct	2	2	100%
Total	6	6	100%

A one-way ANOVA was performed on the ACGIH 8-hour TWAs and percent dose among the football games measured to determine if the variation among the games was statistically significant. The overall variation between the games was found to be slightly significant. The ACGIH TWA ANOVA F statistic was 10.54 (p-value of 0.044) and the percent dose was 10.93 (p-value of 0.042). A pair-wise multiple-comparison of the mean TWAs and percent dose was also conducted to further examine which games may be statistically different from the others. According to the Tukey 95% confidence pair-wise comparison, the games on September 6th and October 4th were considered significantly different for both the ACGIH TWAs and dose. This variation can be seen in Figure 5.7.

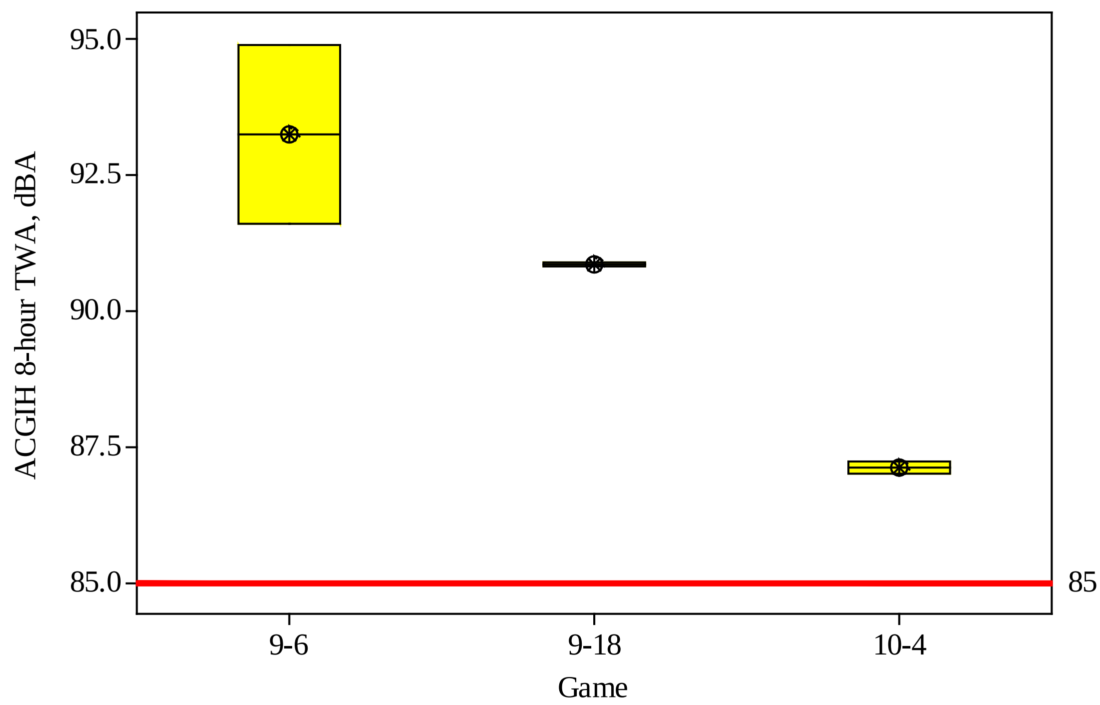

Figure 5.7: Boxplot of ACGIH Fans 8-Hour TWA at Folsom Field

Sound Level Meter Results

Numerous SLM measurements were taken at each game and at various times throughout the individual games. The measurements were taken at the fan locations shown in Figure 5.5. The SLM measurements were used as a back-up to verify the data from the personal noise dosimeters was correct and to determine the frequency spectrum of the crowd noise. Figure 5.8 is one example of the measurements taken during the game on September 18th.

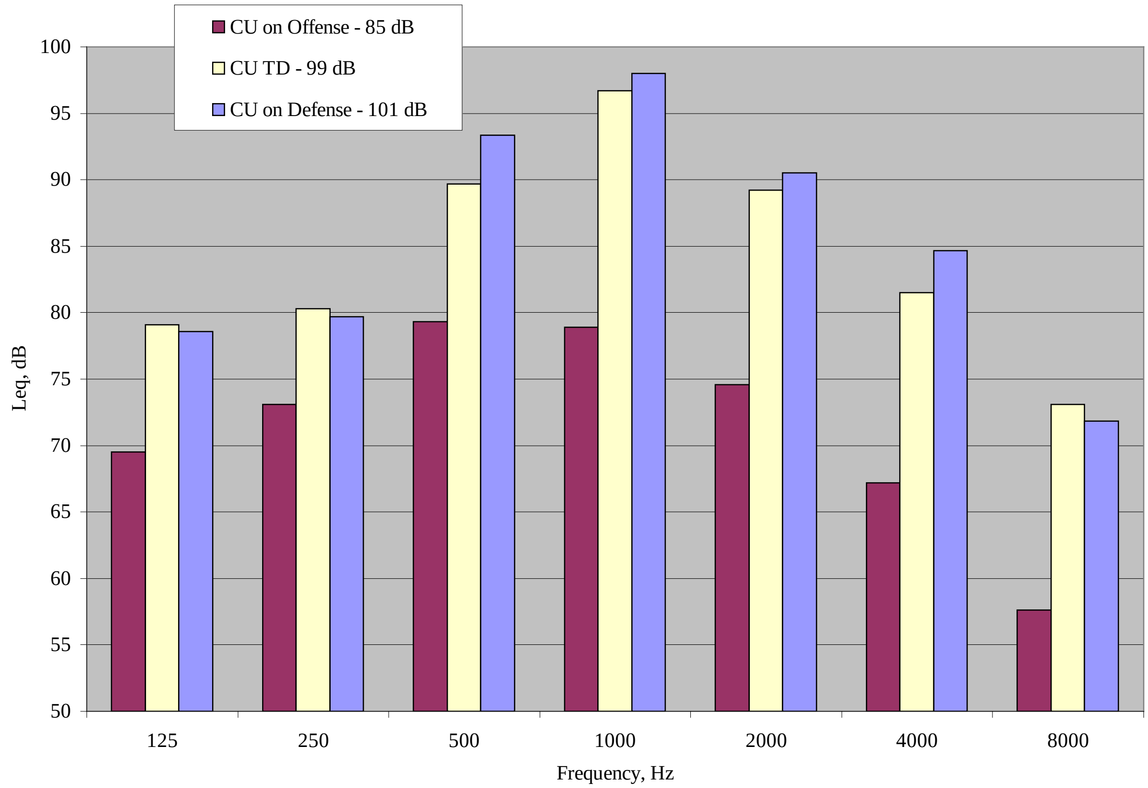

Figure 5.8: September 18th Folsom Field Octave Band Analysis and Overall Leq

As shown in Figure 5.8, the noise was much louder while the home team (CU) was on defense as seen before with the CSU stadium. The average crowd noise while CU was on offense was 85 dB, and it increased by 16 dB when CU was on defense. Similarly, the loudest frequency spectrum of the crowd noise was centered between 500-2000 Hz. One noticeable difference between the two stadiums was the level of noise during a TD. As seen in Figure 5.8, when CU scored a TD the noise was still lower than when they were on defense, whereas Hughes Stadium was just the opposite.

Invesco Field

Fan Personal Noise Dosimeter Results

A total of 15 personal noise exposure samples were taken on fans at three football games inside Invesco Field during the study period (see Figure 5.9). The samples for the three games were averaged together to produce the descriptive statistics shown in Table 5.9.

Table 5.9: Descriptive Statistics for Invesco Field Fans

						OSHA		ACGIH	
Date	**Attendance**		**Leq**	**Max**	**Peak**	**% Dose**	**8-hour TWA**	**% Dose**	**8-hour TWA**
14-Sep	75,915	Mean	97	122	135	76	88	794	94
		SD	4	6	4	37	3	926	4
21-Sep	75,713	Mean	96	117	132	66	87	631	93
		SD	4	3	3	30	3	856	4
5-Oct	75,480	Mean	91	120	134	38	83	316	90
		SD	7	5	3	25	6	788	7
Total									
Mean	**75,703**		**95**	**120**	**134**	**57**	**86**	**501**	**92**
SD	**218**		**5**	**5**	**4**	**36**	**5**	**831**	**5**

Figure 5.9: Fan Locations at Invesco Field

Once again, the WHO recommendation of applying the same occupational standards to fans of entertainment events was used. Therefore, the more scientifically sound ACGIH criteria were used to determine if fans were potentially overexposed to noise during football games. Shown in Table 5.10 are the number of fans that were overexposed and the percentage of overexposure based on ACGIH eight-hour TWA criteria. Ninety-three percent of the fans were overexposed according to ACGIH recommendations. In addition, all of the fans were over the WHO limits regarding the Max SPL of 110 dBA, however only one of the fans had a peak SPL over 140 dB.

Table 5.10: Number of Fans Exceeding ACGIH 8-Hour TWA Criteria

		ACGIH Criteria	
Date	Number of Fans Sampled	Number of Fans ≥ 85 dBA	Percent of Fans ≥ 85 dBA
14-Sep	5	5	100%
21-Sep	5	5	100%
5-Oct	5	4	80%
Total	15	14	93%

A one-way ANOVA was performed on the ACGIH 8-hour TWAs and percent dose among the football games measured to determine if the variation among the games was statistically significant. The overall variation between the games was found not to be significant. The ACGIH TWA ANOVA F statistic was 0.93 (p-value of 0.42) and the percent dose was 2.04 (p-value of 0.173). This variation can be seen in Figure 5.10.

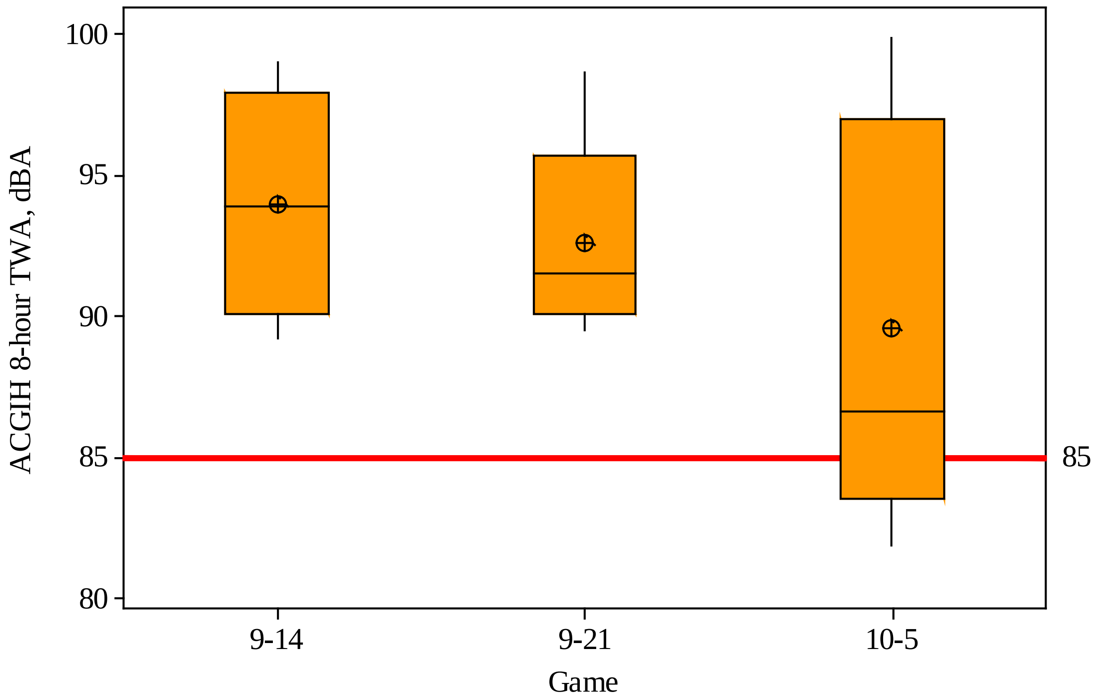

Figure 5.10: Boxplot of ACGIH Fans 8-Hour TWA at Invesco Field

Sound Level Meter Results

Numerous SLM measurements were taken at each game and at various times throughout the individual games. The measurements were taken at the fan locations shown in Figure 5.9 in sections 521 and 523. The SLM measurements were used as a back-up to verify the data from the personal noise dosimeters was correct and to determine the frequency spectrum of the crowd noise. Figure 5.11 is one example of the measurements taken during the game on September 14th.

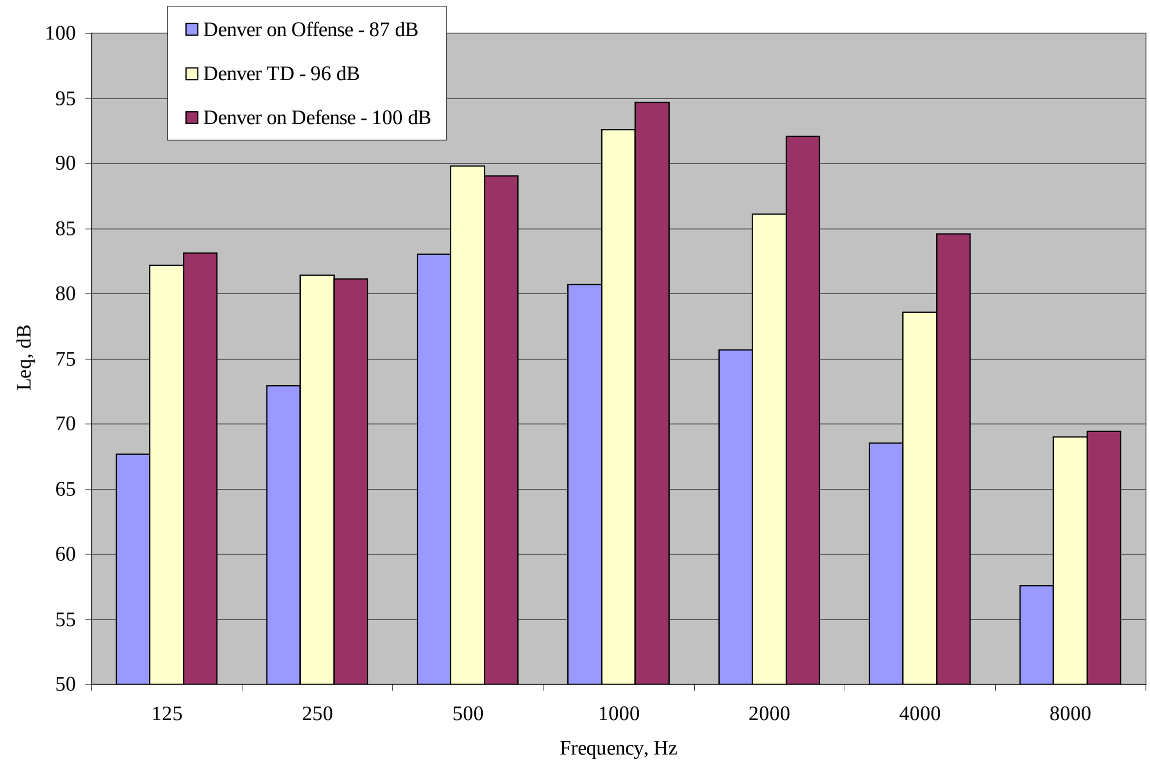

Figure 5.11: September 14th Invesco Field Octave Band Analysis and Overall Leq

As shown in Figure 5.11, the noise was much louder while the home team (Denver) was on defense as seen with the other stadiums. The average crowd noise while Denver was on offense was 87 dB, and it increased by 13 dB when CSU was on defense. Similarly, the loudest frequency spectrum of the crowd noise was centered between 500-2000 Hz. As seen in Figure 5.11, when Denver scored a TD, the noise was still lower than when they were on defense, similar to Folsom Field.

Results of Original Research Questions

The evaluation of the different football stadiums was used to answer the following three research questions:

1. *Are NFL, large-sized college, and medium-sized college football stadium workers and/or fans overexposed to noise?*

Yes, according to ACGIH and WHO criteria, workers and fans were overexposed to noise. Shown in Table 5.11 are the number of workers that were overexposed and the percentage of overexposures based on OSHA and ACGIH eight-hour TWA criteria. None of the workers were overexposed according to OSHA criteria; however 96% of the workers were overexposed following ACGIH recommendations. Although no workers were overexposed to noise following OSHA criteria, 39% were over the action level of 85 dBA which would require a HCP.

Table 5.11: Number of Workers Exceeding OSHA and ACGIH 8-Hour TWA Criteria

		OSHA Criteria				**ACGIH Criteria**	
Stadium	Number of Workers Sampled	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA	Number of Workers ≥ 90 dBA	Percent of Workers ≥ 90 dBA	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA
Hughes	14	3	21%	0	0%	13	93%
Folsom	14	8	57%	0	0%	14	100%
Total	**28**	**11**	**39%**	**0**	**0%**	**27**	**96%**

Shown in Table 5.12 are the number of workers that were overexposed and the percentage of overexposures based on OSHA and ACGIH eight-hour TWA criteria with an increase in two decibels. As discussed earlier, the instrument accuracy can produce results that are either a positive or negative two decibels from the actual exposure environment. The results of the dosimeters were increased by two decibels to give a more conservative approach for protecting the workers' hearing. This increase produced two workers overexposed according to OSHA criteria, or 7% of all workers. In addition, workers that would be considered over the action level of 85 dBA increased to 64%.

Table 5.122: Workers Exceeding 8-Hour TWA Criteria with an Increase of Two dB

		OSHA Criteria				**ACGIH Criteria**	
Stadium	Number of Workers Sampled	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA	Number of Workers ≥ 90 dBA	Percent of Workers ≥ 90 dBA	Number of Workers ≥ 85 dBA	Percent of Workers ≥ 85 dBA
Hughes	14	8	57%	1	7%	13	93%
Folsom	14	10	71%	1	7%	14	100%
Total	**28**	**18**	**64%**	**2**	**7%**	**27**	**96%**

Shown in Table 5.13 are the number of fans that were overexposed and the percentage of overexposure based on ACGIH eight-hour TWA criteria. 96% of the fans were overexposed according to ACGIH recommendations. An increase of two decibels did not change these results.

Table 5.133: Number of Fans Exceeding ACGIH 8-Hour TWA Criteria

		ACGIH Criteria	
Stadium	Number of Fans Sampled	Number of Fans ≥ 85 dBA	Percent of Fans ≥ 85 dBA
Hughes	4	4	100%
Folsom	6	6	100%
Invesco	15	14	93%
Total	**25**	**24**	**96%**

2. *Are the personal noise exposures different when using the OSHA PELs and the ACGIH TLVs?*

Yes, as seen throughout the results section, the ACGIH noise exposure is consistently higher than the OSHA exposures. The mean OSHA eight-hour TWA of all workers was 83 dBA and the mean ACGIH eight-hour TWA was 88 dBA. A two-sample T-test was performed on the difference between the means and the difference was found to be significant (p-value less than 0.0001). The mean OSHA dose of all workers was 41% and the mean ACGIH dose was 197%. A two-sample T-test was performed on the difference between the means and the difference was found to be significant (p-value less than 0.0001).

3. *Are noise levels at NFL, large-sized college, and medium-sized college football stadiums significantly different?*

No, the noise levels were not statistically different between the stadiums with one exception. The Peak SPL was consistently higher at Hughes Stadium than Folsom and Invesco Fields.

Workers at Hughes Stadium and Folsom Field

A one-way ANOVA was performed on the OSHA and ACGIH eight-hour TWAs and their respective percent dose between the two stadiums to determine if the variation among the stadiums was statistically significant. The variation between the two stadiums was found not to be significant. The OSHA TWA ANOVA F statistic was 2.66 (p-value of 0.115) and the ACGIH TWA ANOVA F statistic was 1.0 (p-value of 0.325). The OSHA percent dose ANOVA F statistic was 1.03 (p-value of 0.32) and the ACGIH percent dose ANOVA F statistic was 0.22 (p-value of 0.639). This variation can be seen in Figure 5.12.

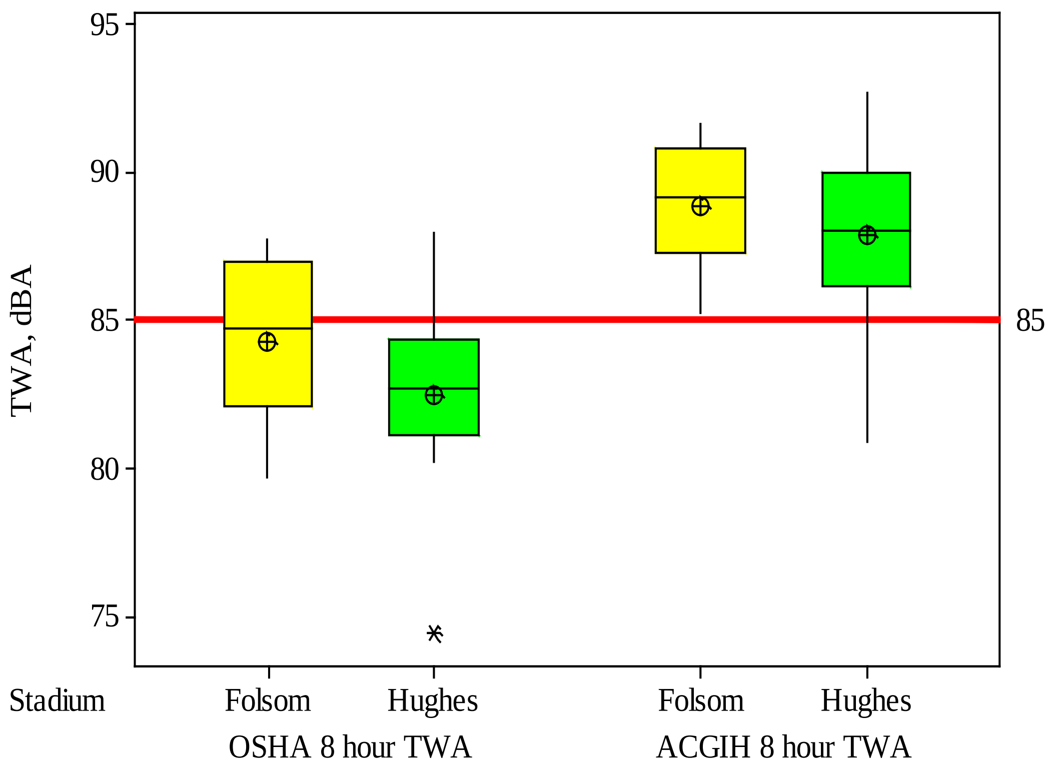

Figure 5.12: Boxplot of OSHA and ACGIH Workers 8-Hour TWA versus Stadium

Further ANOVA was performed on the other variables; including the Leq, Max, Min, and Peak SPLs. All of the variables were found to be not significant with the exception of the Peak SPL. A one-way ANOVA was performed on the Peak SPL between the stadiums measured to determine if the variation among the stadiums was statistically significant. The overall variation was found to be significant. The Peak SPL ANOVA F statistic was 73.70 (p-value less than 0.0001).

Fans at Hughes Stadium, Folsom Field, and Invesco Field

A one-way ANOVA was performed on the ACGIH eight-hour TWAs and percent dose among the football stadiums measured to determine if the variation among the stadiums was statistically significant. The overall variation between the stadiums was found not to be significant. The ACGIH TWA ANOVA F statistic was 0.26 (p-value of 0.776) and the percent dose was 0.11 (p-value of 0.898). This variation can be seen in Figure 5.13.

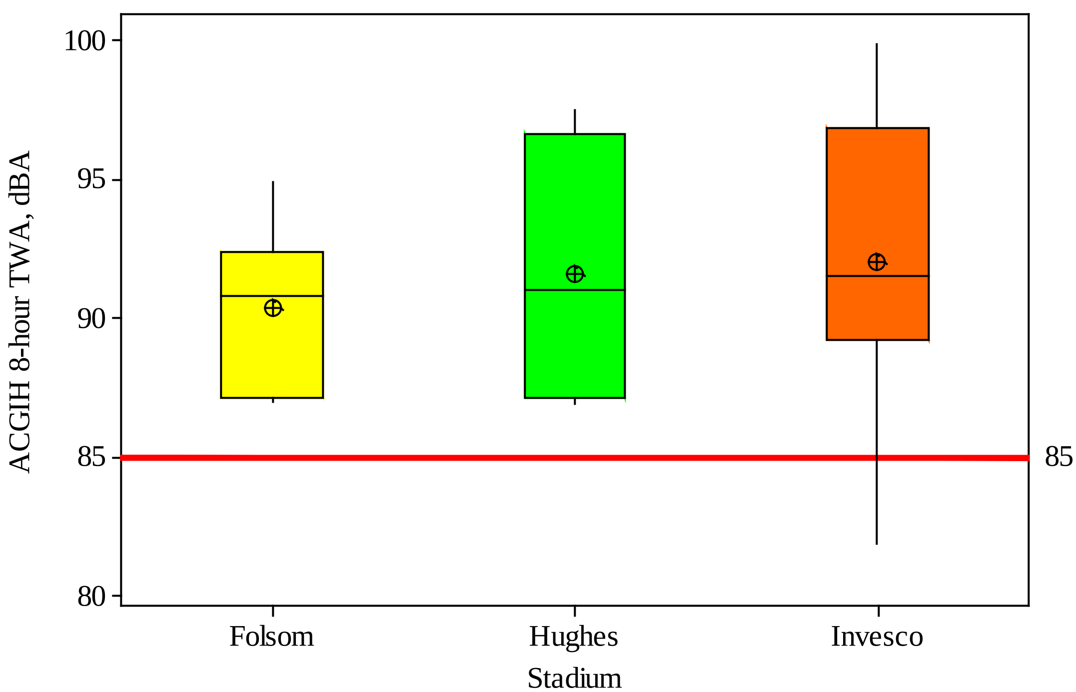

Figure 5.13: Boxplot of ACGIH Fans 8-Hour TWA versus Stadium

Further ANOVA was performed on the other variables; including the Leq, Max, Min, and Peak SPLs. All of the variables were found to be not significant with the exception of the Peak SPL. A one-way ANOVA was performed on the Peak SPL among the stadiums measured to determine if the variation among the stadiums was statistically significant. The overall variation between the stadiums was found to be significant. The Peak SPL ANOVA F statistic was 10.47 (p-value of 0.001). A pair-wise multiple-comparison of the mean Peak SPLs was also conducted to further examine which stadiums may be statistically different from the others. According to the Tukey 95% confidence pair-wise comparison, Hughes Stadium was statistically different than both Folsom and Invesco Fields. Folsom and Invesco Fields were found not to be statistically different from each other.

Discussion

As seen throughout the SLM results, the crowd noise was louder when the home team was on defense. This was to be expected as fans were encouraged to make noise while the visiting team was on offense, but remained relatively quiet while the home team was on offense. This behavior was encouraged because in theory this gives the home team more of an advantage in the game. The loud noise experienced by the visiting team offense could have caused them to not hear offensive play signals and/or the snap count. This dynamic of the crowd made the noise exposure more characteristic of an intermittent noise source with lower noise levels when the home team offense was on the field, during timeouts, or other stops in play.

However, this dynamic can vary widely among games played even in the same stadium. When the football game was very close in score, the fans continued to produce loud noise while the visiting team offense was on the field. The level of the crowd noise when the home team offense is on the field can also increase due to the excitement of the game. In contrast, when one of the teams has a large lead in score, the fans may lose interest in creating noise or might even leave the game early. This variability in the games and subsequent noise levels can be seen in the results, especially in the college stadiums.

The mean OSHA TWA for the November 1st game at Hughes Stadium was 85 dBA, but the game played on November 15th was 80 dBA. These results created a calculated mean OSHA dose of the workers of 50% and 25% respectively. This significant difference can be attributed to the dynamics of the two football games. The November 1st game against BYU was very close in score throughout the entire game and very exciting. In contrast the game on November 15th against New Mexico was won by CSU fairly easily and many fans left the game early.

Similar results were found at Folsom Field. The mean OSHA TWA for the September 18th game was 87 dBA and the October 4th mean was 82 dBA. In this case, the calculated mean OSHA dose of the workers was 66% and only 33% respectively. The game played on September 18th against West Virginia went back and forth in scoring and finally ended in overtime. The game on October 4th against Texas was just the opposite. Texas had control of the game well into the first half. They were so far in the lead by halftime that many fans lost interest in the game and left early.

None of the workers were overexposed according to OSHA standards; however 96% of the workers were overexposed following ACGIH recommendations. This was to be expected as the ACGIH criteria are more protective than the OSHA standard. Recall that the primary difference between the two criteria is the exchange rate. The allowed exposure time is doubled for each five dB decrease in noise level under OSHA and three dB following ACGIH criteria. One of the main factors that increased the ACGIH TWA in this study was the relatively high SPLs above 90 dBA. A TWA of 90 dBA is allowed under OSHA for up to eight hours, however under ACGIH the exposure should be under two hours at this SPL. These noise level peaks therefore increased the ACGIH dose considerably more than the OSHA dose.

Surprisingly, the personal noise exposures were found not to be significantly different among the three stadiums. This is due in large part to the small sample size of the study, the location of the sampled fans and workers, and the variability of the games. In addition, the workers at each of the college stadiums were primarily in front of the student section for each respective school. The loudest section of any college stadium is typically the student section. They are usually more rowdy and produce more noise than the average fan. This researcher noticed a decrease in the noise levels inside Hughes Stadium when taking SLM measurements on the west side of the stadium. The student section is located on the east side of the stadium. During the highest noise events, such as when CSU was on defense, the west side of the stadium had an average Leq of 7 dBA lower than the east side of the stadium. Workers monitored on this side of the field could have lower noise exposures than seen in this study and possibly lower than workers at Folsom Field.

In addition, the attendance at each stadium may have a lower threshold limit, meaning the noise level will not be significantly different once that attendance limit is reached and/or passed. For example, if Hughes Stadium had an attendance of 15,000 this may be enough people to create the noise levels seen in a higher attendance game. However, if the attendance falls below 15,000 there might not be enough fans to create the noise levels seen in this study. As long as there are enough people to create the crowd noise, then an increase in the attendance is irrelevant. An increase in attendance was not shown to significantly increase the noise levels in this study.

Another possibility of this finding could be due to the physics of sound. The sound intensity diminishes inversely as the square of the distance from the noise source. As long as there are enough people to make a significant amount of noise, the workers and fans are so near the noise source that an increase in the number of fans across the stadium would not impact the noise level experienced by the workers and fans.

The frequency spectrum of the noise in each of the stadiums showed similar patterns, with the exception of Hughes Stadium. The loudest frequency spectrum of the noise was centered between 500-2000 Hz. Remember, sound waves in the 2-4 kHz region are amplified by 10 to 15 decibels due to the combined action of the pinna, ear canal, and head. This greatly increases the risk of hearing damage when people are exposed to noise in these frequencies. In fact, most people with NIHL have greater losses in the 2-4 kHz frequencies. Although the results indicated that the peak noise energy was centered at 1 kHz, the noise in the 2-4 kHz was loud enough to warrant concern for an increase in hearing damage. This hearing damage could also affect the ability to understand speech. The typical information-carrying energy in speech occurs in the 500-4000 Hz.[11]

An unexpected finding was the loudest noise source at Hughes Stadium was not the fans but in fact the Army cannon. As seen in Figure 5.4, the noise after a CSU TD is louder than while the team is on defense due in large part to the firing of the cannon. This discrepancy was only found at Hughes stadium. The Peak SPL at Hughes Stadium was louder than at any other stadium studied, which leads this researcher to believe it is due to the impulsive noise of the cannon. The firing of the cannon is what is believed to cause the very high peak SPLs recorded by the personal noise dosimeters at Hughes Stadium.

Fans are allowed to get about two meters away from the cannon at any time, including when it is fired. There were not any signs warning the public of the noise source or a requirement for hearing protection. The investigator noted that some of the Army ROTC cadets that operated the cannon were wearing hearing protection, but not all of them. Many young children, without hearing protection, were very near the cannon when fired. Six meters away the peak SPL was measured at 151 dBA and dBC, well above all published standards or recommendations.

Study Limitations

The main limitation of this study was the small sample size. A small number of workers and fans were solicited for participation in this study due to funding and manpower. Consequently, the workers and fans selected were only a small subset of the true populations at each stadium. The study participants were not randomly selected, therefore many of the noise measurements taken were often in the same area of the respective stadiums.

The workers selected in this study were based on volunteers within one particular department of the universities. With a few exceptions, the workers performed their duties within the same general area of their stadiums, so it was not a random or representative sample of the respective stadiums (see Figures 5.1 and 5.5). A larger study could measure workers exposures on all sides of the stadium to get a more representative sample of all noise exposures.

All of the college fans were sitting next to each other during the games, so they were neither random nor representative of the entire stadium. Two sets of two fans (for a total of four) also sat together during the NFL games, so the same limitation can also apply to Invesco Field. However, more measurements were taken at Invesco Field and the fans were at least spread out within part of the stadium as seen in Figure 5.9.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Workers and fans were found to be overexposed to noise following the ACGIH criteria in the three stadiums studied. In addition, 39% of the workers were over the action limit set by OSHA of 85 dBA. This action limit requires the workers to be included in a comprehensive HCP.

The typical sample duration of the games studied was three and a half to four hours long, so in order to compute an eight-hour TWA the remaining exposure time was assumed to be relatively quiet. However, this assumption does not hold true for all fans and workers. Many of the fans attend pre- and post-parties that might include loud music, nightclubs, and/or noisy bars and restaurants. The noise level at these events could add to the overall TWA exposure, thereby increasing their noise dose. This could also be true of the workers as they typically would work for only an hour or so after the game.

This study did not focus on the weekly or normal day-to-day noise exposures of the workers and fans. However, this is another area that could potentially add to the risk of developing NIHL along with the exposures seen at the football games. The group of CU workers studied included the grounds-maintenance personnel. Their normal duties can include using powered equipment known to create significant noise levels, such as lawn mowers and leaf blowers. The fans could also have a job with high occupational noise exposures thereby severely increasing their risk for NIHL. Non-occupational or personal hobbies can also increase the potential for hearing damage if they are not considered. This can include personal headphone use, listening to loud music, riding motorcycles, firearm use, etc. A study of non-occupational activities as a contribution to total noise exposure in construction workers found one out of every five workers could have non-occupational exposures that place them at risk for NIHL, even before considering their occupational noise exposures.[28]

This researcher also noted another potential risk category not originally thought of until taking measurements at the games. At all of the games studied many children were present, including infants up to teenagers. The world of the child is becoming nosier and attending football games is no exception, as seen similarly in adults. As is the case with many other hazards, young children may be more susceptible to NIHL than adults.[4, 29] Their bodies are continuing to grow and adapt to the world and should be more protected than the typical adult. However, there are no current noise exposure standards or recommendations specifically for children with the exception of the WHO recommendation of the peak SPLs should never exceed 120 dB.[4] This value was exceeded at every game studied.

Recommendations

If the noise level exceeds the PEL or TLVs, engineering controls should be utilized first to reduce the noise source below the standards. However, stadium managers will most likely not implement engineering controls because of the cost, but more importantly they would lose the home field advantage they all seek to gain by an increase in crowd noise. However, administrative controls are an option that could have great success if implemented correctly. The researcher noted a sharp decrease in noise immediately outside the stadium, well below 85 dBA. Workers or fans that leave the stadium for breaks will receive less of a dose than those that stay inside the stadium the entire game. These breaks allow the ears to recover from the noise source and spread their daily dose across the same time period with less exposure.

The calculated average dose rate for the college stadiums showed similar results. Hughes Stadium and Folsom Field both had a high of 0.23 OSHA percent dose per minute for their respective highest exposure game. If the workers are to remain below the action level of 85 dBA or 50% dose, they should limit their exposure inside the stadium to three hours and 39 minutes. This is usually achievable as most games do not last for more than three and a half hours. However, when the occasional game may last longer or if the potential for overtime exists, careful attention should be made to include breaks outside of the stadium.

The average of all the calculated dose rates for the college stadiums also showed very similar results. The OSHA percent dose per minute for Hughes Stadium and Folsom Field was 0.17 and 0.16 respectively. If the workers are to remain below the action level of 85 dBA or 50% dose, they should limit their exposure inside Hughes Stadium to four hours and 54 minutes, and five hours and 12 minutes inside Folsom Field. However, this study has shown variability in the games played even in the same stadium, so the more conservative approach in the preceding paragraph should be used.

Following ACGIH recommendations for workers and fans creates more of a challenge to include planned breaks from inside the stadium. The calculated workers' ACGIH average dose rate for the highest exposure game for Hughes Stadium was 1.59 percent dose per minute and Folsom Field had a high of 1.38 percent dose per minute. To keep the workers from reaching a dose of 100 percent, they could only work inside Hughes Stadium for less than one hour and three minutes, and one hour and 12 minutes inside Folsom Field. This amount of working time inside the stadium is far too short for most managers to accept; therefore the workers should have adequate hearing protection.

The situation is equally as restrictive or more for fans. The highest average ACGIH dose rate of 6.01 percent dose per minute was seen at Hughes Stadium on November 1st. This equates to an allowable exposure time less than 16 and a half minutes. The lowest average ACGIH dose rate was 0.71 percent dose per minute at Folsom Field on October 4th. To keep the fans below a 100% dose the exposure time should be kept below two hours and 21 minutes. Fans should wear hearing protection if they have other potential noise exposures.

OSHA dictates the employer shall administer a continuing and effective hearing conservation program, whenever employee noise exposures equal or exceed an eight-hour TWA of 85 dBA or, equivalently, a dose of fifty percent.[(20)] This requirement was further defined by OSHA in a 2004 standard interpretation letter. If employees are exposed to noise levels in excess of an eight-hour TWA of 85 dBA for one day, they must be included in a HCP.[(30)]

This research has shown the noise inside football stadiums warrants the following recommendations:

Workers

1. All employees that work inside the stadiums should be included in a HCP, which would include audiometric testing, continued exposure monitoring, hearing protection, training, and record keeping. The program should also include all other possible occupational noise sources.
2. According to 29 CFR 1910.95, employers should make hearing protectors available to all employees exposed to an eight-hour TWA of 85 dBA or greater at no cost to the employees. Employees will be given the opportunity to select their hearing protectors from a variety of suitable hearing protectors provided by the employer. The employer shall provide training in the use and care of all hearing protectors provided to employees. The employer shall ensure proper initial fitting and supervise the correct use of all hearing protectors.[20]
3. If the employees work inside the stadium without hearing protection for the duration of the game, employers should rotate workers out of the stadium to reduce their noise exposure. Keep the workers' exposure inside the stadium below about three and a half hours if following OSHA criteria.

Fans

1. The facility managers should include a warning of possible loud noise exposure during any sporting events held at the stadiums in fan guides, pamphlets, websites, etc. This information should include the health effects of loud noise exposure, namely NIHL.

2. A general recommendation to wear hearing protection should also be included, especially if the fans have other potential noise exposures.
3. The above information should also be specifically targeted to parents of young children, including a high recommendation that hearing protection should be worn by all children.
4. "Hearing Protection Required" signs should be placed around the Army cannon at Hughes Stadium.

Future Research

This study has shown that there is a potential for overexposures to noise in football stadiums, even with a small attendance of 20,000 people. This fact can have a far and wide application to the many football stadiums across the country and other entertainment venues. A concerted effort should be made to inform the workers and general public of the potential risk of developing NIHL while at a football game.

There are a variety of jobs within a sporting-events stadium that may have higher noise exposures than seen in this study. Future research should include a diverse cross section of the typical employees working inside football stadiums and at other stadiums. In addition, audiometric testing should be included in future studies to determine if any of the workers or fans experiences a TTS after the games. This study has also shown if there are overexposures in an outside football stadium, there could be significant exposures inside enclosed entertainment venues such as arenas and domes where reverberation could be a problem. More research in these venues should be undertaken.

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