THESIS

EMPLOYEE NOISE EXPOSURE AND OCTAVE BAND ANALYSIS IN A MANUFACTURING SETTING

Submitted by

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ABSTRACT

EMPLOYEE NOISE EXPOSURE AND OCTAVE BAND ANALYSIS IN A MANUFACTURING SETTING

Worker exposure to hazardous levels of noise continues to be a concern in United States (US) industries. The National Institute for Occupational Safety and Health has estimated that twenty-two million US workers are exposed to hazardous levels of noise each year, increasing the risk for noise-induced hearing loss (NIHL). One industry sector of concern for worker exposure to noise is metal can manufacturing because of the types and number of machines used in the production areas. To help further characterize the risk NIHL in the metal can manufacturing sector, a comprehensive noise evaluation was performed at a manufacturing site that produced aluminum metal cans. The purpose of this study was to (1) determine if workers in a metal can manufacturing facility were overexposed to hazardous levels of noise that could potentially result in NIHL; (2) determine the machinery frequencies greater than 85 dBC to which employees were exposed; and (3) provide sound mitigation recommendations to the facility's safety team. Area noise levels were collected with a sound level meter (SLM) and personal noise samples were taken using wearable noise dosimeters. 30 production employees participated in sampling over the course of five days and their measured work shift noise exposures were compared to published occupational exposure limits to determine if they were at increased risk of hearing loss. Personal noise exposures were compared to the Occupational Safety and Health Administration's (OSHA) noise Action Level (AL) and Permissible Exposure Limit (PEL); the American Conference of Governmental Industrial Hygienists' (ACGIH)

Threshold Limit Value (TLV); and the National Institute for Occupational Safety and Health's (NIOSH) Recommended Exposure Level (REL). Of the 30 employees sampled, 100% exceeded the OSHA AL, 100% exceeded the OSHA PEL, and 100% exceeded the NIOSH REL/ACGIH TLV. To provide statistical support of these findings, a 95% confidence interval was calculated for each occupational exposure standard along with upper and lower prediction limits. Additionally, the frequencies greater than 85 dBC obtained from the area noise samples associated with the production machinery ranged from 63 Hz – 6,300 Hz with noise levels that ranged from 97.1 dBC – 99.6 dBC and Z-weighted frequencies greater than 85 dB ranged from 32 Hz – 8,000 Hz. From these findings, noise mitigation recommendations were provided that were focused on establishing hearing attenuation to 80 dBA. This involved ongoing fit testing of hearing protection for employees, training, and addressing the specific frequencies associated with each machine type.

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CHAPTER 1: INTRODUCTION

Occupational noise exposure has been well documented in the literature and is regulated in United States (US) industries to help reduce the incidence of noise-induced hearing loss (NIHL). However, over exposure to hazardous levels of noise still occurs in many industries across the US. The National Institute for Occupational Safety and Health estimates that twenty-two million US workers are exposed to hazardous noise levels at work each year, defined as noise exposures exceeding 85 dBA (CDC, June 2023). Additionally, based on data collected from the 2014 National Health Interview Survey it was estimated that 25% of US workers have a history of hazardous noise exposure with 14% of workers being exposed the previous year (Ellen Kerns, et al., 2018). Further, when specifically considering manufacturing workers, exposure reports are higher with 46% of manufacturing workers being exposed to hazardous levels of noise (CDC, June 2023).

This study focused on the noise exposures at a metal can manufacturing facility that created aluminum metal cans in various shapes and sizes. The Standard Industrial Classification (SIC) code associated with this industry sector is 3411 and the North American Industry Classification System (NAICS) code is 332431. Equipment and background noise were evaluated using a sound level meter/octave band analyzer (SLM/OBA), and a 1/3 octave band analysis was conducted to determine the frequencies associated with noise sources that were greater than 85 dBC. Additionally, individual noise exposures for employees were obtained using personal noise dosimeters with 1/1 octave band capabilities. Each of the personal samples included A- and Z-weighted assessments which provided insight for sound mitigation and hearing conservation recommendations.

The personal noise exposure data were evaluated against occupational noise exposure regulations and/or standards including the Occupational Safety and Health Administration's Action Level and Permissible Exposure Limit (OSHA AL and PEL), the American Conference of Governmental Industrial Hygienists' Threshold Limit Value (ACGIH TLV) and the National Institute for Occupational Safety and Health's Recommended Exposure Limit (NIOSH REL) to determine if workers were overexposed to noise. Of these samples 100% of employees were overexposed to noise compared to the OSHA PEL, 100% were overexposed compared to the OSHA AL, and 100% were overexposed to the ACGIH TLV and NIOSH REL. To provide statistical support of these findings, a 95% confidence interval was calculated for each occupational exposure standard to provide a range of values that have a 95% chance of capturing the true average noise exposure of the total population. Further, upper and lower prediction limits were calculated to provide a range of values that have a 95% chance of capturing a future individual sample within the total population. Following the completion of the study, all associated recommendations were provided to the facility's corporate safety team to reduce the risk of noise-induced hearing loss (NIHL) with the appropriate interventions and control methods.

CHAPTER 2: LITERATURE REVIEW

Human Sound Perception

When discussing auditory perceptions, human hearing is typically described as having the ability to interpret sound frequencies in the range of 20 Hz - 20,000 Hz (Kryter KD., 1985). Notably, frequencies around 4,000 Hz are amplified and are directly related to an increased risk of developing NIHL. Additionally, workers exposed to continuous noise greater than 85 dBA are at an increased the risk of developing NIHL in industrial settings. To evaluate the potential for over exposure to noise and the associated frequencies, it is customary to describe the spectra of sound in accordance with the following spectrum frequency bands: one Hz wide, one-third wide, and one octave wide (Kryter KD., 1985).

Noise-Induced Hearing Loss

Conductive hearing loss and sensory hearing loss are considered the two types of damage that can affect an individual's ability to hear normally. Conductive hearing loss results from significant and rapid changes in local air pressure, physical penetrations of the ear drum, or trauma to the head. However, these hearing loss impacts are typically reversible through surgical intervention and are not a primary concern for chronic loss of hearing sensitivity. In contrast, sensory hearing loss results from noise exposure and is typically considered irreversible due to neural or inner ear damage. The loss of steriocilia and supporting cells; as well as the fusion of cilia, is a progressive process that results in the need for high acoustic energies and increased cochlea function to interpret the sound in the environment. Since damage to the cochlea cannot be measured directly to determine if an individual has developed these physiological changes, NIHL is assessed by measuring auditory sensitivity through absolute threshold testing (E.H Berger et. al., 2003).

Physiological and Psychological Impacts of Noise

While the physiological impacts to the ear are often described when discussing noise and worker exposures, it is also important to recognize the significant impacts to other parts of the body and the psychological health of workers. Firstly, the social interaction between workers suffers due to the masking of verbal sounds in hearing impaired individuals. This results in stress from changes in interpersonal judgements and increased annoyance with the aversive work environment (Dylan Jones, 1981). Likewise, working in an environment with continuous noise at 80 dBA or greater is correlated with increased levels of stress (D. Behzad Fouladi et al., 2012). In addition to increased levels of stress, employees may experience chronic changes in sleep and cardiac functions. Employees that are exposed to sound greater than 75 dBA continuously for eight hours can experience changes in their nocturnal sleep architecture and heart rate (Batmanabane Gitajali and Ramachandran Anath, 2003). Moreover, employees exposed to noise greater than 90 dBA have been associated with an increased risk of hypertension and tachycardia across all sound frequencies (Mohd A. Said et al., 2022). 14% of US workers are likely able to attribute their work-related hypertension to noise exposure with 9% of workers also developing elevated levels of cholesterol (Ellen Kerns et al., 2018). However, these findings are typically associated with a stressful work environment and the type of work that the employee is performing is a significant factor when discussing noise exposures and cardiac impacts (Samuel Melamed et al., 1999).

Manufacturing Worker Noise Exposure

Manufacturing processes can produce a variety of sounds that result in significant workplace noise. As a result, manufacturing production employees are at an increased risk for NIHL. For example, Subramaniam et al. (2018) found that employees working in a metal manufacturing area were exposed to average noise measurements of 103.27 dBA from machinery, well above what is considered a “safe” level of noise. As a result, the authors recommended hearing protection and minimizing time in this environment to reduce the risk of NIHL. The potential for high levels of noise in manufacturing settings is concerning to the industry sector in the current study because aluminum manufacturing workers are at an increased risk of developing NIHL when exposed to continuous noise as low as 85 dBA (Linda F. Cantley et al., 2015). Further, Rodriguez et al., (2012) found that employees working in the aluminum can manufacturing industry are at a greater risk of noise over exposure. More specifically, the authors found that employees working near the printer, lacquer spray, and necker machines used for aluminum can manufacturing were at an increased risk for hazardous noise exposure with potential decibel levels reaching 100 dBA or greater.

Noise Control Methods

Scientific minds have inquired into the nature and control of sound over the millennia. Each of these individuals provided a building block for our understanding of sound as pressure changes and our knowledge for controlling these physical phenomena. Noise control can take place at the source of the noise, along the path of the noise, and/or by protecting the receiver of noise (Lewis H. Bell, 1982). Further, noise is physically controlled by absorption, blocking, and/or cancelling of the noise along the previously described paths. This can be done by implementing shields, sound mitigating materials, and/or elimination of associated frequencies through engineering methods (Lewis H. Bell, 1982). An example of an early attempt at controlling noise comes from Wallace Clement. Around the year 1900, Wallace completed a series of research papers on sound reverberation in various rooms which are credited for being a starting point for architectural acoustics (Randall F. Barron, 2003). Later research in the 1920’s provided additional insight into the hazards associated with loudness and the human ear. As a result of this information, efforts to implement noise controls began in airplanes, automobiles, and buildings. Additionally, the scientific community was encouraged to increase research efforts in sound absorption by porous acoustic materials. These research efforts were again increased during World War II in an effort to improve communication among military personnel and research into noise control continued after the war had ended (Randall F. Barron, 2003).

As of 2023, there has been a great amount of sound research which has provided a better understanding of how sound functions and the subsequent methods for best controlling noise. For example, impact noise in industry can be reduced by extending a punch press's cycle time and decreasing the peak impact force (David A. Bies et al., 2018). This is important because it demonstrates that when a process minimizes the "time rate" of change-of-force, there is an associated decrease in noise production. Additionally, it is now understood that minimizing the acoustic radiation efficiency (ARE) of a surface will decrease the vibration of the material and the associated noise. This can be applied to industry by replacing materials with high ARE, such as metal panels, with woven or perforated panels. Furthermore, it is known that the material type needed to absorb a given sound is dependent on the frequency of that sound. While a significant amount of research has been performed regarding various material types, the important aspect of choosing a material suitable for the environment is obtaining an acceptable sound absorption co-efficient based on the frequencies present in the area (David A. Bies et al., 2018). Bies et al., (2018) suggested that implementation of engineering design changes at the beginning stages of development is the best way to minimize noise exposures. Technical improvements in noise mitigation through engineering methods have shown diminishments in noise by 20 dB. Despite achieving a 20 dB decrease in with the use of hearing protection, it has also been found that noise reduction levels drastically decrease by approximately 9 dB with improper instruction on the use of personal protective equipment (Jos H. Verbeek et al., 2017).

OSHA requires that employees approach noise exposure in a preventative manner by implementing a hearing conservation program (HCP) when employees are exposed to noise in excess of 85 dBA as an eight-hour time weighted average (OSHA, 2008). The OSHA Occupational Noise Exposure standard requires employers to conduct annual audiometric testing, that meets American National Standards Institute (ANSI) SC-1969 specifications, on employees and provide the option of hearing protection at 85 dBA, but to enforce the use of hearing protection at 90 dBA (OSHA, 2008). Additionally, the OSHA Technical Manual (2022) requires an exchange rate of 5 dB, threshold of 80 dB and criterion level of 90 dB when sampling for employee noise exposures in assessing for compliance with the noise AL (CDC, June 2023).

Unfortunately, it has been found that Hearing Conservation Programs (HCP) alone do not effectively decrease the risk of hearing loss and noise should be controlled following the hierarchy of controls similar to any other hazard (Alice H. Suter, 2012). The hierarchy of controls has five levels of actions aimed at reducing or eliminating noise hazards. The preferred order of action aimed at maximizing effective control begins with elimination of the noise source and is followed by substitution, engineering controls, administrative controls, and finally personal protective equipment (CDC, 2023). Since it has been shown that employees working in environments with noise levels at 85 dBA or lower have a smaller statistical chance of developing NIHL, it is suggested that the controls aim to reduce noise levels below this value through the hierarchy of controls and regular maintenance for better employee health outcomes (Jos H. Verbeek et al., 2017).

Hearing protection is a form of personal protective equipment and is considered a last line of defense for noise control. Earplugs and earmuffs are common examples of hearing protection used in occupational settings. Unfortunately, noise does persist in modern work environments and hearing protection is often used first as noise control in industries (Elliott H. Berger, 1993). The decibel reduction in noise afforded by hearing protection is described by the Noise Reduction Rating (NRR). The NRR is the standard used to determine effective noise reduction by assigning a standardized value to various forms of hearing protection (Elliott H. Berger, 1993). However, it has been found that 50% or greater derating should be applied to all forms of hearing protection using an NRR due to inherent inaccuracies in practical applications (Elliott H. Berger, 1993). This reduction in the rating is reinforced by OSHA requirements of a 50% reduction for all hearing protection using an NRR (OSHA, 2008). Additionally, it is recommended that employees be fitted with a combination of earplugs and earmuffs when exposed to noise greater than 95 dB (Elliott H. Berger, 1993). By combining these two forms of hearing protection, OSHA allows for 5 dB to be added to the NRR after the 50% adjustment, representing a significant increase in protection (Elliott H. Berger, 1993). However, it is also important to not overprotect workers to avoid disruption to communication. Overprotecting workers in industrial settings, as highlighted by Neitzel et al.'s 2019 study on metal manufacturing workers, can have unintended consequences. While worker safety is paramount, excessive overprotection can disrupt communication and compromise their ability to carry out tasks effectively. Neitzel et al.'s study, which revealed that 86% of metal manufacturing workers were overprotected, underscores the importance of finding a balance between protecting employees from excessive noise exposure and ensuring they can still communicate and function optimally. Adhering to guidelines such as those set by the British Standards Institute to maintain attenuated exposure levels above 70 dBC is crucial in striking this balance, allowing workers to remain safe without hindering their productivity and effective communication on the job.

Industry Background

The Bureau of Labor Statistics (BLS) categorizes the industry sector in the current study under Fabricated Metal Production Manufacturing with the corresponding NAICS 332. Per BLS statistics for 2022, approximately 58,000 employees worked as cutting, punching, and machine press machine setters and operators (BLS, 2022). Additionally, 106,000 employees held the title of machinist and 67,000 were first line supervisors or managers (BLS, 2022). Ultimately, there were 3.6 total recordable cases per 100 full-time workers with 2 involving days away from work, job restriction, or transfer (BLS, 2022). Of the 14,500 hearing loss illness cases in the private industry sector during 2019, there were 1,400 cases attributed to fabricated metal product manufacturing (BLS, 2019).

Occupational Noise Exposure Limits

OSHA mandates a noise PEL (or criterion level) of 90 dBA as an 8-hour time weighted average (TWA) using an exchange rate of 5 dB and a threshold of 90 dB. An exchange rate is the number of decibel increase that relates to a halving of the exposure time permitted and a threshold is the level of noise below which data are not accumulated (Larson, 2023). In addition, OSHA has an impulsive or impact noise limit at 140 dB peak sound pressure level (OSHA, 2008). To better protect employees from NIHL, OSHA published the Hearing Conservation Amendment (HCA) in 1981 to establish a general industry action level of 85 dBA as an 8-hour TWA with a criterion level of 90 dBA, an exchange rate of 5 dB, and a threshold of 85 dBA (OSHA, 2008). If an employee exposure exceeds the AL of 85 dBA, the employer is required to enroll the employee in an HCP.

The ACGIH recommends a Threshold Limit Value (TLV) of 85 dBA as an eight-hour TWA, with an exchange rate of 3 dB, and a threshold of 80 dB (ACGIH, 2023). Recommendations for annual audiometric testing, training, and following NRR guidelines were provided by the ACGIH similar to OSHA.

The NIOSH noise Recommended Exposure Limit (REL) is 85 dBA as an 8-hour TWA (NIOSH, 1998). Additionally, it is recommended to have an exchange rate of 3 dB, threshold of 80 dB and criterion level of 85 dB when sampling for employee noise exposures (NIOSH, 1998). These sampling criteria were recommended since the 40-year life time risk of NIHL is reduced from 25% at 90-dBA to 8% at 85 dBA (NIOSH, 1998). NIOSH writes that a noise exposure less than 85 dB can be accomplished by understanding noise exposure, eliminating or reducing noise, implementing engineering controls, using administrative controls, providing hearing protection, and finally (re)evaluation and documentation (NIOSH, 1998).

CHAPTER 3: PURPOSE AND SCOPE

Purpose

The purpose of this study was to (1) determine if workers in a metal can manufacturing facility were overexposed to hazardous levels of noise that could potentially result in NIHL; (2) determine the machinery frequencies greater than 85 dBC to which employees were exposed; and (3) provide sound mitigation recommendations to the facility's safety team. By measuring personal noise exposures, taking area noise measurements, and performing octave band evaluations, noise mitigation recommendations; including, but not limited to, noise reduction materials and hearing conservation protocols could be provided to the corporate safety team.

Hypothesis and Research Questions

The research team was guided by the following hypotheses:

H0 1: The noise from the metal can manufacturing equipment is less than 85 dBA at one meter.

HA 1: The noise from the metal can manufacturing equipment is greater than or equal to 85 dBA at one meter.

This hypothesis was tested by measuring noise emissions from machinery, equipment, and processes in the production areas at a distance of one meter.

H0 2: Production employees are not exposed to a noise level that exceed published occupational exposure limits.

HA 2: Production employees are exposed to noise exceeding published occupational exposure limits.

This hypothesis was tested by taking personal noise dosimetry measurements and comparing the results to published occupational noise exposure limits.

Scope

The participants in this study included production employees in a metal can manufacturing facility located in Colorado, US. The facility had a total of 350 employees with approximately 84 employees, divided over four shifts, working in the production areas termed “Aluminum Bottle” and “Screw Lid Can”. Of these 84 production employees, 30 that were working the 6am-6pm shift were selected over the course of five days for personal noise sampling. Additionally, a 1/3 octave band analysis was performed on machinery in the areas of concern to determine the C-weighted noise frequencies associated with the production processes to be used in conjuction with acoustic studies previously obtained by the facility.

CHAPTER 4: METHODS AND MATERIALS

Site Selection

The current study was performed at an aluminum manufacturing facility in Colorado. The site was chosen based on personal communication with a facility safety manager who had identified elevated noise levels. The specific areas in the facility identified for the study were chosen based on area noise measurements taken by the researcher during a normal-working hours walkthrough. Two production areas were noted as having the greatest concern for hazardous noise exposure, the Aluminum Bottle and Screw Lid Can areas where real-time A-weighted spot measurements indicated noise levels greater than 100 dBA.

Facility Description

The primary purpose of the facility was aluminum can production of various sizes and shapes. While all specifics of the can-manufacturing process will not be discussed in this paper, general operations associated with the equipment of concern and the employees sampled will be described. Since the noise monitoring campaign included two production areas, the following descriptions will be categorized into the Aluminum Bottle and Screw Lid Can production areas.

Aluminum Bottle Process Description

The Aluminum Bottle area end product is aluminum cans with a label, but without a top. The production process is initiated by placing aluminum coils on an uncoiler with lubrication. The aluminum is then fed into the Minster (DAC-150-24125) Cupper Press which creates cups that are dispersed to a series of eight 5500 Canmakers (741.S). The cans are trimmed and base coats are applied as indicated. After being moved through the production room on conveyors, the cans are decorated by the “Decorator” and given an internal coating at a series of eight Stolle

Machines (1S206802). Finally, the cans are transported to the twelve Bottle Neckers (A30-030) before flanging, final inspections, and palletization.

During the initial area noise evaluation, it was noted that all steps of the Aluminum Bottle process produced intermittent real-time noise measurements greater than 100 dBA. Since there was indication that the entire process contributed hazardous noise levels in this work area, employees working in the Aluminum Bottle area were solicited for participation in the study. In addition, noise measurements of the specific production machinery involved in the Aluminum Bottle process were taken.

Screw Lid Can Process Description

The Screw Lid Can area end product is a finished cap for the top of their respective cans. As with the Aluminum Bottle process, the Screw Lid Can process is initiated by placing aluminum coils on an uncoiler with lubrication. The aluminum is then fed into two Minster (P2H-160-29708) shell presses followed by curling and compound sealing. After being moved through the production room on a series of conveyors, the cap enters a liner oven for heated application of an interior shell. Lastly, the cap tabs are finalized, and the caps are palletized for later use.

During the initial area noise evaluation, it was noted that the areas near the two Minster presses had real-time noise measurements greater than 100 dBA. The remainder of the process was evaluated for area noise but found to have relatively lower noise levels. Therefore, workers performing tasks near the Minster presses were the focus of the Screw Lid Can area and they were solicited for participation in the study.

Production Machinery

While additional machinery such as conveyors were present in the production areas, not all of these machines were measured for noise emission. A list of the major machinery that was evaluated during the study for noise emission is provided in Table 1.

Table 1: Machinery Evaluated for Noise Emissions

Machinery	Serial Number
Minster Shell Press	P2H-160-29708
Minster/Sequa Cupper Press	DAC-150-24125
5500 Canmaker	741.S
Decorator	Unknown
Bottle Necker	A30-030
Stolle Machines	1S206802

Sound Level Meter Equipment

A TSI QUEST (Shoreview, MN, USA) sound level meter was used to take average C-weighted sound pressure level (SPL) measurements of the production machinery at a distance of one meter. A 1/3 octave band analysis was included in the data collection and was used for noise frequency categorization and noise damping recommendations. All noise samples were uploaded to the G4 LD Utility software (ver. 4.9.1) and later Microsoft Excel (ver. 16.77.1) for statistical analysis and table/graph creation.

Employee Recruitment

During the time this study took place, 84 employees worked in the Aluminum Bottle and Screw Lid Can production areas. The Alumninum Bottle area had 13 employees working per shift over four shifts (52 workers) and the Screw Lid Can area had 8 employees working per shift over four shifts (32 workers). Employees working the 6am-6pm shift were solicited for the study over the course of five samplings days. Each day, 4 volunteer subjects were selected from the Aluminum Bottle area and 2 volunteer subjects were selected from the Screw Lid Can area for a total of 20 Aluminum Bottle and 10 Screw Lid Can employees. Of the 30 samples collected, 5 were repeat volunteer subjects and all subjects were over 18 years of age. All aspects of the study were performed in accordance with a human subjects study protocol approved by the researchers' Institutional Review Board.

Personal Noise Dosimetry

Study subjects were fitted with SPARTAN 730 personal noise dosimeters (Depew, NY, USA) near the beginning of their work shifts, and the dosimeters were collected near the end of their work shifts (approximately 11 hours). All personal noise samples were uploaded to the G4 LD Utility software (ver. 4.9.1) and later Excel (ver. 16.77.1) for statistical analysis. The specifications related to the personal noise dosimeters used are summarized in Table 2. The measurement settings used for the dosimeters are presented in Table 3.

Table 2: SPARTAN Model 730 Specifications

Specifications	Code	Dosimeters/Serial Number	
ANSI	S1.25-1991	10044	11263
IEC	61252:2017	11256	11103
FCC ID	2AA9B04	11241	
IC ID	12208A-04	11110	

Table 3: Personal Noise Dosimeter Settings

Virtual Dosimeter	1	2	3	4
Mode	DOSE	DOSE	DOSE	DOSE
Title	OSHA-PEL	OSHA-HC	ACGIH	NIOSH
Frequency Weighting	A	A	A	A
Time Weighting	Slow	Slow	Slow	Slow
Peak Weighting	C	C	C	C
Exchange Rate	5 dB	5 dB	3 dB	3 dB
Threshold	90.0 dB	80.0 dB	80.0 dB	80.0 dB
Criterion Level	90.0 dB	90.0 dB	85.0 dB	85.0 dB
Shift Time	12 hours	12 hours	12 hours	12 hours

Statistical Analysis

All data collected in the current study were compiled into a Microsoft Excel (ver. 16.77.1) sheet for storage and analyzed using traditional descriptive statistical methods. The data were then used for subsequent graph creation. The analysis of the data included a 95% confidence interval with upper and lower prediction limits associated with both eight and twelve hour TWAs, describing the range of noise exposures that have a 95% chance of containing the true population average and potential individual exposures respectively.

Equations for Calculations

The TWA (8) was calculated by compressing the sampling time to estimate the 8-hour exposure using Equation 1 and the projected TWA (12) was calculated to estimate the 12-hour exposure by expanding the sampling time using Equation 2. Table 4 provides the exchange rates used in the calculations and the associated q value (Larson Davis, 2023). Standard Error was then calculated using Equation 3, so it could be used to calculate the Margin of Error with Equation 6. Lastly, for each occupational exposure standard, a 95% confidence interval was calculated using equation 7 along with upper and lower predictions using equation 8 (Nist, 2023). All equations used for calculations are summarized in table 5.

Table 4: Exchange Rate Constants

Exchange rate	q value
3	10
5	16.61

Table 5: Equations for Calculations

TWA (8) = $L_{avg} + q * \text{Log}_{10}$ (shift sample time/8)	(Equation 1)
Projected TWA (12) = $L_{avg} + q * \text{Log}_{10}$ (12/8)	(Equation 2)
Standard Error (SE) = $\frac{\textit{Standard Deviation}}{\sqrt{\text{Sample Size}}}$	(Equation 3)
Aluminum Bottle Critical Value for T-Distribution = +/- 2.093	(Equation 4)
Screw Lid Can Critical Value for T-Distribution = +/- 2.262	(Equation 5)
Margin of Error (MOE) = Critical value * ($\frac{\text{SE}}{\sqrt{\text{Sample Size}}}$)	(Equation 6)
95% Confidence interval = Mean +/- MOE	(Equation 7)
Upper and Lower Prediction limits = Mean +/- (Standard deviation * $\sqrt{1 + \frac{1}{\text{Sample Size}}}$)	(Equation 8)

TWA (8) = 8 hour time-weighted average noise exposure
Projected TWA 12 = Projected 12 hour time-weighted average
L_{avg} = Average sound pressure level
q = A constant of 10 when an exchange rate of 3 is used and a constant of 16.61 when an exchange rate of 5 is used.

CHAPTER 5: RESULTS

Equipment Noise

The Aluminum Bottle production area had a total of five machine types that were evaluated using the SLM/OBA: the Minster Cupper Press, 5500 Canmaker, Decorator, Bottle Necker, and Stolle Machine. In total, The Aluminum Bottle area had one Minster Cupper Press, eight Stolle Machines, eight 5500 Canmakers, twelve Bottle Neckers, and one Decorator. However, only one of each machine type was selected for sampling and the remainder of the machines continued running during sample collection. The average sound pressure levels ranged from 97.1 – 99.6 dBC with the frequencies greater than 85 dBC ranging from 63 Hz – 6,300 Hz. These dBC results are presented in Table 6. Figures 1-5 summarize the octave band data obtained for each machine type in the Aluminum Bottle area.

Table 6: Noise Emission of Select Machinery

Machine	Sound Pressure Level at 1 meter dBC	Frequency range > 85 dBC (Hz)
Minster Cupper Press	99.6	63-2,500
5500 Canmaker	99.6	500-6,300
Decorator	99.3	500-4,000
Bottle Necker	97.8	160 ; 250-315 ; 2,000-4,000
Stolle Machine	97.1	500; 1,000-2,500

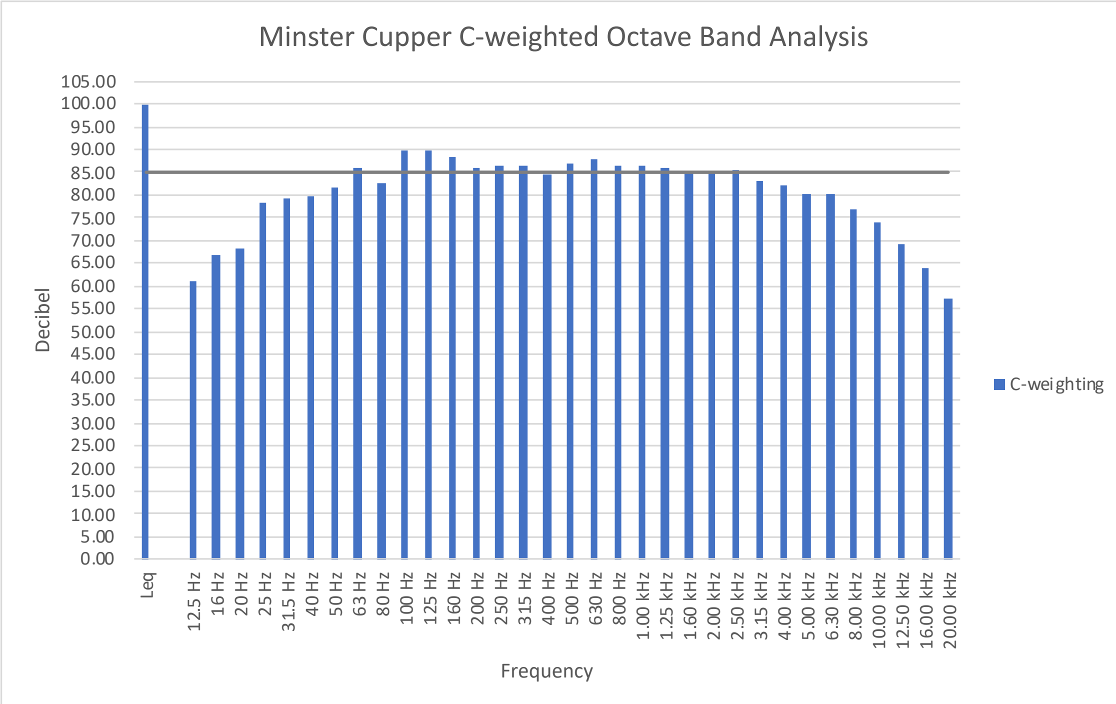

Figure 1: C-weighted Octave Band Results for the Minster Cupper Press

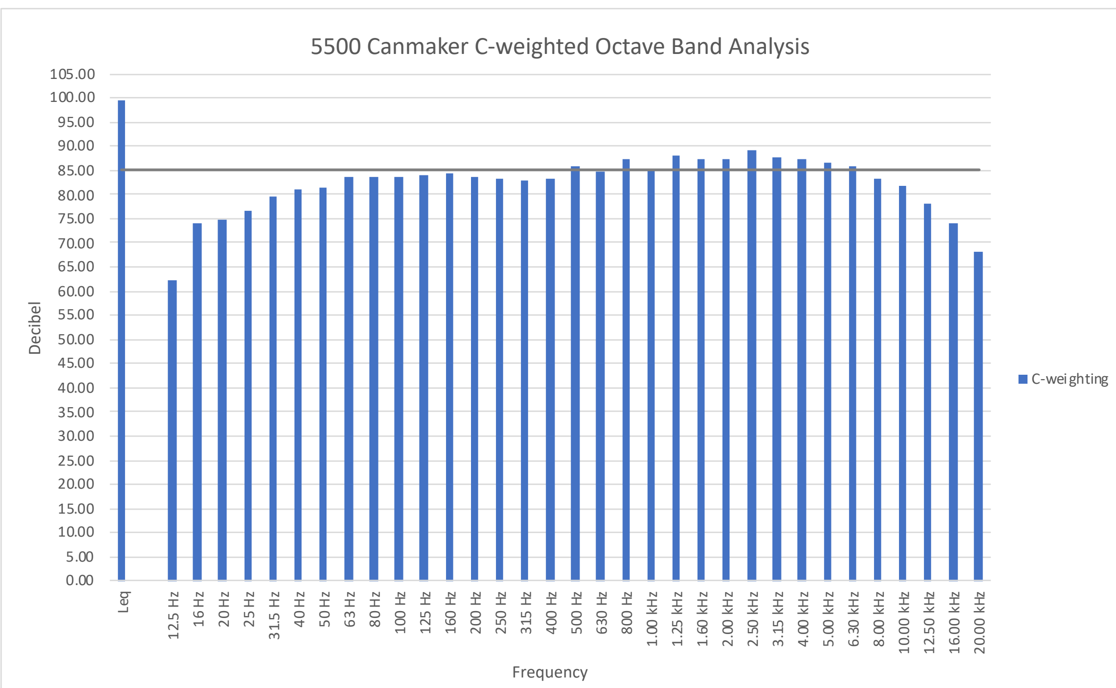

Figure 2: C-weighted Octave Band Results for the 5500 Canmaker

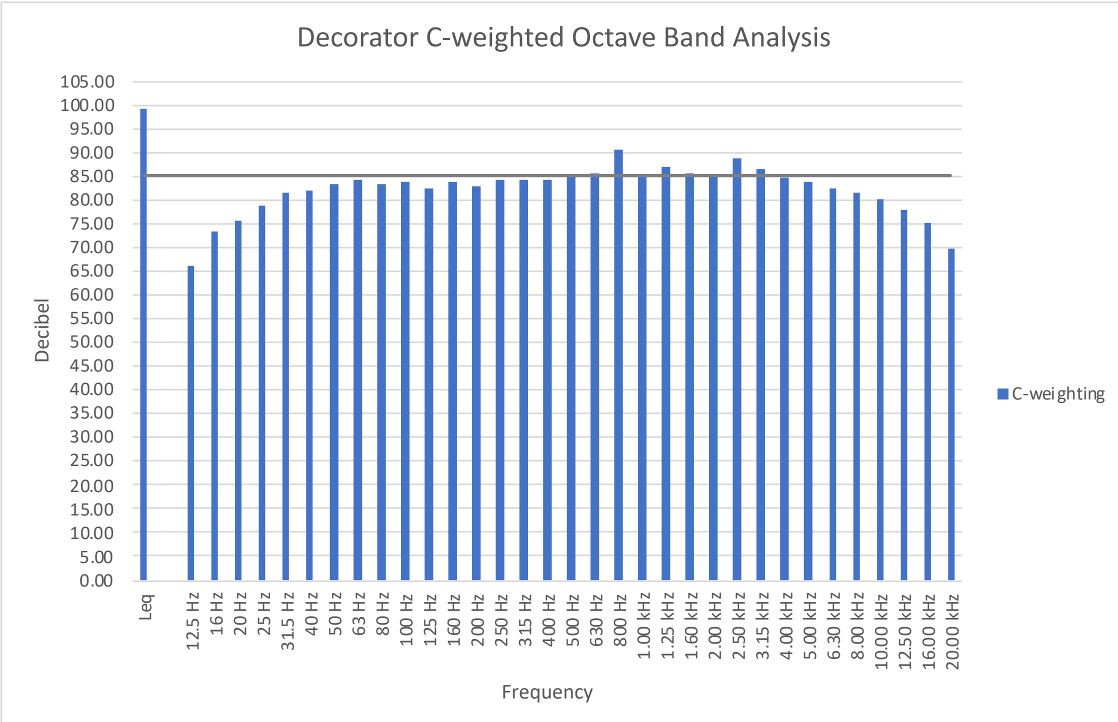

Figure 3: C-weighted Octave Band Results for the Decorator

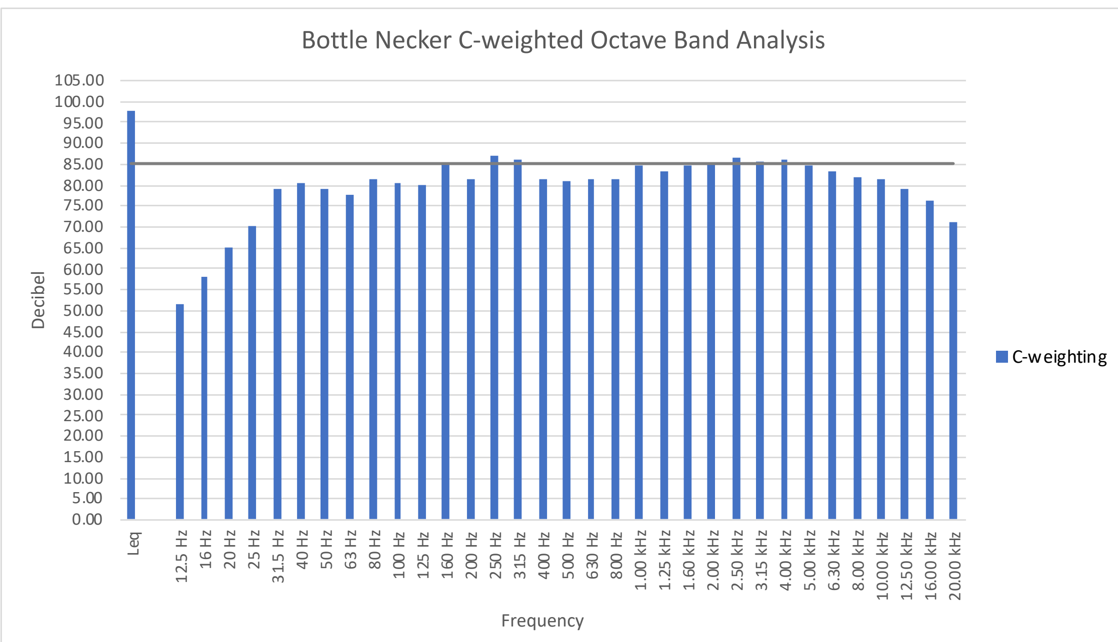

Figure 4: C-weighted Octave Band Results for the Bottle Necker

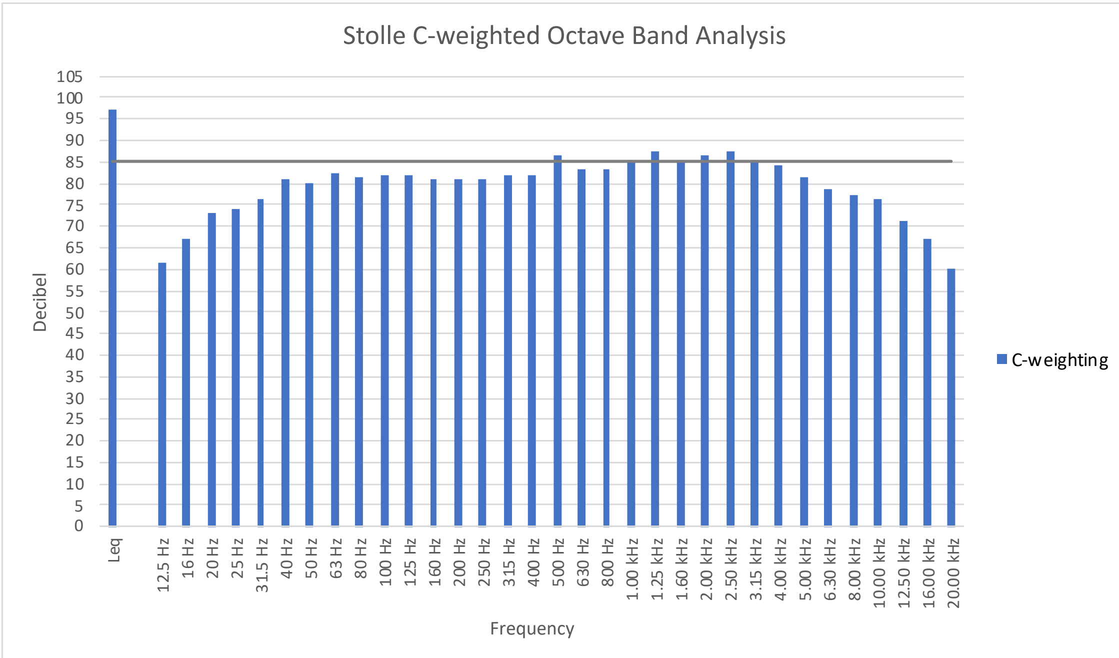

Figure 5: C-weighted Octave Band Results for the Stolle Machine

The Screw Lid Can production area had one machine type that was evaluated using the SLM/OBA since it was the primary noise source in this area: the Minster Shell Press. Unfortunately, the measurement data were lost due to technical error during upload and re-assessment was not possible due to changes in production rate. Therefore, the 1/1 octave band data collected from the personal noise dosimeters worn by the study subjects were used to determine frequency exposures and are summarized in Table 18 in the Personal Dosimetry 1/1 Octave Band Measurements sub section.

<u>Personal Noise Dosimetry</u>

30 personal noise samples were collected over five days at the aluminum can manufacturing facility. 20 of the samples were collected from the Aluminum Bottle production area and the remaining 10 samples were collected from the Screw Lid Can production area. The sample times ranged from 10 hours, 41 minutes to 11 hours, 40 minutes for the 12-hour shifts. Since these sample times were not exactly 8 or 12 hours, the samples were mathematically

adjusted to 8 and 12 hours for comparison to 8 and 12 hour TWA standards with the use of Equations 1 and 2 in Table 5. A summary of the personal dosimetry results for the 20 employees sampled in the Aluminum Bottle area are presented in Tables 7 and 8 while the results for the 10 employees working in the Screw Lid Can area are presented in Tables 9 and 10.

Table 7: Aluminum Bottle Employee Personal Dosimetry Results

Sample #	L_{Avg} (PEL)	L_{Avg} (AL)	L_{Avg} (TLV/REL)	L_{ASmax}	L_{Cpk}
1	98.9	99	100.3	126.2	142.7
2	93.9	94	99.8	137.6	146.2
3	97	97.1	98.6	116.2	131.6
4	92.4	92.9	93.7	110.5	145.3
5	98.4	98.5	99.5	113.6	128.9
6	95.6	95.7	97.3	123.4	145.3
7	95.8	95.9	98.2	121.5	135.7
8	93.3	93.3	98	133.4	145
9	94.1	94.2	95.9	111.6	140.7
10	92.8	93.3	96.2	121	136.7
11	97	97.3	98.6	115.7	129.8
12	99.2	99.2	99.8	121	142.8
13	94.8	95.1	97.7	123.9	145.7
14	96.6	96.6	98.2	120.7	140.9
15	99.9	99.9	100.1	111.7	142
16	100.4	100.4	101.1	113	147
17	99.1	99.1	100.6	114.3	134.4
18	96.9	97	98.3	113	130
19	94.1	94.1	95.4	115.8	132.5
20	92.6	92.9	93.2	107	136.9
Average	96.14	96.28	98.03	118.56	139.01

L_{Avg} = Average sound pressure level
L_{ASmax} = Maximum sound pressure level, slow mode, A-weighted
L_{Cpeak} = Peak sound measurement, C-weighted
AL = OSHA Action Level
PEL = OSHA Permissible Exposure Limit
TLV/REL = Threshold Limit Value/Recommended Exposure Level

Table 8: Aluminum Bottle Employee Exposures for TWA (8) and projected TWA (12)

Sample #	TWA 8 (PEL)	Projected TWA 12 (PEL)	TWA 8 (AL)	Projected TWA 12 (AL)	TWA 8 (TLV/REL)	Projected TWA 12 (TLV/REL)
1	101.5	101.8	101.5	101.9	101.9	102.1
2	96.4	96.8	96.5	96.9	101.3	101.6
3	99.5	99.9	99.6	100.0	100.1	100.3
4	94.9	95.3	95.4	101.4	95.2	95.5
5	100.9	101.4	100.9	101.4	101	101.3
6	98.1	98.5	98.1	98.6	98.8	99.1
7	98.3	98.8	98.4	98.8	99.7	100.0
8	95.7	96.2	95.8	96.3	99.4	99.7
9	96.6	97.0	96.7	97.1	97.4	97.6
10	95.3	95.7	95.8	96.2	97.7	97.9
11	99.5	99.9	99.8	100.2	100.1	100.3
12	101.7	102.1	101.7	102.1	101.3	101.6
13	97.1	97.8	97.4	98.1	99	99.4
14	98.8	99.5	98.8	99.5	99.5	99.9
15	102.1	102.8	102.1	102.8	101.5	101.9
16	102.6	103.3	102.6	103.3	102.4	102.9
17	101.4	102	101.4	102.1	102	102.4
18	99.3	99.9	99.3	99.9	99.7	100.0
19	96.4	97	96.4	97.1	96.8	97.2
20	94.9	95.5	95.2	95.9	94.6	95.0
Average	98.6	99.1	98.7	99.5	99.5	99.8

TWA 8 = Time Weighted Average for an eight hour time frame
Projected TWA 12 = Projected Time Weighted Average for a twelve hour time frame
AL = OSHA Action Level
PEL = OSHA Permissible Exposure Limit
TLV/REL = Threshold Limit Value/Recommended Exposure Level

Table 9: Screw Lid Cap Employee Personal Dosimetry Results

Sample #	L_{Avg} (PEL)	L_{Avg} (AL)	L_{Avg} (TLV/REL)	L_{ASmax}	L_{Cpk}
1	91.5	92.1	96.9	134.3	142.9
2	86.3	89.4	91.9	120.1	140.3
3	89.3	90.9	94.4	119	144.8
4	85.2	87.6	90.8	113.5	139.5
5	91.1	91.8	94	110.5	139.6
6	86.6	88.5	91.4	117.7	133.2
7	86.5	89.3	91.5	121.8	144.3
8	83.2	87.9	90.2	113.1	136
9	87.6	89.2	92.3	115.2	131.5
10	91.3	92.4	94.2	119.6	138.9
Average	87.86	89.91	92.76	118.48	139.10

L_{Avg} = Average sound pressure level
L_{ASmax} = Maximum sound pressure level, slow mode, A-weighted
L_{Cpeak} = Peak sound measurement, C-weighted
AL = OSHA Action Level
PEL = OSHA Permissible Exposure Limit
TLV/REL = Threshold Limit Value/Recommended Exposure Level

Table 10: Screw Lid Can Employee Exposures for TWA (8) and projected TWA (12)

Sample #	TWA 8 (PEL)	Projected TWA 12 (PEL)	TWA 8 (AL)	Projected TWA 12 (AL)	TWA 8 (TLV/REL)	Projected TWA 12 (TLV/REL)
1	94.1	94.4	94.7	95.0	98.4	98.7
2	89	89.2	92.1	92.3	93.6	93.7
3	91.8	92.2	93.4	93.8	95.9	96.2
4	87.7	88.2	90.1	90.5	92.3	92.5
5	93.8	94.0	94.5	94.7	95.6	95.8
6	89.3	89.5	91.2	91.4	93	93.2
7	88.7	89.5	91.5	92.2	92.8	93.3
8	85.3	86.1	90	90.9	91.4	91.9
9	90	90.5	91.6	92.1	93.8	94.1
10	93.7	94.3	94.8	95.3	95.6	95.9
Average	90.3	90.8	92.4	92.8	94.2	94.5

TWA 8 = Time Weighted Average for an eight hour time frame
Projected TWA 12 = Projected Time Weighted Average for a twelve hour time frame
AL = OSHA Action Level
PEL = OSHA Permissible Exposure Limit
TLV/REL = Threshold Limit Value/Recommended Exposure Level

OSHA Action Level

Of the 20 employees working in the Alumninum Bottle area, 20 of 20 (100%) were exposed to noise levels greater than 85 dBA when evaluated using OSHA AL criteria. Employees in this area were exposed to average decibel levels ranging from 95.2 – 102.6 dBA with a total average of 98.7 dBA when evaluated using an 8 hour TWA. When samples were projected for a 12 hour TWA, the employee exposures ranged from 95.9 – 103.3 dBA with a total average of 99.5 dBA.

Of the 10 employees working in the Screw Lid Can area, 10 of 10 (100%) were exposed to noise levels greater than 85 dBA when evaluated using OSHA AL criteria. Employees in this area were exposed to average decibel levels ranging from 90 – 94.8 dBA with a total average of 92.4 dBA when evaluated using an 8 hour TWA. When samples were projected for a 12 hour TWA, the employee exposures ranged from 90.5 – 95.3 dBA with a total average of 92.8 dBA. To determine the confidence of these findings, a 95% confidence interval along with upper and lower prediction intervals were performed for the TWA (8) and TWA (12) of both production areas (Table 11 and Table 12).

Table 11: OSHA AL TWA (8) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (8)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	98.7	97.6	99.9	93.5	104.0
Screw Lid Can	92.4	91.1	93.7	88.0	96.8

Table 12: OSHA AL TWA (12) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (12)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	99.5	98.4	100.6	94.4	104.6
Screw Lid Can	92.8	91.6	94.1	88.7	97.0

OSHA Permissible Exposure Level

Of the 20 employees working in the Alumninum Bottle area, 20 of 20 (100%) were exposed to noise levels greater than 90 dBA when evaluated using OSHA PEL criteria. Employees in this area were exposed to average decibel levels ranging from 94.9 – 102.6 dBA with a total average of 98.6 dBA when evaluated using an 8 hour TWA. When the samples were projected for a 12 hour TWA, the employee exposures ranged from 95.3 – 103.3 dBA with a total average of 99.1 dBA.

Of the 10 employees working in the Screw Lid Can area, 10 of 10 (100%) were exposed to noise levels greater than 90 dBA when evaluated using OSHA PEL criteria. Employees in this area were exposed to average decibel levels ranging from 85.3 – 94.1 dBA with a total average of 90.3 dBA when evaluated using an 8 hour TWA. When samples were projected for a 12 hour TWA, the employee exposures ranged from 86.1 – 94.4 dBA with a total average of 90.8 dBA. To determine the confidence of these findings, a 95% confidence interval along with upper and lower prediction intervals were performed for the TWA (8) and TWA (12) of both production areas (Table 13 and Table 14).

Table 13: OSHA PEL TWA (8) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (8)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	98.6	97.4	99.8	93.1	104.1
Screw Lid Can	90.3	88.2	92.4	83.3	97.3

Table 14: OSHA PEL TWA (12) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (12)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	99.1	97.9	100.3	93.6	104.6
Screw Lid Can	90.8	88.8	92.8	84.1	97.5

ACGIH Threshold Limit Value and NIOSH Recommended Exposure Limit

Of the 20 employees working in the Alumninum Bottle area, 20 of 20 (100%) were exposed to noise levels greater than 85 dBA when evaluated using ACGIH and NIOSH standards. Employees in this area were exposed to average decibel levels ranging from 94.6 – 102.4 dBA with a total average of 99.5 dBA when evaluated using an 8 hour TWA. When samples were projected for a 12 hour TWA, the employee exposures ranged from 95 – 102.9 dBA with a total average of 99.8 dBA.

Of the 10 employees working in the Screw Lid Can area, 10 of 10 (100%) were exposed to noise levels greater than 85 dBA (10/10) when evaluated using ACGIH and NIOSH standards. Employees in this area were exposed to average decibel levels ranging from 91.4 – 98.4 dBA with a total average of 94.2 dBA when evaluated using an 8 hour TWA. When samples were projected for a 12 hour TWA, the employee exposures ranged from 91.9 – 98.4 dBA with a total average of 94.5 dBA. To determine the confidence of these findings, a 95% confidence interval along with upper and lower prediction intervals were performed for the TWA (8) and TWA (12) of both production areas (Table 15 and Table 16).

Table 15: ACGIH TLV and NIOSH REL TWA (8) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (8)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	99.5	98.5	100.5	94.8	104.2
Screw Lid Can	94.2	92.7	95.7	89.2	99.2

Table 16: ACGIH TLV and NIOSH REL TWA (12) Confidence and Prediction Limits

Aluminum Bottle and Screw Lid Can 95% Confidence and Prediction Limits of TWA (12)					
Category	Average	Lower Confidence	Upper Confidence	Lower Prediction	Upper Prediction
Aluminum Bottle	99.8	98.8	100.8	95.1	104.5
Screw Lid Can	94.5	93.0	96.0	89.6	99.4

Personal Dosimetry 1/1 Octave Band Measurements

Each personal dosimeter measured 1/1 octave band data to determine the Z-weighted frequencies of exposure to the participants. The sample population average for the octave band measurements are summarized in Table 17 for the Aluminum Bottle employees and Table 18 for the Screw Lid Can employees. In the Aluminum Bottle area, frequencies ranging from 32 – 8,000 Hz all exceeded 85 dB. In the Screw Lid Can area, employees were exposed to noise of 85 dB or greater at frequencies 250 – 1,000 Hz and 4,000 – 8,000 Hz.

Table 17: Aluminum Bottle 1/1 OBA Personal Dosimeters

Metrics	32Hz	63Hz	125Hz	250Hz	500Hz	1,000Hz	2,000Hz	4,000Hz	8,000Hz
LZeq	86.7	88.2	88.6	88.5	91.7	92.0	90.5	90.5	90.0
LZSmax	108.7	107.3	107.3	107.4	113.7	116.2	111.6	111.6	111.4
LZSmin	64.6	60.5	56.9	54.5	51.2	47.1	43.1	40.4	41.0

Table 18: Screw Lid Can 1/1 OBA Personal Dosimeters

Metrics	32Hz	63Hz	125Hz	250Hz	500Hz	1,000Hz	2,000Hz	4,000Hz	8,000Hz
LZeq	83.2	84.0	82.8	85.1	87.2	86.3	84.3	86.4	87.6
LZSmax	107.9	106.9	106.4	106.0	111.9	114.4	107.5	108.3	110.9
LZSmin	62.2	57.6	51.8	48.4	45.1	41.2	37.7	36.8	39.7

CHAPTER 6: DISCUSSION

The ultimate purpose of the study was to determine if workers in an aluminum can manufacturing environment were exposed to hazardous levels of noise as defined by OSHA, ACGIH, and NIOSH with subsequent recommendations for noise exposure mitigation. To achieve this purpose, area noise samples were taken from a total of six production machine types across two production areas termed “Aluminum Bottle” and “Screw Lid Can”. Additionally, 20 Aluminum Bottle employees and 10 Screw Lid Can employees were selected for voluntary participation in personal noise sample collection. The average decibel exposures from these samples were used to calculate an eight hour TWA and a projected twelve hour TWA. The eight hour TWA is typically used as a standard measure of employee noise exposure to compare with occupational exposure limits and to determine compliance with those limits. However, since employees at this facility worked twelve hour shifts, projected twelve hour TWAs were also provided to better estimate their exposures. These adjustments and comparisons were made by following the guidelines set forth by OSHA, NIOSH, and ACGIH.

The C-weighted frequency range of the five machine types in the Aluminum Bottle production area greater than 85 dBC spanned from 63 Hz – 4,000 Hz when assessed using a 1/3 octave band analysis. Furthermore, the averge C-weighted sound pressure level ranged from 97.1 dBC – 99.6 dBC. In addition to the SLM data, the personal noise dosimeters recorded an average of 99.8 dBA with a range of 95 dBA - 102.9 dBA and an upper prediction limit of 104.5 dBA when assessed using a projected twelve hour TWA and ACGIH/NIOSH criteria.

The Screw Lid Can production area SLM data were lost, but OBA 1/1 data from the personal noise dosimeters worn in this area displayed dominant Z-weighted frequencies ranging from 250 Hz – 1,000 Hz and 4,000 Hz – 8,000 Hz. In addition, the personal noise dosimeters recorded an average of 94.5 dBA with a range of 91.9 dBA - 98.7 dBA and an upper prediction limit of 99.4 dBA when assessed using a projected twelve hour TWA and ACGIH/NIOSH criteria.

The frequency and decibel ranges of both the Aluminum Bottle and Screw Lid Can production areas have been shown to cause damage to human hearing (E.H Berger et. al., 2003). Further, these decibel levels can lead to chronic hypertension, elevated cholesterol (Mohd A. Said et al., 2022) and impact the psychological health of employees by increasing stress and agitation, leading to an increased chance of industrial accidents (Dylan Jones, 1981).

Of the 20 employees sampled in the Aluminum Bottle production area, 100% were overexposed to noise per the OSHA PEL, the OSHA AL, the ACGIH TLV and the NIOSH REL. Likewise, of the 10 employees sampled in the Screw Lid Can area, 100% were over exposed to noise per the OSHA PEL, the OSHA AL, the ACGIH TLV, and the NIOSH REL. In summary, 30 of the 30 employees sampled were exposed to noise that was greater than 90 dBA (OSHA PEL) or 85 dBA (OSHA AL, NIOSH REL, ACGIH TLV) as an eight hour TWA; and the employees were exposed to noise that was greater than 82.5 dBA as a projected twelve hour TWA (the exposure limit for a 12-hour shift for the OSHA AL, NIOSH REL, and ACGIH TLV). These findings indicate that all employees must participate in the use of hearing protection under a hearing conservation program and abide by the remainder of OSHA hearing regulations when working in either production area due to an increased risk of NIHL (E.H Berger et. al., 2003; OSHA, 2008). Additionally, further noise mitigation techniques will need to be implemented to decrease production area noise and therefore minimize the personal noise exposures of employees.

Contributing Noise Exposure Factors

In addition to the tasks and processes described, there are many other factors potentially contributing to the overall noise exposures of the production employees. Two examples of additional noise sources in the production areas were numerous conveyors and industrial trucks which can vary depending on production levels. Additionally, the Public Address (PA) system produced significant sound levels and worker-to-worker communication was difficult resulting in employees raising their voices and reducing distance to communicate verbally.

Comparison With Relevant Studies

The findings in this study were fairly similar to the results found in other studies on noise exposures in aluminum manufacturing settings. Similar to the findings of Rodriguez et al., (2012), the current study demonstrated that aluminum manufacturing employees are at a greater risk of over exposure to noise. Specifically, employees working near the Printer, Lacquer Spray, and Necker machines were of particular concern due to decibel levels reaching 100 dBA or greater. These conclusions align with the findings of the current study which revealed that each the Minster Cupper Press, 5500 Canmaker, Decorator, Bottle Necker, and Stolle machines produced average noise levels equal to or greater than 97 dBA. Further, Subramaniam et al. (2018) discovered that metal manufacturing employees are at an increased risk of NIHL which is similar to the findings in this study that demonstrated noise over exposure for employees in aluminum can manufacturing. In addition, Cantley et al., (2015) found that aluminum manufacturing workers are at an increased risk of NIHL when exposed to noise levels as low as 85 dBA. Since employees in the current study had exposure levels that greatly exceeded 85 dBA, the concern for NIHL among the sampled population has validty and noise mitigation is warrented. However, with considererdation of Neitzel et al.'s, study in 2019 on metal manufacturing workers, percautions were recommended to ensure that while addressing overexposure risks, employees are not overprotected to the extent that it disrupts their work efficiency and communication.

Study Limitations

The contributing noise exposures, such as the PA system and industrial trucks, had the potential to impact the overall noise exposure of employees monitored in the current study; however, direct measurements of these processes and/or machines were not obtained. In addition to these additional noise exposure sources, the employees were not directly observed for their entire shifts throughout the day. As a result, it is unknown specifically where the employees were located at any given time throughout the work day. Since their specific locations were not tracked throughout the study, direct comparisons of the data from the personal noise dosimeters could not be related to time spent near specific machines. This uncertainty may also include the possibility of an employee removing the personal dosimeter after placement and then repositioning the device without awareness by the researcher. Lastly, these results are not completely generalizable to the can-making industry sector since there are fluctuations in production levels throughout the year, affecting the frequency of production machinery use.

CHAPTER 7: CONCLUSION AND FUTURE WORK

Hypotheses Conclusions

The assessments performed in the current study were conducted to answer the hypothesis questions presented by the investigators. Firstly, it was asked if noise emissions from machinery, equipment, and processes in the production area are greater than 85 dB at one meter. The null hypothesis stating that the metal manufacturing equipment noise is less than 85 dB at one meter from machinery was rejected. Secondly, it was asked if production employees were exposed to noise levels that exceed the published occupational exposure limits from OSHA, ACGIH, and NIOSH. Again, the null hypothesis stating that production employees are not exposed to a noise level that exceed published occupational exposure limits was rejected.

Recommendations

Several recommendations were made based on the noise samples obtained at the manufacturing facility.

1. Replace machinery enclosures and internal components where feasible (i.e., outer sheet metal and/or internal mechanical components) with materials that have a low acoustic radiation efficiency, such as woven or perforated options. The types of materials (i.e., design or substances) used for the exterior of the machinery greatly impacts the noise produced during production. (David A. Bies et al., 2018). Therefore, the safety team should work with the engineering department to review the exterior and interior aspects of the machinery to determine if feasible options for woven, perforated, or similar design choices are available to replace existing elements. The previously obtained acoustic sampling should be used during this step.

2. Consider the use of sound absorbing materials. When choosing sound proofing materials to place in the production areas, it is important to choose sound absorbing materials that protect against the frequency ranges associated with each machine type as shown in the results section of this report and summarized below. The previously obtained acoustic sampling should be used in conjuction with the C-weighted SLM data and Z-weighted personal dosimetry data obtained in this study.

-Minster Cupper Press: 63 Hz – 2,500 Hz
-5500 Canmakers: 500 Hz – 6,300 Hz
-Decorator: 500 Hz – 4,000 Hz
-Bottle Necker: 160 Hz ; 250 Hz – 315 Hz ; 2,000 Hz – 4,000 Hz
-Stolle Machine: 500 Hz ; 1,000 Hz – 2,500 Hz
-Minster Shell Press area: 250 – 1,000 Hz and 4,000 – 8,000 Hz.

3. Determine if adjustments to maintenance schedules need to be made. A discussion with the maintenance team to determine inefficiencies or concerns related to their work flows may help indicate potential options for adjustments in the current maintenance schedules. Increasing regular maintance on machinery could result in a decrease in average noise exposures and improvements to the overall production process (Jos H. Verbeek et al., 2017).

4. If feasible, consider adjusting punch press cycle times and minimizing peak impact force. Manufacturing industry noise can be reduced with extensions to a punch press's cycle time and decreases of the peak impact force (David A. Bies et al., 2018).

5. Require employees to wear both earplugs and earmuffs. When projecting for 12-hour shifts and ACGIH/NIOSH criteria, employees in the Aluminum Bottle production area were exposed to a range of 95 – 102.9 dBA with a total average of 99.8 dBA and an upper prediction limit of 104.5 dBA. Additionally, employees in the Screw Lid Can production area were exposed to a range of 91.9 – 98.7 dBA with a total average of 94.5 dBA and an upper prediction limit of 99.4

dBA. Since employees working in both production areas have the potential to exceed 95 dBA for a projected TWA 12, the concurrent use of earplugs and earmuffs should be used (Elliott H. Berger, 1993).

6. Noise reaching the employees' ears should be attenuated to 80 dBA. In the Aluminum Bottle area, there was an upper prediction limit of 104.5, indicating the need for 24.5 dBA attenuation. In the Screw Lid Can area, there was an upper prediction limit of 99.4 dBA, indicating the need for a 19.4 dBA attenuation. However, it is recommended that attenuation with fit testing is monitored closely to not exceed an attenuation level of 70 dBA to avoid disruptions in communication (Richard, L. Neitzel, et al. (2019).

7. Use NRR Ratings for hearing protection, but use a 50% or greater derating. Due to inherent inaccuracies in the practical use of hearing protection, it has been determined that a 50% or greater derating is indicated (Elliott H. Berger, 1993). Additionally, the reduction in NRR ratings by 50% is enforced by OSHA requirements. However, OSHA does allow for 5 dB to be added to the NRR rating of the hearing protection with the higher NRR after the 50% adjustment for double hearing protection (OSHA, 2008).

8. Create and train the production employees on standardized hand signals for hazardous situations and indicators for common work tasks. By providing employees with standardized signals, they will not have to soley rely on verbal communication which is limited in the work environment.

9. Have the production employees take a qualitative and/or quantitative survey on their perceptions of stress and potential solutions. By acknowledging the stress of employees and taking actions to reduce their everyday mental and physical stress, the physiological and

physiological impacts associated with noise exposure are reduced (Samuel Melamed et al., 1999).

10. Review current Hearing Conservation Program training and set internally recognized standards for employee comprehension. Given that OSHA requires employers to approach noise in a preventative manner through a HCP, it is vital that the safety team ensure the HCP is adequately established and that employees are participating as required (OSHA, 2008)

Future Work

This noise exposure assessment evaluated the exposure of workers in an aluminum metal can manufacturing facility and found statistical evidence of over exposure in reference to OSHA, ACGIH, and NIOSH standards. These findings were consistent with evidence provided by similar studies on aluminum manufacturing workers and noise exposures. Since this type of work environment has shown repeated evidence of noise over exposure, specific research on control methods should be performed for the following machine types; Minster Cupper Press, Stolle Machines, 5500 Canmakers, Bottle Necker, Decorator, and Minster Shell Press. By performing detailed research into control methods for these machines, engineers can consider changes in the design stage that will be beneficial for noise reduction. Additionally, precise recommendations for sound absorbing materials can be provided to facilities that are performing production processes with these machine types. Lastly, future researchers should consider performing a study that determines perceived stress levels of aluminum manufacturing workers with correlation to the physical tasks being performed and the exposures to loud noise.

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