THESIS

NOISE CHARACTERIZATION AND EXPOSURE AT A SKI RESORT

Submitted by

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ABSTRACT

NOISE CHARACTERIZATION AND EXPOSURE AT A SKI RESORT

This study examined the noise exposures of employees at a ski resort working in the job categories of snowmaker, snow groomer, or chair lift operator. Noise exposures for all employees were obtained using personal noise dosimetry. Snowmakers were monitored during their normal 12-hour work shifts (n=19 for both night and day shifts) and results indicated that 70% of the snowmakers exceeded the OSHA 12-hour AL (82 dBA), 32% exceeded the OSHA recommended 12-hour PEL (87 dBA), 11% exceeded the OSHA PEL (90 dBA), and 63% exceeded the ACGIH® 12-hour TLV® (83 dBA).

When comparing noise exposures of the day-shift snowmaker crew to the night-shift crew, results indicated that 100% of the night-shift crew exceeded the OSHA12-hour Action level (82 dBA), 40% exceeded the OSHA recommended12-hour PEL (87 dBA), 10% exceeded the OSHA PEL (90 dBA), and 100% exceeded the ACGIH® 12-hour TLV® (83 dBA). Results also indicated that of the day-shift snowmaker crew, 33% exceeded the OSHA12-hour AL (82 dBA), 22% exceeded the OSHA recommended12-hour PEL (87dBA), 11% exceeded the OSHA PEL (90 dBA), and 44% exceeded the ACGIH® 12-hour TLV® (83 dBA). Snowmaker equipment was also analyzed using a sound level meter for eight different snowmaking machines, with results revealing a range of 83 dBA to 116 dBA.

The chair lift operation population (n=20) was monitored for work shifts varying from 8 to 10 hours. The findings indicated that 5% exceeded the OSHA 10-hour AL (83 dBA), none of the chair lift worker population exceeded the OSHA recommended 10-hour PEL (88 dBA), none exceeded the OSHA PEL (90 dBA), and 10% exceeded the ACGIH® 10-hour TLV® (84 dBA). Chair lift equipment was also analyzed using a sound level meter, which indicated a range of 75 dBA to 81 dBA.

Noise exposures for snow groomers were ascertained for entire 10-hour work shifts (n=19). The results from this study indicated that none of the snow groomers exceeded any published occupational

noise criteria from OSHA or ACGIH®. Snow grooming machines were also characterized using a sound level meter for four different snow grooming machines, which illustrated a range of 74 dBA to 78 dBA.

It is recommended that management take steps in order to reduce the exposure times to excessive noise for snowmaker employees, either by obtaining snowmaking machines that generate noise at a safe level or by decreasing work shifts of snowmaker employees. It is also recommended that snowmaker employees continue to wear and maintain their current hearing protection devices. It is recommended that this ski resort continue the participation of all snowmaker employees in the current hearing conservation program. Further research is also recommended in order to determine if chair lift operator employees should be enrolled into a hearing conservation program to help ensure that no employees are at risk of sustaining hearing damage.

ACKNOWLEDGEMENTS

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DEDICATION

For my loving husband, my dearest friend.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ACGIH®	American Conference of Governmental Industrial Hygienists
CFR	Code of Federal Regulations
CSU	Colorado State University
dB	Decibel
dBA	Decibel, A-weighted
HCP	Hearing Conservation Program
HPDs	Hearing Protection Devices
Hz	Hertz
IRB	Institutional Review Board
Leq	Equivalent Continuous Sound Pressure Level
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OBA	Octave Band Analyzer
ONIHL	Occupational noise-induced hearing loss
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPE	Personal Protective Equipment
SLM	Sound Level Meter
SPL	Sound Pressure Level
TWA	Time Weighted Average

CHAPTER 1: INTRODUCTION

The ability to hear is a critical human sense, allowing individuals to be connected with the world around them. Hearing is the major route of learning for most all humans from the time of birth and can also bring people much pleasure in hearing things, such as music, birds chirping, or a waterfall. The ability to hear the noise of daily life can also serve as a warning signal, such as an ambulance siren or a car horn. Sound is a part of everyday life for most people, but can also be damaging when at elevated levels that posses the ability to impair or altogether negate normal hearing abilities.

It is first essential to make the distinction between noise and sound. Sound is defined as a form of energy produced when air molecules vibrate and move in a wave pattern known as a sound wave.(1) These sound waves then propagate a pressure wave through an elastic medium, such as air.(2) Noise is largely described as any unattractive or unsatisfactory, loud sound of any kind. Noise-induced hearing loss (NIHL) is defined as damage to the hair-like structures of the ear (stereocilia) as a result of exposures to hazardous levels of noise and is a common cause of sensorineural hearing loss.(3) Sensorineural hearing loss is a permanent condition in which the stereocilia are no longer able to transmit sound information to the brain as a result of irreparable damage from hazardous noise exposures and is termed occupational noise-induced hearing loss (ONIHL) when occurrence is due to an individual's occupation.

According to the National Institute for Occupational Safety and Health (NIOSH), work-related hearing loss continues to be a critical workplace safety and health issue, and it is estimated that 30 million workers are exposed to hazardous levels of noise. NIOSH has stated that occupational-related hearing loss persist as a crucial occupational safety and health issue and has classified occupational hearing loss as one of the 21 priority areas for research in the next century. NIOSH also estimates that 10 million workers have sustained irreversible NIHL as a result of exposure to on-the-job hazardous noise that has resulted in irreversible damage to the ear. Although NIHL is permanent and irreversible, it is also 100 percent preventable.(4)

NIHL is one of the most common occupational diseases sustained by workers and is the second most self-reported occupational illness or injury according to NIOSH.[4] Noise is recognized as an occupational hazard and has been determined to be a critical issue facing the workforce while continuing to be an ongoing battle in the workplace. The focus of this study was to evaluate personal occupational noise exposures and to characterize the noise exposures to personnel employed at a ski resort.

CHAPTER 2: LITERATURE REVIEW

The definition of noise is a sound that is undesired and unpleasant in nature. The normally functioning human ear, with an intact nervous system, possesses the phenomenal ability to receive and perceive sound. Sound is perceived by a human ear through the transmission of energy in the form of a pressure wave conducted through air or another elastic medium.(5) The pitch and intensity of this pressure wave is established by the characteristics of the wave itself. The pitch and sound of the wave are determined by frequency, measured in Hertz (Hz), which is a function of waves/cycles per second. The volume of a sound regarded by the human ear depends on the pressure of sound and is measured on a logarithmic scale and conveyed in decibels (dB), which is used to define sound pressure level (SPL) measurements.(6)

Three different weighting scales were developed due to the human perception of loudness at different frequencies and are used to measure sound. The three different weighting scales are known as the A, B and C weighting scales. Although the human ear maintains the ability to detect sound on all three scales, the scales are not equally perceived by the human ear in regards to perception of loudness. The A-weighting scale is most closely representative of the characteristics of normal human hearing, pronouncing measurements of high frequencies and minimizing the measurements of low frequencies. The C-weighting scale is commonly used to characterize impulse noise and is also used in concurrence with the A-weighted scale to detect low frequency noise. While the B-weighting scale is comparable in nature to the A-weighting scale, it is seldom used.(6) Table 1 displays the relative responses according to the three different weighting scales.

Table 1: Relative Response for A, B, and C-Weighting[7]

Frequency (dB)	*A weighting (dB)*	*B weighting (dB)*	*C weighting (dB)*
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	-8.5
20	-50.5	-24.2	-6.2
25	-44.7	-20.4	-4.4
31.5	-39.4	-17.1	-3
40	-34.6	-14.2	-2
50	-30.2	-11.6	-1.3
63	-26.2	-9.3	-0.8
80	-22.5	-7.4	-0.5
100	-19.1	-5.6	-0.3
125	-16.1	-4.2	-0.2
160	-13.4	-3	-0.1
200	-10.9	-2	0
250	-8.6	-1.3	0
315	-6.6	-0.8	0
400	-4.8	-0.5	0
500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1,000	0	0	0
1,250	0.6	0	0
1,600	1	0	-0.1
2,000	1.2	-0.1	-0.2
2,500	1.3	-0.2	-0.3
3,150	1.2	-0.4	-0.5
4,000	1	-0.7	-0.8
5,000	0.5	-1.2	-1.3
6,300	-0.1	-1.9	-2
8,000	-1.1	-2.9	-3
10,000	-2.5	-4.3	-4.4
12,500	-4.3	-6.1	-6.2
16,000	-6.6	-8.4	-8.5
20,000	-9.3	-11.1	-11.2

Physiology of the Ear

The human ability to hear sound is an astonishing feat. The average healthy human adult has the ability to detect sound from a frequency range of 20-20,000 Hz. Hearing, also termed audition, is a result of the translation of a pressure wave through a medium such as air and is then interpreted in the brain as a nerve impulse. The human ear is divided into three main regions which are responsible for hearing; the outer ear, the middle ear and the inner ear.[4]

Outer Ear

The visible portion of the outer ear is known as the pinna, which gathers and conducts sound waves into a channel-like structure known as the external auditory canal. This leads to the tympanic membrane or eardrum. Together, the pinna and the external auditory canal change the spectrum of the sound waves that reach the eardrum as a result of the shape and dimensions of the outer ear. In order to resonate sound at select frequencies and in an effort to enhance sound transmission, the external auditory canal also maintains an environment of constant temperature and humidity. The pinna, the head, and the external auditory canal also amplify sounds by 10-15 dB in the 2000-4000 Hz frequency range, therefore, sound within this frequency range can prove to be the most damaging to human hearing. Also, certain frequencies are amplified while others are attenuated due to the unique shape of the outer ear.[4]

Middle Ear

The middle ear region is an air-filled chamber which serves to transmit sound, converting pressure waves into a mechanical force, which is then transported to the inner ear. The middle ear begins at the tympanic membrane, also known as the eardrum, and continues to the oval window. The tympanum is attached firmly to the external auditory canal and actually vibrates when in contact with a pressure wave, resulting in a mechanical force that stimulates the lever action of small ossicle bones. The ossicles are three tiny bones in the middle ear that together act to connect the tympanum to the oval window and function to transfer sound pressure waves. These bones are known as the malleus, incus and stapes and are held in place by ligaments.[4]

The tensor tympani, housed within the middle ear, is attached to the malleus while the stapedius is attached to the stapes. The tensor tympani constantly pulls inward on the malleus, while the stapedius constantly pulls outward on the stapes. This configuration of opposing forces result in a rigidity of the ossicles, allowing attenuation of 30-40 dB of low frequency sounds and therefore removes a large portion of background noise. This reflex protects the inner ear from possibly damaging energy vibrations that could occur in the presence of an environment where excessive noise is present.[(4)]

Inner Ear

The inner ear begins at the oval window and finds its end at the round window. The primary hearing structure housed within the inner ear is the cochlea, which is filled with endolymph fluid and shaped like a snail. Within the cochlea is a membrane running from the beginning to the end of the cochlea and is referred to as the basilar membrane. The cochlea also contains the organ of corti, where hair cells called stereocilia are situated. As a result of a vibration of the oval window, a pressure wave is formed in the cochlear fluid which results in vibration of the flexible basilar membrane. This vibration produces a shearing force to the receptor-topped stereocilia that are embedded in the basilar membrane, causing nerve impulses to travel to the brain and then interpreted as sound. The stereocilia are sensory cells that generate electrical signals which are carried to the brain where they are translated into a “sound” that humans are able to understand and recognize. Almost all frequencies of sound will stimulate the stereocilia located in closest proximity to the oval window, which is one reason that higher frequency hearing loss is most often seen first in individuals who suffer from noise induced hearing loss.[(4)]

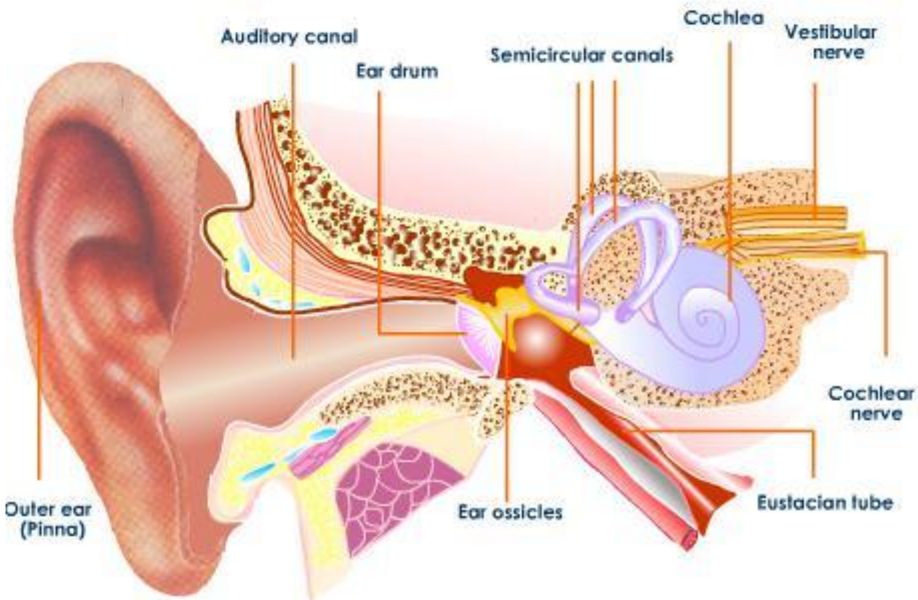

Figure 1: Structures of the Human Ear (tutorvista.com 2011)

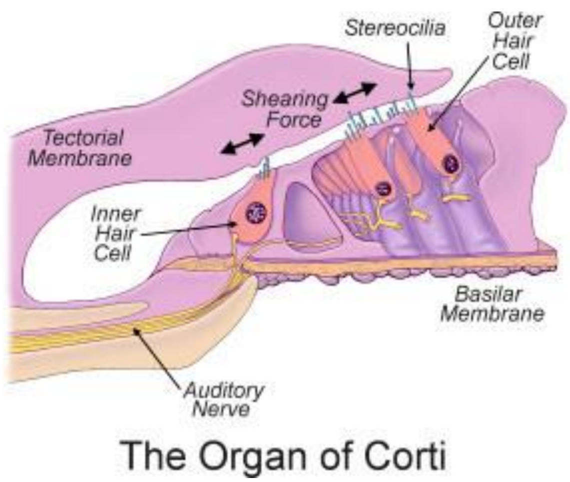

Figure 2: Structures of the Inner Ear and Shearing Interaction Between Stereocilia and Tectorial Membrane (Baylor College of Medicine 2012)

Noise-Induced Hearing Loss

NIHL has been well identified in humans since the Industrial Revolution in the 1800's. During that time in history, NIHL was referred to as "boilermaker's disease" because so many workers who made steam boilers eventually developed this condition.(8) In society of today, it is becoming evident that even young adults are at risk of developing NIHL due to noise environments at home, school and during leisure activities.

There are several types of hearing loss, including the following: conductive, functional, sensorineural, occupational, and nosacusis. Conductive hearing loss occurs when anything blocks noise from traveling from the environment through the outer and middle ear to reach the cochlea. This type of hearing loss is most commonly treatable and may result from a ruptured tympanum, earwax accumulation, damage to the oval or round window, and damaged or missing ossicles or otosclerosis. In order to correct conductive hearing loss, surgery, antibiotics or antihistamines may be necessary.[2]

Functional hearing loss may occur because of impairment of the ability of the brain to receive and decode the electrical impulses produced by the organ of corti. Functional hearing loss impacts the central brain or the nerve pathway that leads from the stereocilia to the brain. Examples of functional hearing loss may be a lesion or nerve damage, possibly resulting from brain damage or neural dysfunction. Functional hearing loss has also been known to result from psychogenic causes. It is important to note that functional hearing loss is not related to nerve dysfunction of the hair-like stereocilia within the cochlea.[2]

Sensorineural hearing loss manifests when nerve cells within the cochlea sustain damage from hazardous levels of noise. This type of hearing loss is most often a result of exposure to hazardous noise within the frequency range of 3000-6000 Hz. Sensorineural hearing loss may occur as a result of swelling, breakage or fusion of the stereocilia, detachment of the tectorial membrane, reduction of enzymes within the cochlear fluid or disintegration of the actual nerve cells housed within the cochlea. Presbycusis, sociocusis, tinnitus and occupational comprise of the four types of sensorineural hearing loss. Presbycusis is associated with human aging and is not currently known to have a specific cause. Approximately 33% of American adults 60 years of age or older suffer from this type of sensorineural hearing loss.[2]

Sociocusis is a type of NIHL that results from living in societies with high levels of noise, and is not prevalent in pastoral societies that lacked a noisy and mechanized environment. Tinnitus results from damage to the actual nerve cells housed within the cochlea from exposure to hazardous noise levels. Tinnitus is defined as a "ringing" sound in the ears after an individual is removed from a noisy environment. There is currently no known cure for tinnitus and chronic tinnitus may potentially interfere with quality of life by disrupting sleep and distracting the affected individual from mental tasks.[2]

Occupational hearing loss is the second most common sensorineural hearing loss after presbycusis. Exposure to hazardous noise is the cause of occupational sensorineural hearing loss, which may be temporary or permanent. Nosacusis hearing loss is a general or all-encompassing term that is used to describe all other causes of hearing loss not named above.[2]

Relevant Occupational Noise Exposure Criteria

Standards and regulations are published by the Occupational Safety and Health Administration (OSHA), NIOSH and The American Conference of Governmental Industrial Hygienists (ACGIH®) to address occupational noise exposures in the United States. OSHA regulations were enacted to protect workers in both general industry, and specifically construction, and may be found in the Title 29 Code of Federal Regulations (CFR) 1910.95 and 1926.52, respectively. The OSHA regulation requires that employers must take steps in order to protect their workers when exposures for an eight-hour time weighted average (TWA) reach 90 dBA, based on a 5 dB exchange rate [(the OSHA permissible exposure limit (PEL)]. The regulation also requires that when TWAs reach 90 dBA, engineering and/or administrative controls must be implemented and personal protective equipment (PPE) for all employees must be provided when engineering and/or administrative controls are unable to attenuate noise levels below the eight-hour TWA.[9,10]

The OSHA AL was ascertained using the following formula: Action level=90 + 16.61 x$[\frac{log 50}{(12.5\ x\ \#\ of\ hours\ worked)}]$. The OSHA recommended PEL was ascertained using the allowable exposure time equation from Table G-16 found in Appendix A of 29 CRF 1910.95): $T = \frac{8}{2^{(L-90)/5}}$, where T is the allowable exposure time based on the measured A-weighted sound pressure level, L. The recommended PEL is calculated by setting T equal to the actual exposure time and solving for L.[9] The ACGIH® TLV® was ascertained using the following formula: L – 10 log (T/8), where T is the reference duration and L is the exposure limit.[11]

In addition, OSHA requires that all employees be enrolled in a hearing conservation program (HCP) when exposed to noise levels exceeding the AL of 85 dBA as an eight-hour TWA or 50% dose [the OSHA AL (AL)] as measured by a personal noise dosimeter. The adjusted OSHA AL for a 10-hour work shift is 83 dBA and 82 dBA for a 12-hour work shift. Although not enforced by law, OSHA also recommends the PEL be reduced to 88 dBA for a 10-hour work shift and 87 dBA for a 12-hour work shift.[9] The OSHA standard lists the details of the HCP that employers are required to follow, including noise monitoring, annual audiometric testing, proper record keeping, and providing workers with hearing protection devices (HPDs). The OSHA regulation stipulates that all employees enrolled in a HCP shall be properly trained and educated on the proper use, maintenance and proper fit of hearing protection, as well as the associated risks of NIHL. Employees whose noise exposures exceed the OSHA AL shall be required to participate in a HCP at no cost to them. Compliance of the employers with the OSHA PEL for noise is enforceable by law. OSHA also requires that noise levels be assessed using a sound level meter (SLM) or a personal noise dosimeter, with settings for an A-weighting filter, slow integrating response, 5 dB exchange rate and a measurement threshold of 90 and 80 dBA in order to respectively compare the PEL to the AL.[9,10] Although the OSHA regulations for noise are enforceable for compliance, the NIOSH and ACGIH® published standards are suggestions for best practice.

As previously stated, ACGIH® and NIOSH published standards are recommendations, however; they are not enforceable. NIOSH and ACGIH® publish standards that are more protective against NIHL than OSHA regulations, with an occupational noise exposure limit of 85 dBA for an eight-hour TWA with a threshold of 80 dBA. NIOSH and ACGIH® also recommend that noise levels be assessed using a SLM or personal noise dosimeter with settings for an A-weighting filter, slow integrating response, 3 dB exchange rate and a measurement threshold of 80 dBA. These differences from the OSHA standard result in more conservative and more protective recommendations from NIOSH and ACGIH®. The more protective 3 dB exchange rate results in shorter allowable times at higher noise level exposures than the OSHA regulation. The exchange rate defines how level and time is traded at a rate that will double the permissible exposure time for each 3 dB or 5 dB decrease in noise level. However, if the employee's noise environment is moderately steady for the entire work shift, then both criteria from the OSHA regulation as well as the ACGIH® and NIOSH recommendations would be equally protective with all other aspects being equivalent.[(2)] Although NIOSH and ACGIH® share the same exposure limits, NIOSH also includes recommendations for program administration that ACGIH® does not include.[(11, 12)]

Relevant Studies

Although there are currently no published studies analyzing occupational noise exposures for employees of ski resorts, there are published studies analyzing snowmobile noise generation. These previous studies revealed a noise generation SPL range of 86 dBA to 136 dBA by snowmobiles.[(13, 14)]

CHAPTER 3: PURPOSE AND SCOPE

Purpose

The purpose of this study was to determine the occupational noise exposures of workers employed at a ski resort and to identify equipment that may generate harmful noise levels.

Research Questions

The noise evaluation of a ski resort was used to answer the following two research questions:

(1) Are ski resort workers overexposed to noise from equipment emitting noise levels exceeding published exposure limits may lead to noise-induced hearing loss?

(2) Is there a significant difference between exposures of those working in different areas?

Scope

Employees working at a ski resort in Colorado were solicited for participation in this study. The ski resort was chosen due to their genuine interest in the health and safety of their employees. Three different employee classifications were chosen based on the thoughts and suggestions from the current safety manager. Personal dosimetry was conducted on workers operating noise-generating machinery or working in a noisy environment in order to obtain an eight-hour time weighted average to compare to current occupational exposure limits set by the OSHA and ACGIH®. Equipment was also evaluated in order to identify and characterize noise emissions. Sampling was conducted during the ski season of 2011.

CHAPTER 4: MATERIALS AND METHODS

Site Selection

The ski resort was identified in Colorado by the researcher through personal acquaintance. The facility's Environmental Health and Safety Department management was contacted in order to solicit support and cooperation for this research. After the research purpose, scope, confidentiality measures, recruitment and voluntary participation of employees were explained; facility management indicated their willingness to participate in the research and their interest in receiving results regarding occupational noise exposures of the employees at the ski resort. All contact with the facility and its employees was made in accordance with procedures approved by the Colorado State University (CSU) Institutional Review Board (IRB) and the Research Integrity and Compliance Review Office.

Recruitment

The facility's Environmental Health and Safety Department management revealed three job classifications that were thought to have the highest noise exposures. Employees within the three job classifications were recruited into the research study using a verbal script. All subjects provided written informed consent for participation in the study before any participation took place. All research and affiliated activities with this study were conducted according to the protocol approved by the Research Integrity and Compliance Review Office at CSU.

Personal Noise Monitoring

Dosimetry samples were gathered using Larson Davis Personal Noise Dosimeters, models 706RC and 703+, which are manufactured in Provo, Utah. The personal noise dosimeters were used to measure noise exposures based on both OSHA and ACGIH® criteria as indicated in Table 2 below. The microphones of the personal noise dosimeters were covered with a rubber protector while monitoring the snowmaker group to prevent water damage to the microphone. Although the covers are not commercially made for dosimeters, the manufacturer of the personal noise dosimeters was contacted regarding this limitation and stated that there should be no significant interference.

Table 2: Dosimeter Settings

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

All personal noise dosimeters were pre- and post-calibrated at 94 and 114 dB in accordance to manufacturer's specifications to ensure accuracy and consistency with measurement readings and all calibrations were documented. Employees were informed to not speak, blow or yell directly into the microphone and to not tap or hit the microphone. Employees were asked if one side of their body would receive louder levels of noise and if so, the microphone was placed on that side of the body. Microphones were placed as closely to the hearing zone as possible and employees were told to conduct work as usual. Dosimetry was conducted in accordance with the OSHA Technical Manual.(15) The chair lift operators and the snow groomers do not wear any type of head set or personal music device while working. However, the snowmakers do wear headset radios so that they can communicate with each other.

Area Noise Monitoring

A Larson Davis System 824 SLM/Octave Band Analyzer (OBA), also manufactured in Provo, Utah, was used to conduct all area noise monitoring. Two-minute area samples of SLM and OBA were taken at approximate levels of the hearing zone of the employees. Samples were taken of the snowmaking machines at an estimated one foot away while snow grooming machines and chair lift machine engines at an estimated two meters away. The SLM measurements of the snow grooming equipment were taken both inside the cab and outside roughly two meters away for the outside measurements, while the overall value was reported.

The SLM was used to acquire a Leq, which is the equivalent steady sound level of noise energy and is averaged over time. The SLM was also utilized to obtain an OBA, which characterizes the sound according to different frequencies in order to identify the predominant frequencies of the noise according to the different weighting systems. In order to ensure accuracy, validity and reliability, the SLM/OBA was pre- and post-calibrated to 94 and 114 dB and all calibrations were recorded.

Data Management and Statistical Analysis

The statistical laboratory at CSU was consulted prior to data collection in an effort to determine an appropriate number of samples required for the study. Power analyses based on similar previous studies researching noise exposure in football stadiums and working with heavy equipment were analyzed by professional statistical consultants and the total number of samples was determined using Lenth's online power calculator based on a two-sample t-test. [16,17,18] Using a conjectured standard deviation of 5 dB, difference between means of 5 dB, and the power greater than 0.85, a sample size of n=20 per group was determined to be adequate.[18]

The data obtained using the Larson Davis personal noise dosimeters were downloaded and analyzed using the Larson Davis Blaze software (version 6.0.1). Data from the personal noise dosimeters were then analyzed on the basis of: peak, max, SPL, OSHA eight-hour TWA, OSHA % dose, ACGIH® eight-hour TWA, and ACGIH® % dose. The peak measurement indicates the maximum sound level reached by the sound pressure on the C-weighting scale without a time constant applied. The max level is the maximum single highest level of sound measured. The OSHA eight-hour TWA is a time weighted average exposure of noise over the course of an eight-hour work shift using a 5 dB exchange rate. The

OSHA % dose is the accumulated dose of noise exposure based on the OSHA eight-hour TWA. The ACGIH® eight-hour TWA is a time weighted average noise exposure over the course of an eight-hour work shift using a 3 dB exchange rate. The ACGIH® % dose is the accumulated dose of noise exposure based on the ACGIH® eight-hour TWA.[2]

CHAPTER 5: RESULTS AND DISCUSSION

Personal Dosimetry

Snowmakers

There were 12 total employees comprising of the entire snowmaker population at this ski resort. Thirty-three percent (33%) and 100% of day-shift and night-shift snowmakers exceeded the 12-hour OSHA AL of 82 dBA, respectively (see Table 4). Twenty-two percent (22%) and 40% of day-shift and night-shift snowmakers exceeded the OSHA recommended 12-hour PEL of 87 dBA, respectively (see Table 4). Eleven percent (11%) and 10% of day-shift and night-shift snowmakers exceeded the OSHA PEL of 90 dBA, respectively (see Table 4). Also, 44% and 100% of day-shift and night-shift snowmakers exceeded the ACGIH® 12-hour TLV® 83 dBA, respectively (see Table 4).

Chair Lift Operators

The entire chair lift operator population consisted of 150 employees working at this ski resort. Five percent (5%) of the chair lift operators exceeded the 10-hour OSHA AL of 83 dBA (see Table 5). None of the chair lift operators exceeded the OSHA recommended 10-hour PEL of 88 dBA (see Table 5). None exceeded the OSHA PEL of 90 dBA (see Table 5); and 10% exceeded the ACGIH® TLV® of 84 dBA (see Table 5).

Snow Groomers

The entire snow groomer population was comprised of a total of 12 workers at this ski resort. No snow groomers (0%) exceeded the OSHA AL of 83 dBA (see Table 6); none exceeded the OSHA12-hour recommended PEL of 88 dBA (see Table 6). None exceeded the OSHA PEL of 90 dBA (see Table 6); and none exceeded the ACGIH® TLV® of 84 dBA (see Table 6).

Table 3: Summary Statistics for Worker Exposures

Job Classification	Sample Size	SPL (dBA) Mean (SD)	Max (dB) Mean (SD)	Peak (dB) Mean (SD)	OSHA % Dose Mean (SD)	OSHA TWA (dBA) Mean (SD)	ACGIH® % Dose Mean (SD)	ACGIH® TWA (dBA) Mean (SD)
Snowmakers Night-Shift	10	94 (3)	125 (5)	144 (6)	82 (25)	86 (2)	1187 (844)	94 (3)
Snowmakers Day-Shift	9	86 (9)	118 (10)	149 (4)	51 (68)	77 (10)	834 (1449)	85 (9)
Chair Lift Operators	20	81 (3)	108 (7)	135 (7)	12 (9)	73 (5)	38 (34)	80 (4)
Snow Groomers	19	76 (3)	102 (8)	139 (19)	4 (5)	61 (7)	10 (13)	72 (4)

Table 4: Proportion of Snowmakers Exceeding Occupational Noise Criteria

Work Shift	Employee Data	Criteria: OSHA AL (82 dBA)	OSHA Recommended PEL (87 dBA)	OSHA PEL (90 dBA)	ACGIH® TLV® (83 dBA)
Night-Shift	*Number of Employees Below Criteria*	0	6	9	0
	Number of Employees Above Criteria	10	4	1	10
Day-Shift	*Number of Employees Below Criteria*	6	7	8	5
	Number of Employees Above Criteria	3	2	1	4

Table 5: Proportion of Chair Lift Operators Exceeding Occupational Noise Criteria

Employee Data	Criteria			
	OSHA AL (83 dBA)	OSHA Recommended PEL (88 dBA)	OSHA PEL (90 dBA)	ACGIH® TLV® (84 dBA)
Number of Employees Below Criteria	19	20	20	18
Number of Employees Above Criteria	1	0	0	2

Table 6: Proportion of Snow Groomers Exceeding Occupational Noise Criteria

Employee Data	Criteria			
	OSHA AL (83 dBA)	OSHA Recommended PEL (88 dBA)	OSHA PEL (90 dBA)	ACGIH® TLV® (84 dBA)
Number of Employees Below Criteria	19	19	19	19
Number of Employees Above Criteria	0	0	0	0

Table 7: Proportion of Workers Exceeding Occupational Noise Criteria

Job Classification	OSHA PEL	OSHA Recommended PEL	OSHA Action Limit	ACGIH® TLV®
Snowmakers	11%	32%	70%	63%
Night Snowmakers	10%	40%	100%	100%
Day Snowmakers	11%	22%	33%	44%
Snow Groomers	0%	0%	0%	0%
Chair Lift Operators	0%	0%	5%	10%

Area Monitoring

The SLM results of the snowmaking machinery revealed a Leq range of 83 dBA to 116 dBA and a peak range of 102 dBA to 132 dBA. The SLM results for the chair lift equipment revealed a Leq range of 75 dBA to 81 dBA and a peak range of 101 dBA to 108 dBA. The SLM results of the snow grooming machinery revealed a Leq range of 74 dBA to 78 dBA and a peak range of 103 dBA to 128 dBA.

In conjunction, octave band analysis was also performed at the same locations as stated above. The octave band analysis of the snowmaking machinery revealed that higher frequencies were predominant, specifically from the 1000 Hz to the 8000 Hz range. The octave band analysis of the chair lift equipment revealed that the lower frequencies were predominant, specifically the 125 Hz to the 1000Hz range. The octave band analysis for the snow grooming equipment also revealed that lower frequencies were predominant, specifically from the 125 Hz to the 1000 Hz range. Figure 3 displays the Leq and Peak SPL measurements recorded for eight different snowmaking machines. Figure 4 displays the octave band analysis measurements of all eight snowmaking machines together in one graph. Figures 5-11 display the octave band analysis of each snowmaking machine measured individually. Noise generated by snowmaking machines varied by up to 30 dB difference due to the different types of machines being used at the ski resort.

Figure 12 displays the Leq and Peak SLM measurements of all chair lift equipment measured. Figure 13 displays the octave band analysis for the chair lift equipment measured. Figure 14 displays the Leq and Peak SLM measurements of the snow groomer equipment measured. Figure 15 displays the octave band analysis of the snow groomer equipment measured.

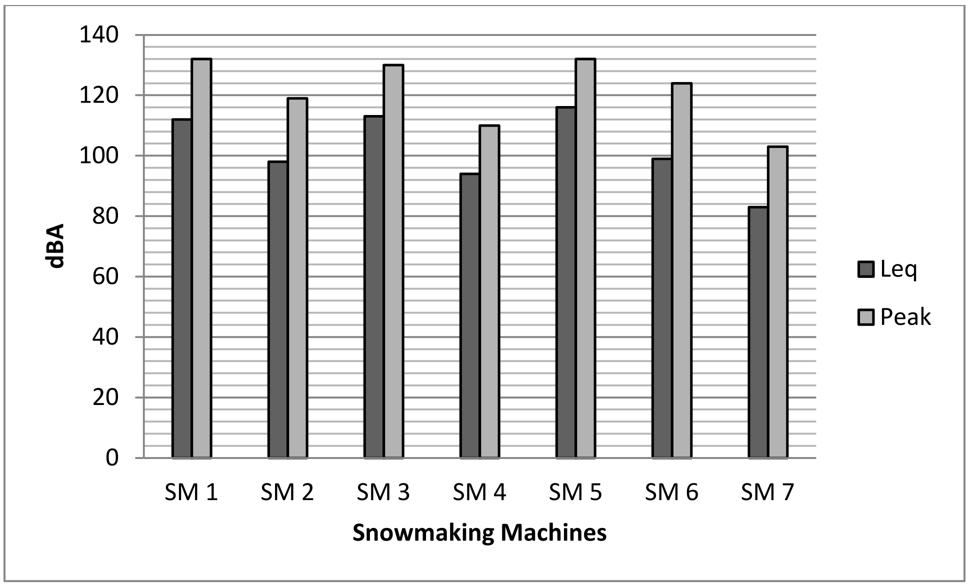

Figure 3: Leq and Peak SPL Measurements of Snowmaking Machines

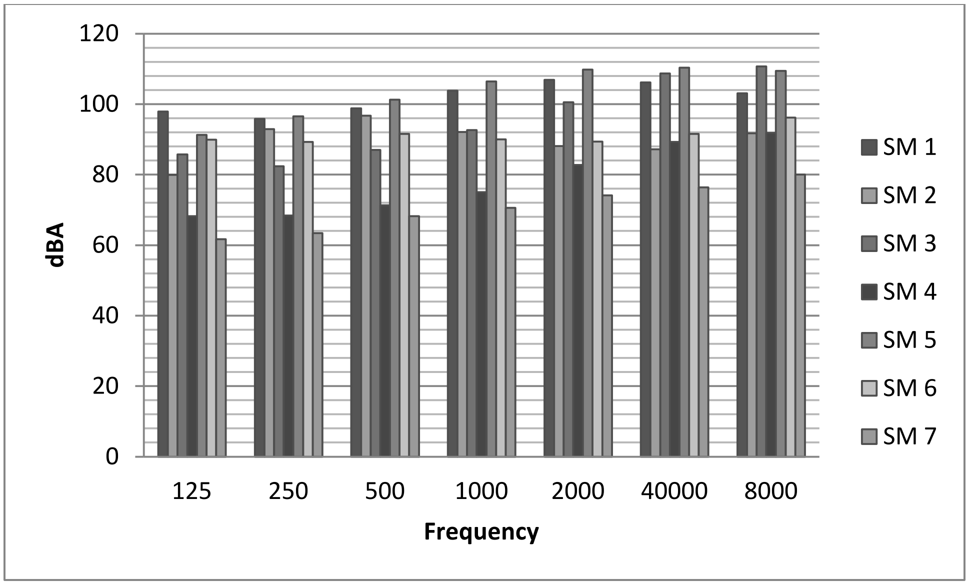

Figure 4: Octave Band Analysis of Snowmaking Machines

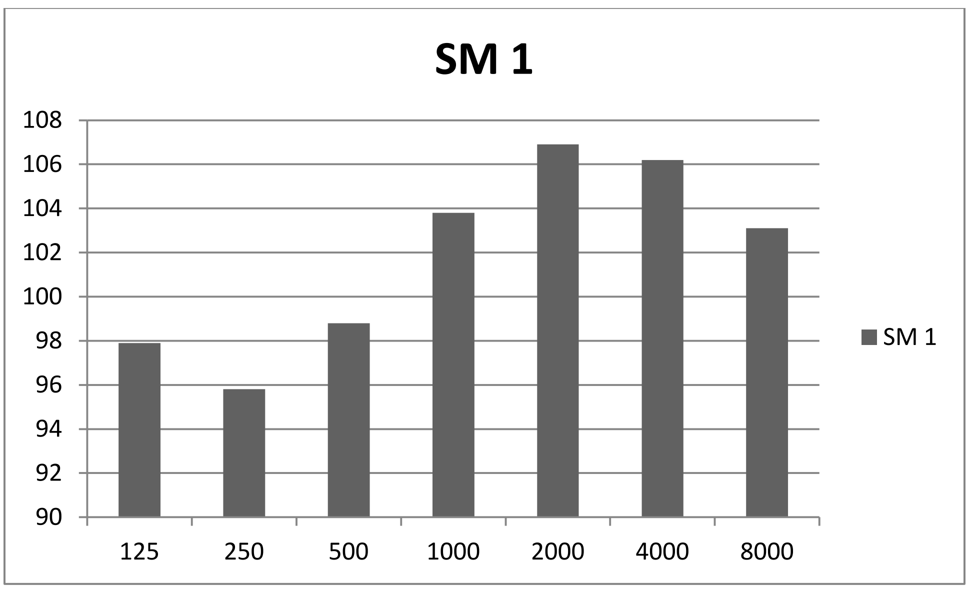

Figure 5: Octave Band Analysis of #1 Snow Making Machines

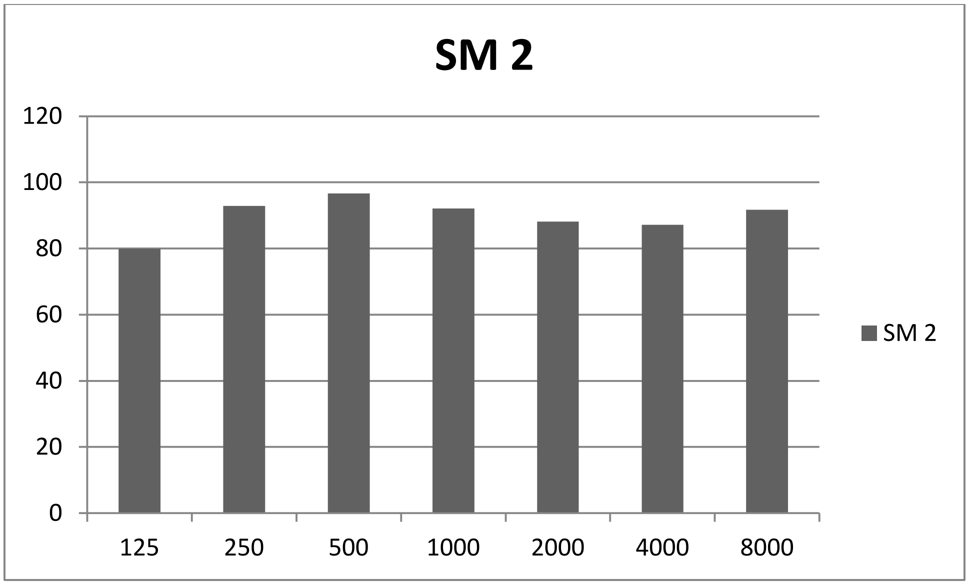

Figure 6: Octave Band Analysis of #2 Snowmaking Machine

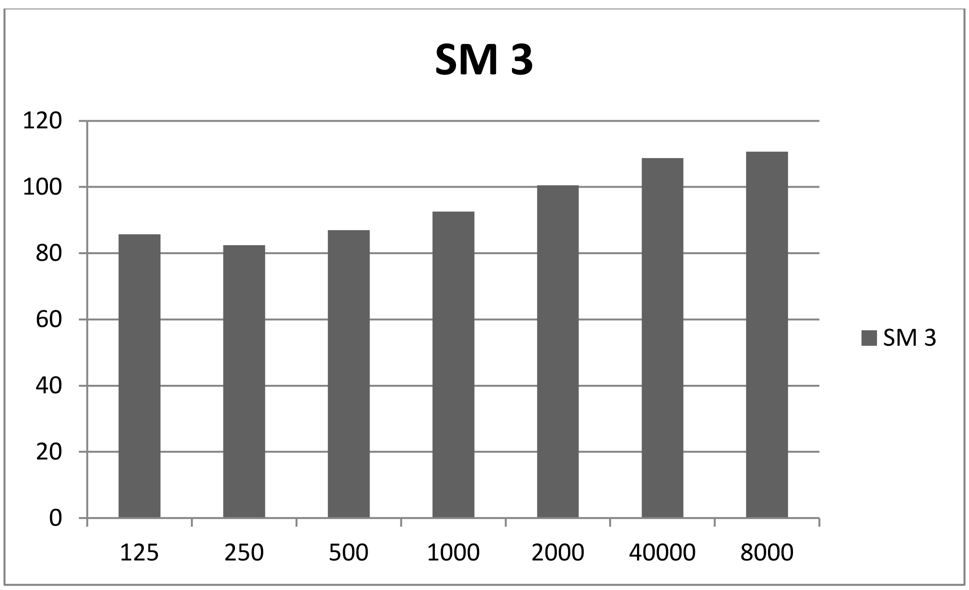

Figure 7: Octave Band Analysis of #3 Snowmaking Machine

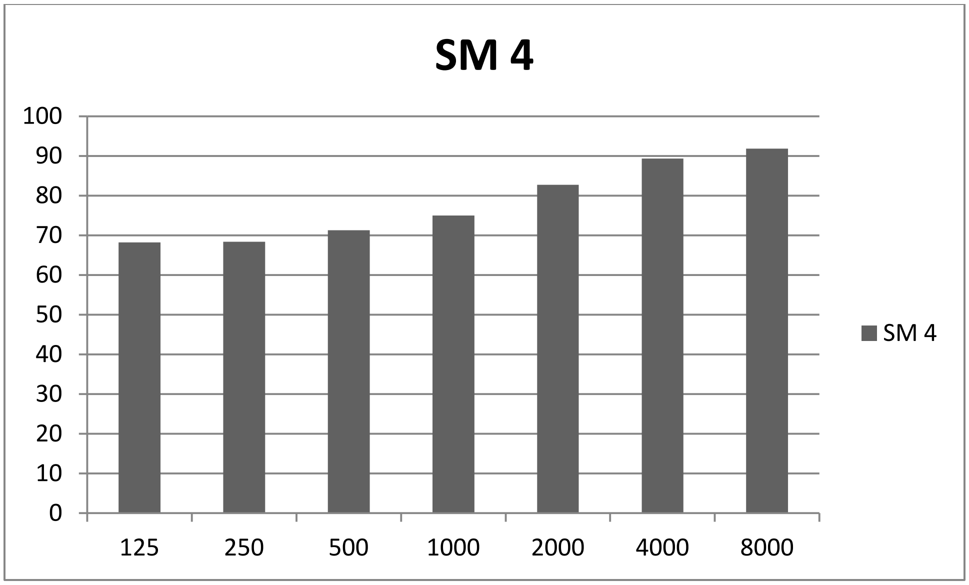

Figure 8: Octave Band Analysis of #4 Snowmaking Machine

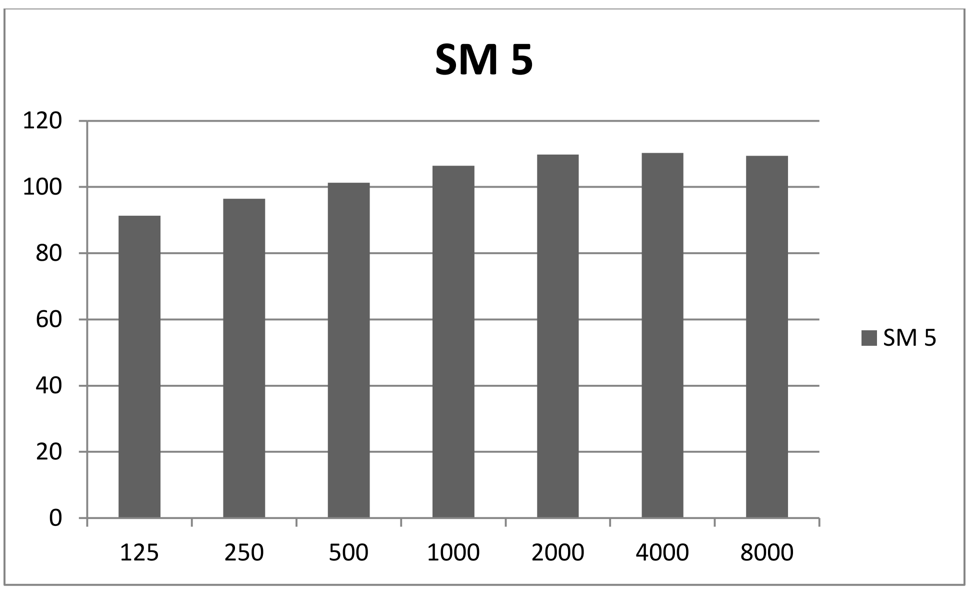

Figure 9: Octave Band Analysis of #5 Snowmaking Machine

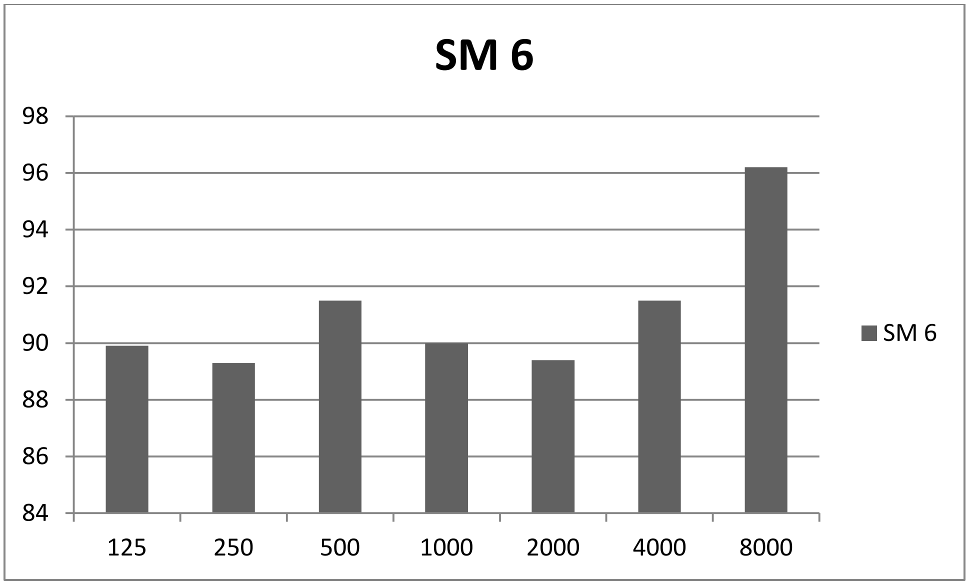

Figure 10: Octave Band Analysis of #6 Snowmaking Machine

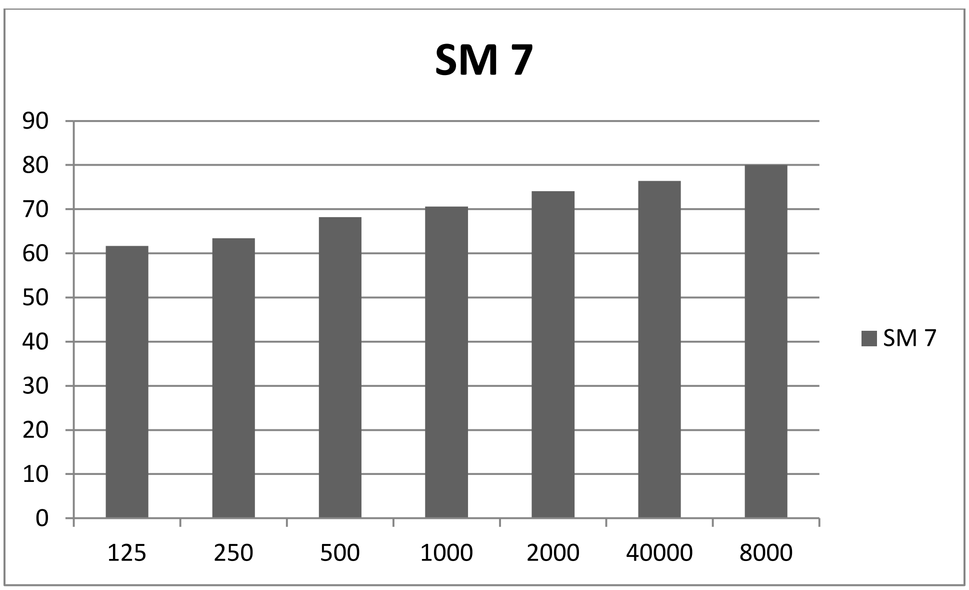

Figure 11: Octave Band Analysis of #7 Snowmaking Machine

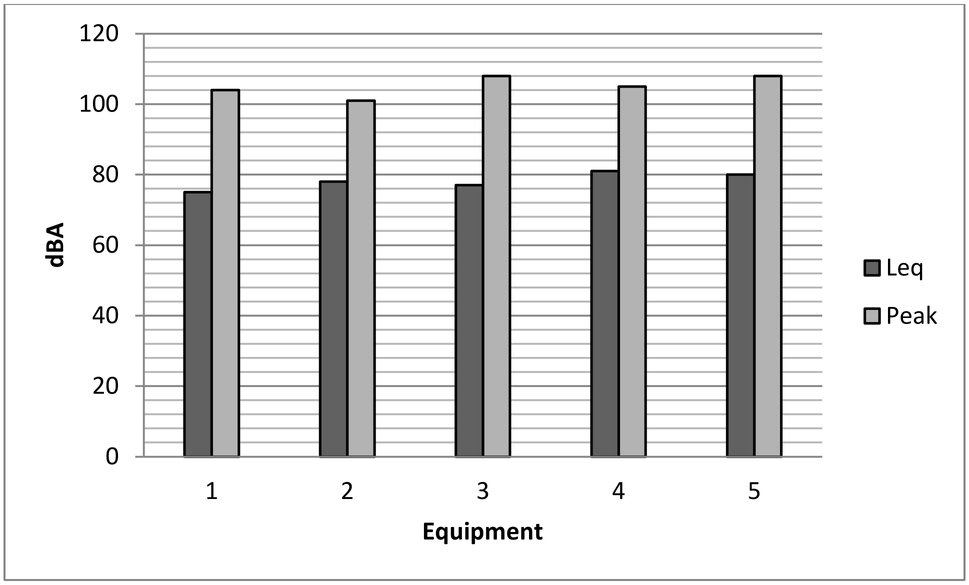

Figure 12: Leq and Peak SPL of Chair Lift Equipment

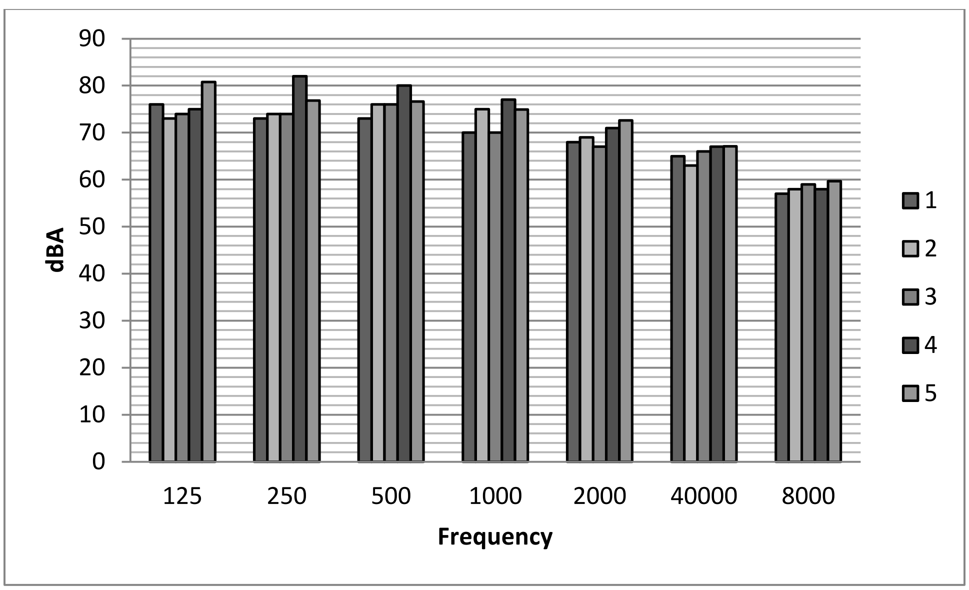

Figure 13: Octave Band Analysis of Chair Lift Equipment

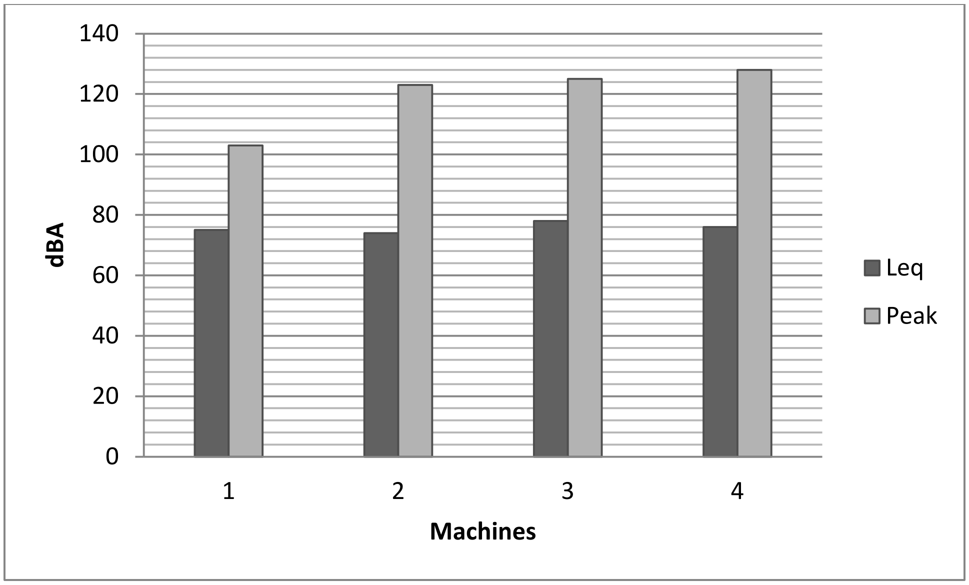

Figure 14: Leq and Peak SPL of Snow Groomer Equipment

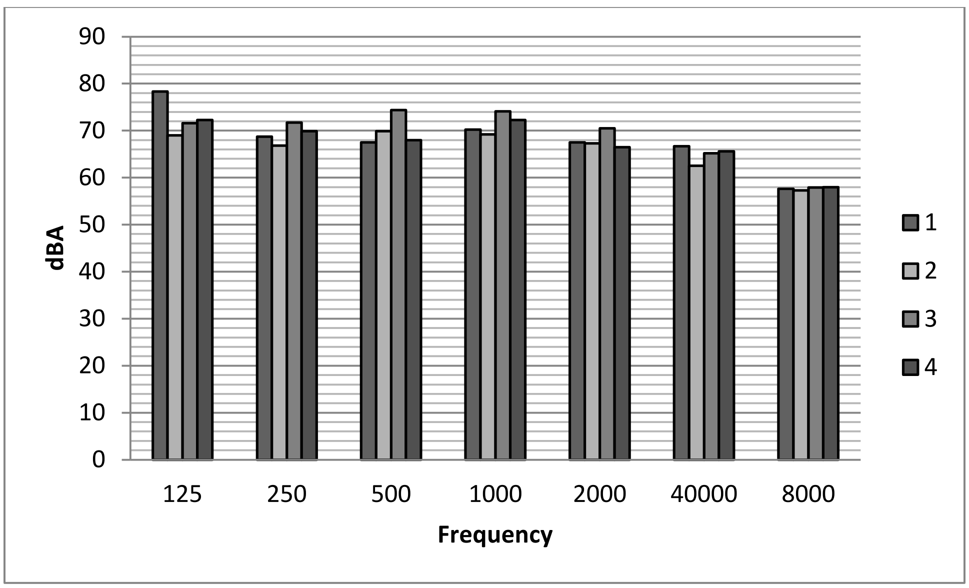

Figure 15: Octave Band Analysis of Snow Groomer Equipment

Statistical Analysis

In order to ensure statistical validity, tests of normality were performed on all noise dosimetry data. The assumption of normality was satisfied for the chair lift operator group and the snow groomer group, however; when analyzing the entire snowmaking population together, this assumption was not satisfied in this group. When stratifying the snowmaker population by night and day, the assumption of normality was satisfied for both groups. Wilcoxon Signed Rank Test was first performed on the snowmaker population data before stratifying by night and day-shift to test the null hypothesis that the median was less than the OSHA AL, OSHA recommended PEL, OSHA PEL, and ACGIH® TLV®. The snowmaker population data were then stratified by night and day-shift, and each group was then tested using a one-sample t-test to determine if the mean TWA exceeded noise criteria for OSHA and ACGIH®.

Based on the one-sample t-tests, it was determined that the mean day-shift snowmaker noise levels did not exceed the OSHA 12-hour AL, the OSHA 12-hour recommended PEL, the OSHA PEL, or the ACGIH® 12-hour TLV® (all p-values greater than 0.24) (see Tables 8-11). However, based on the one-sample t-tests, it was determined that the mean night-shift snowmaker noise levels exceeded the OSHA 12-hour AL and the ACGIH® 12-hour TLV® (p-values <0.001). The mean night-shift snowmaker noise levels did not exceed the OSHA 12-hour recommended PEL nor the OSHA PEL (all p-values greater than 0.823) (see Tables 8-11).

Based on the one-sample t-tests, it was determined that the mean chair lift operator noise levels did not exceed the OSHA 10-hour AL, the OSHA 10-hour recommended PEL, the OSHA PEL, or the ACGIH® 10-hour TLV® (all p-values equal to one) (see Tables 12-15). Based on the one-sample t-tests, it was determined that the mean snow groomer noise levels did not exceed the OSHA 10-hour AL, the OSHA 10-hour recommended PEL, the OSHA PEL, or the ACGIH® 10-hour TLV® (all p-values equal to one) (see Tables 16-19).

Figures 16-23 display box plot comparisons of the snowmaker group stratified by night and day-shifts, chair lift operators and snow groomers. The box plots compare both OSHA TWA and ACGIH® TWA between the different job classifications sampled. Significant differences were found between the night and day-shift snowmakers, as well as a significant difference between the chair lift operators and snow groomers. As seen in Figure 16, there is also a much wider range in dB for the day-shift as compared to the night-shift snowmaker data. This difference in dB range between the two shifts is thought to be attributed to the fact that there is less snowmaking occurring on the day-shift as compared to the night-shift, so fewer employees are exposed to the noise generation from the snowmaking machines.

Table 8: One Sample t Test of Null Hypothesis Snowmaker Mean < OSHA AL (82 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snowmakers (Day)	76.67	9.66	3.22	70.68	-1.66	0.932	0.05
Snowmakers (Night)	86.3	2.26	0.72	84.99	6.01	0	0.05

Table 9: One Sample t Test of Null Hypothesis Snowmaker Mean < OSHA Recommended PEL (87 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snowmakers (Day)	76.67	9.66	3.22	70.68	-3.21	0.994	0.05
Snowmakers (Night)	86.3	2.26	0.72	84.99	-0.98	0.823	0.05

Table 10: One Sample t Test of Null Hypothesis Snowmaker Mean < OSHA PEL (90 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snowmakers (Day)	76.67	9.66	3.22	70.68	-4.14	0.998	0.05
Snowmakers (Night)	86.3	2.26	0.72	84.99	-5.71	1	0.05

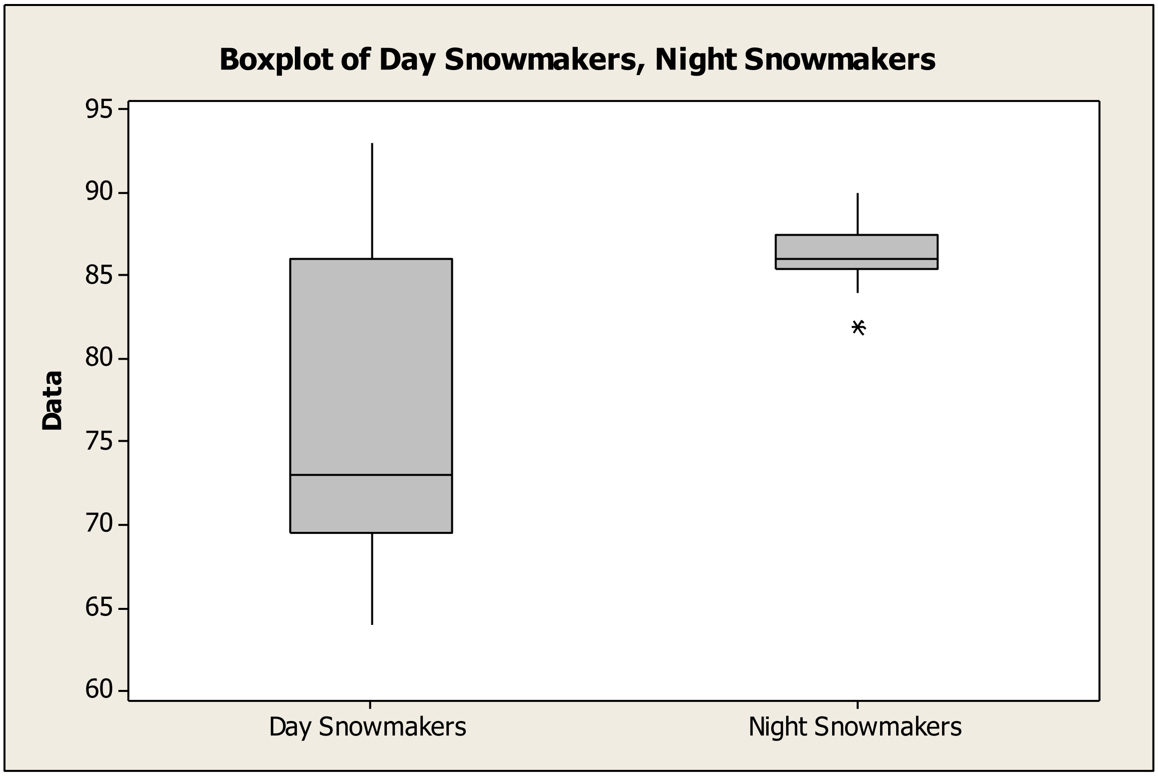

Figure 16: Box Plot of OSHA TWA for Night and Day Snowmakers

Table 11: One Sample t Test of Null Hypothesis Snowmaker Mean < ACGIH® TLV® (83 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snowmakers (Day)	85.22	9.01	3	79.64	0.74	0.24	0.05
Snowmakers (Night)	93.6	2.88	0.91	91.93	11.66	0	0.05

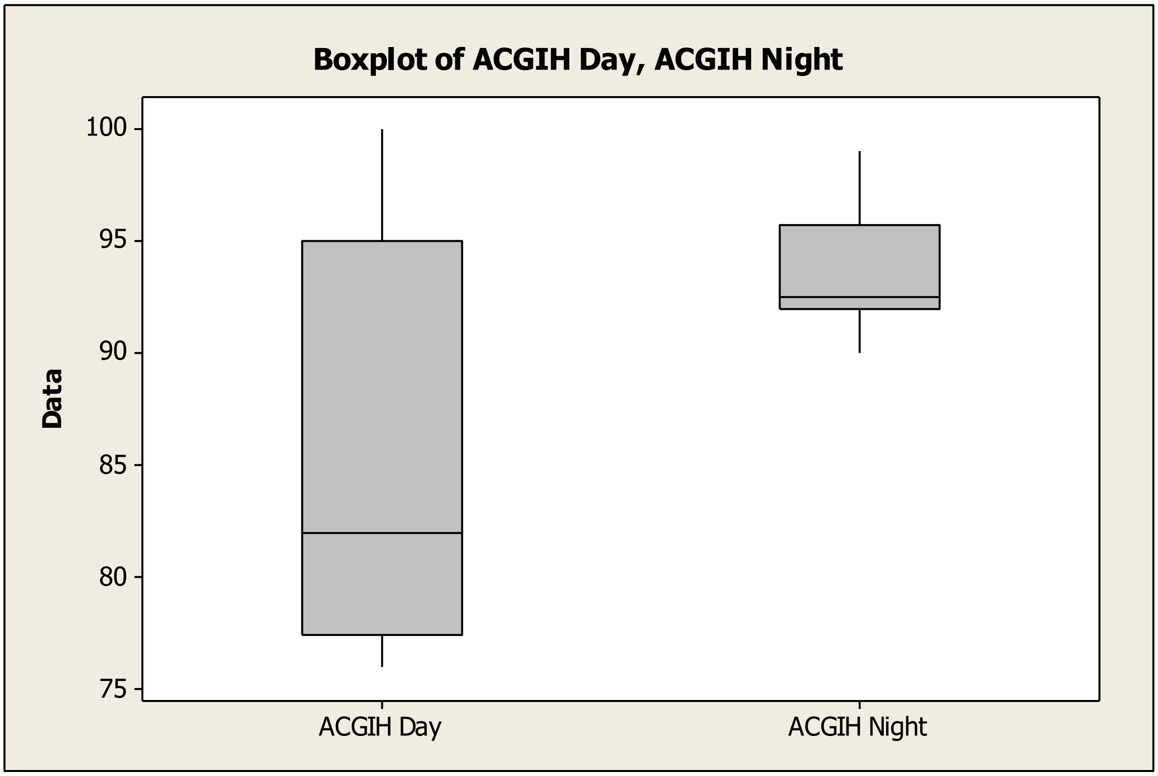

Figure 17: Box Plot of ACGIH® TWA for Night and Day Snowmakers

Table 12: One Sample t Test of Null Hypothesis Chair Lift Operator Mean < OSHA AL (83 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Chair Lift Operators	73.35	4.84	1.08	71.48	-8.92	1	0.05

Table 13: One Sample t Test of Null Hypothesis Chair Lift Operator Mean < OSHA Recommended PEL (88 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Chair Lift Operators	73.35	4.84	1.08	71.48	-13.54	1	0.05

Table 14: One Sample t Test of Null Hypothesis Chair Lift Operator Mean < OSHA PEL (90 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Chair Lift Operators	73.35	4.84	1.08	71.48	-15.39	1	0.05

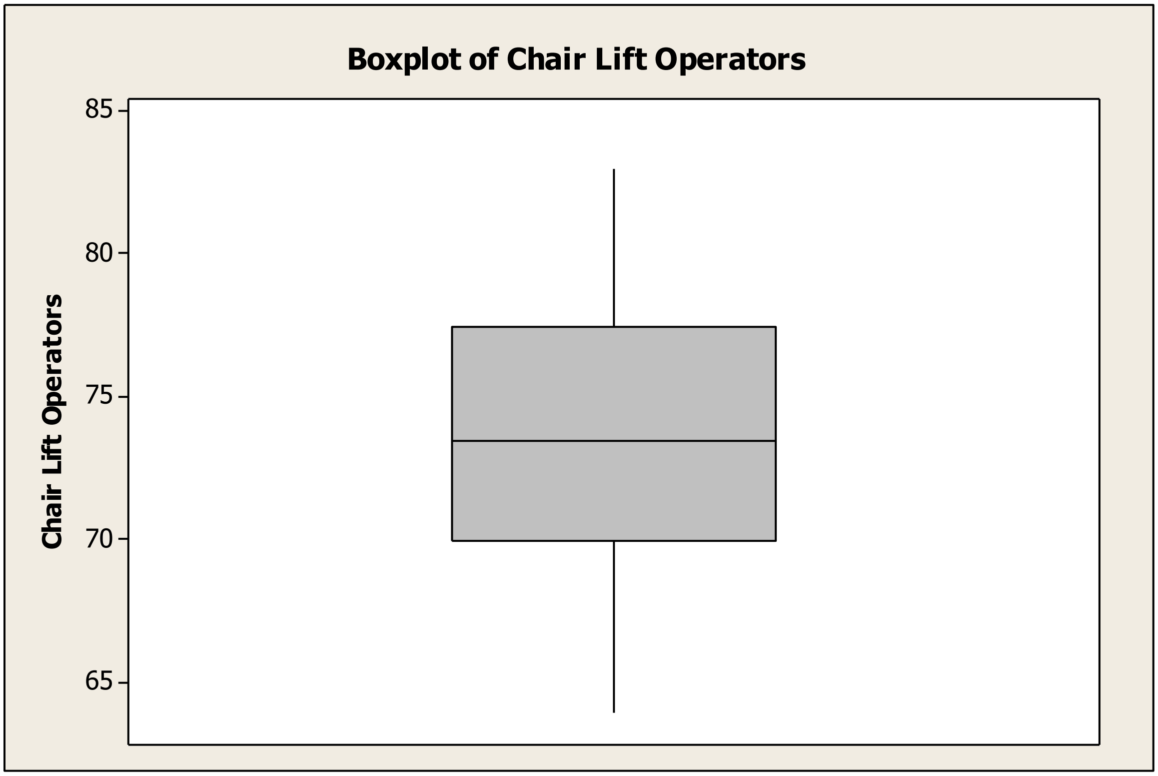

Figure 18: Box Plot of OSHA TWA for Chair Lift Operators

Table 15: One Sample t Test of Null Hypothesis Chair Lift Operator Mean < ACGIH® TLV® (84 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Chair Lift Operators	79.45	3.43	0.77	78.13	-5.94	1	0.05

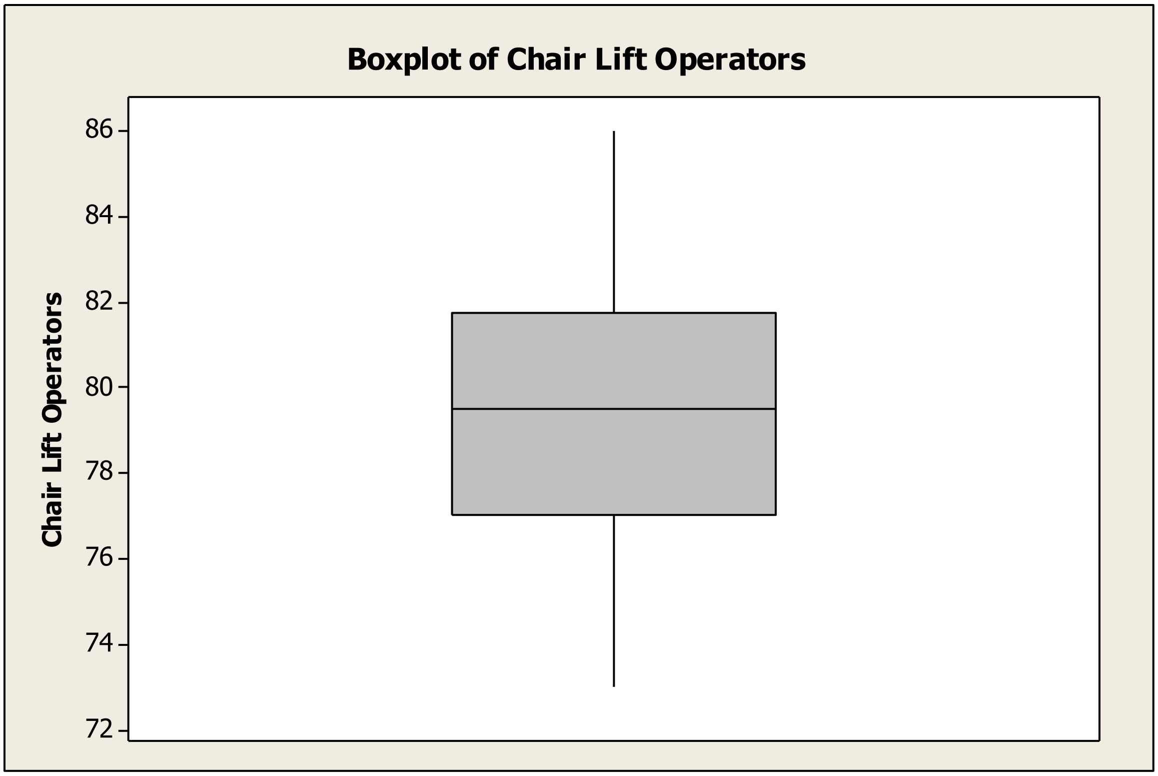

Figure 19: Box Plot of ACGIH® TWA for Chair Lift Operators

Table 16: One Sample t Test of Null Hypothesis Snow Groomer Mean < OSHA AL (83 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snow Groomer	61.11	6.64	1.52	58.46	-14.37	1	0.05

Table 17: One Sample t Test of Null Hypothesis Snow Groomer Mean < OSHA Recommended PEL (88 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snow Groomer	61.11	6.64	1.52	58.46	-17.65	1	0.05

Table 18: One Sample t Test of Null Hypothesis Snow Groomer Mean < OSHA PEL (90 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snow Groomer	61.11	6.64	1.52	58.46	-18.97	1	0.05

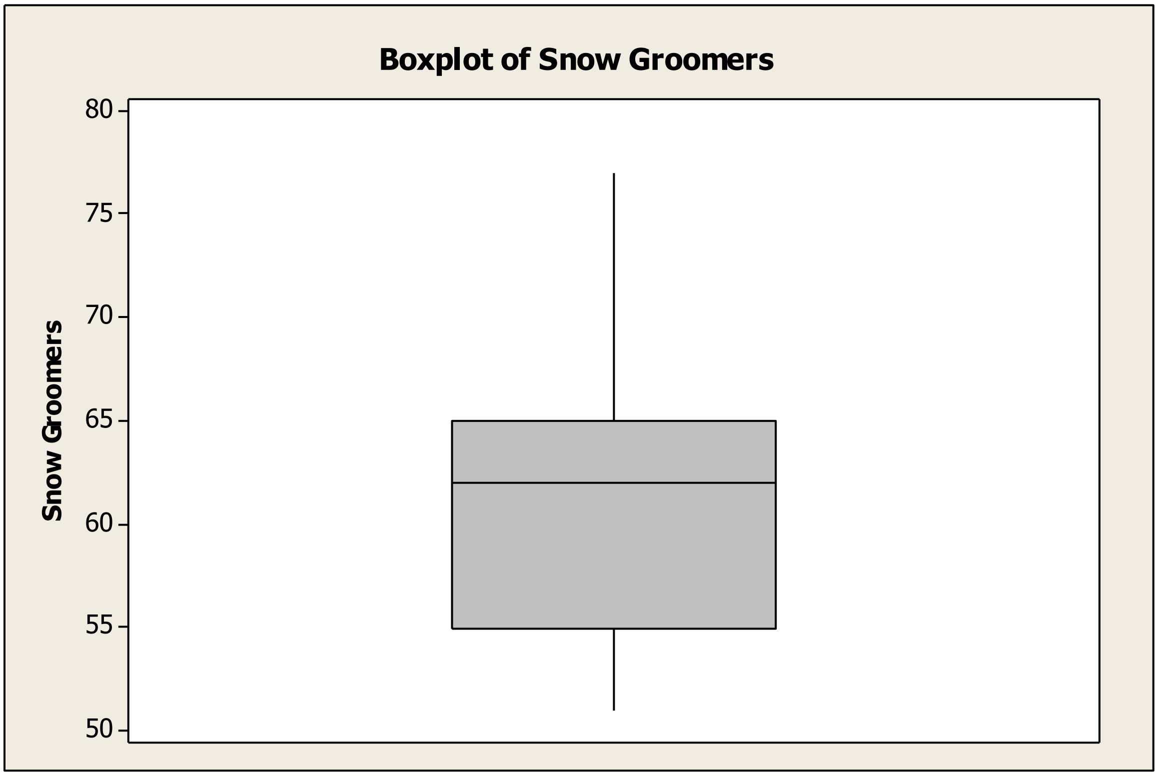

Figure 20: Box Plot of OSHA TWA for Snow Groomers

Table 19: One Sample t Test of Null Hypothesis Snow Groomer Mean < ACGIH® TLV® (84 dBA)

Employee Classification	Mean	St. Dev.	SE Mean	95% Lower Bound	t-value	P-value	Alpha
Snow Groomer	71.68	4.3	0.99	69.98	-12.5	1	0.05

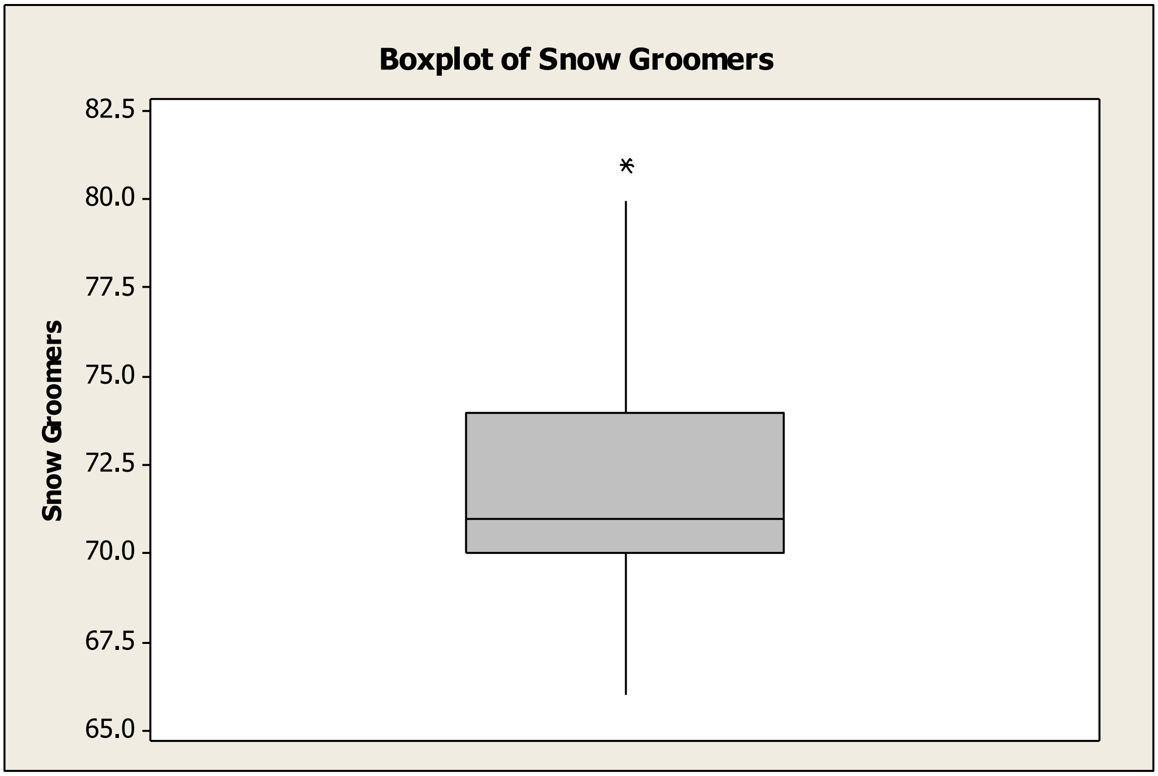

Figure 21: Box Plot of ACGIH® TWA for Snow Groomers

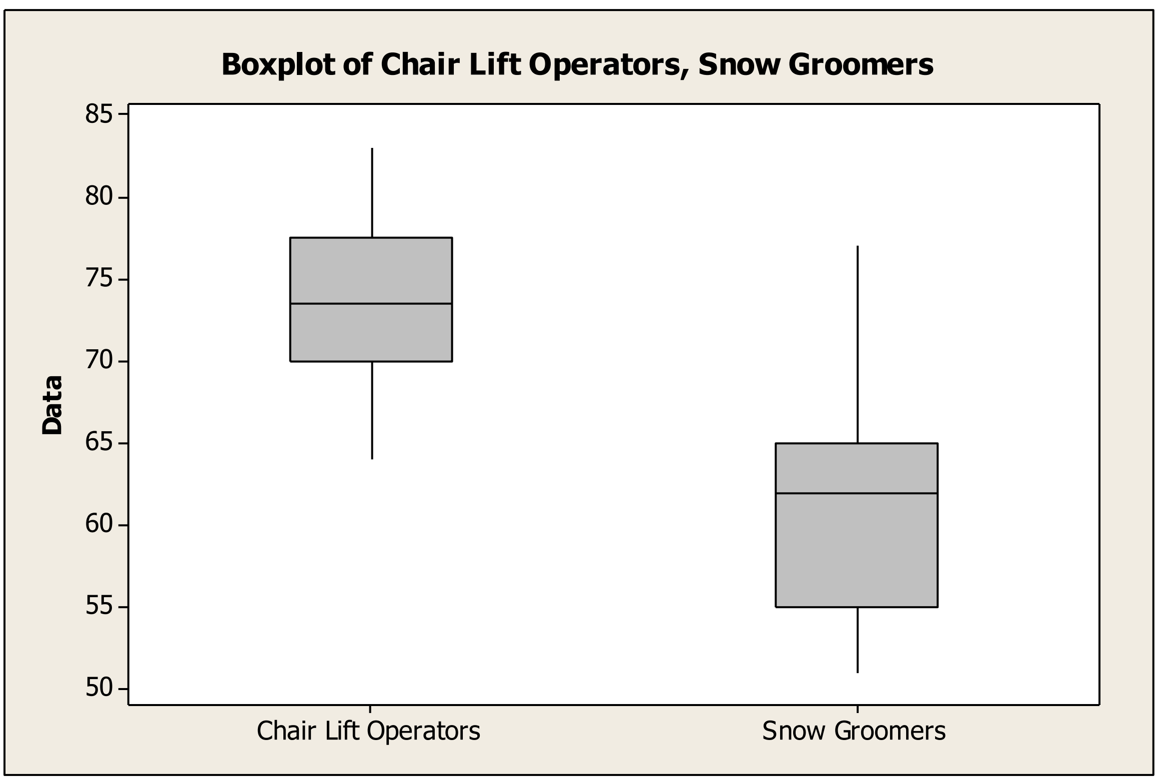

Figure 22: Box Plot Comparison of OSHA TWA for Chair Lift Operators and Snow Groomers

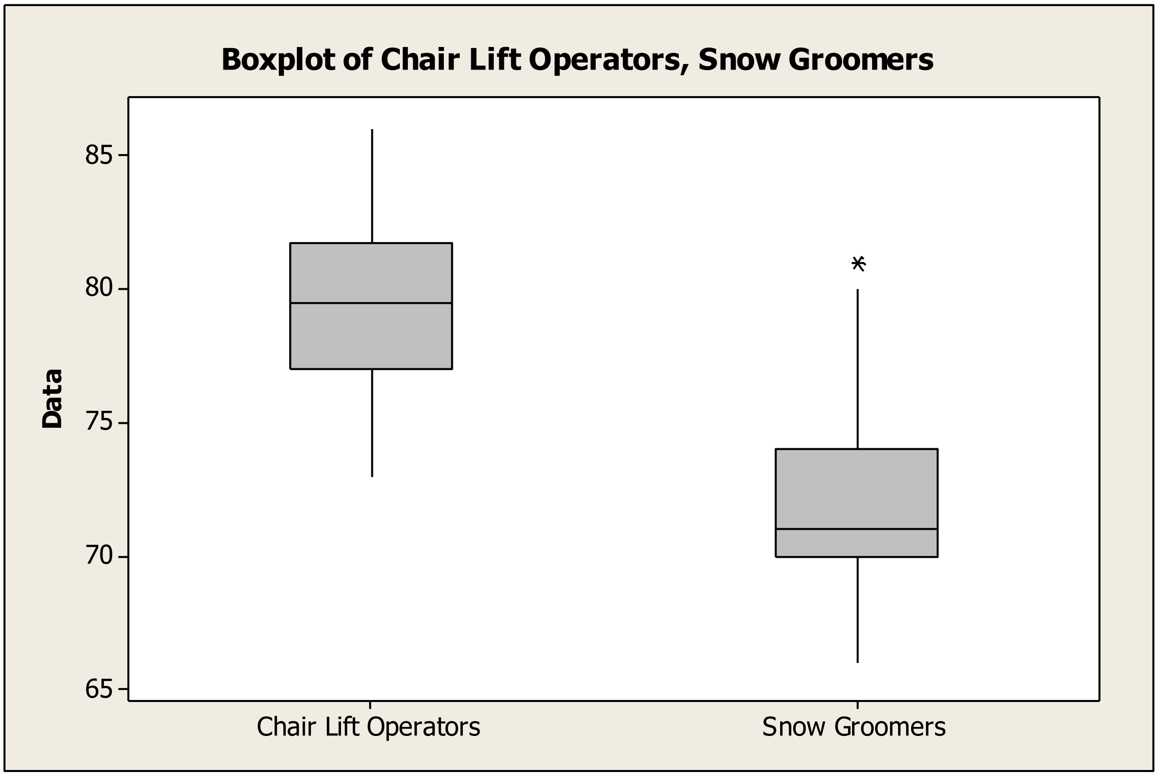

Figure 23: Box Plot Comparison of ACGIH® TWA for Chair Lift Operators and Snow Groomers

Discussion

Snowmakers

Significant differences were found between the night and day-shifts within the snowmaker worker population sample. The night- shift snowmaker group had higher noise exposures than did the day-shift snowmaker group. These differences are most likely attributed to the fact that the mountain is open during the day to skiers, prohibiting the snowmakers from operating as many snowmaking machines as the night-shift that operates when the mountain is closed to the public. This difference would also decrease the exposure to the noise generated by snowmobiles due to the decreased need in traveling to different snowmaking machines during the day-shift. Also, the temperatures are lower at night than in the day, allowing the night-shift snowmakers to capitalize on the favorable temperature conditions which allow more snow to be generated.

Although there did not appear to be any other significant differences in work structure between the two shifts, the significant difference in noise exposure for the day versus night-shift could also be due to the different types of snowmaking machines being used according to the difference in noise generation seen in the SLM results of the different snowmaking machines. As observed in the SLM results of the snowmaking equipment, results varied by 30 dB between the different types of machines. Some snowmaking machines where louder than others, depending on the design. In order to decrease noise exposures, the resort could only use the quieter snowmaking machines. When servicing and adjusting the snowmaking machines, employees are within one foot of the machines. The snowmaker group is exposed to hazardous levels of noise from working with the snowmaking machines and possibly from their mode of transportation around the mountain on the snowmobiles.

Although the mean TWAs for the snowmaking day-shift group were not statistically greater than OSHA and ACGIH® occupational exposure limits, 33% of the sample population did exceed the adjusted OSHA AL and 44% exceeded the adjusted ACGIH® TLV®. Furthermore, the night-shift snowmaker group mean OSHA TWA was not statistically greater than the OSHA recommended PEL. However; 40% of the sample population exceeded the OSHA recommended PEL. Also, 11% of the day-shift and 10% of the night-shift snowmakers exceeded the OSHA PEL. Another important aspect is that the snowmaker employees wear radio headsets to communicate with each other while working all over the mountain. In order to overcome the background noise of the snowmaking machines approximately one foot away and snowmobiles, the headset volume is most likely at a hazardous level as well. The dosimetry results match the SLM measurements taken which indicated a noise generation Leq range of 86 dBA to 116 dBA by the snowmaking machines. The dosimetry results also match previous studies that have shown a noise generation SPL range of 86 dBA to 136 dBA by snowmobiles.[13,14]

Chair Lift Operators

As expected from the results of the SLM measurements of the chair lift machinery (ranging from an Leq of 75 dBA to 81 dBA), the personal noise dosimetry indicated that only 5% of the chair lift operators exceeded the adjusted OSHA 10-hour AL, 10% exceeded the adjusted ACGIH® 10-hour TLV®, none exceeded the OSHA 10-hour recommended PEL and none exceeded the OSHA PEL. Evidence suggests that chair lift operators are not overexposed to noise according to OSHA and ACGIH® occupational noise standards and regulations. There was a difference in noise generation between chair lift operator equipment of approximately 5 dB.

Snow Groomers

SLM measurements taken outside of the snow groomer equipment revealed a Leq range of 74 dBA to 78 dBA. These results explain the personal noise dosimetry that indicated no overexposures based on OSHA and ACGIH® occupational noise standards. The operators of the snow groomer equipment were also enclosed inside of a cab, which likely further reduces noise exposures. There was a difference in noise generation between snow groomer equipment of approximately 4 dB.

Limitations

The primary limitation of this study was the inability to closely observe employees who were being monitored with personal noise dosimeters. The snowmakers work all over the mountain by themselves for the entirety of their shift, and it would not have been feasible to impede upon them the duty of allowing a researcher to ride along with them for the entirety for their shift. Even if this had been feasible, since they do not work in groups, one researcher would only be able to collect one noise dosimetry sample per shift, which is also not reasonable. The same reasoning applies for the snow groomer employee classification. The chair lift operators were observed at different intervals, but again, because they work all over the mountain, it would not be possible to monitor all of the study participants at once. Because worker practices could not be observed, differences in personal noise dosimetry data cannot be accounted for with certainty.

Also, the SLM is a “type one” instrument and the personal noise dosimeters used in this study were “type two” instruments, describing the accuracy of the instruments to be ±1 dB and ±2 dB respectively, which accounts for the accuracy range of the instrument and variability with measurement. The precision error associated with these instruments is a limitation because the data gathered could underestimate the actual noise exposures observed. Another limitation is that personal noise dosimeters are not capable of measuring the noise contribution of the personal headset radios that are worn by the snowmakers, which may be excessive because of the noisy working environment from the snowmaking machines and snowmobiles. Due to this limitation, it is likely that the noise exposures gathered for the snowmaker population is an underestimate of actual noise exposures.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

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

(1) Are ski resort workers overexposed to noise from equipment emitting noise levels exceeding published exposure limits which may possibly lead to noise-induced hearing loss?

Sampling data indicated that 100% of the snowmaker employee population sampled for the night-shift exceeded the adjusted OSHA12-hour AL (82 dBA), 40% of the population exceeded the OSHA recommended12-hour PEL (87 dBA), 10% exceeded the OSHA PEL (90 dBA) and 100% exceeded the adjusted ACGIH® 12-hour TLV® (83 dBA). Results also indicated that of the day-shift snowmaker crew, 33% of the workers sampled exceeded the adjusted OSHA12-hour AL (82 dBA), 22% of the population exceeded the OSHA recommended12-hour PEL (87 dBA) and 44% exceeded the adjusted ACGIH® 12-hour TLV® (83 dBA). Sampling data also indicated that of the chair lift operator group, 5% exceeded the adjusted OSHA 10-hour AL (83 dBA) and 10% exceeded the adjusted ACGIH® 10-hour TLV® (84 dBA). No snow groomers sampled exceeded any occupational noise criteria.

(2) Is there a significant difference between exposures of those working in different areas?

Results from a two-sample t-test indicated a statistical difference in the night-shift snowmaker group data mean OSHA TWA when compared to the day-shift snowmaker mean OSHA TWA (p-value < 0.05). Results from a two-sample t-test also indicated a statistical difference between the chair lift operator OSHA TWA and the snow groomer OSHA TWA (p-value < 0.05).

Recommendations

Snowmakers

A hearing conservation program is recommended for both night and day-shift snowmakers to ensure that all employees are protected from sustaining ONIHL. Employees should be properly trained on the importance of hearing protection, its proper insertion, maintenance and care. All snowmaking employees shall be provided an audiometric test annually. If possible, future snowmaking machinery purchases shall be based on their noise generation. As seen in the SLM results, noise generation of snowmaking machinery ranged by different types from 83 dBA to 116 dBA.

Also, it should be considered to reduce the work shift duration in an effort to reduce noise exposure length. Reducing the work shift will also allow more time for the ear to recover between work shifts, which will also help protect workers from ONIHL. The current OSHA PEL of 90 dBA does not take into consideration the decreased time allowed for the human ear to recover from elevated levels of noise when working 12-hour shifts as opposed to eight-hour shifts. The extended work shift of 12-hours allows four hours less each day than a regular eight-hour shift for the human ear to recover. Prior to the beginning of this study, snowmaker employees were already enrolled in a hearing conservation program, consisting of annual audiograms, training, and the requirement of hearing protection devices to be worn. Another recommendation is to purchase models of snowmobiles, which generate lower levels of noise.

Chair Lift Operators

Although the chair lift operator data indicated no statistical significance that employees sampled exceeded any occupational noise standards, there were still 5% who did exceed the adjusted OSHA 10-hour AL (83 dBA) and 10% who exceeded the adjusted ACGIH® 10-hour TLV® (84 dBA). It would be best practice to gather additional personal noise dosimetry to determine if it should be a requirement for chair lift operators to take annual audiograms to ensure that no employees suffer from ONIHL. According to Table A.1 of Technical Appendix A published by NIOSH, a sample size of 29 would be needed to detect the top 10% highest exposure group with 95% confidence for the total chair lift population of 150 employees.[19]

Snow Groomers

There are no recommendations for the snow groomer worker population at this time.

Future Research

This study has illustrated overexposures of ski resort employees to occupational noise criteria. Future research could be conducted to determine the noise generation from the snowmobiles that are used by the snowmaking worker population to assess the need for engineering controls on the snowmobiles. Also, future research could be conducted to analyze the noise exposure from the headset radios worn by the snowmaker worker population to determine if the noise levels from the radio headsets are at hazardous levels. Future research could also be conducted to analyze noise exposures for snowmaking employees that use snowmaking machinery with minimized noise generation. Also, another potential study would be attempt to answer the same research questions with larger sample sizes of snowmakers, snow groomers, chair lift operators and equipment.

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