

DISSERTATION

INDOOR HOCKEY OFFICIALS' NOISE EXPOSURE, TEMPORARY HEARING LOSS,
AND EFFECT OF HELMET VISOR LENGTH ON EXPOSURE TO WHISTLE NOISE

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ABSTRACT

INDOOR HOCKEY OFFICIALS' NOISE EXPOSURE, TEMPORARY HEARING LOSS, AND EFFECT OF HELMET VISOR LENGTH ON EXPOSURE TO WHISTLE NOISE

Noise is one of the most common occupational hazards and noise exposure in non-occupational environments is a growing concern. Generally, sporting events are a source of non-occupational noise for spectators and employees, in which minimal research has been conducted or published. In particular, hockey officials' noise exposures during competitions have not thus far been studied. More than 23,000 hockey officials are registered with USA Hockey, the governing body of amateur hockey in the United States. Many officials are not registered, constructing a population of more than tens of thousands of hockey officials that may be at high risk of hearing loss. In addition, many officials begin officiating competitions as early as ten years of age, placing them at risk of an earlier onset of symptoms of hearing loss. The hockey officials of the Western States Hockey League (WSHL) officiate indoor competitions for elite amateur players ranging in age from 16 to 20 in fan-driven markets providing development opportunities for players, coaches and officials. Similarly, the officials in the American Collegiate Hockey Association (ACHA) preside over indoor collegiate competitions for college hockey programs that do not desire to compete within the National Collegiate Athletic Association structure. Noise exposure and hearing thresholds of indoor hockey officials of the WSHL and ACHA were measured to assess the impact of noise during hockey games on hearing sensitivity. The research was conducted in northern Colorado during a pilot study in the 2013-2014 hockey season and a main study in southeastern Wyoming during the 2014-2105 hockey season.

The pilot and main studies included noise dosimetry and pre- and post-game pure-tone audiometric testing of participants who officiated junior and/or collegiate level hockey competitions. Personal noise dosimetry was conducted to determine if officials were exposed to hazardous levels of noise averaged over the duration of the game, which would result in an equivalent sound pressure level (L_{eq}) \geq 85 dBA. Hearing thresholds were measured with pure-tone audiometry before and after participants officiated hockey games to determine if a 10 dB or greater temporary threshold shift in hearing occurred during the competition. Audiometric testing was conducted in both ears at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz.

The pilot study population included 23 hockey officials who officiated collegiate and junior league hockey competitions in two arenas in northern Colorado. All of the participants were exposed to an $L_{eq} \geq$ 85 dBA over an average hockey game time of two hours and 42 minutes. The mean L_{eq} and mean peak sound pressure level (L_{peak}) were 90 dBA (SD=2.13) and 133 dB (SD=5.49), respectively. None of the officials were overexposed to noise based on the OSHA noise criteria, yet 65 % were overexposed to noise based on ACGIH recommendations. The audiometry portion of the pilot study included 18 hockey officials who officiated at one indoor hockey arena in northern Colorado. Ten of eighteen (56%) sampled officials demonstrated a \geq 10 dB increase in hearing threshold after officiating a competition. Temporary threshold shifts were identified in more than one ear and/or frequency in seven of the ten (70%) participants. Two of the ten (20%) participants who experienced a threshold shift exhibited an increase in hearing threshold of 15 dB or greater. The results of the pilot study suggested that hockey officials were exposed to hazardous levels of noise and may be at an increased risk for hearing loss, thus warranting further research.

The main study included similar methodology to that of the pilot study. The study population included 29 hockey officials who officiated Tier II Junior A hockey competitions in an arena in southeastern Wyoming. All of the participants in the main study were exposed to an $L_{eq} \geq 85$ dBA over an average hockey game time of two hours and 48 minutes. The average L_{eq} , maximum sound pressure level (L_{max}), and L_{peak} were 93 dBA (SD= 2.2), 116 dBA (SD=2.8) and 134 dB (SD=5.0), respectively. Hearing threshold shifts of 10 dB or greater were observed in 86.2% (25/29) of officials, with 36% (9/25) of those individuals exhibiting threshold shifts of 15 dB or greater. The largest proportion of hearing threshold shifts occurred at 4000 Hz, including 35.7% (10/28) of right ear shifts and 31.8% (7/22) of left ear shifts. The exhibited threshold shifts between the pre- and post-game audiometry were statistically significant in the left ear at 500 (p=.019), 2000 (p=.0009), 3000 (p<.0001), and 4000 Hz (p=.0002) and in the right ear at 2000 (p=.0001), 3000 (p=.0001), and 4000 Hz (p<.0001), based on Wilcoxon-ranked sum analysis. Although not statistically significant (p>0.05), with each increase of one dB of equivalent sound pressure measured from personal noise dosimetry, the odds of a ≥ 10 dB TTS were increased in the left ear at 500 (OR=1.33, 95% CI 0.73-2.45), 3000 (OR=1.02, 95% CI 0.68-1.51), 4000 (OR=1.26, 95% CI 0.93-1.71) and 8000 Hz (OR=1.22, 95% CI 0.76-1.94) and in the right ear at 6000 (OR=1.03, 95% CI 0.14-7.84) and 8000 Hz (OR=1.29, 95% CI 0.12-13.83). The findings in the main study supported those of the pilot study that indicated indoor hockey officials were exposed to hazardous levels of noise and exhibited temporary hearing loss after officiating games. More information is required on the noise exposure of indoor hockey officials. However, based on the current study results, it is recommended that the hockey officials be enrolled in a hearing conservation program including annual audiometric exams and the use of hearing protection. Further temporary threshold shift research has the potential to

identify officials of other sporting events that experience temporary threshold shifts and may be at an increased risk of noise-induced hearing loss.

Personal protective equipment (PPE) is intended to protect the body from injury or illness. Indoor hockey officials wear specialized equipment including a league-approved helmet with half-face visor of varying lengths for head, face, and eye protection. During competitions, officials signal penalties and infractions using a mouth-blown whistle. The effect of the helmet visor length on the level of whistle-generated noise to which hockey officials are exposed was evaluated in an effort to determine if the visors introduced a reflective plane for the whistle noise, resulting in increased noise exposure.

A Knowles Electronic Manikin for Acoustic Research (KEMAR) head and torso assembly with a left ear microphone, in conjunction with the Larson Davis 824 Sound Level Meter (SLM)/Octave Band Analyzer (OBA), was used to measure the peak sound pressure levels from the noise generated from simulated whistle blowing. The KEMAR was equipped with a Bauer 4500 hockey helmet and three different helmet/visor configurations for the study: no visor, a 2.75" long visor, and a 4.0" long visor (as measured at the middle of the visor). A Fox 40[®] Super Force[®] finger grip pea whistle was mounted adjacent to the left side of the manikin's mouth in an orientation similar to that of officials observed in the pilot and main studies. Whistle noise was generated with a short blast of air from a portable air compressor to produce approximately 115 dB of whistle noise. The generated whistle noise was measured in an empty indoor ice hockey arena in northern Colorado. The KEMAR assembly was positioned on the ice to replicate the positions of the hockey official's head and torso in five face-off spots located in the rink. The face-off spots included the two spots in the end zone, two at the end of the neutral zone, and one in the center of the rink. Short bursts of whistle noise were generated and

measured in the left ear of the KEMAR five times in each of the five locations, with a total of 25 samples for each of the three different helmet/visor configurations.

Peak noise levels measured in the manikin ear were significantly different between the helmet/visor configuration equipped with the long (4.0”) visor and the other two configurations. The difference between the mean L_{peak} between the long and no visor, long and short visor, and short and no visor helmet configurations were 3.96 dBA ($p < .0001$, 95% CI 3.52-4.40), 3.64 dBA ($p < .0001$, 95% CI 3.20-4.08), and 0.32 dBA ($p = 0.1558$, 95% CI -0.76-0.12), respectively. These results indicate that officials wearing helmets equipped with longer visors are likely experiencing greater exposure to sound pressure levels of noise from their mouth-blown whistles. The longer helmet visors offer more face and eye protection but may also act as a reflective plane for whistle noise and increase hockey officials’ noise exposure from their mouth-blown whistles. A finding that longer visors may increase the officials’ noise exposure from whistle noise may perhaps provide insight for better design of helmet visors in the future.

Ultimately, the results of this study provide important preliminary data supporting further research into the noise exposure and temporary hearing loss of officials at sporting events, as part of the implementation of a comprehensive hearing conservation program to reduce the risk of NIHL. In addition, further research is warranted to investigate the contribution of the visor length to the hockey officials’ exposure to mouth-blown whistle noise. The results of this study support that the hearing health and safety impacts of the visor length should be considered in the assessment and design of helmet visors in the future.

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DEDICATION

For Camden and Keaton. You are my sunshine.

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AL	Action Level
ACHA	American Collegiate Hockey Association
ANSI	American National Standards Institute
ASHA	American Speech-Language-Hearing Association
CDC	Centers for Disease Control and Prevention
CSU	Colorado State University
dB	Decibel
dBA	Decibel, A-weighted
dBC	Decibel, C-weighted
HRTF	Head-Related Transfer Function
HCP	Hearing Conservation Program
Hz	Hertz
ISO	International Organization for Standardization
L_{eq}	Equivalent Sound Pressure Level
L_{peak}	Peak Sound Pressure Level
NHL	National Hockey League
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NIDCD	National Institute on Deafness and Other Communication Disorders
OSHA	Occupational Safety and Health Administration

PEL	Permissible Exposure Limit
PPE	Personal Protective Equipment
SLM	Sound Level Meter
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
TLV	Threshold Limit Value
TWA	Time-Weighted Average
WHO	World Health Organization
WSHL	Western States Hockey League

CHAPTER 1

INTRODUCTION

Noise is ubiquitous, and exposure to hazardous levels of noise may cause irreversible noise-induced hearing loss (NIHL). Several researchers have established that the severity of hearing loss is dependent on noise intensity and duration of exposure, and that susceptibility to noise-induced hearing loss (NIHL) varies among individuals.⁽¹⁻³⁾ The National Institute on Deafness and other Communication Disorders (NIDCD) and the American Speech-Language-Hearing Association (ASLHA) state that exposure to sounds at or above 85 decibels (dB) is considered hazardous noise and may increase the risk of permanent hearing loss.^(4, 5) Exposure to hazardous levels of noise may be detrimental to hearing, and may also cause stress and affect one's health, sleep, communication, safety, and quality of life. Exposure to hazardous levels of noise may result in a temporary hearing loss, or temporary threshold shift (TTS).⁽⁴⁾ Symptoms of a TTS include a temporary hearing loss and may also include ringing in the ears (tinnitus) and/or a feeling of fullness in the head. The hearing threshold recovery time varies, with full recovery typically occurring within 48 hours.⁽⁶⁾ Repeated TTSs have been found to be a risk indicator for permanent NIHL that may occur if exposure to hazardous noise continues.⁽³⁾

NIHL is one of the most common occupational diseases and is entirely preventable.⁽⁷⁾ It has been reported that 15% of Americans between the ages of 20 and 69 years old have permanent hearing loss,⁽⁴⁾ and 16% of worldwide hearing losses are attributed to occupational noise exposure,⁽⁸⁾ with over \$242 million spent annually on workers' compensation for hearing loss disability in the United States.⁽⁹⁾ Excessive noise exposures from recreational settings and their contribution to NIHL has been a growing concern of the World Health Organization

(WHO).⁽¹⁰⁾ Reducing recreational noise exposures is important as occupational exposure limits (OEL) for noise are based on occupational exposure duration and noise levels with the assumption that exposure to non-occupational noise levels are low enough to allow the ear to recover. It is also important to recognize that occupational and recreational noise exposures resulting in a TTS at an early age may produce early onset of permanent cochlear nerve degeneration.^(1, 11)

Occupational noise exposure has been studied extensively since the mid-nineteenth century, but research in the effects of non-occupational, or recreational noise sources has been minimal. Some research on noise levels at concerts, discotheques, and live sporting events has been conducted,⁽¹²⁻¹⁵⁾ with only a few of those studies assessing the noise exposure of spectators and employees at sporting events.⁽¹⁶⁻¹⁸⁾ A comprehensive review of the relevant literature indicated that research on the health and safety of sports officials is lacking with only one published study investigating noise exposures of collegiate basketball referees.⁽¹⁹⁾

Hockey officials are a population of individuals who may be at a high risk for NIHL because their exposures have not been evaluated and they are exposed to numerous uncontrollable noise sources (e.g., crowd, whistle, puck-to-glass, music, public address system) in an enclosed, indoor space with multiple noise reflective surfaces (e.g., plexiglas[®], ice). Hockey officials' noise exposure was of particular interest because individuals may begin officiating as early as ten years of age,⁽²⁰⁾ and in many cases noise exposure from hockey games is supplemental to any noise exposure experienced during the other hours of the officials' day (e.g. work, music concerts). There are tens of thousands of amateur and professional hockey officials in the United States alone, with over 23,000 hockey officials registered with USA

Hockey. These individuals' noise exposures from officiating indoor hockey competitions have not been investigated.

A plethora of research supports the relationship between exposure to hazardous levels of noise and TTSs and NIHL. Therefore, researchers were interested in determining if hockey officials experienced a TTS after officiating a game. A change in hearing sensitivity usually occurs incrementally over time and may go unnoticed. Pure-tone audiometry is one method used to measure the hearing acuity for each ear at different frequencies and loudness. The audiometric test measures individual's hearing sensitivity in dB relative to the quietest sounds that a young healthy individual should be able to hear. The inner-ear hair cells that respond to 4000 Hz sound energy are particularly vulnerable to damage because the outer and middle ear transmit the energy of sound frequencies near 4 kHz very efficiently. The characteristic decrease in hearing acuity due to NIHL produces an audiometric threshold pattern termed the 4000 Hz "notch" (4K notch). NIHL is typically indicated on an audiogram by a decrease in an individual's hearing sensitivity (threshold shift) at 4 kHz or 6 kHz. Continued hazardous noise exposure may widen the notch observed on the audiogram into adjacent frequencies.

Spectators, participants, and employees of sporting events may be exposed to numerous noise sources at the event. The noise exposure of an official is unique due to the use of the mouth-blown whistle in close proximity to the ear. Researchers have investigated the noise levels generated from mouth-blown whistles and postulated that sports officials may be at an increased risk of NIHL.^(19, 21) The number of times the whistle is signaled in a game is dependent on the officials' management of the game (e.g., infractions, timeouts, goals). The determination of hockey officials' exposure to mouth-blown whistle noise may be influenced by different configurations of reflective or absorptive surfaces in close proximity to the whistle. In particular,

the official's helmet visor may act as a reflective surface for the whistle noise,⁽²²⁾ increasing the hockey official's exposure to whistle noise. Utilizing a manikin equipped with an in-ear microphone to assess if the visor of the hockey official's helmet introduces a reflective plan for the whistle noise may be the preliminary step in future design and production of visors. The goal of the current research is to measure the noise exposure and any changes in hearing thresholds of a population of individuals who, so far, have been overlooked. The goals of the research are summarized below with three specific aims.

Specific Aim 1: Determine the noise exposure levels of Western States Hockey League (WSHL) and American Collegiate Hockey Association (ACHA) indoor hockey officials who officiated in ice hockey venues in northern Colorado and southeastern Wyoming. The approach was to use a personal noise dosimeter to measure the noise exposure level of the indoor hockey officials for the duration of the game. The data from the noise dosimeter were analyzed to determine the proportion of hockey officials exposed to an equivalent sound pressure level (L_{eq}) equal to or greater than 85 dBA.

Specific Aim 2: Determine the proportion of WSHL and ACHA indoor hockey officials that experience a decrease in hearing sensitivity (temporary threshold shift) after officiating a game. The approach was to administer a hearing history questionnaire and otoscopic exam to each official prior to the pre-game audiometric test. The pre- and post-game audiometric test results were compared to determine the proportion of officials who experienced a 10 dB or greater decrease in hearing sensitivity at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The data were also evaluated to determine if a significant relationship between the officials' noise exposure (L_{eq}) and the presence of a ≥ 10 dB temporary threshold shift in hearing occurred at the tested frequencies.

The pilot and main studies used similar noise monitoring and audiometric testing methodologies from specific aims one and two, and were conducted in the 2013-2014 and 2014-2015 hockey seasons, respectively. The results of the pilot study are presented in Chapter 3 in a version of the manuscript entitled, “Noise Exposure and Temporary Hearing Loss of Indoor Hockey Officials: A Pilot Study.” The manuscript is in press for November 2016 publication in the *Journal of Environmental Health*. The results of the main study are presented in Chapter 4 in a version of the manuscript entitled, “A Faceoff with Hazardous Noise: Noise Exposure and Hearing Threshold Shifts of Indoor Hockey Officials.” The manuscript is in press for February 2017 publication in the *Journal of Occupational and Environmental Hygiene*.

Specific Aim 3: Measure the whistle noise in the ear of a KEMAR manikin wearing three different helmet/visor configurations: no visor, 2.75” long visor, and 4.0” long visor. The approach simulated a hockey official’s exposure to whistle noise generated adjacent to the mouth of the KEMAR manikin equipped with an in-ear microphone. The peak sound pressure level (L_{peak}) from the whistle was measured at the manikin’s ear for each of the helmet configurations. The results of this study are presented in Chapter 5 in a version of the manuscript entitled, “A Simulation of Hockey Official Whistle Noise and Use of KEMAR to Evaluate the Effect of Helmet Visor Length on Exposure to Whistle Noise.” The manuscript is planned for submission to the *Journal of Occupational and Environmental Hygiene* in 2017.

CHAPTER 2

LITERATURE REVIEW

Sound and Noise

A sound source causes rapid variations in energy, or vibrations, that disturb particles in the surrounding medium, in an outward-moving, wavelike pattern. The sound wave is the pattern of the disturbed medium caused by the movement of energy as it propagates away from the source of the sound. The frequency of a sound wave, or the pitch, is the number of vibrations per second, measured in hertz (Hz). The average range of audible frequencies for a healthy young person is between 20 and 20,000 Hz, but varies considerably among individuals.^(23, 24) A pure-tone sound consists of a single frequency whereas most of the sounds created in everyday environments are multi-tonal, or multi-frequency. The intensity of sound, or sound pressure level, is measured in decibels (dB). The decibel represents the ratio of the sound pressure level of the source sound in relation to the pressure level of the threshold of human hearing. The upper end of sound pressure levels of sources detected by human hearing is approximately ten million times that of the lower end, or human hearing threshold, sound pressure level.⁽²⁴⁾ Consequently, the decibel scale is logarithmic and compresses the range of ratios of sound pressure levels that are audible to the human ear into a more manageable scale.

The human ear does not transmit sound energies in all frequencies equally. To account for this variation, the measurement of sound frequency has become internationally standardized to the A, C, and Z weighting networks.^(10, 25-27) The A-weighted sound pressure level measurements model the frequency-related variability of human hearing, therefore due to attenuation of low frequency sound by the ear, the sound pressure levels of lower frequencies

with the A-weighting are reported as lower than if they were measured without the weighting. The A-weighted sound pressure levels have been adopted by governmental agencies as well as hearing conservation professionals internationally for use in identifying noise with damaging effects on human hearing.⁽²⁷⁻²⁹⁾ The C-weighted sound level scale minimally attenuates the lower frequencies and is often used to characterize low frequency sound that may induce vibration in buildings or the human body. The Z-weighted scale has zero weighting and is the alternate method for measuring low frequency sound. The relative frequency weighting models are exhibited in Figure 2.1.

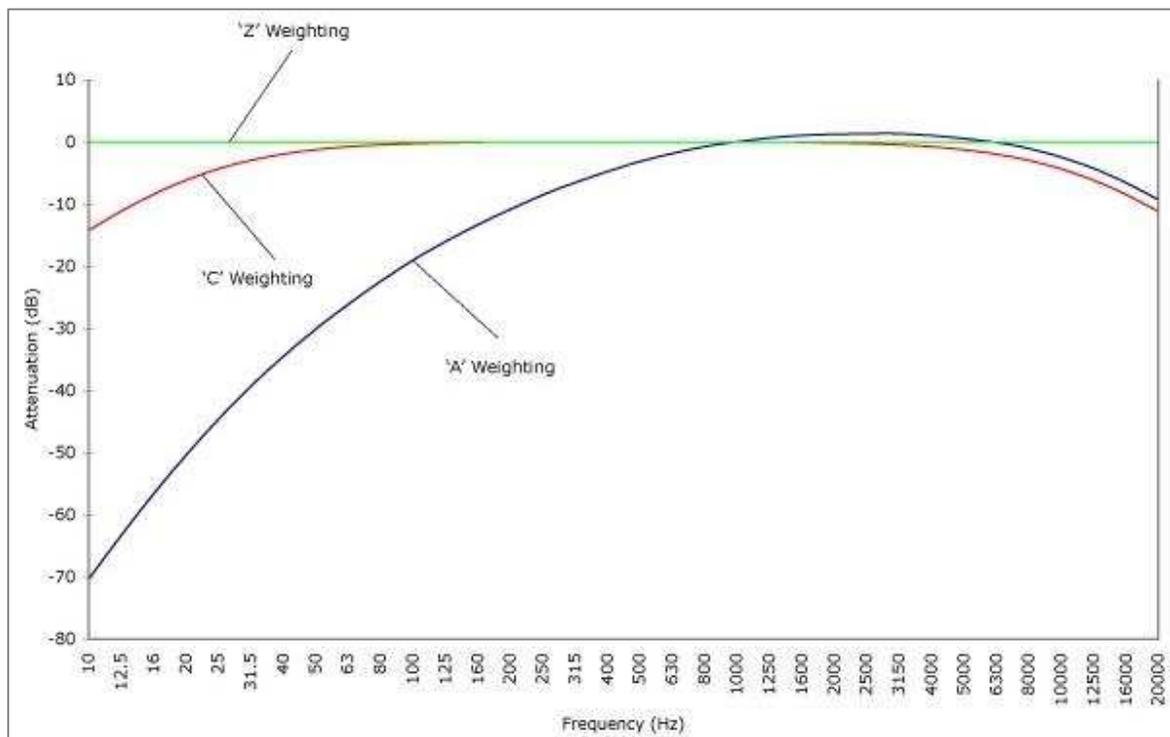


Figure 2.1: A, C and Z frequency weighting curves (NoiseNews®, 2016)

The range of frequencies from 20 Hz to 20,000 Hz can be divided into octave bands when more details are needed about a sound's characteristics. A sound level meter can electronically divide the frequencies, normally into 10 bands. Octave bands, in Hz, are used to measure the various frequency constituents of sounds and are named for the center frequency of

the band. The frequency at the upper edge of the band is twice the frequency of the lower edge of the band. The center frequencies for these bands are: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz and 16 kHz. All sound is not created equally; undesirable, unwanted, and annoying sound is often described as noise. Using octave band analysis, or frequency spectrum analysis, allows for designing more effective engineering controls for minimizing or eradicating noise.

Noise may be described as continuous or intermittent. Continuous noise has negligibly small fluctuations of sound level within the period of observation and the highest noise levels occur more often than once per second.⁽²⁷⁾ Intermittent noise has sound levels that are interrupted by intervals of higher or lower sound levels.⁽²⁶⁾ Intermittent noise includes impact and impulse noise, which often consist of high intensity and short duration noise. Impact noise is created when an object strikes another surface resulting in the sound pressure rising and falling rapidly. Impulse noise is created with a release of energy with a rapid rise and slower decay of sound pressure than that seen with impact noise (e.g. gunshot, explosion).

The measurements of noise referenced in this dissertation include: equivalent sound pressure level (L_{eq}); peak sound pressure level (L_{peak}); and time-weighted average (TWA). The L_{eq} is the true equivalent sound level that includes all of the time-varying sound energy in the measurement period. The L_{peak} is the highest instantaneous sound level that is detectable, without averaging, and a TWA is an individual's average noise exposure over a specified period of time.

Sound Propagation

Perceived sound pressure levels are influenced by the energy emitted and distance from the sound source, as well as the environment surrounding the sound source. Sound emitted by a

source in a free field is one that propagates energy uniformly in all directions, with no reflected sound waves.⁽²⁴⁾ The sound pressure levels produced by the source are the same in every direction and equivalent equidistant from the source. The physics of sound propagation follows the inverse-square law, such that each time the distance from the point source of noise is doubled, the intensity of the sound decreases to a fourth of the source intensity. Within the decibel measurement scale for sound, this reduction of intensity is equivalent to a sound pressure level decrease of six dB.⁽²⁴⁾

The propagation of sound changes drastically in spaces defined by sound-absorbing porous material, walls, or other sound-reflecting surfaces. In the presence of reflective surfaces (Figure 2.2), sound waves may reverberate, or reflect back, transmit through the surface, or be absorbed by the surface, rather than dissipating uniformly, as in the free field. The reverberation of sound waves affects the sound intensity such that the sound pressure level does not decrease as rapidly as in the free field and can persist after the noise source has terminated.

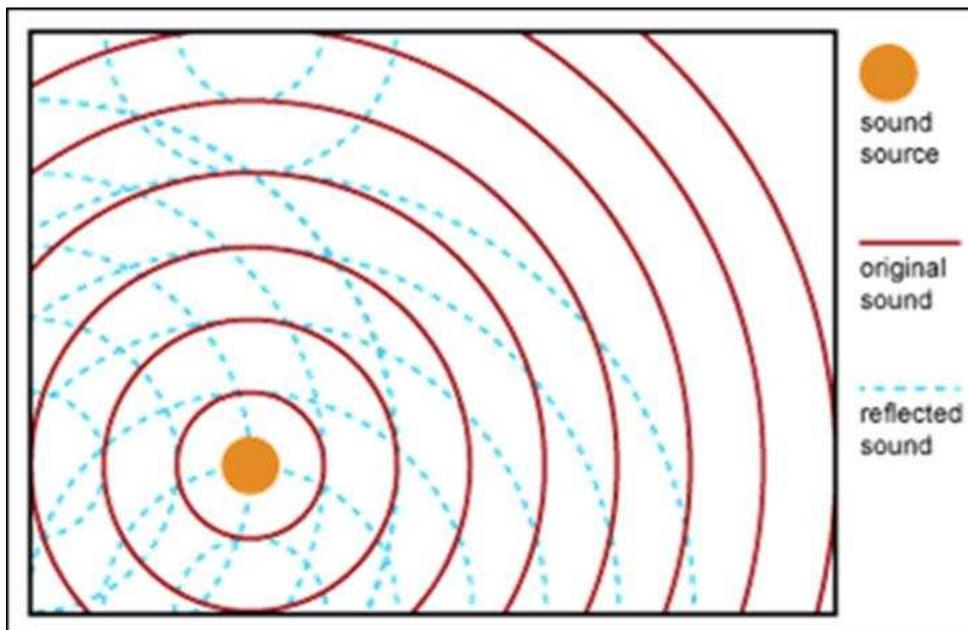


Figure 2.2: Original and reflected sound waves from a sound source near reflective surfaces (OSHA, 2016)

A reflective surface that is located close to a noise source will affect the measured intensity of the source noise radiated as well as the directional properties of the source noise. At a constant distance, the addition of each reflective surface will concentrate the sound and increase the measured sound pressure level by 3 dB, doubling its intensity.⁽²⁴⁾ The shape of the reflective surface also influences the propagation of sound waves. The angle of incidence and the angle of reflection of the sound waves are uniformly equal when a source emits sound toward a planar reflective surface (Figure 2.3a). A concave surface does not provide uniformly equal reflection and reflects the noise toward a focal point, creating areas of increased and lower intensities (Figure 2.3b). A convex surface widely disperses the noise source sound wave, as seen in Figure 2.3c.

Sound propagation may create a noise problem, depending on its source, transmission path, and/or receiver (direct or indirect).⁽³⁰⁾ If the noise source is unable to be controlled to an acceptable noise level, control along its propagation path is recommended and all possible avenues along which noise may reach the ear have to be considered. It is pertinent to understand the acoustic properties of the noise source when designing effective engineering controls. For instance, high frequency sound has a lower amount of diffraction (sharpness of bending around obstacles) which makes it is easier to control along its propagation path.

Whenever the wavelength of the noise is shorter than an obstacle, or shield, the sound wave will not diffract around that obstacle. However, lower frequency sound is more difficult to control because it diffracts around obstacles or through a hole in a barrier. An obstacle, or shield, has very little effect on low frequency noise unless it is very large. The last resort in addressing a noise problem is to control the noise at the receiver with personal protective

equipment and should only be considered when options to control the noise at the source or along the propagation path are unfeasible.

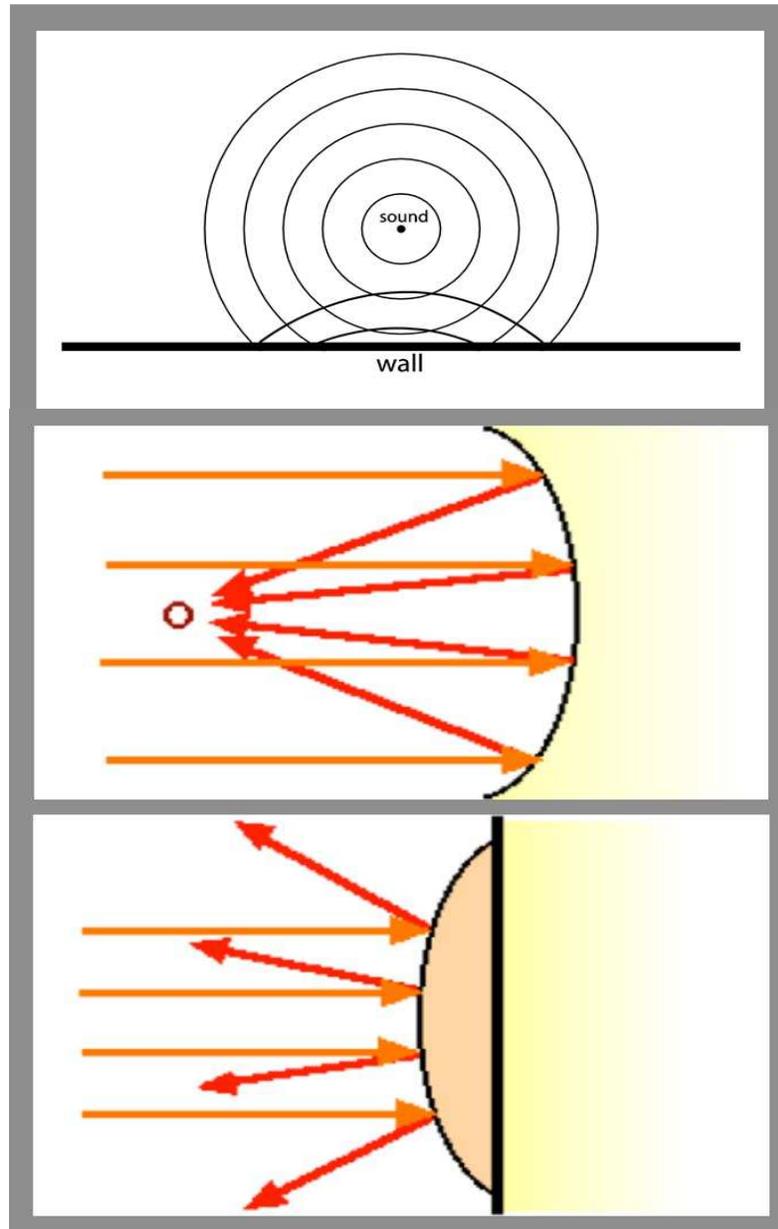


Figure 2.3: Sound pressure wave interactions (top to bottom): a. Sound pressure waves of a sound source near a planar reflective surface (www.askaudio.com) b. Sound pressure waves of a sound source near a concave surface c. Sound pressure waves of a sound source near a convex surface (<http://hyperphysics.phy-astr.gsu.edu/2016>)

Noise Exposure Regulations and Recommendations

The Occupational Safety and Health Administration (OSHA) is the regulatory agency responsible for ensuring safe working conditions in the United States.⁽³¹⁾ Occupational noise exposure is regulated by OSHA's noise standard 29 CFR 1910.95. The National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) have also established exposure guidelines for occupational exposure to noise. These hearing damage-risk criteria provide the basis for recommending noise exposure limits based on noise level and exposure duration. Standards and recommendations are based on average risk and do not account for individual variance in susceptibility.

Occupational exposure limits (OELs) for noise are based on exposure duration and noise level, assuming non-occupational noise levels are low enough to allow the ear to recover. OSHA permits an 8-hour time-weighted average (TWA) exposure to 90 dBA (permissible exposure limit (PEL)) and requires a 5 dB exchange rate. An exchange rate is also called a doubling rate. For instance, for every 5 dB increase in noise level, the allowable exposure time is reduced by half; and for every 5 dB decrease in noise level, the allowable exposure time is doubled.⁽³²⁾ OSHA also states that employee exposure to impulsive or impact noise may not exceed a 140 dB peak sound pressure level at any time. Those employees exposed to an 8-hour TWA of 85 dB or greater must be enrolled in a hearing conservation program which mandates controls for hazardous noise and hearing exams for workers. The NIOSH recommended exposure limit (REL) and ACGIH threshold limit value (TLV) recommend an 8-hour TWA sound level of 85 dBA and require a 3 dB exchange rate.^(7, 33) The OSHA, NIOSH, and ACGIH allowable noise duration criteria are displayed in Table 2.1, with time allowed at each dBA assumed to have equal risk.

Table 2.1. Duration (hours) of allowable noise exposures at certain SPL based on OSHA and NIOSH/ACGIH noise criteria

	Allowable Exposure Duration (hours)									
SPL (dBA)	85	88	90	91	94	95	97	100	105	110
OSHA	16	10.6	8	7	4.6	4	3	2	1	0.5
NIOSH/ACGIH	8	4	2.5	2	1	0.79	0.5	0.25	.079	.025

The American Speech-Language-Hearing Association (ASLHA) and the National Institute on Deafness and Other Communication Disorders (NIDCD) report that long or repetitive exposure to sound at or above 85 dB is hazardous and can cause hearing loss.^(4, 5) An example of more stringent exposure limits were identified by the Environmental Protection Agency (EPA) in 1974 that identified a 24-hour exposure level of 70 dB as the level of environmental noise (e.g. from work, home, leisure activities) which will prevent any measurable hearing loss over a lifetime.⁽³⁴⁾ Based on the recommendations of ASLHA and NIDCD that all noise exposure levels should be ≤ 85 dBA, an equivalent sound pressure level (L_{eq}) greater than or equal to 85 dBA was identified as hazardous in the current study.

Non-Occupational Noise Exposure

Non-occupational noise may also be referred to as recreational noise, including noise from activities such as hunting/shooting, snowmobiling, attending music concerts, hobby-use of power tools, attending sporting events, and using personal music devices.⁽¹⁰⁾ According to the World Health Organization (WHO), noise exposure in recreational settings is a growing concern and may increase the risk of NIHL.⁽¹⁰⁾ The effects of recreational noise exposure on undergraduate students at East Carolina University were evident in a study by Balanay and

Kearney.⁽³⁵⁾ The investigators found that the highest percentages of students with self-reported ear pain, hearing loss, permanent tinnitus and noise sensitivity also attended sporting events.⁽³⁵⁾

Noise exposure and temporary hearing loss have been assessed in several recreational environments, including concerts, discotheques and live sporting events.⁽¹²⁻¹⁵⁾ A cross-sectional survey of 1,432 individuals in Australia, aged 11 to 35 years old, was conducted by Williams, Carter, and Seeto. The researchers examined the relationship between self-reported historical work and leisure noise exposures and pure-tone audiometry test results. The audiometry and historical exposure data were used to estimate a cumulative lifetime noise exposure.⁽³⁶⁾ Contrary to the findings of those researchers mentioned above, Williams et al. did not find a correlation between cumulative lifetime noise exposure and pure-tone audiometry test results.⁽³⁶⁾

A limited number of noise exposure studies have been conducted on spectators and employees in sports venues.⁽¹⁶⁻¹⁸⁾ Cranston et al. studied the noise exposures of fans and ushers at two indoor hockey arenas and found that fans and ushers at collegiate and semi-professional hockey games exceeded ACGIH noise exposure criteria.⁽¹⁷⁾ Investigators who assessed the noise exposures of fans and workers at various sized football stadiums found that 96% of workers and 96% of fans were overexposed according to the ACGIH recommendations.⁽¹⁶⁾ According to the literature reviewed, only two studies have been published regarding noise exposures and hearing threshold shifts at sports venues. Hodgetts and Liu performed a small study during the 2006 Stanley Cup and found that the average noise exposure levels were above 101 dB and the hearing thresholds of two subjects deteriorated by 5 to 10 dB for most frequencies.⁽¹⁴⁾ More recently, England et al. studied the intensity of noise exposure and hearing thresholds of attendees during collegiate basketball games at Utah State University and found that the hearing thresholds of the attendees deteriorated by 4.43 dB.⁽¹⁸⁾

Noise Measurement

The two most commonly used instruments for noise measurement include the sound level meter (SLM) and personal noise dosimeter. The SLM is an instrument that samples the intensity of sound for a very short period of time, which requires numerous measurements at different times of the day to estimate a noise exposure over a certain time period (e.g. workday).⁽²³⁾ The SLM is predominantly used to measure noise levels in an area. A SLM may be positioned within the immediate vicinity of the exposed individual to obtain an estimate of personal exposure, if the individual is relatively stationary. To collect a measurement, the microphone of the SLM is positioned near the individual's head, and may be moved in conjunction with minimal movements of the individual. If noise levels fluctuate, the amount of time the noise occurs at each of the various measured levels must be determined, which may be difficult to do without a time-integrating SLM.

The SLM measures sound pressure levels in dB and the responses are frequency-weighted to represent A, C and/or Z scales. The SLM uses a continuous averaging process that weighs current and past data differently. The SLM response varies based on a *fast* or *slow* exponential averaging process, with *fast* corresponding to a 125-millisecond (ms) time-constant and *slow* corresponding to a 1-second time-constant.⁽²⁶⁾ The OSHA noise standard requires the use of the A-weighted, slow exponential average when measuring typical occupational noise to provide an estimate of the damaging effects on human hearing.^(7, 23) The Z- or C-weighted scales on the SLM are often used to characterize low frequency sound that may induce vibration. The SLM paired with an octave band analyzer (OBA) filter may also be used for frequency spectrum analysis to identify the sound pressure levels within the octave bands.

When individuals are mobile or when the noise intensity tends to fluctuate over time, personal noise dosimetry is the more accurate choice of noise measurement.⁽²³⁾ A dosimeter is similar to a SLM except that it stores sound level measurements and integrates the measurements over time, reporting an average noise exposure and percent noise dose for a given time period, such as a workday. Proper positioning of the dosimeter microphone is necessary to obtain accurate measurements. The upright microphone is placed in the hearing zone, an approximately two-foot diameter sphere around the head, and attached to the lapel or shoulder of the individual's clothing.⁽²⁴⁾ The personal dosimeter measures the noise levels to which an employee is exposed as the employee travels to different locations. After the designated sampling period, the average exposure measurement is retrieved from the instrument. The noise sampling methodology used in this research is found in Appendix A.

Overview of the Auditory System

The human auditory system includes the outer, middle and inner ear (Figure 2.4). The pinna, or outer ear, funnels sound waves and directs the variations in air pressure through the meatus to the tympanic membrane, or eardrum.⁽³⁷⁾ The variations in air pressure cause the eardrum to vibrate. These vibrations are amplified and transmitted by the small bones, or ossicles, located in the middle ear. The ossicles include the malleus, incus and stapes bones and they transmit the sound pressure/vibrations experienced by the eardrum to the inner ear. The amplified vibrations are transmitted mechanically to the membrane of the oval window, inducing waves in the fluid-filled inner ear. The inner ear contains the cochlea, which consists of sensory cells, called inner and outer hair cells. The outer hair cells amplify and increase the stimuli delivered to the inner hair cells, which respond to the movement of the basilar membrane and send electrical impulses along the auditory nerve to the brain. Excessive sound levels or lengthy

exposure to sound can cause damage ranging from exhaustion of the hair cells to cell death. A fixed number of the cochlear sensory cells are present at birth, and once they have been damaged beyond repair, they do not regenerate.^(1, 38)

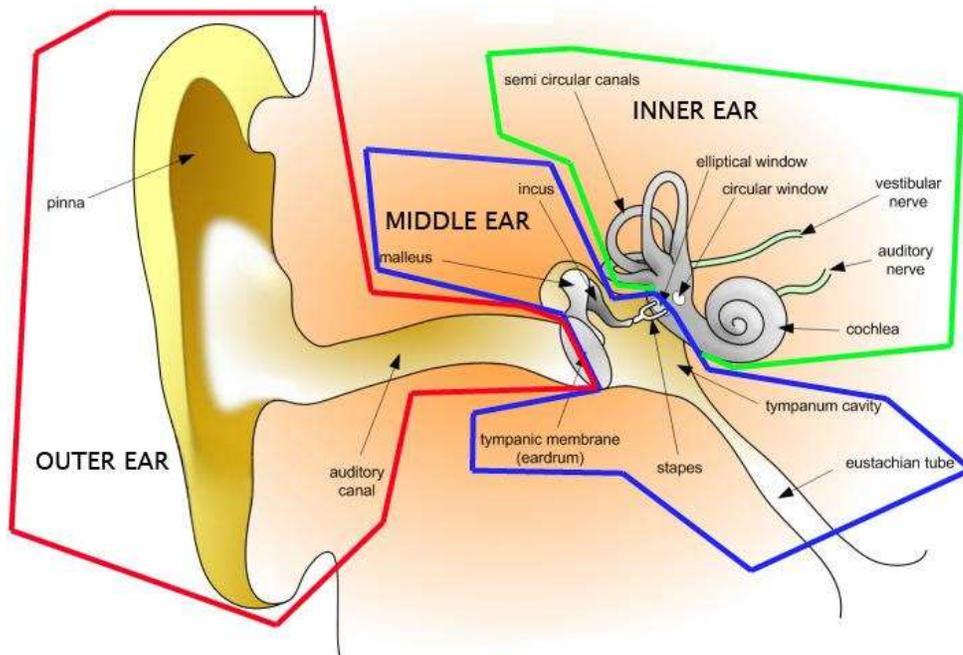


Figure 2.4: The outer, middle, and inner ear (www.humananatomybody.info)

Health Effects of Noise Exposure

Auditory Effects:

The three types of hearing loss are categorized based on the area of the auditory system that is affected and include conductive, sensorineural, or a combination of the two.⁽⁵⁾ A condition in the outer or middle ear that interferes with the sound wave passing to the inner ear may result in conductive hearing loss. Excessive cerumen (wax) in the auditory canal, an injury to the head, or a ruptured tympanic membrane may result in a conductive hearing loss. This type of hearing loss is most commonly reversible with medical or surgical treatment, but may also be

irreversible.⁽³⁹⁾ Sensorineural hearing loss is associated with irreversible damage to the inner ear and is usually not medically or surgically treatable. Excessive noise exposure and aging are the most noteworthy causes of sensorineural hearing loss.

NIHL is the result of exposure to sound levels or exposure durations that damage the hair cells of the cochlea and may be temporary or permanent. The NIHL depends upon a number of factors, including, but not limited to: the intensity level, or sound pressure level (SPL) of the noise; the spectrum, or frequency, of the noise; the duration of the noise exposure; the temporal pattern of the noise exposure; the genetic predisposition of the individual; and the hearing sensitivity of the exposed individual.^(3, 40-42) As noise exposure increases, the inner and outer hair cells may inflame, fatigue, and eventually disintegrate.⁽²⁵⁾ Long exposure to sounds at or above 85 dBA may cause hearing loss, whereas exposures to sounds of less than 75 dBA are not likely to cause hearing loss.⁽⁴³⁾ Researchers have found that exposures to sounds at or above 85 dB are hazardous, increase risk of hearing loss, and may cause permanent hearing loss.^(4, 5)

Long-term exposure to excessive levels of noise, physical trauma to the head, or other physiological conditions may cause tinnitus, a condition in the inner ear that the brain interprets as sound or noise. Tinnitus is described as a ring, hum, whistle, buzz or roar in the ear and may be temporary or permanent. Repeated exposure to hazardous noise levels may initially result in a temporary threshold shift (TTS) in hearing, with symptoms including tinnitus and/or a feeling of fullness in the head, with full recovery usually within 48 hours.^(4, 6) A TTS may be defined as a temporary decrease in hearing sensitivity as a result of noise exposure and may be a risk indicator of possible permanent NIHL if exposure to hazardous noise continues.⁽³⁾ Research by Lawton concludes that noise exposures of 80 dBA produce a temporary threshold shift from which subjects recover within minutes of removal of noise exposure, yet recovery from a TTS

may be prolonged when noise exposure is from high-intensity, high-frequency intermittent noise.⁽⁶⁾

Sense of hearing has played an important role in safety and survival for tens of thousands of years; providing alerts of dangers while hunting and gathering to protecting from an impending attack. Hazards abound at work, home, and leisure activities and hearing allows identification of these dangers in order to avoid injury. Driving, working in construction, manufacturing, and officiating a hockey game can all be dangerous. Auditory warning signals alert individuals of unsafe conditions. Deleterious auditory effects from noise exposure can make the signals unnoticeable to individuals and possibly negatively affect those people in danger.

Several researchers have investigated the effect of noise exposure on occupational injuries.⁽⁴⁴⁻⁴⁸⁾ A retrospective study investigating the association between occupational noise exposure at the time of hearing tests, permanent NIHL, and work-related injuries was conducted by Picard et al. The study utilized the Quebec National Institute of Public Health registry to identify male workers, aged 16-64 years, who had known noise exposure ≥ 80 dBA on a daily basis and whose hearing was measured at least once between 1983 and 1996.⁽⁴⁴⁾ The study included 52,982 workers and the researchers concluded that a combination of an 8-hour exposure to $L_{eq} \geq 90$ dB and NIHL contributed to 12.2% of accidents. The results also showed an association between accident risk and hearing sensitivity, with several limitations.⁽⁴⁴⁾ For instance, the researchers identified that the very large database had incomplete frames of reference used in the accident analysis (e.g. task, tool design, individual characteristics that affect job safety) and the findings are most likely exclusive to the particular set of industrial sectors included in the study.⁽⁴⁴⁾

A study by Choi et al. investigated self-reported hearing impairment and the risk of injuries in agriculture. The study population included 150 farmers from an Iowa Certified Safe Farm study that completed annual pure-tone audiometry from 1998 to 2002, and telephone interviews at two- to five-month intervals.⁽⁴⁶⁾ The researchers found that hearing asymmetry determined by audiometric testing (RR=1.67) and self-reported fair/poor hearing (RR=1.96) were significantly associated with the risk of agricultural injuries.⁽⁴⁶⁾ Based on the results of the study, the self-reported hearing impairment was a significant risk factor and had a stronger association with injuries than the hearing characteristics measured with pure-tone audiometry.⁽⁴⁶⁾

Cordeiro et al. conducted a population-based case-control study that utilized self-reported hearing status to determine the risk for occupational injuries. The study was conducted in Brazil from May to October 2002 and investigated whether or not exposure to occupational noise is a risk factor for work-related injuries. The cases were identified as workers who had suffered work-related injuries within 90 days of the study date, and controls were randomly selected, non-injured workers from the same population. The self-reported hearing levels were based on normal speaking volume and were given dummy variables of a) always or b) sometimes exposed to high noise levels if they could not hear coworkers speaking.⁽⁴⁸⁾ The researchers reported that the relative risk of having an injury for those workers who were sometimes exposed to high levels of noise was 3.7 (95% CI 1.8-7.4; $p=0.0003$), and 5.0 (95% CI 2.8-8.7; $p<0.001$) for those always exposed to high levels of noise.⁽⁴⁸⁾

A longitudinal analysis of audiometric data during a four-year period by Leensen and Dreschler attempted to provide insight into the development of NIHL as a function of noise exposure and age during the first decade of noise exposure.⁽⁴⁹⁾ After reviewing audiometry data of 3,111 construction workers who received three hearing tests throughout the four-year period,

researchers found that the annual rate of change in hearing loss was positively associated with both age ($F[1,12,253] = 123.73, p < 0.001$) and noise exposure level ($F[1,12,253] = 11.51, p < 0.001$).⁽⁴⁹⁾ However, Leensen and Dreschler also found that the later follow-up hearing thresholds were better than the baseline hearing thresholds at the lower frequencies and the resulting development of NIHL during the first decade of noise exposure was inconclusive.

It is also important to recognize that occupational and recreational noise exposures resulting in a TTS at an early age may result in cochlear nerve degeneration, which results in permanent, age-related hearing loss at an earlier age than expected.^(1, 11) For instance, the effects of recreational noise exposure on young adults were evident in the study by Balanay et al., who investigated the effects of recreational noise exposure on 2,151 undergraduate students, aged 17 years and above, at East Carolina University. The researchers found that the highest percentages of students with self-reported ear pain, hearing loss, permanent tinnitus and noise sensitivity participated in sporting events.⁽³⁵⁾

Non-Auditory Effects

Over the years, researchers have found that exposure to noise may induce numerous non-auditory health effects, including but not limited to: interference with communication, sleep disturbance, hypertension, ischemic heart disease, disrupted development of fetus, upset stomach, and decreased performance.^(5, 25, 50-54) Noise-induced, stress-related cardiovascular disorders, hormone and immune system effects, and reproduction and development effects have also been identified, but individual susceptibility varies.^(25, 50) Some examples of the psychological consequences of excessive noise exposure may include a sense of isolation, decreased morale, depression, and annoyance.⁽²³⁾

The Committee on Noise and Health from the Health Council of the Netherlands concludes that there are epidemiological data that support a possible relationship between noise exposure and development of cardiovascular disease.⁽⁵⁰⁾ An investigation into the cardiovascular effects of noise in children was conducted by Belojevic et al. The researchers found that systolic pressure was significantly higher (5 mm Hg on average) among children from noisy residences and kindergarten classrooms compared to the quiet versions of each ($p = 0.001$), but diastolic pressure and mean arterial pressure were similar between the groups.⁽⁵¹⁾ They also found that the heart rate in children from noisy residences was significantly higher (2 beats/min on average) than that of children from quiet residences ($p < 0.05$).⁽⁵¹⁾

Audiometry

Audiometric exams are used to evaluate an individual's hearing function. There are several tests that may be used to identify a hearing loss, including: pure-tone audiometry, tympanometry, brainstem auditory evoked response (BAER), electrocochleography (ECOG), and otoacoustic emissions (OAEs).⁽⁵⁾ The review of literature indicated that pure-tone audiometry and distortion product otoacoustic emissions (DPOAE) were the most common and feasible hearing tests administered by hearing conservationists that were not formally trained in audiology. DPOAE testing requires instrumentation that generates otoacoustic emissions from the cochlea while simultaneously stimulating the cochlea by two pure-tone frequencies whose ratio is between 1.1 to 1.3.⁽⁵⁾ Although DPOAE and pure-tone audiometry have both been used to evaluate hearing function, pure-tone audiometric testing was found to be the most common method used by NIHL researchers.^(13, 14, 18, 55-61)

NIHL usually occurs incrementally and may go unnoticed until a substantial deficit in hearing sensitivity is reached.⁽⁴⁾ Hearing sensitivity is determined with audiometry, the

measurement of hearing acuity for each ear at different frequencies and levels of loudness. The test is administered by requiring an individual to indicate hearing of pure-tone sound at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in each ear at different loudness levels. The audiogram is the numerical or graphical record of how well an individual hears at a given time, place and under given conditions.⁽⁵⁾

The characteristic audiometric pattern for hearing loss resulting from exposure to hazardous levels of noise is the 4000 Hz “notch” (4K notch). Regardless of the frequency spectrum of the noise exposure, individuals exposed to hazardous levels of noise will develop hearing loss in the 3000 to 6000 Hz frequency range.^(1, 62) The 4K notch is the consequence of increased sensitivity of human hearing between 1000 and 5000 Hz and that sound in the 4000 Hz region resonates in the external auditory canal.⁽⁵⁾ The audiometric 4K notch has been found by several researchers who used pure-tone audiometry to identify the presence of a TTS after exposure to loud music.^(13, 61, 63) For instance, Sadhra et al. measured the noise exposure and hearing thresholds of employees in a noisy environment and found that the correlation between TTS and personal noise exposure was higher at 4000 Hz.⁽¹³⁾ Le Prell et al. also found the characteristic 4K notch after young adult college student volunteers listened to pop or rock music from digital music players.⁽⁶¹⁾ Research results from the past few decades have reported that full recovery from a TTS may take anywhere from a few minutes up to 48 hours after the noise exposure ceases.^(4, 56, 64, 65) Several researchers who have conducted follow-up hearing tests within 48 hours after the noise exposure found that the TTS recovery was essentially complete with the first four hours.^(13, 18, 61)

The effects of analgesic use on hearing have been investigated and research has shown that analgesic use may increase the risk of hearing loss. Acetaminophen, aspirin and ibuprofen, a

nonsteroidal anti-inflammatory drug (NSAID), are the three most commonly used drugs in the United States,⁽⁶⁶⁾ and research has shown that analgesic use may increase the risk of hearing loss.^(67, 68) Curhan et al. investigated the relation between the frequency of analgesic use and risk of hearing loss among men and women in two different studies.^(67, 68) The results of both prospective studies indicate that regular use of analgesics (two or more times per week) increases the risk of hearing loss. Among men using NSAIDs and acetaminophen, the risk increased with longer duration and regular use.⁽⁶⁷⁾ The multivariate hazard ratios were adjusted for age, body mass index, alcohol, physical activity, folate, smoking, hypertension, diabetes, profession, race, and other analgesics.⁽⁶⁷⁾ The magnitude of the association was substantially higher for men younger than 50 years old and increased from 1.12 (95% CI, 1.04-1.20) to 1.33 (95% CI, 1.03-1.72) for regular aspirin use, from 1.21 (95% CI, 1.11-1.33) to 1.61 (95% CI, 1.15-2.26) for NSAIDs use, and from 1.22 (95% CI, 1.07-1.39) to 1.99 (95% CI, 1.34-2.95) for acetaminophen use.⁽⁶⁷⁾ Among women, the researchers found that the ibuprofen and acetaminophen use were independently associated with increased risk of hearing loss, but aspirin was not.⁽⁶⁸⁾

Knowles Electronic Manikin for Acoustic Research (KEMAR)

The sound pressure levels to which an individual is exposed may be measured by placing a noise dosimeter or SLM microphone in the hearing zone. Exceptional circumstances (e.g., extremely high or low temperatures) may not allow for the use of the noise dosimeter or SLM and the conditions must be simulated. The Knowles Electronic Manikin for Acoustic Research, KEMAR, was designed in 1972 as the first anthropometric head and torso simulator for acoustic research. It was designed to simulate a human head and torso and similarly affect sound waves as they would interact (diffract and reflect) with the human ear.⁽⁶⁹⁾ Early applications included its use in laboratories to perform simulated in-situ measurements of hearing aids. The KEMAR

is recognized as an industry standard for researchers in the fields of telecommunications, hearing conservation, sound recording, sound quality evaluation, and noise abatement.⁽⁶⁹⁾

Prior to the KEMAR, the ability of the human ear to localize sound in the vertical plane was investigated by Roffler and Butler. The experiment involved extensive auditory stimulus generating equipment and listeners wearing an uncomfortable plexiglas[®] headband to flatten the pinnae against the head such that the sound was only able to go directly into the external auditory canal.⁽³⁷⁾ The results of the study indicated that pinnae were required for a listener to localize an auditory stimuli.⁽³⁷⁾ Chung et al. used a KEMAR to investigate the effects of directional microphones on the ability of hearing aid users to localize speech. The manikin pinnae were fitted with bilateral in-the-ear hearing aids including microphones with adjustable directivity.⁽⁷⁰⁾ The researchers found that matched directional microphones worn bilaterally do not have a negative effect on the ability to localize speech.⁽⁷⁰⁾

The KEMAR has been utilized to measure the listening volume of headsets in order to estimate the users' noise exposure. For example, Patel and Broughton conducted a study in call centers in Britain to determine if the headsets were damaging the employees' hearing. The study included 150 call center operators that represented 15 call centers in financial services, shopping, and telecommunications. The researchers used the KEMAR fitted with small pinnae because they were representative of the size of the ears of the majority of the study population.⁽⁷¹⁾ The headsets were removed from ten operators per workstation during normal operation and placed on the KEMAR for a 15-minute period.⁽⁷¹⁾ The researchers concluded that the noise exposure of the call operators was less than 85 dBA and the risk of hearing loss was low.⁽⁷¹⁾

According to the American Speech-Language-Hearing Association (ASLHA) and the National Institute on Deafness and Other Communication Disorders (NIDCD), long or repetitive

exposure to sound at or above 85 dB is hazardous and can cause hearing loss.^(4, 5) The output level of earphones for portable media players (PMPs) and its role in noise-induced hearing loss (NIHL) has been an increasing concern,^(10, 72-76) and the KEMAR has been a useful tool in measuring the earphone output level for several researchers.^(72, 73, 75, 76) In 1987, Rice, Rossi, and Olina used the KEMAR to measure the preferred listening volume of over 60 PMP users.^(77, 78) The researchers found that approximately five percent of the PMP users preferred to listen at a nearly 90 dBA equivalent sound pressure level,^(77, 78) possibly increasing their risk of NIHL.^(4, 5) The sound level output of headphones of several commercially available compact disc players was measured by Fligor et al.⁽⁷²⁾ The KEMAR was used to measure the output levels of multiple types of headphones and the researchers determined the supra-aural headphones, resting on the ears, would reach the maximum allowable noise dose within approximately one hour of listening at 70% the maximum output level.⁽⁷²⁾

The left ear of the KEMAR 45 BA with IEC60711 coupler was used by Kahari et al. to measure 60 seconds of the PMP listening level of those passing through Stockholm Central Station.⁽⁷⁶⁾ The researchers spent 12 hours at the station, made 41 sound level measurements on the KEMAR, and found that ear buds were the preferred type of earphone. Based on the study results of Kahari et al., the KEMAR estimated that 71% of the subjects chose a listening level \geq 85 dB, 46% chose a listening level \geq 90 dB, and 17% chose a listening level \geq 95 dB.⁽⁷⁶⁾

Portnuff, Fligor, and Arehart used a KEMAR to investigate the relationship between volume control settings and output levels of multiple portable listening devices (PLDs). Five PLDs' and five earphones' output levels were investigated while playing five music genres.⁽⁷³⁾ The KEMAR was fitted with a hard rubber right pinna and a soft, silicone rubber left pinna and the researchers found that the softer pinna achieved a better fit during measurements.⁽⁷³⁾ The

output levels of the earphones were measured in the right and left ear of the KEMAR simultaneously and a one-way ANOVA identified a significant difference among the maximum output levels of the earphones when all music genres were considered ($F(4, 124) = 85.3$, $p < 0.001$).⁽⁷³⁾ The use of the KEMAR enabled Portnuff et al. to suggest that the PLDs could reach output levels that may increase the listener's risk of music-related hearing loss.

The KEMAR is not the only option for measuring noise exposure levels at the ear. Kennedy et al. compared on-road motorcycle helmet noise measured at the ear to results using an at-ear microphone on a polystyrene mannequin head in a wind tunnel simulation.⁽⁷⁹⁾ A significant difference was found between the flow conditions in the wind tunnel compared to the atmospheric flow conditions during the on-road measurements.⁽⁷⁹⁾ Discrepancies between the simulated and on-road results were explained by wind speed during the on-road testing, but simulation was successful in identifying the contributors (i.e. engine, windscreen, and helmet) to the at-ear sound sources.⁽⁷⁹⁾

After extensive review of the literature, the researchers concluded that the KEMAR is commonly used for researching in-ear sound levels, mainly for headphone use. It is also evident that this research operating the KEMAR with multiple helmet configurations to determine if the hockey helmet's visor length affects measured peak sound pressure levels from the whistle noise is innovative.

CHAPTER 3

“NOISE EXPOSURE AND TEMPORARY HEARING LOSS OF INDOOR HOCKEY OFFICIALS: A PILOT STUDY”¹

Summary

Indoor hockey officials may be at high risk of hearing loss at an earlier age because their noise exposures have not been evaluated and officiating may begin as early as 10 years of age. Officials of junior and collegiate hockey leagues in northern Colorado participated in noise dosimetry and pre and postgame pure-tone audiometry to determine if a ≥ 10 decibels (dB) decrease in hearing sensitivity resulted from noise exposures during the game. All of the officials ($n = 23$) were exposed to equivalent sound pressure levels ≥ 85 A-weighted decibels (dBA) and 65% were overexposed based on noise criteria set by the American Conference of Governmental Industrial Hygienists. Of the sampled officials, 10 of 18 demonstrated a ≥ 10 dB increase in hearing threshold, seven of whom included shifts in more than one ear and/or frequency and two of whom demonstrated a 15 dB shift. The results of this study suggest exposure to hazardous levels of noise and a possible increased risk for hearing loss among hockey officials.

¹Adams, K.L., A. Langley, and W. J. Brazile: Noise Exposure and Temporary Hearing Loss of Indoor Hockey Officials: A Pilot Study. *Journal of Environmental Health* 79(4): (2016). Reprinted with permission from the Journal of Environmental Health and the National Environmental Health Association.

Introduction

Exposure to hazardous levels of noise may cause hearing damage and may affect one's health, communication, and quality of life. Prolonged exposures to sounds of less than 75 decibels (dB) are not likely to cause hearing loss, yet repetitive exposures to sounds at or above 85 dB are hazardous, increase risk of hearing loss, and may cause permanent hearing loss.^(5, 43) Researchers have found that repeated exposure to hazardous noise levels eventually results in a temporary threshold shift (TTS) in hearing (e.g. tinnitus, fullness in head),⁽⁶⁾ and repeated TTSs may cause permanent shifts.⁽³⁾

Damage-risk criteria provide the basis for recommending occupational noise exposure limits based on noise level and exposure duration, assuming non-occupational noise levels are low enough to allow the ear to recover. The Occupational Safety and Health Administration (OSHA) permits an eight-hour time-weighted average (TWA) sound level of 90 dBA with a 5 dB exchange rate,⁽³²⁾ whereas the American Conference of Governmental Industrial Hygienists (ACGIH) recommend an eight-hour TWA sound level of 85 dBA with a 3 dB exchange rate.^(7, 33)

Various noise exposure studies have been conducted on the spectators and employees at sporting events.⁽¹⁶⁻¹⁸⁾ Researchers studying noise exposures of fans and ushers at two indoor hockey arenas found that fans and ushers at collegiate and semi-professional hockey games exceeded ACGIH noise exposure criteria.⁽¹⁷⁾ Investigators who assessed the noise exposures of fans and workers at various sized football stadiums found that 96% of workers and 96% of fans were considered overexposed, according to the ACGIH recommendations.⁽¹⁶⁾

There have been a limited number of temporary threshold shift studies for sports venues. Researchers performed a pure-tone audiometry study during the 2006 Stanley Cup and found the average noise exposure levels for each game above 101 dB and hearing thresholds of two

subjects deteriorated by 5 to 10 dB for most frequencies.⁽¹⁴⁾ Recently, researchers studied the intensity of noise exposure and hearing thresholds of attendees during basketball games at Utah State University and found that the hearing thresholds of the attendees deteriorated by 4.43 dB.⁽¹⁸⁾

Although spectators of various sports have been evaluated for noise exposure and temporary threshold shifts, sports officials have not been assessed, possibly to the detriment of their hearing. A review of the literature revealed that indoor hockey officials' noise exposure levels and temporary hearing losses have not been previously studied. This population of over 23,000 registered hockey officials, not including non-registered officials, is unique for various reasons: officiating may begin as early as 10 years of age,⁽²⁰⁾ noise exposures include sources on and off the ice (e.g. whistle, crowd noise), and the hockey game noise exposure is supplemental to any noise exposure experienced during the official's normal work day. The purpose of this pilot study was to determine if indoor hockey officials are exposed to hazardous levels of noise and whether or not they experienced a temporary hearing loss.

The pilot study was conducted at two small indoor hockey arenas in northern Colorado with less than 200 spectators in attendance. Investigators monitored the noise exposures of indoor hockey officials of the American Collegiate Hockey Association (ACHA) and the Western States Hockey League (WSHL) that officiated collegiate and junior league hockey games. Pre- and post-game audiometric tests were administered in areas adjacent to the ice arena. The results of this study may identify a population that may be at an increased risk of noise induced hearing loss (NIHL) at an early age and may reduce the future NIHL cases of hockey officials and officials of other sporting events.

Methods

Study participants included indoor hockey officials of the WSHL and ACHA who officiated junior and collegiate hockey games in two northern Colorado ice arenas during the 2013-2014 hockey season. All study participants were male and 21 years of age or older. All aspects of this study were conducted in compliance with a human subjects study protocol approved by Colorado State University's Institutional Review Board.

Audiometry

Audiometric tests were conducted on 18 hockey officials and administered November 2013 through January 2014. All officials completed a hearing history questionnaire and received an otoscopic exam prior to each pre-game hearing test. The questionnaire was used to determine the length of time since the last excessive noise exposure and non-occupational noise exposures (e.g. music, firearms). The otoscopic examination was conducted to identify conditions that could exclude the official from participation in the study (e.g. excessive cerumen, ruptured tympanic membrane). Areas used for audiometric testing were selected to best achieve acceptable background noise levels, as per Table D-1 of OSHA 1910.95 Appendix D. An exercise room, adjacent to the ice in arena I, and the stairwell closest to the officials' locker room in arena II were used for administering hearing tests. The background octave band sound pressure levels (SPLs) were measured at 500, 1000, 2000, 4000 and 8000 Hz, before and after the pre- and post-game hearing tests. Background ambient noise levels were measured using a CEL 383 sound level meter/octave band analyzer (SLM/OBA) (Milford, NH), which was pre- and post-calibrated with the CEL 282 calibrator at 114 dB to assure calibration was maintained.

Audiometric tests were performed by a Council of Accreditation in Occupational Hearing Conservation (CAOHC) certified researcher using an Earscan 3 ES3S pure-tone audiometer (Micro Audiometrics, Murphy, NC). A functional, “look and listen” calibration of the audiometer was performed prior to the first hearing test of each sampling day. The modified Hughson-Westlake Technique was used to manually test the threshold for each ear at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. The descending (10 dB) and ascending (5 dB) process was repeated until the official responded at a specific intensity at least 50% of the time at each of the frequencies. Post-game audiometry was conducted after the official’s departure from the ice.

Personal Noise Dosimetry

Personal noise dosimetry was conducted on twenty-three officials in January and February 2014. Each official was fitted with a Larson Davis, Model 706 RC (Provo, UT) noise dosimeter. The dosimeters were calibrated before and after sampling using a Larson Davis CAL 150 at 94 and 114 dB, and collected data was downloaded with the 2014 version J Blaze[®] software (Larson Davis, Provo, Utah). Noise sampling was performed in accordance with the OSHA Technical Manual (OTM), Section III, Chapter 5. The dosimeter was secured to each official before the start of the game. The microphone (including windscreen) was attached to the official’s shoulder or lapel on the dominant side (opposite the whistle hand). The microphone and cable were secured with adhesive tape in order to keep the microphone upright and the cable from snagging on players’ hockey sticks. Each official was instructed to not remove, tap or yell into the microphone and operating conditions of the dosimeter and microphone were confirmed and adjusted, if necessary, at each of the intermissions. The dosimeter was stopped and removed from the official after he exited the ice at the end of the game.

Statistical Analysis

SAS version 9.4 (SAS Institute, Cary, NC) was used to perform statistical analysis. Descriptive statistics were used to express the proportion of officials exceeding the 85 dB L_{eq} and the OSHA noise regulations and ACGIH recommendations. The proportion of officials who experienced a 10 dB or greater decrease in hearing sensitivity was determined. The non-parametric Wilcoxon signed-rank test was conducted on the pre- and post-game audiometric data at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz to determine if there were statistically significant differences between the pre- and post-game audiometry data.

Results

Audiometry

A total of 18 questionnaires were completed by the officials prior to the pre-game hearing test. The study participants were male and ranged from 21 to 65 years of age, with an average of 12.9 years (range 4-37 years) of officiating experience. When asked to report the source of their most recent noise exposure, 27.8% (5/18) reported hockey, and 11.1% (2/18) reported music. No recent noise exposure was reported by 61.1% (11/18) of officials.

Audiometric tests were conducted in the most feasible space adjacent to the ice rink in each arena. The background SPLs for each testing area were under the maximum allowable SPLs for audiometric test rooms for 2000, 4000 and 8000 Hz but exceeded the allowable limit at 500 and 1000 Hz.

Eighteen pre- and post-game hearing tests were conducted on 15 different officials. One official was sampled three times and another was sampled twice. An increase in hearing threshold of 10 dB or greater was exhibited in more than half (55.6%) of the sampled officials. Of those officials with the ≥ 10 dB decrease in hearing sensitivity, 70.0% experienced a threshold

shift in more than one ear and/or at more than one frequency, and 20% experienced a 15 dB threshold shift. The proportions of those officials with ≥ 10 dB deterioration of hearing thresholds in each ear at each of the tested frequencies are shown in Figure 3.1. The Wilcoxon signed-rank test was performed on the paired audiometry data because it was not normally distributed. Based on the results of the Wilcoxon signed-rank test, there were significant differences between the pre- and post-game hearing thresholds at 2000 Hz for the left ear ($p=0.012$) and at 4000 Hz for the right and left ears ($p=0.037$, $p=0.017$, respectively). The differences at the other frequencies for both ears were not significant ($p>0.05$).

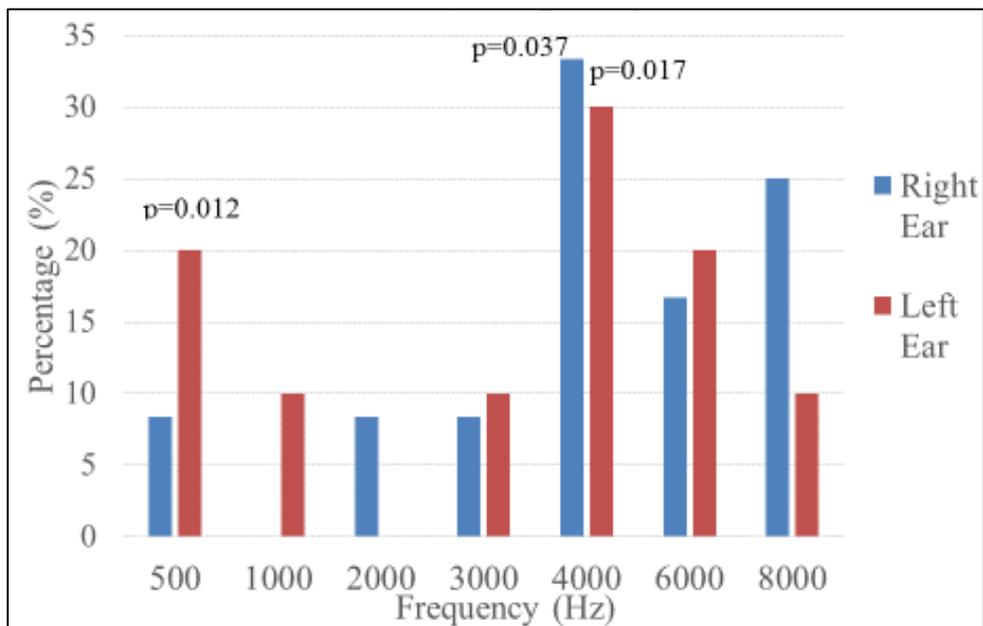


Figure 3.1: Pure-tone audiometry results: percentage of hockey officials with ≥ 10 dB increase in hearing threshold by frequency (n=18)

Personal Noise Dosimetry

Noise dosimetry was conducted during four hockey games at Arena I and two hockey games at Arena II. A total of 23 personal noise dosimetry samples were collected over an average hockey game time of two hours and 42 minutes (Table 3.1). The mean equivalent sound

pressure level (L_{eq}) and mean peak sound pressure level (L_{peak}) were 90 dBA and 133 dB, respectively. None of the officials were overexposed to noise based on the OSHA noise criteria, yet sixty-five percent of hockey officials were overexposed to noise based on ACGIH recommendations.

Table 3.1: 2013-2014 hockey official noise dosimetry results for arenas I and II*

Parameter	Noise Criteria			
	OSHA AL ^a		ACGIH TLV ^b	
	Mean	SD	Mean	SD
Dose (%)	19.2	5.63	119.9	96.3
L_{eq} (dBA)	90	2.13	90	2.13
TWA (dBA)	86	1.78	90	2.16
L_{max} (dBA)	115	4.5	115	4.5
L_{peak} (dB)	133	5.49	133	5.49

Notes: * n=23 officials

^a Dosimeter settings for OSHA Action Limit (AL) criteria include: A-weighting, slow averaging, 85 criterion level, 8-hour criterion time, 80 threshold level, 5 dB exchange rate

^b Dosimeter settings for ACGIH TLV include: A-weighting, slow averaging, 85 criterion level, 8-hour criterion time, 80 threshold level, 3 dB exchange rate

^c TWA for time sampled: average of 2 hours, 42 minutes

Discussion

Audiometry

The hearing history questionnaire was used to determine the length of time since the officials' last excessive noise exposure. Of the 18 officials queried, 11 (61%) reported no recent noise exposure, whereas five (28%) reported a previous hockey game as a noise exposure. In retrospect, it may have been more appropriate to ask the source and duration of the noise exposure within the last 48 hours, including sports officiating. Officiating more hockey games than documented or the increased background noise levels in the audiometric testing rooms may explain a higher pre-game hearing threshold (≥ 25 dB) found in 10 (56%) of the officials. The questionnaire should have included a question regarding the presence of TTS symptoms prior to and after the hockey game, similar to that done by researchers investigating the hearing loss associated with loud music exposure.⁽¹³⁾ Although the noise exposures from the officials' non-occupational/leisure noise exposures were not measured in this study, they are likely contributing to the official's overall noise exposure and associated symptoms, as supported in the literature review of noise exposures from leisure activities by Clark.⁽⁸⁰⁾

Pure-tone threshold shifts of 10 dB or greater were identified at all of the tested frequencies in one or both ears, with the largest percentage of shifts occurring at 4000 Hz. These results are similar to those found by Hodgetts and Liu during a Stanley Cup game.⁽¹⁴⁾ The researchers found a pure-tone shift of 5-10 dB for most of the tested frequencies, with one subject experiencing a 20 dB shift in one ear. However, the audiometric testing only occurred on two spectators in the Hodgetts and Liu study and the results may not be representative. The current study results are also consistent with those of several researchers who have used pure-tone audiometry to identify the presence of a TTS after exposure to loud music.^(13, 61) In

particular, the results and design of the Sadhra et al. study are similar to the current study in that it measured the noise exposure and hearing thresholds of employees in a noisy environment, not just the spectators/attendees. Sadhra et al. found that the correlation between TTS and personal exposure was higher at 4000 Hz and Le Prell et al. found the 4000 Hz “notch” that is typical of NIHL, after noise exposure from digital music players.

The differences between pre- and post-game hearing thresholds were significantly different at 4000 Hz in both ears and at 2000 Hz in the left ear. The Wilcoxon signed-rank test results were less powerful due to the small sample size and sampling officials multiple times occurred because only a small pool of 28-32 officials work the hockey games in northern Colorado. England et al. used t-tests with Bonferroni adjustments and found significant differences between pre- and post-game pure-tone audiometry at basketball games at all tested frequencies in both ears, except for the left ear at 1000 Hz and right ear at 6000 Hz. The inconsistency in results with the current study may be explained by the unfavorable audiometric testing conditions in the current study.

Background noise levels of audiometric testing areas did not meet the acceptable levels for 500 and 1000 Hz and the results at those frequencies may not be indicative of actual hearing thresholds since 61% of officials had pre-game hearing thresholds ≥ 25 dB at those frequencies. Limited funding, time, and instrumentation did not allow for optional testing environments or continual background noise measurements. The inconsistencies may also be due to several of the post-game hearing tests being conducted after more than 30 minutes after the game’s end, possibly underestimating the number of hearing threshold shifts. Ideally, the audiometric testing would occur in an audiometric testing booth that meets or exceeds the requirements outlined in

OSHA's Appendix D and within less time after the game since the ear begins to heal from a TTS in as little as a few minutes after removal of the noise source.^(41, 81, 82)

Previous researchers^(13, 18, 61) included a follow-up hearing test within 48 hours of the noise exposure and found that the TTS recovery was essentially complete with the first four hours after exposure. Unlike previous studies, the researchers were unable to coordinate a follow-up hearing test and assumed that the threshold shifts were only temporary. The study participants were notified to contact a physician if symptoms persisted for more than 48 hours.

Noise Dosimetry

All of the hockey officials that participated in this study were exposed to an L_{eq} greater than 85 dBA, with a mean L_{eq} of 90 dBA. The mean L_{eq} of 90 dBA in this study was similar to the mean L_{eq} of 85 dBA found by England et al. in basketball arenas, and within the L_{eq} range found by area monitoring at two indoor hockey venues by Cranston et al. During National Hockey League (NHL) playoff games, researchers found an L_{eq} range from 101 to 104 dBA (Hodgetts and Liu, 2006), which were greater than the L_{eq} found in the current study. The previous study had more attendees, as would be expected for a NHL Stanley Cup playoff, and crowd noise was most likely a contributing factor.⁽⁸³⁾

The researchers measured a mean L_{peak} of 133 dB in the current study that is consistent with the L_{peak} range (130-146 dB) found by Engard et al., yet higher than the area monitoring L_{peak} range of 105-124 dB at Venue 1 and 110-117 dB at Venue 2 found by Cranston et al. The variations between personal and area monitoring may explain the difference in results. Area sampling in the current study may have been beneficial in assessing the frequency spectra of the noise in various locations in the hockey arenas.

The researcher's findings that 65% of officials exceeded the ACGIH noise exposure criteria are consistent with the findings of Cranston et al. The researchers of the current and previous study concur in that none of the study participants exceeded the OSHA noise criteria. The Engard et al. study results support the current study's findings based on the ACGIH criteria, yet those researchers found that 20% of fans exceeded the OSHA PEL of 90 dBA. These differences may be the result of different arena/stadium acoustics, location of personal sampling and number of people in attendance.

For example, the current study included less than 200 spectators while the Engard et al. study included a range of 19,721 to 75,703 spectators. The larger crowd may have produced more noise, which may have increased the noise exposure levels in the Engard study.⁽⁸³⁾ It is also possible that the results from the smaller venue with fewer spectators underestimated the noise exposures of officials in larger arenas.

The hockey officials in the study often use officiating as supplementary income to their primary employment. Personal noise dosimetry data was only collected for the duration of the hockey game but the occupational noise criteria are based on an 8-hour work day. The researchers chose not to report results that compared to the OSHA or ACGIH 8-hour TWA because the calculations would have assumed that the officials' remaining noise exposure for the day was less than the threshold dB value, which is unlikely. For instance, other common noise sources integrated in a daily noise exposure may include noise from another job or occupation, music, hunting, power tools, and other sporting events, as is supported by Clark's review of literature of noise exposures from leisure activities.⁽⁸⁰⁾

Conclusions

This pilot study was the first step in evaluating the noise exposure and temporary hearing loss of indoor hockey officials. Preliminary surveys indicate engineering controls are not feasible and officials do not wear hearing protection. Exposure to hazardous levels of noise increases the risk of repetitive TTSs, which may increase the risk of permanent hearing loss. Based on the results of this study, indoor hockey officials are exposed to levels of noise that may result in repetitive TTSs and further research is warranted.

Future research should include noise monitoring at a larger venue, audiometric testing in a room with allowable background noise levels, and post-game audiometry within minutes of the game's end. Additional research has the potential to identify officials of other sporting events, regionally and nationally, who may be at an increased risk of NIHL. In an effort to reduce noise exposure, hockey officials should consider wearing hearing protection while officiating games.

CHAPTER 4

“A FACEOFF WITH HAZARDOUS NOISE: NOISE EXPOSURE AND HEARING THRESHOLD SHIFTS OF INDOOR HOCKEY OFFICIALS”²

Summary

Noise exposure and hearing thresholds of indoor hockey officials of the Western States Hockey League were measured to assess the impact of hockey game noise on hearing sensitivity. Twenty-nine hockey officials who officiated the league in an arena in southeastern Wyoming in October, November and December 2014 participated in the study. Personal noise dosimetry was conducted to determine if officials were exposed to an equivalent sound pressure level greater than 85 dBA. Hearing thresholds were measured before and after officiating hockey games to determine if a 10 dB or greater temporary threshold shift in hearing occurred. Pure-tone audiometry was conducted in both ears at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. All of the participants were exposed to an $L_{eq} \geq 85$ dBA over an average hockey game time of two hours and 48 minutes. The average L_{eq} , maximum sound pressure level (L_{max}), and L_{peak} were 93 dBA (SD= 2.2), 116 dBA (SD=2.8) and 134 dB (SD=5.0), respectively. Hearing threshold shifts of 10 dB or greater were observed in 86.2% (25/29) of officials, with 36% (9/25) of those

²Adams, K. L. and W. J. Brazile: A Faceoff with Hazardous Noise: Noise Exposure and Hearing Threshold Shifts of Indoor Hockey Officials. *Journal of Occupational and Environmental Hygiene*. DOI: 10.1080/15459624.2016.1225158 (2017). Reprinted by permission from the Journal of Occupational and Environmental Hygiene and the American Industrial Hygiene Association.

individuals experiencing threshold shifts that were 15 dB or greater. The largest proportion of hearing threshold shifts occurred at 4000 Hz, supporting the characteristic 4K notch of NIHL. The 4K notch was exhibited in 35.7% of the right ear shifts and 31.8% of the left ear shifts. The threshold shifts between the pre- and post-game audiometry were statistically significant in the left ear at 500 (p=.019), 2000 (p=.0009), 3000 (p<.0001), and 4000 Hz (p=.0002), and in the right ear at 2000 (p=.0001), 3000 (p=.0001), and 4000 Hz (p<.0001), based on Wilcoxon-ranked sum analysis. Although not statistically significant at alpha = 0.05, logistic regression indicated that with each increase of one dB of equivalent sound pressure measured from personal noise dosimetry, the odds of a ≥ 10 dB TTS were increased in the left ear at 500 (OR=1.33, 95% CI 0.73-2.45), 3000 (OR=1.02, 95% CI 0.68-1.51), 4000 (OR=1.26, 95% CI 0.93-1.71) and 8000 Hz (OR=1.22, 95% CI 0.76-1.94) and in the right ear at 6000 (OR=1.03, 95% CI 0.14-7.84) and 8000 Hz (OR=1.29, 95% CI 0.12-13.83). The officials blew their whistles on the left side of the mouth which may contribute to the findings that the left ear had more identifiable TTSs than the right ear. These findings suggest that indoor hockey officials are exposed to hazardous levels of noise and experience temporary hearing loss after officiating games, and a hearing conservation program is warranted. Further temporary threshold shift research has the potential to identify officials of other sporting events that are at an increased risk of noise-induced hearing loss.

Introduction

Noise is ubiquitous and, in excessive levels, may cause irreversible sensorineural hearing loss. Several researchers have established that the severity of hearing loss is dependent on noise intensity and duration of exposure, and the susceptibility to noise-induced hearing loss (NIHL) varies among individuals.⁽¹⁻³⁾ It has been reported that 15% of Americans between the ages of 20 and 69 years old have permanent hearing loss and 16% of worldwide hearing losses are

attributed to occupational noise exposure.^(4, 8) Noise exposure may also be detrimental to quality of life and cause stress, disruption of sleep, hypertension, and/or fatigue. NIHL may contribute to communication difficulties later in life, the inability to hear environmental sounds, and possibly increase the occurrences of safety-related injuries and illnesses.

In addition, excessive noise exposures from recreational environments may cause NIHL. According to the World Health Organization (WHO), noise exposure in recreational settings is a growing concern.⁽¹⁰⁾ Noise exposure has been assessed in several recreational environments, including concerts, discotheques and live sporting events.⁽¹²⁻¹⁵⁾ Exposure to sounds ≤ 75 dBA have not been found to be detrimental to hearing thresholds, yet exposure to sounds ≥ 80 dBA for longer durations have been found to cause a decrease in hearing sensitivity.⁽⁸⁴⁾ Occupational exposure limits (OEL) for noise are based on exposure duration and noise level, assuming non-occupational noise levels are low enough to allow the ear to recover. The more conservative OEL of an eight-hour time-weighted average (TWA) sound level of 85 dBA with a 3 dB exchange rate is recommended by the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH).^(7, 33) However, researchers have found that exposures to sounds at or above 85 dB are hazardous, increase risk of hearing loss, and may cause permanent hearing loss.^(4, 5)

Investigators have also found that repeated exposure to hazardous noise levels may result in a temporary threshold shift (TTS) in hearing, with symptoms including ringing in the ears (tinnitus) and/or a feeling of fullness in the head, with full recovery within 48 hours.^(4, 6) TTSs have been found to be a risk indicator that permanent NIHL may occur if exposure to hazardous noise continues.⁽³⁾ It is also important to recognize that occupational and recreational noise exposures resulting in a TTS at an early age may result in cochlear nerve degeneration, which

results in permanent, age-related hearing loss at an earlier age than expected.^(1, 11) Effects of recreational noise exposure on young adults were evident in a study of undergraduate students at East Carolina University. The investigators found that the highest percentages of students with self-reported ear pain, hearing loss, permanent tinnitus and noise sensitivity participated in sporting events.⁽³⁵⁾

The characteristic audiometric pattern for hearing loss resulting from exposure to hazardous levels of noise is the 4000 Hz “notch” (4K notch). NIHL is characteristically presented by an increase in hearing threshold at 4000 Hz or 6000 Hz, widening to adjacent frequencies as exposure continues. Regardless of the frequency spectrum of the noise exposure, individuals will develop hearing loss in the 4000 Hz region if exposed to hazardous levels of noise.^(1, 62)

Minimal research has been conducted on the noise exposure of spectators and employees at sporting events.⁽¹⁶⁻¹⁸⁾ Those studying noise exposures of fans and ushers at two indoor hockey arenas found that fans and ushers at collegiate and semi-professional hockey games exceeded ACGIH noise exposure criteria.⁽¹⁷⁾ Investigators who assessed the noise exposures of fans and workers at various sized football stadiums found that 96% of workers and 96% of fans were considered overexposed, according to the ACGIH recommendations.⁽¹⁶⁾ There have been a limited number of temporary threshold shift studies for sports venues. Researchers performed a small study during the 2006 Stanley Cup and found that the average noise exposure levels were above 101 dB and the hearing thresholds of two subjects deteriorated by 5 to 10 dB for most frequencies.⁽¹⁴⁾ More recently, investigators studied the intensity of noise exposure and hearing thresholds of attendees during collegiate basketball games at Utah State University and found that the hearing thresholds of the attendees deteriorated by 4.43 dB.⁽¹⁸⁾

Review of the literature indicates that sports officials' noise exposure and associated temporary hearing loss have not been investigated. Although Flamme and Williams investigated the noise exposure from officials' whistle signaling and identified they may be at an increased risk of NIHL, personal noise dosimetry was not conducted.⁽²¹⁾ Whistle use is dependent on the officials' management of the game (e.g., infractions, timeouts, goals) and is a unique noise source because it is repeatedly blown in close proximity to the ear. Flamme and Williams studied the acoustic characteristics of several whistle models and determined the amount of time the whistles could be blown to equal 100% noise dose, using the NIOSH criteria. The total whistle signaling times necessary to reach the OEL ranged from 5 to 90 seconds, dependent on whistle model, with some whistles registering equivalent sound pressure levels of 116 dB at the ear.⁽²¹⁾

Indoor hockey officials' noise exposure and associated temporary hearing loss were assessed in a pilot study by the current researchers.⁽⁸⁵⁾ The pilot study consisted of personal noise dosimetry and pre- and post-game audiometry of those who officiated collegiate and junior league hockey games in two small indoor hockey arenas in northern Colorado. All of the officials sampled in the pilot study were exposed to an equivalent sound pressure level (L_{eq}) > 85 dBA and 55.6% of sampled officials exhibited a ≥ 10 dB increase in hearing threshold. Limitations in the pilot study were identified and improved in the main study but precluded the use of pilot study data in this manuscript.

There are tens of thousands of amateur and professional hockey officials, with over 23,000 of them registered with USA Hockey. The hockey official population is unique because officiating may begin as early as 10 years of age,⁽²⁰⁾ noise exposure from the hockey game is supplemental to any noise exposure experienced during the officials' regular work day, and noise

exposures at the hockey game include those from sources on and off the ice rink. Examples of noise sources on the ice include: impact noise from the stick-on-puck and puck-on-plexiglas[®] contact, player body-checking, and whistle noise. The noise exposures off the ice are similar to those of spectators and employees in the arena, including crowd noise, public address system, music, and noise-makers. Since hockey officials may begin officiating in adolescence, exposure to hazardous levels of noise may begin at an early age and result in premature permanent age-related hearing loss.⁽¹⁾

The purpose of this study was to determine the proportion of indoor hockey officials that are exposed to an L_{eq} greater than 85 dBA, and whether or not they experience a temporary hearing loss. The number of whistle blows per official was estimated to determine the total time the officials were exposed to whistle noise. The results of this study may lead to the surveillance of a population that is at an increased risk of NIHL at an early age, as well as officials of other sporting events.

Methods

All facets of this study occurred at a 2000-seat capacity ice arena located in southeastern Wyoming, October through December, 2014. The study population included male, indoor hockey officials of Western States Hockey League (WSHL), aged 21 – 42 years. The study participants officiated for a Tier III junior hockey team at the arena. The study protocol was approved by the Institutional Review Board of Colorado State University.

Personal noise dosimetry and pre- and post-game audiometry were conducted on indoor hockey officials during 10 games of the 2014 hockey season. The number of spectators was documented at the end of the second period for each game and was based on ticket sales. The number of times an official blew the whistle was recorded during the first period of four games.

The data were used to estimate the total number of whistle blows during each game in order to estimate the contribution of whistle noise to the officials' total noise exposure. The number of whistle blows counted in the first period was multiplied by three to estimate the total number of whistle blows in a game. All statistical analyses were performed using Statistical Analytical System (SAS) version 9.4 (Cary, North Carolina).

Audiometry

Hearing thresholds were determined during 10 indoor hockey games with manual pure-tone audiometry, using an Earscan 3 ES3S Pure Tone Audiometer (Micro Audiometrics Corporation, Murphy, NC). The audiometric tests were administered to twenty-nine officials before and after officiating a hockey game. Prior to each pre-game hearing test, all officials completed a hearing history questionnaire, adapted from the U.S. Public Health Service/Federal Occupational Health Audiogram History Report.⁽⁸⁶⁾ The questionnaire was used to determine the length of time since the last perceived loud noise exposure within the last 48 hours, the duration of the noise exposure, and other data regarding the officials' hearing history and non-occupational noise exposures. The official also received an otoscopic (Welch Allyn, Skaneateles Falls, NY) exam, with visual inspection of the pinna, ear canal and tympanic membrane of both ears to rule out pathological conditions that could exclude the official from participation in the study.

Pure-tone audiometry must be conducted with an audiometer and transducer that meet the specifications of audiometers found in ANSI S3.6-2004 American National Standards Institute, 2004b). The transducers and earphones are specific to the audiometer and are dictated by the testing required. Appendix C of the OSHA noise standard lists the requirements for the audiometric measuring instruments and their calibration.⁽³²⁾ Functional audiometer calibrations

must be conducted each day before administering a hearing test. An example of the functional calibration that was conducted on the audiometer used in this study before each day of use is found in Appendix B. An acoustic calibration consisting of intensity, linearity, and frequency checks is required in alternating years with the exhaustive calibration, which is a more extensive evaluation of the instrumentation.⁽⁸⁷⁾ A pure-tone audiometer with circumaural earphones having an accuracy of +/- 1 dB⁽⁸⁸⁾ was used in accordance with the instrumentation requirements mentioned above.⁽²⁷⁾

A researcher certified by the Council of Accreditation in Occupational Hearing Conservation administered the otoscopic exam and audiometric tests. The modified Hughson-Westlake Technique was used to manually test the hearing threshold for each ear at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. A 10 dB tone was presented through the circumaural headphones at each frequency and the 5 dB ascending and 10 dB descending process was repeated until the official responded to the lowest decibel level at least one half of the time. At a minimum, two out of three responses at a single decibel level were required to identify a threshold of hearing. Audiometric exams were conducted before the game and within approximately twenty minutes after the official's departure from the ice. The hearing test instructions for the study participants and the methodology used to administer the hearing tests are found in Appendices C and D, respectively.

An accurate hearing test requires that the background noise level in the testing booth or room be less than or equal to the maximum allowable octave-band sound pressure levels for audiometric test rooms as stated in Appendix D-1 of the OSHA noise standard or the ANSI S3.1 2008 standard,⁽³²⁾ as seen in Table 4.1. The ANSI S3.1 permissible ambient noise levels are more stringent than those of the OSHA noise standard for audiometric test rooms. This research

was in compliance with the OSHA noise standard requirements. An example of the form used to document background noise of the audiometric testing area used in this research is found in Appendix E.

Table 4.1: OSHA and ANSI maximum allowable octave band sound pressure levels for audiometric test rooms

Octave band center frequency (Hz)	500	1000	2000	4000	8000
OSHA 1910.95 Standard SPL (dB)	40	40	47	57	62
ANSI S3.1 Standard SPL (dB)	19.5	26.5	28.0	34.5	43.5

Pure-tone audiometric testing was conducted in the Model 252 Series Mini Shelter (Industrial Acoustics Company (IAC), Lincoln, Nebraska). The booth was located in a temperature-controlled storage room, adjacent to the ice arena. The background octave band sound pressure levels (SPLs) were recorded inside the booth at 500, 1000, 2000, 4000 and 8000 Hz, before and after the pre- and post-game hearing tests, using a Larson Davis Model 824 Precision Sound Level Meter (SLM) and Real Time Analyzer (Provo, Utah). The SLM was calibrated before and after the game at 94 dB and 114 dB with a CAL200 Precision Acoustic Calibrator (Larson Davis, Provo, Utah). The measurements were obtained to assure compliance with the maximum permissible ambient noise levels for audiometric test rooms, as per the Occupational Safety and Health Administration (OSHA) Noise Standard.⁽³²⁾

Personal Noise Dosimetry

Personal noise monitoring was conducted on twenty-nine officials using Larson Davis Personal Noise Dosimeters, Models 706 RC and 703+ (Provo, Utah). Each dosimeter was calibrated before and after sampling at 94 dB and 114 dB, using a CAL150 Precision Acoustic Calibrator (Larson Davis, Provo, Utah). Calibration and exposure data were downloaded using

2014 version J Blaze[®] software (Larson Davis, Provo, Utah). Noise measurements were conducted in accordance with the OSHA Technical Manual (OTM), Section III, Chapter 5. The dosimeter was secured to each official prior to the start of the game and removed at the game's end. The microphone with attached windscreen was secured on the shoulder or lapel of the official's jersey on the dominant side, opposite the side with the hand holding the whistle. The researcher instructed each official to not remove, tap or yell into the microphone and checked functionality of the dosimeter and microphone placement at each intermission.

Personal noise dosimetry data were collected for the duration of the hockey game. The researchers chose not to compare the noise dosimetry results of this study to the 8-hour occupational noise criteria because the calculations would have assumed that the official's remaining noise exposure for the day was less than the threshold dB value, which is unlikely. Although each dosimeter collected simultaneous dose measurements with the OSHA action limit (AL) and ACGIH threshold limit value (TLV) parameters, with 5 dB and 3 dB exchange rates, respectively, the researchers chose to report L_{eq} .

Statistical Analysis

SAS version 9.4 (SAS Institute, Cary, NC) was used to perform statistical analysis. Descriptive statistics were used to express the proportion of officials exceeding the 85 dB L_{eq} and the OSHA noise regulations and ACGIH recommendations. The proportion of officials who experienced a 10 dB or greater decrease in hearing sensitivity was determined. The paired pre- and post-game audiometry data did not meet the parametric requirements and the Wilcoxon signed-rank test was conducted to determine if there were statistically significant differences between the pre- and post-game audiometry data.

Logistic regression was used to evaluate the association between noise level and change in hearing sensitivity of ≥ 10 dB. The association was examined in separate logistic regression models at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Repeated measures within person were accounted for and the small sample size and low power inhibited the examination of effect modifiers.

Results

The attendance for the 10 hockey games ranged from 237 to 589 spectators, with an average of 446 (SD=117.8). Study participants ranged from 21 to 42 years of age, with an average of 8.9 years of officiating experience (ranging from 4 to 21 years). None of the officials were excluded upon otoscopic exam. Forty-five percent (13/29) of the study participants reported excessive noise exposures within the last 48 hours, ranging from 15 minutes to nine hours in duration. Of those who reported an excessive noise exposure, five (38.5 percent) reported music, and five (38.5 percent) reported hockey as the source of noise. A history of firearm use was reported by five officials and no officials self-reported a history of hearing loss. The estimated number of whistle blows in a game ranged from 150 to 210 times in the four games sampled, with an average of 180 (SD=25) blows. A statistically significant association was not found between average whistle blows and average L_{eq} in the first four games.

Audiometry

The SPLs were measured at 500, 1000, 2000, 4000 and 8000 Hz inside the audiometric testing booth before and after the pre- and post-game hearing tests. All SPLs were below the maximum allowable SPLs for audiometric test rooms, as outlined in the OSHA noise standard.⁽³²⁾

Twenty-nine pre- and post-game hearing tests were conducted on 13 different officials. Participation was dependent on official scheduling and resulted in multiple samples collected on eight officials. An increase in hearing threshold of 10 dB or greater was exhibited in 25 of 29 (86.2 percent) sampled officials with nine of the 25 (36 percent) experiencing a 15 dB or greater threshold shift. A ≥ 10 dB threshold shift in both ears was found in eight of the 25 (32 percent) shifts and 14 of 25 (56 percent) threshold shifts exhibited a shift in multiple frequencies. A summary of the total number of ≥ 10 dB threshold shifts in each ear at tested frequencies is displayed in Table 4.1. Six officials exhibited a mild hearing impairment (26-40 dB hearing threshold) at the pre-game hearing test yet still experienced a ≥ 10 dB threshold shift, half of which experienced a ≥ 15 dB threshold shift. The median hearing thresholds (dB) in the right and left ears of the hockey officials before and after the game are graphically displayed in Figures 4.1 and 4.2, respectively.

Table 4.2: Occurrence of ≥ 10 dB threshold shifts in hockey officials by frequency

Frequency (Hz)	Right Ear (% Total)	Left Ear (% Total)
500	2 (3.9)	1 (2.0)
1000	0 (0)	0 (0)
2000	3 (5.9)	3 (5.9)
3000	5 (9.8)	3 (5.9)
4000	10 (19.6)	7 (13.7)
6000	5 (9.8)	5 (9.8)
8000	3 (5.9)	4 (7.8)

Based on the results of the Wilcoxon signed-rank test, there were significant differences between the pre- and post-game hearing thresholds at 2000, 3000, and 4000 Hz for the right ear

($p \leq 0.0001$) and at 500, 2000, 3000, and 4000 Hz for the left ear ($p = 0.0099$, $p = 0.0009$, $p < 0.0001$, $p = 0.0002$, respectively).

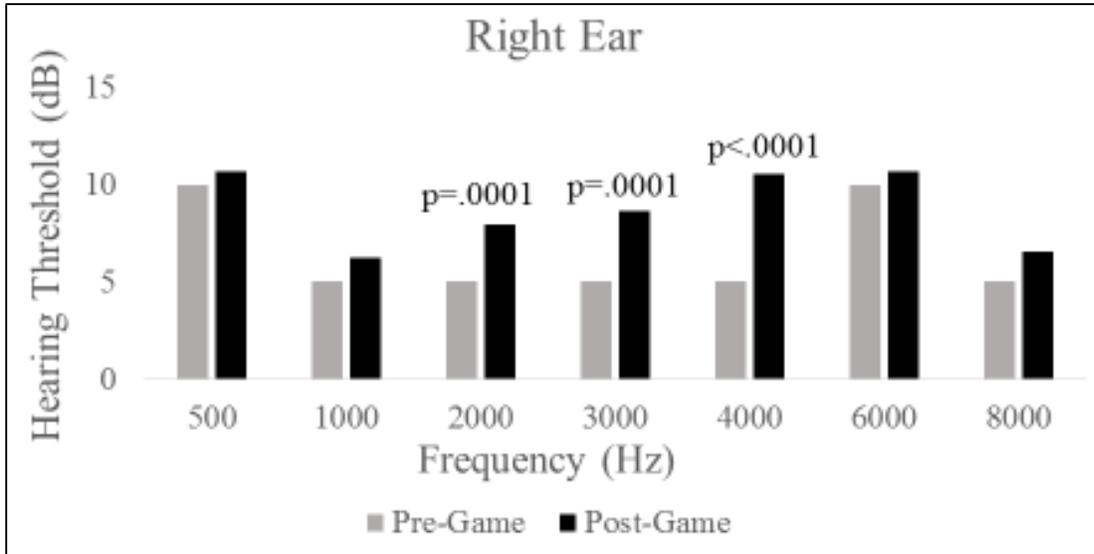


Figure 4.1: Hockey officials' median hearing thresholds (dB) in right ear before and after officiating game (n=29)

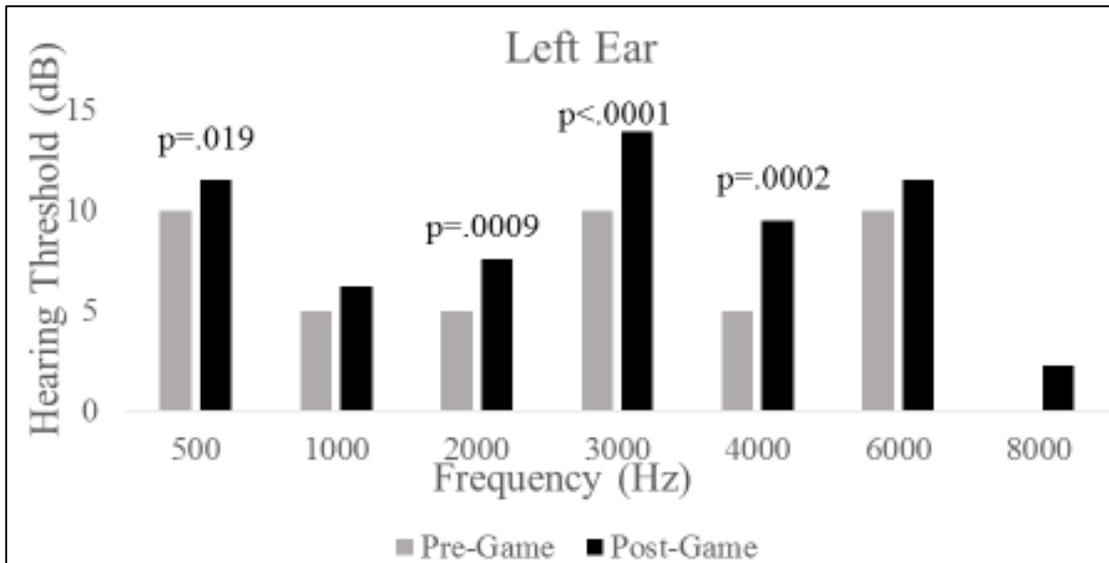


Figure 4.2. Hockey officials' median hearing thresholds (dB) in left ear before and after officiating game (n=29)

Personal Noise Dosimetry

Twenty-nine personal noise dosimetry samples were collected over an average hockey game time of two hours and 48 minutes. The average L_{eq} , maximum sound pressure level (L_{max}), and peak sound pressure level (L_{peak}) were 93 dBA (SD= 2.2), 116 dBA (SD=2.8), and 134 dB (SD=5.0), respectively. A summary of personal noise dosimetry results is displayed in Table 4.2.

Table 4.3: 2014 Hockey Official Personal Noise Dosimetry Results (N=29)

Parameter	Noise Criteria			
	OSHA AL ^a		ACGIH TLV ^b	
	Mean	SD	Mean	SD
Dose (%)	27.3	7.0	181.6	94.6
L_{eq} (dBA)	93	2.2	93	2.2
TWA (dBA) ^c	89	1.7	92	2.2
L_{max} (dBA)	116	2.8	116	2.8
L_{peak} (dB)	134	5.0	134	5.0
8-hour TWA (dBA)	81	1.7	88	2.1

Notes:

^a Dosimeter settings for OSHA Action Limit (AL) criteria include: A-weighting, slow averaging, 85 criterion level, 8-hour criterion time, 80 threshold level, 5 dB exchange rate

^b Dosimeter settings for ACGIH TLV include: A-weighting, slow averaging, 85 criterion level, 8-hour criterion time, 80 threshold level, 3 dB exchange rate

^c TWA for time sampled: average of 2 hours, 48 minutes

The threshold shifts between the pre- and post-game audiometry were statistically significant in the left ear at 500 (p=.019), 2000 (p=.0009), 3000 (p<.0001), and 4000 Hz (p=.0002) and in the right ear at 2000 (p=.0001), 3000 (p=.0001), and 4000 Hz (p<.0001), based

on Wilcoxon-ranked sum analysis. Logistic regression with repeated measures within person (multiple observations per person, not just the pre-game to post-game audiometry) was used to examine the association between L_{eq} and a ≥ 10 dB increase in hearing threshold from pre- to post-game audiometry, in separate models at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Fixed effects included noise exposure and side (left or right) and random effects included official. Although none of the results of the logistic regression analysis were statistically significant at $\alpha = 0.05$, for each additional one dB increase of L_{eq} , the odds of a ≥ 10 dB TTS are multiplied by 33% for the left ear at 500 Hz, 2% for the left ear at 3000 Hz, 26% for the left ear at 4000 Hz, 3% for the right ear at 6000 Hz, 22% for the left ear at 8000 Hz, and 29% for the right ear at 8000 Hz. Please refer to Table 4.3 for the logistic regression results summary.

Table 4.4: Odds ratio of ≥ 10 dB increase in hearing threshold from pre- to post-game audiometry due to 1 dBA increase of equivalent sound pressure level (L_{eq}) measured with personal noise dosimetry

Frequency (Hz)	Ear	OR	95% CI
500	L	1.33	0.73-2.45
	R	0.40	0.02-7.69
2000	L	0.84	0.51-1.39
	R	0.64	0.09-4.39
3000	L	1.02	0.68-1.51
	R	0.71	0.10-4.96
4000	L	1.26	0.93-1.71
	R	0.58	0.17-1.96
6000	L	0.99	0.67-1.16
	R	1.03	0.14-7.84
8000	L	1.22	0.76-1.94
	R	1.29	0.12-13.83

Discussion

The hearing history questionnaire was used to gather noise and hearing background information. The medical history and other non-occupational noise exposure data from the questionnaire were not reported in the manuscript because of reporting inconsistencies among those officials sampled multiple times. Although reporting inconsistencies were found, the six participants who exhibited mild hearing impairment during the pre-game hearing test did not self-report a hearing loss. While the questionnaire results pertaining to the source of loud noise and duration of exposure within the last 48 hours were reported, the researchers understand that the data collected may not be completely accurate. In contrast, Balanay and Kearney found that the highest percentages of self-reported hearing-related symptoms (e.g., pain, tinnitus, hearing loss) were from those students involved in sporting events.⁽³⁵⁾ The current study's hearing history questionnaire should have inquired about TTS symptoms experienced before and after the game on the day of sampling, similar to that done by researchers investigating the hearing loss associated with exposure to loud music.⁽¹³⁾ The history of TTS symptoms was queried, but it may have been more important to know the current symptoms in order to determine if those officials who had mild hearing impairment prior to the hockey game were experiencing a TTS or a permanent impairment. It was not feasible for the researchers to measure the officials' occupational and recreational noise exposures in this study, but they are likely contributing to the official's overall noise exposure and associated symptoms, as supported in the literature review of noise exposures from leisure activities by Clark.⁽⁸⁰⁾ The small study population and inconsistencies in the officials' responses regarding medical history and other non-occupational noise exposures on the questionnaire made it difficult for the researchers to find statistically

significant correlations between hearing thresholds and other recreational noise exposures (e.g., firearms, head injury).

The estimated number of whistle blows in a game ranged from 150 to 210 times. Assuming all of the officials used the Fox 40[®] Super Force[®] finger grip pea whistle that was used by most of the officials sampled, a study by Flamme et al. estimated that it would take 12 seconds of whistle noise to reach 100% noise dose, as per the NIOSH noise criteria.⁽²¹⁾ If the estimated average of 180 blows were 200 milliseconds (msec) in duration, similar to the duration of signals in the Flamme and Williams study, the officials would be exposed to 36 seconds of whistle noise, resulting in almost three times the allowable time.⁽²¹⁾ Assuming the officials were only exposed to whistle noise at the hockey game, which is unlikely, they would only be allowed to blow the above mentioned whistle 60 times at 200 msec intervals. Researchers found that the number of times the whistle was blown in one period was relatively close to the allowable number of whistle blows for the entire game, making it nearly impossible to stay below the allowable dose for whistle noise. An obvious limitation in this portion of the study includes the estimation of the actual number of whistle blows in the entire game, based on the number of signals in the first period of the game. Variability in number and duration of whistle blows is dependent on the officials' management of goals, time-outs, violations, substitutions, injuries, face-offs, and other aspects of the game.⁽²⁰⁾ Due to the variability of whistle blows and small sample size in this study, the results reported may not be representative of the number of signals found during hockey games of varying leagues and skill level.

Audiometry

Six officials exhibited a mild hearing impairment (26-40 dB audiometric threshold) at the pre-game hearing test and were still included in the study, similar to several Brazilian disc

jockeys who participated in a study by Santos et al.⁽⁵⁸⁾ It was found that all of the officials with pre-existing hearing impairment experienced a ≥ 10 dB threshold shift, with half of them experiencing a ≥ 15 dB threshold shift, and five of them exhibiting a 4K notch. Three of the six officials with pre-game hearing loss reported excessive noise exposure within 48 hours of the audiometry and may have been experiencing symptoms of a TTS, based on the findings that full recovery from a TTS may take up to 48 hours after removal from the noise exposure.^(4, 64) It is possible that the three officials who reported previous excessive noise exposure were experiencing a TTS at the time of pre-game audiometry, but researchers in this study were unable to confirm TTS recovery.

The researchers found statistically significant differences between the pre- and post-game hearing thresholds at 500 Hz in the left ear and 2000, 3000, and 4000 Hz for the right and left ear ($p < 0.001$). The largest percentage of shifts occurred at 4000 Hz (35.7 % of right ear shifts, 31.8% of left ear shifts), supporting an audiometric 4K notch that is characteristic of NIHL. England et al. used t-tests with Bonferroni adjustments and found significant differences between pre- and post-game pure-tone audiometry at basketball games at all tested frequencies in both ears, except for the left ear at 1000 Hz and right ear at 6000 Hz.⁽¹⁸⁾ The significant difference between the pre-and post-game hearing thresholds for the hockey officials in the present study is also supportive of those threshold shifts reported by researchers of spectators in other recreational environments.^(14, 18, 57) The current study results are consistent with those of several researchers who have used pure-tone audiometry to identify the presence of a TTS in employees.^(13, 56, 61) Sadhra et al. found that the correlation between TTS and personal exposure was highest at 4000 Hz,⁽¹³⁾ and Le Prell et al. found the 4K notch that is typical of NIHL, after noise exposure from digital music players.⁽⁶¹⁾ Although the researchers in the current study did not

find a significant correlation between TTS and noise exposure, the largest percentage of TTSs occurred at 4000 Hz, in both ears. It is plausible that the disparate results were due to the small sample size or the later timing of the post-exposure audiometric test in the current study.

The Wilcoxon signed rank test was used to determine that the differences between pre- and post-game hearing thresholds were significantly different at 500 Hz in the left ear and 2000, 3000, and 4000 Hz in both ears, as supported by the statistical analysis of several researchers investigating TTSs after noise exposures.^(56, 57, 60) England et al. used t-tests with Bonferroni adjustments of audiometry data from basketball games and found significant differences between pre- and post-game pure-tone audiometry at all of tested frequencies in both ears, except for the left ear at 1000 Hz and right ear at 6000 Hz.⁽¹⁸⁾ The difference in results with the current study may be the result of differing testing conditions, parametric versus non-parametric statistical analysis, or the timing of post-audiometric testing.

Post-game audiometry was conducted as soon as the officials exited the ice but researchers were limited by the use of one audiometer, possibly underestimating the number of hearing threshold shifts since it has been found that a 2-5 dB recovery, or increase in hearing sensitivity, may occur in as little time as it takes to test one ear.⁽⁸⁹⁾ The implication of such healing may underestimate of the proportion and severity of the TTSs recorded in the current study. Sadhra et al., England et al., and Le Prell et al. included a follow-up hearing test within 48 hours of the noise exposure and confirmed a temporary threshold shift.^(13, 18, 61) Idota et al. and the researchers in the current study were unable to confirm a full recovery from the TTS because a follow-up hearing test was not feasible. A follow-up hearing test may have confirmed the hearing losses as permanent or temporary, alerting the official of the need for follow-up care

with a physician. The study participants in the current study were notified to contact a physician if TTS symptoms persisted for more than 48 hours.

Noise Dosimetry

Personal noise monitoring was conducted for the duration of the hockey game, averaging two hours and 48 minutes. Within the sampling time, hockey officials received an average of approximately 20% of their daily noise dose, according to OSHA criteria. All of the officials were exposed to an $L_{eq} > 85$ dBA (88 dBA – 97 dBA), with a mean L_{eq} of 93 dBA (SD=2.2), which support the mean L_{eq} of 90 dBA found in the pilot study by Adams et al.⁽⁸⁵⁾ Researchers have found similar personal noise exposure levels in other recreational venues with music as the primary source of exposure. For instance, Sadhra et al. monitored part-time student bar and security staff in three areas used for musical entertainment and found an average L_{eq} of 90 dBA and L_{peak} of 113 dB among bar staff and an average L_{eq} of 94 dBA and L_{peak} of 124dB among security staff, concurring with the current study. Idota et al. monitored twelve employees who wore earphones to communicate in facilities containing pinball and slot machines and found a mean personal exposure L_{eq} of 92.1 dBA, very similar to the L_{eq} of the current study.⁽⁵⁶⁾

Similar noise exposure levels have been found by researchers of other sports venues. For instance, Engard et al. found that the L_{eq} ranged from 91 to 95 dBA for workers and fans in football stadiums, Ramma et al. found the L_{eq} ranged from 85.3 to 98.9 dBA for spectators of two South African Premier Soccer League (PSL) matches, and Swanepoel and Hall found the mean L_{eq} was 100.5 dBA for spectators of a South African PSL match at a FIFA training stadium.^(16, 59, 60) England and Larsen conducted personal noise monitoring on attendees at 10 intercollegiate basketball games, finding an average L_{eq} of 84.6 dBA, which is lower than the current study's average L_{eq} of 93 dBA. The discrepancy between the current and previous

studies' findings may be due to differing noise sources and sampling periods. For instance, an average basketball game time (1:59) is typically less than the average hockey game time (2:48). The mean L_{peak} of 134 dB (SD=5.0) in the current study is also consistent with the L_{peak} range of 130 to 146 dB found by Engard et al., and the range of 130.6 to 143.1 dB found by England and Larson.^(16, 18)

The relatively small variations in the noise dosimetry among the studies may be the result of different noise sources, arena/stadium acoustics, location of personal sampling and number of people in attendance. The current study recorded attendance of hockey games with 237 to 589 spectators while the Engard et al. study included a range of 19,721 to 75,703 spectators. The larger crowd may have generated more noise, which may have increased the noise exposure levels in the Engard study. It is also possible that the results from the smaller venue with fewer spectators underestimated the noise exposures of officials in larger arenas.

The current study was conducted during three months of a Tier III junior hockey team season at one ice arena and the population was limited to those officials in the WSHL. The results of this study may not be representative of noise exposures and associated hearing loss of hockey officials in arenas of differing hockey leagues, attendance, spectator characteristics, and acoustics. A larger study population, including officials exposed to < 85 dBA, may have exhibited a statistically significant relationship between the officials' noise exposure (L_{eq}) and the presence of a ≥ 10 dB temporary threshold shift in hearing.

Conclusions

The researchers in this and the pilot study were the first to evaluate the noise exposure and temporary hearing loss of indoor hockey officials. All of the hockey officials were exposed to a $L_{\text{eq}} > 85$ dBA, with an average L_{eq} of 93 dBA (SD= 2.2) and 86.2% of the officials

experienced a ≥ 10 dB increase in hearing threshold after officiating the game, with 36% of the threshold shifts equaling 15 dB or greater. A ≥ 10 dB threshold shift was found in both ears of 32% of the officials and at multiple frequencies in 56% of the officials. The largest percentage of hearing threshold shifts occurred at 4000 Hz, supporting the characteristic audiometric 4K notch of NIHL. The hockey official blew the whistle an estimated average of 180 times and it would only take a total of 12 seconds of whistle noise to reach 100% noise dose, according to the results of the Flamme and Williams study.⁽²¹⁾

Based on the results of this study, indoor hockey officials are exposed to levels of noise that result in TTSs, which may increase their risk of permanent NIHL and further research is warranted. The noise exposure from the hockey game is supplemental to any noise exposure experienced during the officials' regular work day and should be included when determining the total noise exposure of the official. The noise dosimetry results, based on the ACGIH criteria, indicate that the officials may already be exceeding their daily allowable noise dose (181.6%) from exposure to the noise levels during the hockey game. In an effort to reduce noise exposure, hockey officials are encouraged to wear hearing protection that offers protection from the noise sources and allows for communication while officiating games. Future research should include noise monitoring and pre- and post-game audiometry on hockey officials at larger venues, particularly those hosting semi-professional and professional hockey games. Follow-up audiometry should be conducted after 48 hours of officiating to confirm if identified hearing loss is temporary.

Further research has the potential to identify amateur and professional officials of other sporting events, regionally and nationally, that are at an increased risk of NIHL. Although the

results of this study are unable to recover or repair the hearing loss that has already occurred in hockey officials, it will hopefully thwart further or future hearing damage.

CHAPTER 5

“A SIMULATION OF HOCKEY OFFICIAL WHISTLE NOISE AND USE OF KEMAR TO EVALUATE THE EFFECT OF HELMET VISOR LENGTH ON EXPOSURE TO WHISTLE NOISE”³

Summary

The effect of the helmet visor length on the sound pressure level of whistle noise to which hockey officials are exposed was evaluated to determine if visors may introduce a reflective plane for the whistle noise, resulting in increased noise exposure. A Knowles Electronic Manikin for Acoustic Research (KEMAR) head and torso assembly with a left ear microphone, in conjunction with the Larson Davis Sound Level Meter (SLM)/Octave Band Analyzer (OBA), was used to measure the peak sound pressure levels from the noise generated from whistle blowing. The KEMAR was equipped with a Bauer 4500 hockey helmet and three visor configurations for the study: no visor, 2.75” visor, and 4.0” visor. A Fox 40[®] Super Force[®] finger grip pea whistle was mounted adjacent to the manikin’s mouth and attached to a portable air compressor to produce approximately 115 dB of whistle noise. The whistle noise was measured in an empty indoor ice arena in northern Colorado and the KEMAR assembly was placed on the ice in the five, face-off spots. The whistle was blown five times in each location with a total of 25 samples for each helmet configuration. Measured peak noise levels in the

³Adams, K. L. and W. J. Brazile: A Simulation of Hockey Official Whistle Noise and Use of KEMAR to Evaluate the Effect of Helmet Visor Length on Exposure to Whistle Noise. (2016). Unpublished Manuscript.

manikin ear were significantly different between the helmet/visor configuration with the long (4.0”) visor and the other configurations ($p < 0.05$). The measured peak noise levels were not significantly different between the helmet without a visor and with the shorter, 2.75” visor ($p > 0.05$). Results suggest that longer helmet visors may act as a reflective plane for whistle noise and increase hockey officials’ noise exposure. Understanding that longer visors may increase the officials’ noise exposure from whistle noise may provide insight for better design of helmet visors in the future.

As the researchers were collecting data only on the relative sound levels among helmet/visor configurations, the head-related transfer function (HRTF) was not applied. Researchers utilizing the KEMAR to estimate personal noise exposure levels must apply the HRTF to data in adherence to ISO 11904-2:2004 for the determination of sound emission from sound sources placed close to the ear.⁽⁹⁰⁾

Introduction

USA Hockey is the governing body for organized amateur ice hockey in the United States and the National Hockey League (NHL) is the governing body for professional ice hockey in the United States and Canada. For the purpose of this study, the authors will refer to the recommendations and rules set forth by USA Hockey and followed by the officials of the Western States Hockey League (WSHL), unless otherwise noted. There are over 23,000 officials registered with USA Hockey, however registration is not required. Additionally, ice hockey officials may begin officiating as early as ten years of age, depending on state child labor laws.⁽²⁰⁾

Ice hockey has inherent hazards and risks for the players as well as the officials. It is an intensely physical sport with the probability of contact among players and contact with hockey

sticks, pucks, boards, and skate blades.^(91, 92) The hazards of ice hockey are numerous, with the most common injuries associated with the head, eyes, and face. It has been reported that a higher incidence of injury occurs during competition, rather than practice,^(92, 93) which is when the hockey officials are on the ice to enforce the rules of the game and maintain order.

Several studies have been conducted regarding injuries in sports, with more focus placed on head and neck injuries in ice hockey.^(92, 94-96) More specifically, the review of literature revealed that research of ice hockey-related injuries has been primarily concerned with concussions, brain injuries, and spinal injuries.^(94, 95, 97, 98) In 2000, more than 42,000 sport or recreation-related eye injuries were reported,⁽⁹⁹⁾ yet only a limited number of researchers have investigated eye and face injuries in ice hockey.^(92, 94, 95)

Personal protective equipment (PPE) has been developed to protect an individual against injury and other adverse effects occurring at, or away from, work. The purpose of PPE in ice hockey is to protect against hazards, yet not interfere with the game or cause injuries.^(95, 100) Beginning in 2013-2014, all players with less than 25 games of NHL experience are required to wear a helmet with a visor, yet officials are only required to wear a league-approved helmet.⁽¹⁰¹⁾ Per USA Hockey rules, the officials' PPE includes a black hockey helmet with a half-shield visor properly attached, and a chin strap properly fastened.⁽¹⁰²⁾ Although the visor is required for the officials' eye and face protection, only one study was found that investigated the effect of a hockey visor and sports goggles on field of vision.⁽¹⁰³⁾

Occupational noise exposures have been studied in industries such as construction,⁽¹⁰⁴⁾ mining,⁽¹⁰⁵⁾ and steel fabrication,⁽¹⁰⁶⁾ but noise exposure studies of sporting events are limited. Noise exposures of spectators and employees outside the game area have been studied by several researchers,^(16, 17, 59, 60) yet the referees and officials on the playing surface have only been studied

by Adams et al., and Masullo et al.⁽¹⁹⁾ It is important to recognize the difference in noise exposures of the spectators and officials because of the close proximity of the official to the whistle, a point source of noise.

Noise from a point source in a free-field is considered non-directional and radiates noise equally in a spherical pattern.⁽²⁴⁾ However, a noise source is typically in proximity to various reflective surfaces, (e.g. walls, floors) which will concentrate the noise pressure waves in particular directions rather than allow radiation uniformly in all directions. The noise source location in relation to the reflecting surfaces, and the directionality of the noise source itself must both be considered when assessing the sound pressure levels associated with the noise. A directivity factor is assigned to the pattern of noise radiation based on the various surfaces surrounding the noise source.⁽²⁴⁾ For those surfaces surrounding the noise source, intensity of the sound pressure level (SPL) doubles, or adds 3 dB for every surface added.

Noise from a point source near a concave surface may cause noise reflections to be concentrated in one area, or focal point, rather than being dispersed (Figure 5.1).⁽²⁴⁾ An increased sound pressure level of noise is experienced by listeners located in the focal point of the reflected noise. Reflected noise may also reflect along a concave surface, conveying delayed reflected noise around a room. The point source in the current study is the official's whistle. The helmet visor, when attached to the helmet, introduces a concave, reflective surface near the whistle. The researchers studied the effect of the reflective surface of the visor on the resulting noise exposure at the ear produced by blowing a whistle.

Hockey officials are responsible for enforcing the rules of the game and use their hands and a whistle as signaling devices. The pea whistle is the type of whistle most commonly sold to those officials registered with USA Hockey.⁽²⁰⁾ Specifically, the Fox40 Finger grip with a

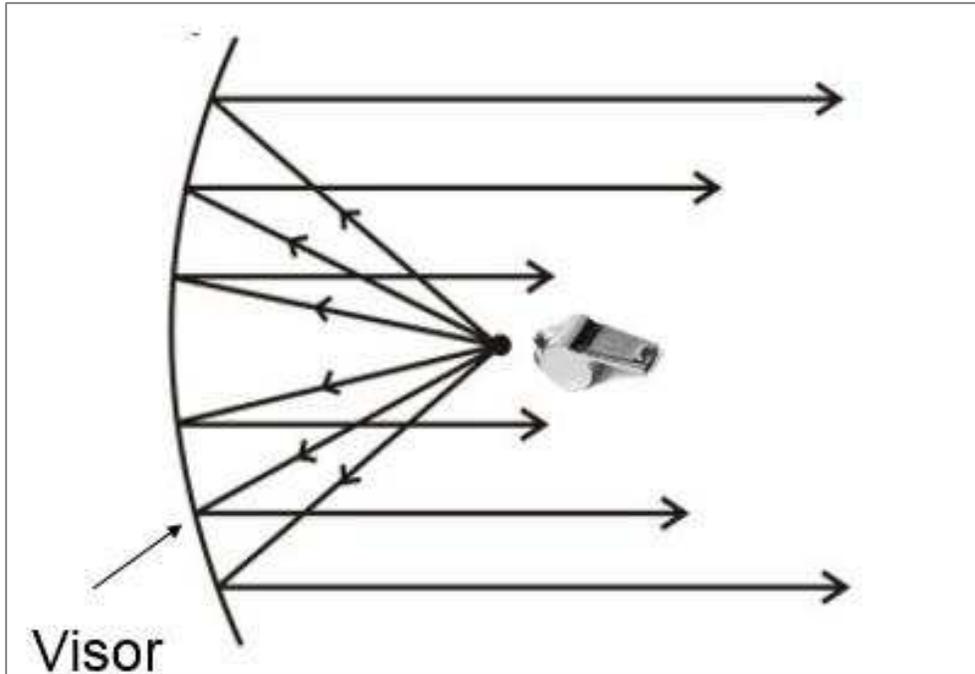


Figure 5.1: Whistle Noise Source Near a Reflective Concave Surface (www.dronstudy.com)

moisture resistant sound ball is the whistle most commonly used by the officials of the WSHL. A whistle without a sound ball delivers a more monofrequency tone, which may be difficult to discern in a hockey game. Therefore, the trilling sound of a sound-ball whistle is used to alert players as needed by the official.⁽¹⁰⁷⁾

Personal noise dosimetry is the most accepted method to measure the noise exposure of officials, but personal dosimetry does not allow for isolation of the whistle noise. In order to isolate the whistle noise and determine if the visor may affect the whistle's contribution to hockey officials' noise exposure, a Knowles Electronic Manikin for Acoustical Research (KEMAR) was used to simulate a hockey official blowing the whistle on the ice. The KEMAR (Figure 5.2) has been used by researchers to simulate in-situ measurements of hearing aids and to investigate individual ear acoustics in hearing aid prescriptions.^(69, 108)



Figure 5.2: Knowles Electronic Manikin for Acoustical Research (KEMAR) Type 45 BA

The researchers of the current study took a novel approach by using the KEMAR to determine if the protective eyewear for hockey officials results in increased noise exposure due to the visor producing a reflective plane for a point source (whistle). The researchers compared the peak sound pressure levels (L_{peak}) of whistle noise measured in the left ear of the manikin wearing a helmet without a visor and with 2.75 inch and 4.0 inch visors to determine if there is a significant difference in the mean L_{peak} among the helmet/visor configurations. The results of this study may serve as an initiative for revising the future design and production of hockey officials' eye protection.

Methods

A vacant NHL-sized ice rink in northern Colorado was used for this study. The rink is 200 x 85 feet with seating for 200 spectators and is currently used for public skating, hockey clinics, and figure skating clinics.⁽¹⁰⁹⁾ The noise measurements were taken July 14, 2014 at the four end zone face-off spots and the center ice face-off spot. The helmet and visors utilized in the study was representative of that worn by WSHL officials working in northern Colorado and southeastern Wyoming. The operating temperature parameters of the study instrumentation encompassed the temperatures recorded during the study in the ice arena.

Manikin

The KEMAR is an anthropomorphic manikin that was used to simulate in-situ noise measurements of indoor hockey officials. A G.R.A.S Sound and Vibration (Twinsburg, OH) 45BA KEMAR head and torso simulator, fitted with a 43AG Left Ear Simulator with a large left anthropometric pinna, and a Type 26 AC preamplifier with an IEC 711 coupler was used in accordance with the British Standard International Organization for Standardization (ISO) EN 11904-2:2004 for the determination of sound emission from sound sources placed close to the ear (Figures 5.3a-d).⁽⁹⁰⁾

Following manufacturer guidance, the right ear opening of the KEMAR was occluded with a foam ear plug (Figure 5.3d) and a cotton hand towel was placed inside the head orifice to reduce or eliminate any reverberation of noise in the head of the manikin during measurements.

A Class 1 Larson Davis Model 824 Precision Sound Level Meter (SLM) and Real Time Analyzer (Provo, UT) was used to measure L_{peak} of the whistle sound. The whistle noise was

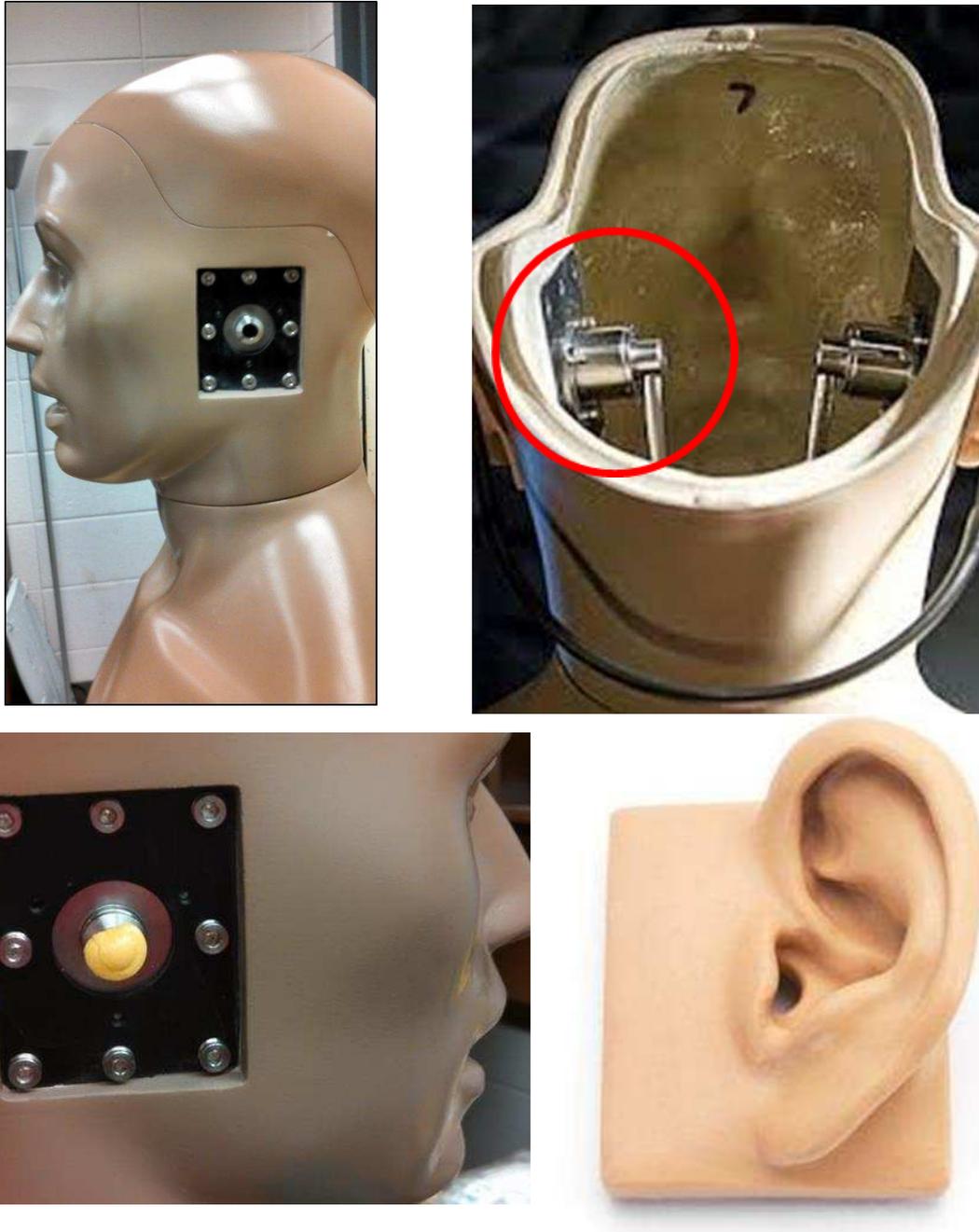


Figure 5.3: KEMAR manikin attributes (clockwise from top left) a. 43 AG left ear simulator for the KEMAR Type 45 BA; b. Type 26 AC preamplifier with an IEC 711 coupler for the KEMAR Type 45 BA; c. left ear pinna for the KEMAR Type 45 BA; d. right ear simulator of KEMAR Type 45 BA occluded with foam ear plug for duration of monitoring (www.gras.com)

measured in only one ear of the KEMAR due to funding constraints. The ear was chosen as the authors had previously determined that, regardless of dominant hand side, WSHL officials held

the finger grip whistle in the left hand and blew it on the left side of the mouth.⁽⁸⁵⁾ The ear microphone was removed from the manikin and directly calibrated with the Larson Davis CAL 200 primary calibrator (Provo, UT). The Larson Davis SLM recorded the calibration of the ear microphone. Calibration was conducted before and after the sampling at 94 and 114 dB off the ice rink.

Whistle-blowing Apparatus

A Fox 40[®] Super Force[®] finger grip pea whistle (Niagara Falls, NY) was used to generate the whistle noise. The selected whistle was representative of the whistle used and approved by the WSHL officials, NHL, and USA Hockey.^(20, 101) The whistle was secured adjacent to the manikin's mouth with a cast iron support and a three-prong clamp (Figure 5.4a). Silicon tubing was used to attach the whistle to a Husky brass blow-gun (The Home Depot[®], USA), that had a quarter inch female national pipe thread air inlet (Figures 5.4b-d). The blow-gun was attached to a 6-gallon, 2 horsepower Campbell Hausfeld portable air compressor (Harrison, OH) with easy-connect fittings. A Husky low-pressure regulator and gauge (The Home Depot[®], USA), 160 pounds per square inch (psi) maximum pressure, was connected to the air compressor. The air pressure was regulated at 18-20 psi to produce approximately 115 dB of whistle noise.

The KEMAR assembly included a portable air compressor and the following items placed on a plastic service cart: manikin, whistle apparatus, and the Larson Davis SLM/OBA (Figure 5.5). The cart and attached air compressor were placed on the five-faceoff locations on a Northeastern Colorado ice hockey rink. The sampling locations are exhibited in Figure 5.7, with the KEMAR assembly facing away from the closest boards and approximately one foot (12 inches) from the faceoff spots. The KEMAR assembly was placed at the center ice faceoff spot facing away from the players' benches, towards the spectator stands. The faceoff locations were

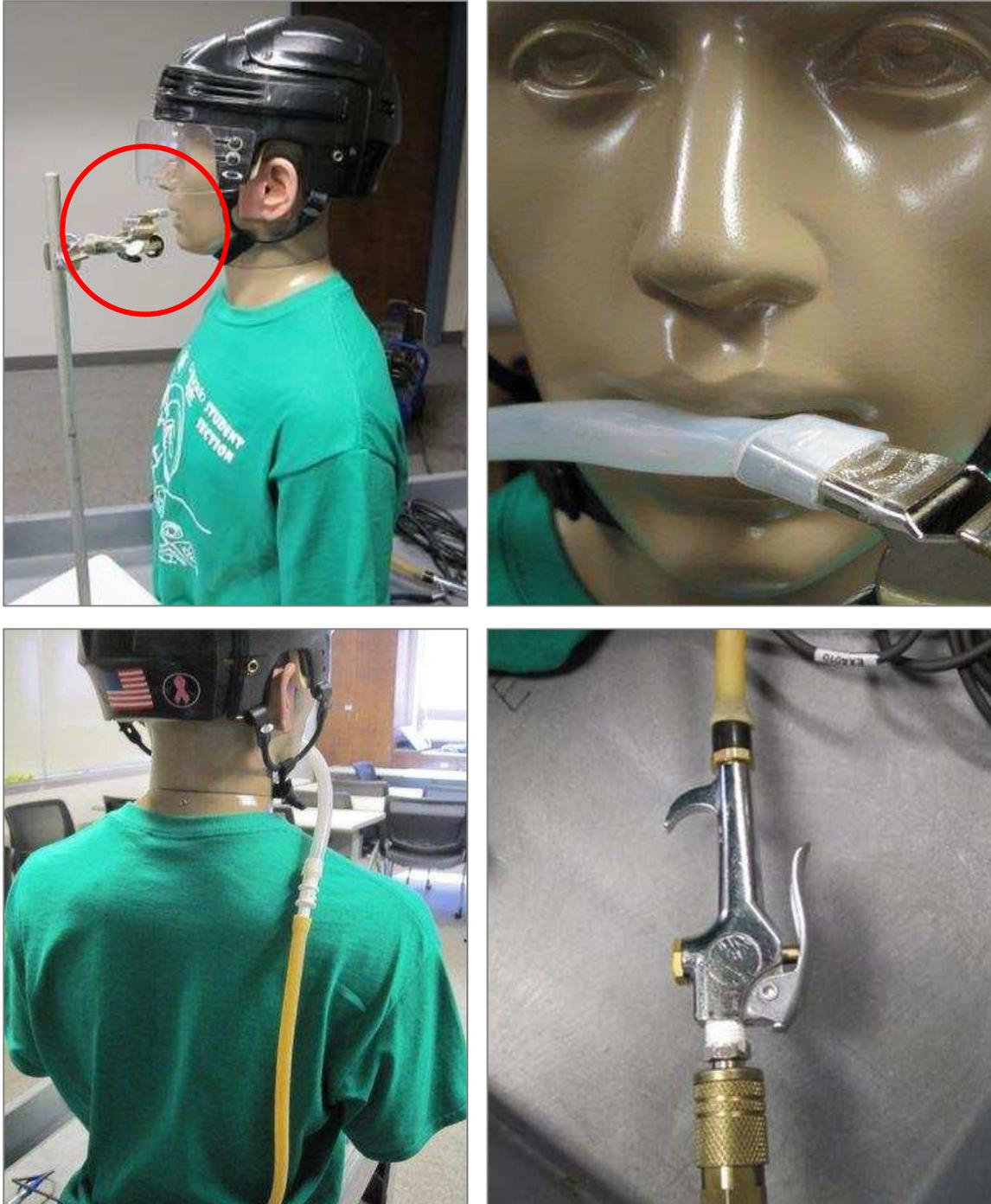


Figure 5.4: KEMAR whistle noise simulator (clockwise from upper left) a. Fox 40[®] Super Force[®] finger grip pea whistle mounted on stand and placed near mouth of KEMAR Type 45 BA; b. silicon tubing connecting whistle near KEMAR Type 45 BA mouth to compressed air source; c. blow gun trigger assembly located on cart behind KEMAR Type 45 BA; d. silicon and rubber tubing connecting Fox 40[®] Super Force[®] finger grip pea whistle to blow-gun

chosen as the sampling locations because they are the known areas where the officials will blow the whistle.

Prior to measuring L_{peak} at the faceoff locations, the whistle output was confirmed at 115 dB (SD=1) by measuring L_{peak} four feet in front of the whistle and approximately five feet above the ice. The whistle output was measured with a CEL 383 integrating SLM (Severna Park, MD) that was calibrated before and after the sampling with a CEL 282 acoustic calibrator (Severna Park, MD).



Figure 5.5: KEMAR sampling assembly (left) a. side view of KEMAR Type 45 BA assembly fitted with a Bauer hockey helmet, Fox 40[®] Super Force[®] finger grip pea whistle apparatus, and the Larson Davis SLM/OBA; (right) b. front view of KEMAR assembly located on the ice at a northern Colorado ice rink

Helmet Configurations

The researchers used a Bauer[®] 4500 hockey helmet with the translucent ear covers removed, as was representative of the helmet configuration the WSHL officials used in the authors' previous study.⁽⁸⁵⁾ Three helmet configurations were used in the current study: a

helmet without a visor (Figure 5.6a), with a 2.75" Oakley (Allen, TX) VR904 modified straight small visor with slots (Figure 5.6b), and with a 4.0" Oakley (Allen, TX) VR924 CLE pro straight with vents visor (Figure 5.6c). A random number generator was used to determine the order of helmet configurations and face-off spot locations. One helmet configuration was sampled at each of the randomly selected five face-off spots (Figure 5.7) prior to changing the helmet configuration. The Fox 40[®] Super Force[®] finger grip pea whistle was blown for a duration between 250 and 350 milliseconds (msec), a total of five times in each location, with a total of 25 samples for each helmet configuration.



Figure 5.6: Hockey helmet configurations (left to right): a. Bauer[®] 4500 hockey helmet without a visor; b. Bauer[®] 4500 hockey helmet with a 2.75" Oakley[®] VR904 modified straight small visor with slots; c. Bauer[®] 4500 hockey helmet with a 4.0" Oakley[®] VR924 CLE pro straight visor with vents

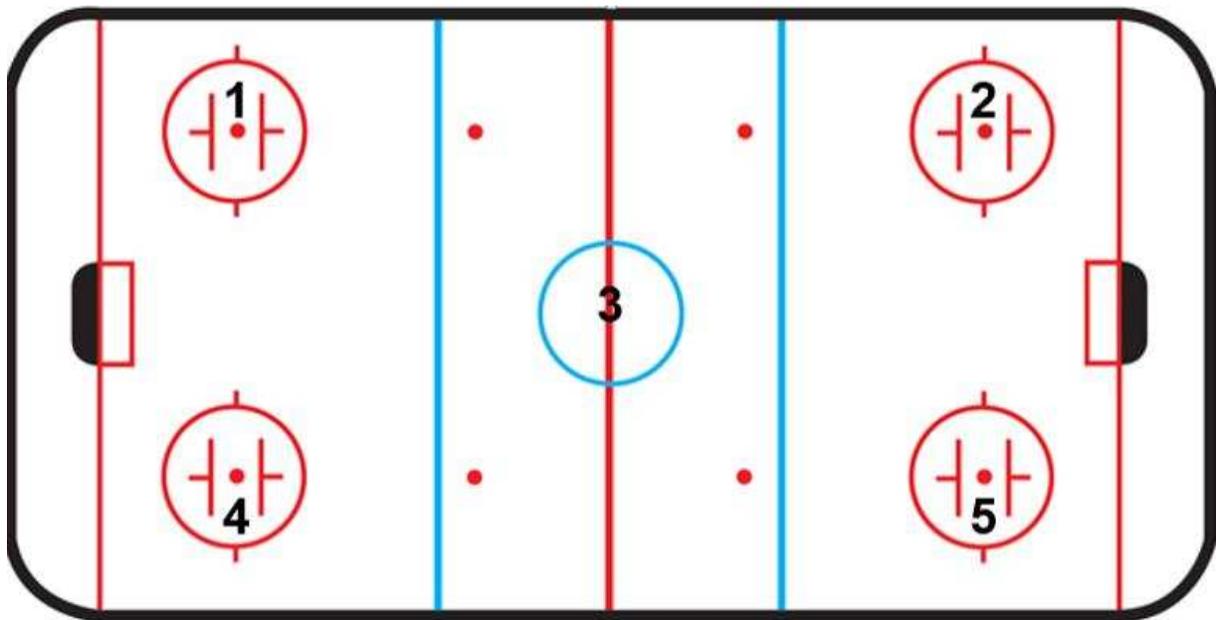


Figure 5.7: Diagram of a hockey ice rink sample locations ([hockeyshare, 2016](http://hockeyshare.com))

Statistical Analysis

Statistical analysis was conducted using SAS version 9.4 (SAS Institute, Cary, NC) and descriptive statistics expressed the mean and standard deviation of the L_{peak} measured in the left ear of the manikin with each of the helmet configurations. Linear regression evaluated the association of the L_{peak} measured in the left ear of the manikin with each of the helmet configurations. The independent variable represented the three different helmet/visor configurations: 1) helmet only (no visor); 2) helmet with short (2.75") visor; and 3) helmet with long (4.0") visor. The dependent variable was the L_{peak} measured at the left ear of the KEMAR.

Results

The descriptive summary of the mean peak whistle noise is provided in Table 5.1. The assumptions for linear regression were tested and met. The difference in the mean L_{peak} was significant ($p < 0.001$) between the no visor / long visor and short visor / long visor configurations. The summary of linear regression results is displayed in Table 5.2.

Table 5.1: Mean peak whistle noise measured in the left ear of the KEMAR

Helmet/Visor Configuration	Location	Peak (dBA) Min. - Max	Peak (dBA) Mean (SD)	Peak (dBA)/Helmet Configuration Mean (SD)
No Visor	1 (n=5)	117 - 118	118 (0.4)	117 (0.3)
	2 (n=5)	118 - 118	118 (0.0)	
	3 (n=5)	116 - 117	117 (0.5)	
	4 (n=5)	118 - 118	118 (0.0)	
	5 (n=5)	117 - 117	117 (0.0)	
Short Visor (2.75")	1 (n=5)	117 - 118	118 (0.4)	118 (0.8)
	2 (n=5)	117 - 118	118 (0.4)	
	3 (n=5)	117 - 117	117 (0.0)	
	4 (n=5)	117 - 118	118 (0.4)	
	5 (n=5)	117 - 117	117 (0.0)	
Long Visor (4.0")	1 (n=5)	121 - 122	122 (0.4)	121 (1.1)
	2 (n=5)	120 - 121	121 (0.4)	
	3 (n=5)	119 - 120	120 (0.4)	
	4 (n=5)	121 - 121	121 (0.0)	
	5 (n=5)	122 - 123	123(0.5)	

Table 5.2: Summary of linear regression results: Differences between the mean L_{peak} for the visor lengths (alpha=0.05)

Visor Length Comparison	Difference Between Means	p value	95% CI
None – Short	-0.32 dBA	0.1558	-0.76 - 0.12
Long – None	3.96 dBA	<0.0001	3.52-4.40
Long - Short	3.64 dBA	<0.0001	3.20-4.08

Discussion

The results indicated that helmet visor length contributed to whistle-blast noise exposure at the manikin’s left ear. In both helmet/visor configurations including a visor, the mean L_{peak} measured at the left ear of the manikin was greater than the mean L_{peak} measured with only a helmet (no visor). The difference in the mean L_{peak} was significant ($p<0.001$) between the no visor / long visor and the short visor / long visor configurations, but not between the no visor / short visor configuration. The attachment of the visor to the helmet introduces a reflective plane in the proximity of the whistle noise source causing more noise to reflect back to the official. The longer visor provides a greater reflective surface for the whistle noise source. In addition, this surface extends further down vertically from the helmet resulting in the bottom edge of the surface being closer to the noise source and occluding more of the space in front of the official’s face. The amount of sound pressure reflected to the manikin’s ear appears to increase based on the length of the visor which would increase the reflected noise. The current study with the longer visor attached to the helmet showed an increase of sound pressure level of approximately three dBA ($p<0.001$) above the helmet configuration with no visor.

The design of the human ear canal makes it difficult to quantify the eardrum’s exposure to noise. For instance, the ear canal resonates or dampens the sound pressure level transmitted to

the eardrum, depending the frequency.⁽²⁴⁾ In the 1960's, researchers Shaw and Teranishi began to experiment with simulated human ear anatomy to measure the eardrum's receipt of the sound pressure from a point source.⁽¹¹⁰⁾ They used a probe microphone to measure the sound pressure levels at varying frequencies in a rubber replica of the human ear canal and compared it to the measurements in six human ears⁽¹¹⁰⁾. The results of the study indicated that the ear replica was representative of the sound pressure level received at the human ear in the frequency range of 1000 to 7000 Hz, but the data were not supported statistically⁽¹¹⁰⁾ and further development of head and ear simulation was conducted.

More recently, Kennedy et al. compared on-road motorcycle helmet noise measured at the ear to results using an at-ear microphone on a polystyrene mannequin head in a wind tunnel simulation.⁽⁷⁹⁾ A significant difference was found between the flow conditions in the wind tunnel compared to the atmospheric flow conditions during the on-road measurements.⁽⁷⁹⁾ Discrepancies between the simulated and on-road results were explained by wind speed during the on-road testing, but simulation was successful in identifying the contributors (i.e. engine, windscreen, and helmet) to the at-ear sound sources.⁽⁷⁹⁾ If the researchers in the current study were using the KEMAR to measure simulated noise exposure levels of hockey officials, similar discrepancies due to wind noise would likely occur because of the rapid movement of the officials on the ice. However, the authors were only investigating the contribution of the helmet visor length on exposure to whistle noise.^(22, 24)

Multiple head and torso simulators are available, but the acoustical properties and facial features similar to the average human made the KEMAR appropriate for the researchers in the current study. The KEMAR was the first anthropometric head and torso simulator designed specifically for acoustic research in 1972 and was primarily used to determine the efficacy of

hearing aids.⁽⁶⁹⁾ While the KEMAR manikin has ear canals that approximate the average adult ear canal, Saunders and Morgan⁽¹¹¹⁾ found that the individual ear canal acoustics may result in as much as a 40 dB difference among individuals, thus supporting the earlier findings of Shaw and Teranishi.⁽¹¹⁰⁾ The KEMAR is designed to simulate the sound waves as they pass around a human head and torso, such as the diffraction and reflection of sound waves around each ear.⁽⁶⁹⁾ The KEMAR allowed the authors to simulate a hockey official on the ice, isolate the whistle noise, and determine the effect of the visor length on the official's exposure to whistle noise.

In 2008, Chung et al. used a KEMAR to investigate the effects of directional microphones on the ability of hearing aid users to localize speech. The manikin was fitted with bilateral in-the-ear hearing aids including microphones with adjustable directivity.⁽⁷⁰⁾ The researchers found that matched directional microphones worn bilaterally do not have a negative effect on the ability to localize speech.⁽⁷⁰⁾

Researchers have also had to rely on the KEMAR to measure the listening volume of headsets, or earphones, and estimate the users' noise exposure. Patel and Broughton conducted a study in call centers in Britain to determine if the headsets were damaging the employees' hearing. The study included 150 call center employees that represented 15 call centers in financial services, shopping, and telecommunications. The researchers used the KEMAR fitted with the small pinnae, because they were representative of the size of the ears of the majority of the study population.⁽⁷¹⁾ The headsets were removed from ten operators per workstation during normal operation and placed on the KEMAR.⁽⁷¹⁾ Noise measurements were taken for a 15-minute period with the use of a splitter, to not interrupt the work of the operator. Similar to the current study methodology, measurements were only made at the left ear and the right ear was sealed to prevent sound from reaching the microphone.

According to the American Speech-Language-Hearing Association (ASLHA) and the National Institute on Deafness and Other Communication Disorders (NIDCD), long or repetitive exposure to sound at or above 85 dB is hazardous and can cause hearing loss.^(4,5) The output level of earphones for portable media players (PMPs) and its role in noise-induced hearing loss (NIHL) has been an increasing concern.⁽⁷²⁻⁷⁶⁾ The KEMAR has been a useful tool in measuring the earphone output level for several researchers.^(72, 73, 75, 76) For instance, in 1987 the KEMAR was used by Rice, Rossi and Olin to measure the preferred listening volume of over 60 PMP users.^(77, 78) The researchers found that approximately five percent of the PMP users preferred to listen at a nearly 90 dBA equivalent sound pressure level,^(77, 78) possibly increasing their risk of NIHL.^(4, 5)

Fligor et al. measured the sound level output of headphones of several commercially available compact disc players.⁽⁷²⁾ The researchers used the KEMAR to measure the output levels of multiple types of headphones and determined that the smaller the headphones, the higher the sound level for a given volume setting.⁽⁷²⁾ Noting that supra-aural headphones rest on, but do not fully envelope the ear, Fligor et al. estimated that an individual using supra-aural headphones would reach the maximum allowable noise dose within approximately one hour of listening at 70% the maximum output level.⁽⁷²⁾

A KEMAR was used by Portnuff et al. to investigate the relationship between volume control settings and output levels of multiple portable listening devices (PLDs). Five PLDs' and five earphones' output levels were investigated while playing five music genres.⁽⁷³⁾ The KEMAR was fitted with a hard rubber right pinna and a soft, silicone rubber left pinna.⁽⁷³⁾ The output levels of the earphones were measured in the right and left ear of the KEMAR simultaneously, but the researchers found that the softer, silicone rubber pinna achieved a better

fit during measurements.⁽⁷³⁾ A one-way ANOVA identified a significant difference among the maximum output levels of the earphones when all music genres were considered ($F(4, 124) = 85.3, p < 0.001$). The researchers conducted the Scheffe post hoc test that revealed significant differences among all but two pairs of earphones.⁽⁷³⁾ The KEMAR enabled Portnuff et al. to suggest that the PLDs could reach output levels that may increase the listener's risk of music-related hearing loss.⁽⁷³⁾

Flamme and Williams reported that sound pressure levels produced by officials' whistles ranged between 104 and 116 dBA, corresponding to total allowable exposure times of 90 and five seconds, respectively.⁽²¹⁾ The authors' reproduction of 115 dBA whistle noise for a 250 to 350 msec duration was based, in part, on the sound pressure levels and durations reported in the Flamme and Williams study. The researchers asked 321 officials from basketball, football, volleyball, wrestling, soccer, ice hockey, and lacrosse to self-report whistle noise exposure and symptoms of tinnitus or hearing loss. The researchers found that approximately 50% of sports officials reported symptoms of tinnitus after officiating, and the Spearman's correlation between self-reported hearing status and the frequency of reported tinnitus was significant ($p < 0.0005$).⁽²¹⁾ The current study's results of linear regression support Flamme and Williams' conclusion that whistle noise may contribute to hearing loss among sports officials. The results of the current study suggest that the use of a longer visor may increase the contribution of the mouth-blown whistle noise by approximately three dB ($p < 0.0001$), doubling the intensity of the noise exposure.⁽²¹⁾

Limitations

The researchers used a Fox 40[®] Super Force[®] finger grip pea whistle and two Oakley[®] visors in the current study. While, multiple options for whistles and visors are available,

selection for this study was based on league regulations, personal preference of the officials, and the sport being officiated. The warbling sound of a pea whistle is produced when movement of the small ball (pea) is enclosed in the whistle's air chamber. The sound of a whistle without a pea is produced when turbulent air travels through the chambers of the whistle. The frequency of the sound is dependent on the length of the whistle, with longer whistles producing lower frequency sound.⁽¹⁰⁷⁾ The differing whistle designs suggest that the use of one whistle in the current study is not representative of all whistles and a larger selection of whistles should be used in future research. The use of only one design of visor of each length (2.75" and 4.0") in the current study also limits any findings. Investigation into a larger sample of various lengths and designs of visors should be continued.

Data were collected on L_{peak} for five whistle blows in each face-off spot with a total of 25 samples for each helmet configuration. As seen in Table 1, there was more variability in the whistle noise measurements at the ear of the KEMAR wearing the 4.0' visor ($SD=1.1$). A larger sample set would likely decrease the standard deviation in the mean L_{peak} and increase the power and robustness of the statistical significance. A larger-scale study including multiple whistles and visor lengths could better frame any issues that would require further investigation into the contribution of reflected sound pressure provided by differing visor lengths attached to hockey officials' helmets.

Conclusions

The World Health Organization (WHO) reports that 1.1 billion young adults are at risk of hearing loss due to exposure to damaging levels of noise at entertainment venues such as sporting events and music concerts.⁽¹⁰⁾ Since hockey officials may begin officiating in

adolescence, exposure to hazardous levels of whistle noise may begin at an earlier age for this population resulting in increased risk of premature hearing loss.

The researchers of the current study instituted a novel approach by using the KEMAR to evaluate the noise effects introduced by protective eyewear for hockey officials. The protective visors attached to the helmets appeared to act as a reflective plane for the whistle-blast noise, resulting in an increased sound pressure level at the manikin's ear. The L_{peak} data from this simulation does not necessarily represent the actual L_{peak} noise exposures of hockey officials. However, the researchers found the measured L_{peak} was significantly higher when the helmet was configured with a 4.0" long visor ($p < 0.05$) than the L_{peak} when the helmet was configured without a visor or with the 2.75" long visor. Based on these findings, it is possible that the longer visor increases the overall noise exposure of hockey officials that is experienced only from whistle-blast noise.

The results of this study suggest that the longer visor may introduce a reflective plane and possibly increase the hockey officials' exposure to whistle noise by approximately three dB. These results serve as an initiative for further research that may provide insight toward an improved design of helmet visors in the future – those that would continue to provide protection of the eyes and face of the hockey official, but not at the expense of their hearing.

CHAPTER 6

SUMMARY

Major Findings

This research was the first to investigate noise exposures of indoor hockey officials experienced during competitions. The investigation included personal noise dosimetry to determine the noise levels to which the hockey officials were exposed during a game and audiometric testing before and after the game to determine if a TTS occurred after officiating the game. The hockey official has many sources of noise exposure while officiating, and this research used the KEMAR in an innovative way to assess the effect of helmet visor length on the officials' in-ear exposure to whistle noise generated by the official.

Specific Aim 1

One aim of this research was to determine the noise exposure levels of indoor hockey officials in the ACHA and WSHL while officiating collegiate and junior league hockey competitions, respectively, in arenas located in northern Colorado and southeastern Wyoming. The hockey officials wore a personal noise dosimeter for the duration of the game and the noise exposure data were analyzed to determine if the hockey officials were exposed to an equivalent sound pressure level (L_{eq}) ≥ 85 dBA, which may increase the risk of NIHL.^(4, 5) Hockey officials' noise exposures were also assessed against the OSHA Permissible Exposure Limit (PEL) and the ACGIH Threshold Limit Value (TLV).

Pilot Study Results

According to the NIDCD and ASLHA, all of the study participants were exposed to hazardous levels of noise, an average L_{eq} greater than 85 dBA, that may increase their risk of permanent hearing loss.^(4, 5) Exposure to hazardous levels of noise may be detrimental to hearing, and may also cause stress and affect one's health, sleep, communication, safety, and quality of life. . Noise dosimetry was conducted during six hockey games of the 2013-2014 hockey season. A total of 23 personal noise dosimetry samples were collected during an average hockey game time of two hours and 42 minutes. The mean L_{eq} and mean L_{peak} of the officials' noise exposures were 90 dBA and 133 dB, respectively. None of the officials were overexposed to noise based on the OSHA noise criteria, yet 65% of hockey officials were overexposed to noise based on ACGIH recommendations.

Main Study Results

Twenty-nine personal noise dosimetry samples were collected during an average hockey game time of two hours and 48 minutes. As was found in the pilot study, 100% of the hockey officials were exposed to an average equivalent sound pressure level (L_{eq}) greater than 85 dBA. The average L_{eq} , maximum sound pressure level (L_{max}) and peak sound pressure level (L_{peak}) of the officials' noise exposures were 93 dBA (SD= 2.2), 116 dBA (SD=2.8) and 134 dB (SD=5.0), respectively. In support of the findings in the pilot study, none of the officials were overexposed to noise based on the OSHA noise criteria, and 89% were overexposed based on the ACGIH recommendations.

Specific Aim 2

Another objective of this research was to determine if the indoor hockey officials experienced a temporary threshold shift, or temporary decrease in hearing sensitivity, after

officiating a hockey game. The hockey officials were given a hearing history questionnaire and otoscopic examination before the game to identify any preexisting medical conditions that may have disqualified them from participation in the hearing test. A pure-tone audiometric test was administered in each ear before and after officiating the hockey game and hearing thresholds were determined at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The pre- and post-game results were compared to determine if a 10 dB or greater decrease in hearing sensitivity occurred after the game at any of the tested frequencies.

Pilot Study Results

Eighteen pre- and post-game audiometric tests were administered. An increase in hearing threshold of 10 dB or greater was exhibited in more than half (55.6%) of the sampled officials. Of those officials with the ≥ 10 dB decrease in hearing sensitivity, 70% experienced a threshold shift in more than one ear and/or at more than one frequency, and 20% experienced a 15 dB threshold shift. Significant differences between the pre- and post-game hearing thresholds were found at 2000 Hz for the left ear ($p=0.012$) and at 4000 Hz for the right and left ears ($p=0.037$, $p=0.017$, respectively) based on the Wilcoxon signed-rank test.

Main Study Results

A 10 dB or greater increase in hearing threshold after officiating a hockey game was identified in 25 of 29 (86.2%) study participants, with nine of the 25 (36%) experiencing a 15 dB or greater threshold shift. A ≥ 10 dB threshold shift in both ears was found in 8 of the 25 (32%) individuals with threshold shifts and 14 of 25 (56%) individuals with threshold shifts exhibited a shift in multiple frequencies. Six officials presented a mild hearing impairment (26-40 dB hearing threshold) at the pre-game hearing test yet still experienced a ≥ 10 dB threshold shift after officiating a game, and half of these officials experienced a ≥ 15 dB threshold shift. There were

significant differences between the pre- and post-game hearing thresholds at 2000, 3000, and 4000 Hz for the right ear ($p \leq 0.0001$) and at 500, 2000, 3000, and 4000 Hz for the left ear ($p = 0.0099$, $p = 0.0009$, $p < 0.0001$, $p = 0.0002$, respectively) based on the Wilcoxon signed-rank test.

Logistic regression (with repeated measures used to account for multiple observations per subject) was used to examine the association between the equivalent sound pressure level from personal noise dosimetry (L_{eq}) and a ≥ 10 dB increase (shift) in hearing threshold from pre- to post-game audiometry, in separate models at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Fixed effects in the analysis included personal noise exposure and side (left or right ear) and random effects included the individual official. Although none of the results of the logistic regression analysis were statistically significant at $\alpha = 0.05$, for each additional one dB increase of L_{eq} , the odds of a ≥ 10 dB TTS were increased by 33% for the left ear at 500 Hz, 2% for the left ear at 3000 Hz, 26% for the left ear at 4000 Hz, 3% for the right ear at 6000 Hz, 22% for the left ear at 8000 Hz, and 29% for the right ear at 8000 Hz.

Specific Aim 3

A model was developed using the KEMAR and whistle apparatus to simulate hockey officials' noise exposure from a whistle while wearing different configurations of a helmet and visor. The aim of this portion of the research was to measure and compare the whistle-generated noise levels at the ear of the KEMAR in order to determine if the different protective visor lengths affected the level of noise measured at the ear, possibly due to the visor acting as a reflective surface for the whistle noise. The study was conducted in an empty northern Colorado ice rink. One helmet configuration was sampled at each of the randomly selected five face-off spots on the ice prior to changing the helmet configuration. The Fox 40[®] Super Force[®] finger

grip pea whistle was blown five times in each location for intervals of 250 to 350 milliseconds (msec), with a total of 25 samples for each helmet configuration.

The results indicated that helmet visor length contributed to whistle-blast noise exposure measured at the manikin's left ear. In helmet/visor configurations including a long visor, the mean L_{peak} measured at the left ear of the manikin was approximately three dBA greater than the mean L_{peak} measured with the short visor or only a helmet (no visor). The difference in the mean L_{peak} was significant ($p < 0.001$) between the no visor / long visor and the short visor / long visor configurations, but not between the no visor / short visor configuration.

The attachment of the visor to the helmet introduces a reflective plane in the proximity of the whistle noise source causing more noise to reflect back to the official. The longer visor provided a greater reflective surface for the whistle noise source. In addition, this surface extends further down vertically from the helmet resulting in the bottom edge of the surface being closer to the noise source and occluding more of the space in front of the official's face. The amount of sound pressure reflected to the manikin's ear appears to increase based on the length of the visor, which would increase the reflected noise. In this study, the longer visor attached to the helmet resulted in an increase of sound pressure level of approximately three dBA ($p < 0.001$) above the helmet configurations with a short visor and without a visor.

Limitations

This study's population was limited to the number of WSHL and ACHA officials who officiated hockey games in northern Colorado and southeastern Wyoming on the pre-selected sampling dates, covering approximately half of the hockey seasons of 2013 and 2014. This study was also limited by the acoustical design, size, and capacity of the ice arenas chosen for the study, which may have affected the noise levels and may not be representative of all hockey

arenas. Ideally, collecting data on more of the potential pool of hockey officials would have resulted in a larger sample size and would have reduced or eliminated the need for repeated measures on individual officials. In addition, lost sampling data (due to equipment malfunction and/or excessive background noise during audiometry) resulted in more noise dosimetry samples than pre- and post-game audiometry exams precluding uniform pairing of the two sample types.

A limitation specific to the pilot study included the undesirable and non-compliant audiometric testing environment. The maximum allowable octave-band SPLs for audiometric test rooms listed in Appendix D-1 of the OSHA noise standard were unattainable in several of the tested frequencies throughout the testing period. Although the background noise levels were documented, systematic adjustments to the measured audiometric hearing thresholds were not possible due to the variability of the background noise in the testing environment. Continuous ambient noise monitoring would have been necessary to make compensations for background noise to the measured hearing thresholds, but was not available during the study. Instead, it was assumed that the audiometry data collected in the pilot study were weak estimates of the actual hearing threshold shifts and the audiometric testing environment was addressed in the next phase of the research.

A TTS in hearing is transient, as the ear begins to heal almost immediately once the exposure to hazardous levels of noise ceases. However, the healing process for individuals may take up to 48 hours.^(5, 6) Due to resource and scheduling constraints, additional audiometric exams to confirm a full recovery of the TTS within 48 hours were not conducted and it was assumed that the identified hearing loss was temporary. Six officials in the main study exhibited a mild hearing impairment prior to officiating the game and were still included in the study. All of the officials with pre-existing hearing impairment experienced a ≥ 10 dB threshold shift, with

half of them experiencing a ≥ 15 dB threshold shift. Three of the six officials with pre-game hearing loss reported excessive noise exposure within 48 hours of the hearing test. It is possible that the three officials had permanent or temporary hearing loss at the time of pre-game audiometry but the scope of this study did not include follow-up audiometry to confirm recovery.

The instrumentation utilized for the visor study included the delicate, highly-specialized, and expensive KEMAR, in-ear microphone, and Larson Davis SLM/OBA. The cost and required knowledge base of the instrumentation may deter other researchers from using this methodology in future research. The instrumentation was paired with one whistle (Fox 40[®] Super Force[®] finger grip pea whistle) and two Oakley[®] visors (2.75" VR904 modified straight small visor with slots and 4.0" VR924 CLE pro straight visor with vents) in this study. Multiple options for whistles and visors are available, but the researchers' selection was based on the USA Hockey league regulations and the personal preference of the WSHL and ACHA officials. The whistle and visor options were limited in this research. The use of one whistle and only one company's style of visor in two different lengths in the current study did not encompass the wide variety of equipment available for hockey officials but were representative of the products used by officials in the study.

KEMAR noise measurements occurred when the ice rink was vacant and when the whistle noise would not disrupt occupants of adjacent ice rinks. Hence, the availability of the ice rink was limited to the two hours prior to the ice arena's opening. The time constraints dictated that randomization of the helmet configurations and face-off spots was not feasible. Instead, one helmet configuration was sampled five times at each of the five, randomly selected face-off spots prior to changing the helmet configuration.

More variability was found in the whistle noise measurements at the ear of the KEMAR wearing the 4.0" long visor (SD=1.1), and collecting more measurements would have decreased the standard deviation and increased the power and robustness of the statistical significance. A larger-scale study including multiple whistles and visor lengths would better support a recommendation to further investigate the contribution of the visor length on the officials' noise exposure.

Contribution to the Field

This research identified a unique population of individuals whose supplemental employment included recreational noise exposure. The officials' noise exposure during the hockey game is additional to the noise exposures of the day, whether it be from work or other recreational activities (music concerts, motorcycle riding, etc.). The recreational noise associated with hockey competitions may be placing the hockey officials at an increased risk of exposure to hazardous levels of noise and potential hearing loss. The noise exposure and hearing thresholds of a population that has not been previously studied were evaluated and it was concluded that the ACHA and WSHL hockey officials are exposed to hazardous levels of noise ($L_{eq} \geq 85$ dBA) and experience a TTS within the 2 to 3-hour duration of a hockey game. The identification of hockey officials as a population potentially overexposed to noise and at an increased risk of hearing loss will alert health and safety professionals around the world to consider this group in future health and safety surveillance.

This research using the KEMAR with multiple helmet configurations to determine if the hockey helmet's visor affects the in-ear peak sound pressure levels from the noise generated from simulated whistle blowing involved a novel approach with this instrumentation. The KEMAR is typically used to assess the efficacy of communication devices or the listening output

of earphones, but the study design and whistle apparatus employed in this research is original and easily reproducible for additional applications. Knowledge regarding the reflective effect of the longer visor on the whistle noise may provide insight for an improved design of helmet visors in the future.

Future Research Opportunities

The results from this research potentially identify a population of individuals that highlight the impact of recreational noise exposure on NIHL. Combining noise dosimetry and audiometry to determine noise exposure and related effects on hearing sensitivity is not a novel approach. However, this noise exposure study of indoor hockey officials focuses on a new population that may have additional NIHL risks from occupational sources and may have been exposed at an early age (some officials perform as early as age 10). Further research is needed to determine if the effects found in this study are transferable to the group of hockey officials at large. Additional hockey official NIHL research has the potential to identify officials regionally, nationally and world-wide that have an increased risk of NIHL. Research should include a larger sample of hockey officials from various sized venues, both amateur and professional. A larger study population would provide more hearing history questionnaire data (e.g. length of time officiating, hobbies, analgesic use) that may be used in predicting audiometric outcomes. More comprehensive data collection could include characterizing additional sources of hazardous noise exposure for hockey officials. Follow-up audiograms would also help determine when or if recovery from the TTS occurs.

The use of multiple testing stations for simultaneous administration of hearing tests would allow more accurate identification of the number and severity of temporary threshold shifts. The current research was limited to only one audiometric testing area, creating a delay for

some officials that possibly contributed to underestimating the number and severity of hearing shifts. Simultaneous audiometric testing would allow immediate testing of all of the officials and not permit any of them more time than others to begin healing from a TTS, if present. On those officials exhibiting a TTS at the end of the competition, conducting follow-up audiometry 48 hours after officiating would confirm the hearing threshold shift is temporary.

Although the hockey officials were not overexposed to noise according to the OSHA regulations, in an effort to reduce noise exposure and risk of NIHL, it is recommended that they receive training, annual audiometric testing and hearing protection in accordance with the requirements of the OSHA noise standard. A pilot study offering disposable, reusable and custom-molded hearing protection options to a representative sample of indoor hockey officials would potentially identify hearing protective devices that could have application to hockey officials worldwide. The pilot study would include hearing protection selection based on the following criteria: attenuation of high frequency noise that still allows for communication; comfort; ability to be disinfected (if not disposable); cost-effectiveness; secure placement in the ear during physical activity; and ability to be tethered to the helmet in case of accidental dislodgment on ice. The pilot study participants' feedback should be reviewed and analyzed before recommending hearing protection options to other leagues. The components of the pilot study should not only include a selection of appropriate hearing protection options for the hockey officials, but also training regarding the fitting, use, and care of the hearing protection.

Further research into the effects of visor length on the officials' exposure to whistle noise is also warranted. The results of this study suggest that longer visors may act as a reflective surface and increase the officials' exposure to whistle noise. Studies into different materials and configurations of visors could provide insight for design of helmet visors that would reduce the

reflective characteristics. Further KEMAR studies employing a larger selection of whistle designs (with and without pea) and orientations and visor styles and manufacturers are recommended to better support the possible changes. The design of a different visor is a comprehensive task that requires the input and support of hockey officials' and national leadership organizations for long-term acceptance. The KEMAR methodology used in this research has potential applicability for testing existing or new visors in the future.

Conclusions

More than 25,000 hockey officials in the United States may be at increased risk of NIHL. This population is exposed during a recreational activity, during which they do not wear hearing protection. In addition, this population is at risk of suffering NIHL at an earlier age as many begin officiating in adolescence. Within this research, all included officials were exposed to hazardous levels of noise and most experienced temporary hearing loss after officiating a game (86% in the main study, 55.6% in the pilot study). Officials of other sports also operate under similar conditions (crowd noise, public announcement noise, etc.) and may also be at risk for temporary or permanent hearing loss.

The researchers' investigation into the effects of the official's helmet visor length on exposure levels from whistle noise using the KEMAR suggest that longer helmet visors increase noise exposure at the ear compared to no/shorter visors. This effect may be due to the longer visor acting as a reflective plane for whistle noise potentially focusing and increasing sound pressure levels from mouth-blown whistles. This finding may potentially create a difficult choice for officials as the longer visor that is more protective of the hockey officials' eyes and face may also be more damaging to their hearing.

The identification of hockey officials as a population potentially overexposed to noise and at an increased risk of hearing loss alerts health and safety professionals around the world to consider this group in future health and safety surveillance. Although the results of this study are unable to recover or repair the hearing loss that has already occurred in hockey officials, it has the potential to reduce effects in the future and identify officials of other sporting events that may be at an increased risk of NIHL.

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APPENDIX A

METHODOLOGY FOR CONDUCTING NOISE DOSIMETRY

Before Noise Dosimetry Sampling

- Calibrate noise equipment and document calibration for SLM, noise dosimeters, and OBA
- Documentation includes:
 - Calibration date and time
 - Serial number of instrumentation
 - Date of last calibration and/or calibration due date
- Explain who you are, why you are there, and the purpose of the dosimeter
 - Emphasize that the dosimeter does not record speech, just dB levels
- Document the dosimeter SN, name of official, and date on sampling sheet
- Clip the dosimeter on the back waistband or ask the official if he would like to secure it in a zippered pocket
- Clip the microphone to the official's jersey at the shoulder, close to the hearing zone
 - Should be placed in accordance with manufacturer's instructions
 - Secure the cable under the outer jersey and or with tape.
 - Place the microphone on the officials' dominant side
- Ask the official if it feels all right, confirm nothing will bother the official during his activities and them not to remove, tap or yell into the microphone
- Notify the official that you will be checking on them at each intermission and for them to tell you right away if there is a problem with the microphone, cord or dosimeter
 - Explain you will be checking the dosimeter and microphone at intermissions to ensure that the microphone is oriented and functioning properly

- Notify them that YOU will remove the dosimeter once they come off of the ice at the conclusion of the game
- Turn on the dosimeter and record the time

After Noise Dosimetry Sampling

- As the official exits the ice or enter the locker room, remove the dosimeter and record the time
- Ask if there were any problems during the game (e.g. hit with a puck, fell down)
- Thank them for participating and ask them to go directly to the audiometric testing room/booth
- Post-calibrate the noise equipment and fully document the calibration, as before

APPENDIX B

AUDIOMETER FUNCTIONAL CALIBRATION

Look and Listen Functional Check of Audiometer

- Locate the calibration label on the audiometer and confirm that the acoustic or exhaustive calibration has been conducted within the past 12 months

- Check the earphone cords, headband, and ear cushions for wearing, cracking or exposed wires

- Place the earphones on the examiner (red earphone on right ear)
 - Listen to the all the test frequencies in each ear for the presence of:
 - Static
 - Intermittent crackling
 - Distortion
 - Warbling
 - Any unwanted sounds

 - Adjust the attenuator up and down for each ear

 - Listen to the sound quality

 - Move or twist the cords

 - With the tone on one earphone, listen for any unwanted sound in the other earphone

APPENDIX C

AUDIOMETRIC TESTING INSTRUCTIONS FOR THE STUDY PARTICIPANT

The following information is relayed to the study participant prior to administering the hearing test:

- A series of sounds or tones will be heard
- The sounds will go on and off
- Some of the sounds may be very difficult to hear
- If you think you hear the sound but aren't sure, guess
- Push the signal as soon as you hear the sound or tone
- Background noise may come from outside the booth during the test
 - It may be distracting but will not interfere with the test results
 - If the background noise is disruptive, I will pause the test and resume when the disruption has passed
- Please listen carefully

APPENDIX D

METHODOLOGY FOR ADMINISTERING A HEARING TEST

(MODIFIED HUGHSON-WESTLAKE TECHNIQUE)

- Set audiometer loudness to 10 dB at 1000 Hz in the right ear
- Present the pulsed tones
- If the study participant responds, descend the intensity by 10 dB and present the tone again
 - Do not present a tone below 0 dB intensity
- Increase the intensity in 5 dB increments until the study participant responds
- Repeat the descending and ascending process until the study participant responds at a specific intensity level approximately 50 % of the time, but no less than three times
 - The established level of hearing is referred to as the “threshold”
- Record the threshold level for 1000 Hz on the Audiometric History/Report
- Obtain thresholds by testing the following frequencies in the following order:
 - 1000 Hz (Start)
 - 500 Hz
 - 1000 Hz (Only on first ear tested if cooperation is confirmed) *
 - 2000 Hz
 - 3000 Hz
 - 4000 Hz
 - 6000 Hz
 - 8000 Hz

* Repeat the testing of 1000 Hz for only the first ear tested to determine if the study participant is cooperating and understands the instructions. It is not necessary to retest the 1000 Hz for the second ear tested

- After retesting 1000 Hz, thresholds must be within +/- 10 dB. Record the better of the two thresholds.
 - If a > 10 dB difference is observed or the study participant seems uncooperative, reinstruct, reschedule or refer to an audiologist

APPENDIX E

BACKGROUND NOISE OF AUDIOMETRIC TESTING BOOTH

Background Noise for Audiometric Testing							
Date	Time	File #	500 Hz (40 dB)*	1 KHz (40 dB)*	2 KHz (47 dB)*	4 KHz (57 dB)*	8 KHz (62 dB)*

(dB)*: OSHA 1910.195 Appendix D: Maximum Allowable Octave Band SPLs for Audiometric Test Rooms

Instrumentation Model: _____

Instrumentation Calibration Due Date: _____

APPENDIX F

AUDIOMETRIC HISTORY/REPORT EXAMPLE

Identification:

Date _____ Age _____

Name _____

Job Title: _____

Length of time as Official: Years _____

Loud Noise Exposure within the last 2 days (48 hours)

Source(s): _____

Duration of exposure: _____ Days _____ Hours

Other Personal Noise Exposures: (check all that apply)

- Loud music Motorcycles
- Firearms Hearing protection used? ___Yes ___No
- Power tools Hearing protection used? ___Yes ___No
- Heavy machinery Hearing protection used? ___Yes ___No

History (check all that apply):

- Use of analgesics within last 7 days
- Acetaminophen (ex: Tylenol®) Frequency: _____ days per week
- Ibuprofen (ex: Advil®, Motrin®) Frequency: _____ days per week
- Aspirin (ex: Bayer®) Frequency: _____ days per week
- Naproxen (ex: Aleve®) Frequency: _____ days per week
- Prior military service History of hearing aid R L
- History of hearing loss History of ringing in ears
- Family history of hearing loss History of recurrent impacted ear wax
- History of recurrent ear infections History of head injury
- Current cold, flu or allergy symptoms

Comments: _____

TO BE COMPLETED BY TECHNICIAN

Dosimeter S/N _____

Pre-Game Audiogram Results

Right Ear		Left Ear	
Frequency (Hz)	Decibels (dB)	Frequency (Hz)	Decibels (dB)
500		500	
1000		1000	
2000		2000	
3000		3000	
4000		4000	
6000		6000	
8000		8000	

Comments: _____

Physical exam of ears:

Left _____ Right _____

Post-Game Audiogram Results

Right Ear		Left Ear	
Frequency (Hz)	Decibels (dB)	Frequency (Hz)	Decibels (dB)
500		500	
1000		1000	
2000		2000	
3000		3000	
4000		4000	
6000		6000	
8000		8000	

Assessment: (check one)

Normal audiogram TTS (≥ 10 dB loss) or other significant change (Right / Left)

Comments _____ Audiometer: Earscan 3 S/N: 0105030001A4

Exhaustive Calibration Date: 9/18/2013

APPENDIX G

METHODOLOGY FOR KEMAR STUDY

Instrumentation

- KEMAR Manikin Type 45BA
- IEC 60711 Ear Simulator RA0045 for left ear
- Preamplifier
- Large Pinna
- Larson Davis 824 Sound Level Meter/Octave Band Analyzer
- Larson Davis CAL 200

Setup with power modules and externally polarized microphones

- Connect left preamplifier LEMO-to-LEMO extension cables to internal connection at left microphone socket
- Connect LEMO-to-LEMO extension cables from external left microphone socket to power module for externally polarized microphone of Larson Davis 824 SLM/OBA

Calibrating the IEC 60711 Ear Simulator RA0045

- Unscrew the ear simulator and preamplifier from the KEMAR
- Attach GR0917 ear canal extension with straight ear canal to the ear simulator
- Place the CAL 200 over the ear canal extension and push it down gently to the stop and turn on the calibrator
- Calibrate the microphone at 94 and 114 dB
 - Upon initial calibration, manually adjust the calibration of the Larson Davis 824 SLM/OBA to indicate the dB levels from the CAL 200
 - Save the calibration settings on the 824

- Calibration documentation includes:
 - Calibration date and time
 - Serial numbers of instrumentation
 - Date of last calibration and/or calibration due date
- Remove the CAL 200 and GR0917 ear canal extension from the ear simulator
- Attach the ear simulator and preamplifier to the left ear mounting plate
- Tighten the preamplifier to face upwards, toward the top of the head, with the 2.5 mm Allen key if necessary
- Insert foam ear plug into the right ear mounting plate and allow it to expand
- Loosely place a hand towel inside the cavity of the KEMAR head, ensuring that the preamplifier faces upwards
- Attach the right pinna on the mounting plate, making sure the studs on the mounting plate align with the holes in the pinna
- Attach back plate and skull cap of the KEMAR

Peak Noise Measurement

- Place KEMAR, whistle apparatus, and SLM/OBA on cart
- Find a power source for the air compressor
- Place the KEMAR assembly on the randomized five face-off spots, with the manikin positioned on the outer boundary of the face-off spot, facing toward the ice
- Attach left pinna to ear simulator mounting plate, making sure the studs on the mounting plate align with the holes in the pinna
- Place helmet on KEMAR head and tighten the chin strap, ensuring that the pinna is positioned in the designated ear space of the helmet
- Attach tubing and blow gun to air compressor and pressurize to 18-20 psi
- Place air compressor as far as possible behind the KEMAR assembly

- Once pressure has been achieved, stand behind the KEMAR, press the record button on the SLM/OBA, squeeze the blow-gun completely and release, stop the recording on the SLM/OBA and save the data file
- Press the record button on the SLM/OBA, squeeze the blow-gun completely and release, stop the recording on the SLM/OBA, and save the data file four more times, with a total of 5 samples per location
- Document the face-off spot location and file names and move
- Move to the next randomly selected face-off spot and collect 5 samples at each location
- After each of the 5 face-off spots have been sampled, remove the hockey helmet and attach the visor of interest
- Post calibrate the ear simulator according to instructions listed above

APPENDIX H

SUPPLEMENTAL INFORMATION FOR CHAPTER 5

