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Comparative Analysis Of New Techniques For Hearing Conservation Program Selection

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COMPARATIVE ANALYSIS OF NEW TECHNIQUES FOR HEARING CONSERVATION PROGRAM SELECTION

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INDUSTRIAL HYGIENE

ABSTRACT

Hazardous noise is a widespread problem in industry and recreation. Noise induced hearing loss is one of the most frequently reported occupational health claims worldwide. While there has been much research on noise, its effects, and how to prevent hearing loss in industry, there is limited research available to help quantify the difference that monitoring noise at a lower threshold might create in the measured exposure estimate. Additionally, the studies involving the use of different noise monitoring settings do not attempt to explain how the results might change the outcomes when using data and statistical techniques to classify similar exposure groups into hearing conservation programs. The current study attempts to quantify the difference in magnitude of exposure estimates due to using a 0 dB threshold versus the standard 80 dB threshold compares two newer statistical techniques against a proven method by simulating exposures using prerecorded clips and utilizing dosimeters with the capacity to measure noise at both thresholds simultaneously. The study will also analyze any effects on data logging and microphone capacity that might occur, which could affect the accuracy of the exposure estimates. The results of the data analysis show that there is often overlap in which exposure groups are included in hearing conservation between each of the different noise monitoring levels and statistical techniques, but that often the more inclusive threshold and the updated statistical techniques are more conservative, and include more groups into hearing conservation. Little variation is found as a result of using the new noise monitoring methods that might affect the accuracy of the exposure estimates. Overall the study is successful at helping improve the methods that would be used to include worker groups into hearing conservation and the use of lower threshold noise monitoring could result in future studies that can reveal damaging effects at levels once previously thought safe.

Keywords: noise, hearing loss, threshold, statistics, Bayesian

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TABLE OF CONTENTS

LIST OF TABLES

Table *Page*

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACGIH	American conference of Governmental Industrial Hygienists
DOD USN	Department of Defense: United States Navy
HCP	Hearing Conservation Program
ISO	International Standards Organization
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health
NIOSH	National Institute for Occupational Safety and Health
PEL	Permissible Exposure Limit
TWA	Time Weighted Average

INTRODUCTION

Noise is one of the most pervasive issues concerning worker health in the occupational setting. Workers in nearly every industry are exposed at some point or another to excessive noise levels. According to the National Institute for Occupational Safety and Health (NIOSH), about four million Americans work each day where there is noise at damaging levels and twenty-two million American workers are exposed to potentially damaging noise each year (CDC, 2015). While some noise exposures in industry are unavoidable, most are easily reduced. Despite this, it was estimated that in the year 2007, there were as many as 23,000 reported cases of occupational hearing loss, accounting for fourteen percent of all occupational illnesses (CDC, 2015). In addition to this, it is estimated that approximately fifteen percent of people aged 20-69 have hearing loss that could have been caused at work; this is equivalent to 26 million Americans (NIHL, 2015). One study in the early 2000s examined the financial burden of hearing loss to be about $297,000 over the life of an affected person. Over one third of these costs can be contributed to loss of productive work years, an issue that not only affects the person who is unable to work but society as well due to the loss of otherwise capable workers (Mohr., 2000).

Noise is defined as any unwanted sound that disrupts activities or causes discomfort or irritation. Noise is the result of vibrations that travel through the air in the form of waves. These waves are converted into nerve impulses by the ear and transmitted to the brain (NIHL, 2015). Most cases of noise induced hearing loss are caused when tiny hair cells that help transmit the nerve impulses to the brain are damaged and eventually die. The hair cells do not regenerate or grow back and hearing cannot be restored (NIHL, 2015).

The Science of Noise

The vibrations which result in sound waves can be caused by a number of sources, such as impacts of equipment, heavy machinery, or alarms/sirens that occur in the workplace. The sound wave has two major characteristics which can be measured: the frequency, or pitch, and the amplitude, or intensity (OSHA Technical Manual). A sound wave might look like an ocean wave, if it were visible to the human eye. The frequency, measured in hertz, is the number of peaks and valleys in the wave form (OSHA Technical Manual). Smaller, more compact waves will result in a high-pitched squeal while larger, more open waves will result in a low roar. The amplitude of the wave is measured as the distance from the top to the bottom of the wave and is an indication of whether the sound is loud or soft. A larger amplitude is indicative of a louder sound. This characteristic is also referred to the sound pressure, since it is an indication of the amount of energy the wave is carrying (OSHA Technical Manual).

Sound pressure is measured using an absolute scale of micro Pascals (μPa), but since the scale represents minute differences in pressure levels it is a vast scale that is difficult to understand. For instance, the smallest sound pressure level a human can hear and the greatest sound pressure that can be heard without causing pain is 10 million times different (OSHA Technical Manual). A reference measurement of the decibel (dB) is used instead, and represents the sound pressure level and compresses the values into a manageable range that can be more easily understood. The equation to convert from micro Pascals to decibels is $L_p = 10 \times \log_{10}(P/P_{ref})^2$, where P is the instantaneous sound pressure and P_{ref} is the reference pressure and is defined as the quietest noise a healthy young person could hear (20 μPa) (OSHA Technical Manual). The decibel scale is logarithmic, which means that for every 10 dB increase in sound level, instead of adding +10, the intensity is multiplied by ten (OSHA Technical Manual).

Noise measurement is often adjusted to attempt to account for the different ways the ear responds to varying sound levels and frequencies (pitches). The most common adjustment is dBA weighting because it mirrors how the ear responds to certain intensities and frequencies and assigns very high and very low frequencies less weight than those in the moderate frequency range in order to better estimate the risk of hearing loss (Piesotronics, 2013). Adjustment using dBC weighting is sometimes used for specifying peak noise from impact, like gunfire or striking of metal together, and is very similar to unweighted noise measurements (OSHA, 2002).

In the United States, the governing agency on occupational health and safety, the Occupational Safety and Health Administration (OSHA), sets regulations for any potentially harmful exposures that occur at the workplace. For noise, OSHA requires employers in fields where potential damaging sound levels may occur to have what is called a hearing conservation program. These programs can vary by employer but generally include audiograms (hearing tests) of employees in excessive noise areas, regular monitoring of sound levels, modifications of machinery to reduce noise exposure, and other controls to prevent hearing loss i.e. the use of earplugs and other similar forms of personal protective equipment (OSHA, 2002). Exposure estimations are often taken through the use of similar exposure groups. A similar exposure group (SEG), is a group of employees which perform similar job tasks or are located in areas where exposure levels are similar enough and are grouped so that severity estimates may be produced using what exposure data may be available without having to perform monitoring on all employees.

Measuring Noise Level

Two types of equipment can be used to monitor noise: a sound level meter (SLM) and a dosimeter. A sound level meter measures the intensity of the sound in dBA at a given time and gives an immediate reading of the exposure (OSHA Technical Manual). The sound level meter is useful for initial determination of sound levels in a given area and can help pinpoint the source of trouble areas or equipment in the workplace. A dosimeter is utilized to capture the workers' exposure over the entire duration of the shift. The dosimeter takes reading of the sound level at a specified interval: 1 second for the slow setting or 0.125 seconds for fast setting (these are exponential time constants, so the reading is taken on the 10^{1} or $10^{0.125}$ as seen in equations in the next paragraph) and logs the data at a time interval determined by the user to calculate the exposure over the duration of the time interval (Piesotronics, 2013). These devices have several settings for how the exposure is determined: the threshold value which is the level at which no noise below will be logged; the criterion level which is the level at which regulation states is over exposed; the exchange rate which is the perceived doubling of intensity; and frequency weighting. Settings used when following OSHA criteria are 80 dB maximum threshold, 90 dB criterion, 5 dB exchange rate, and A weighting (OSHA, 2002).

Typically noise measurements are taken over the entire work period. The criteria outlined above allow the occupational hygienist to calculate a time weighted average

(TWA) using the equation: TWA = q*log10[1/T$q * log_{10}\left[\frac{1}{T}\int_{T_2}^{T_1} 10^{(L_{AS})/q}\, dt\right]$, where T is the measurement period or run time, L_{AS} is the sound level at a specified frequency weighting (how the dosimeter corresponds to peak noise levels, typically A setting is used), and exponential-time constant of the detector (how frequently the dosimeter logs collected data), and q is the exchange rate constant (Piesotronics, 2013). This study uses an exchange rate, and the constant is $q=5/Log_{10}(2) \approx 16.61$. If the noise level falls below the specified threshold set for the monitoring event, L_{AS} is equal to $-\infty$ (Piesotronics, 2013). The time weighted average is a measure of the approximate constant level of sound in decibels that a certain time period of varying levels of sound over the same period of time (Piesotronics, 2013). The time weighted average of a measurement would be compared to the occupational exposure limit for noise to determine if a worker is close to, or is overexposed. Dose (percent) can be calculated for the exposure as well, using the equation: Dose = $(100/T_c)\int_{T_2}^{T_1} 10^{[L_{AS}-L_c/q]} dt$. The equation inputs are the same as described for the TWA calculation. T_c represents the criterion duration, or duration of the typical exposure time, and L_c represents the criterion level, or specified occupational exposure limit (Piesotronics, 2013). Percent dose can be calculated using a similar equation: Dose = $(100 * 10^{[TWA-L_c/q]}$, where TWA is substituted for L_{AS}. A measurement of percent dose tells what percent of the occupational exposure limit an employee is exposed to during the noise sampling event. If the criterion time, exchange rate, threshold, criterion level, or weighting are changed, it effects the resulting exposure estimate. Using a lower threshold for noise monitoring can help to examine the total exposure profile and will increase the overall exposure estimate. Additionally, Dosimeters can measure noise using multiple settings simultaneously, which is a major component for the present study.

US Army TG 181 Method

The US Army statistical method published by the US Army in the USACHPPM TG 181 criteria for noise measurement and statistical analysis states, in agreeance with NIOSH, that measuring noise below 80 dB can interfere with exposure estimate accuracy when calculating the statistics by artificially increasing the standard deviation between exposure estimates which are used to calculate risk estimates (US Army, 1999). The US Army method determines which SEGs will be included into one of three hearing conservation program categories: not necessary to include, need to include, or need to include and also use hearing protection (US Army, 1999).

The statistical methods outlined by US Army criteria in the USACHPPM TG 181 noise monitoring criteria method uses an upper tolerance limit (UTL) of 90 percent at 75 percent confidence and a 90^{th} percentile calculated from exposure data for each similar exposure group. The 90/75 upper tolerance limit sets the parameter values that should not be rejected with the same sample when tested. In essence, the upper tolerance limit here would reflect a decibel level at which we are 75 percent confident that 90 percent of the exposures for the total population would not exceed (US Army, 1999). The percentile is similar to a median of the data and represents a value at which 90 percent of the data points are smaller (IRTC, 2013). A higher statistical confidence, such as 95 percent inclusion with 95 percent confidence, is usually more acceptable, but the US Army method uses the described statistics in order to adequately protect workers, but not inlcude some worker groups in non-noise hazardous areas into hearing conservation (US Army, 1999) (Oestenstad et al, 2008).

Based on the statistics, a severity rating for each SEG is determined and corresponds to a category for the use of hearing conservation. In this scenario a rating of 2 would not warrant the requirement of hearing conservation enrollment, a rating of 3 would warrant the requirement of hearing conservation enrollment, and a rating of 4 would warrant the requirement of hearing conservation enrollment along with the use of hearing protection (US Army, 1999). A chart of the determination of severity rating based on the above specifications can be seen below in Table 1.

Bayesian Statistical Methods

One of the major statistical methods used to sort SEG grouping into hearing conservation program classifications in this study is Bayesian analysis. The informative priors Bayesian method involves the use of prior data from previous sampling or other methods to set model parameters. This method requires some knowledge of Bayesian statistics. Bayesian inference is based on conditional probabilities through the use of Bayes' Theorem. In particular, the *posterior distribution* of the model parameters, θ, given the observed data, Y, can be written as a product of the likelihood: (the statistical model for the data given the model parameters; e.g. the exposures are assumed to follow a log-normal distribution) and the *prior distribution (*the assumed distribution of the parameters *prior* to observing the data e.g. represents the strength on beliefs about the data from previous experiments) divided by the *marginal* distribution of the data, p(Y). In practice, this marginal distribution is simply expressed as the integral of the likelihood times the prior, and thus the posterior distribution is often viewed as being *proportional to* the likelihood times the prior, as shown below (Carlin & Louis, 2008).

$p(\theta|Y)= [p(Y|\theta)\ p(\theta)] / \int p(Y|\theta)\ p(\theta)\ d(\theta)$

$p(\theta|Y)\ \alpha\ p(Y|\theta) * p(\theta)$

To understand the concept better, an example of flipping a coin can be used. The coin has some inherent parameters, θ, such as its fairness and the outcome of the events of flipping the coin can be denoted as Y. In a traditional statistical approach, the question to answer would be: what is the probability of landing heads 5 times out of 9 coin tosses, given the fairness of the coin [p(Y|θ)]? (Sarwan, 2016). A Bayesian approach asks: Given the outcome, Y, what is the probability of the coin being fair i.e., θ=0.5? In this example, the prior distribution represents our belief about the fairness of the coin based on previous experience, p(θ). Assuming I've never seen this coin before, I may wish to use a prior with (seemingly) no prior influence, such as a uniform prior over the range [0,1]. If, on the other hand, I wanted to include some prior information (e.g., I've never once observed an unfair coin), I may wish instead to use a Beta distribution with its mass concentrated around 0.5 (Sarwan, 2016). The likelihood distribution represents the probability of observing heads or tails, p(Y|θ), and depends on the fairness of the coin, θ (Sarwan, 2016). For a binomial distribution, counting the number of heads (5) out of N=9 tosses, each with Prob(Heads)= θ (Quick et al, 2017). To yield a posterior distribution, p(θ|Y), which is easily understood by the user a prior belief is chosen to obtain a distribution which will be multiplied by a likelihood function (Sarwan, 2016).

If the coin toss scenario is translated into exposure estimation, the parameters are a exposure control banding model, the prior distribution would be previous exposure data or professional judgement about how well controlled the exposure is, and the likelihood distribution would be assessed using current exposure sampling data. The statistical question would be: how controlled is the exposure according to the exposure assessment framework, given the exposure data at hand? (Carlin & Lewis, 2008)

Specific to the field of industrial and occupational hygiene, the decision-making process used in Bayesian modeling can allow the use of the prior distribution in the form of professional judgment, exposure data taken from previous sampling events, or past research studies. Bayesian methods offer a rational framework to integrate subjective judgment and available monitoring data for decision making and can be used with more sporadic data as is often seen in occupational exposure monitoring (Hewett, 2006).

A key component in the Bayesian framework is the utilization of the geometric mean (GM) and geometric standard deviation (GSD) to construct a restrictive boundary for the model distribution. Unlike its arithmetic counterpart, GM is in an indicator of the central tendency of a set of numbers which uses the product of the data values, instead of their sum. The GSD describes how spread out a set of numbers is from its geometric mean. In this setting, the Bayesian formulas use the GM and GSD to create model parameters in which the conditional probabilities fit. In the IHDA approach using generic priors, the GM and GSD are set to a range that is large enough that it would be impossible to have a set of data where the characteristics fall outside of the boundaries created by those statistics (Hewett, 2006). In the informative prior Bayesian approach, the prior information is set based on available GM and GSD Rinformation data taken from previous exposure sampling events. This Bayesian method is subject to substantial information, so the results found using that method could vary slightly should the researcher use different information (Hyunh et al, 2015).

Two Bayesian techniques are used to analyze the 0 dB threshold data: IH Data Analyst software (IHDA) and an informative priors method published by Quick et al (2016). The method of analysis using the IHDA software is performed by assigning generic prior weights to each of five categories based on the American Industrial Hygiene Association (AIHA) exposure banding model of 0-4 and uses the 95th percentile of the data. In the model 0= <1% of the occupational exposure limit (OEL), 1= 1-10% OEL, 2=10-50% OEL, 3=50-100% OEL, and 4= >100% OEL (Hewett, 2016). These are then used to construct uniform priors over the range of parameter values corresponding to each exposure category (Hewett, 2006). The IHDA software uses a GSD ranging from 1.05 to 4, depending on the GSD given from the current data (Hewett, 2006) and the resulting likelihood and posterior distributions are identical. In the informative priors Bayesian method of Quick et al (2017), priors are constructed using prior sample size and external information (e.g., past data, relevant literature) to obtain suitable non-uniform prior distributions (Quick et al, 2017). The Informative Priors method also uses the AIHA exposure banding model when assigning weights to the distributions. This method is performed using a statistical software program, R, and code constructed by Quick et al, both of which are free to download.

The Bayesian methods are primarily to be used to analyze the data in percent dose from the 0 dB threshold monitoring. For these methods, a distribution for each data set with exposure ratings based on the American Industrial Hygiene Association's exposure banding model of exposure severity ratings. The higher categories represent a poorly controlled exposure and a significant distribution in category 3 represents the need to enroll in hearing conservation and significant distribution in category 4 represents the need to enroll in hearing conservation with hearing protection use.

A table outlining the criteria for the two methods can be seen below in Table 2. These ratings for both methods reflect the OSHA standard for maximum noise exposure of 90 dB, where an exposure of 50% dose requires the enrollment in hearing conservation and an exposure of 100% dose requires the enrollment in hearing conservation with hearing protection use (OSHA, 1974). In both methods, a severity rating of 2 or less represents a well-controlled exposure and does not require inclusion into hearing conservation, a severity rating of 3 represents a poorly controlled exposure and requires inclusion into hearing conservation, and a severity rating of 4 represents an extremely poorly controlled exposure and requires inclusion into hearing conservation along with the use of hearing protection devices. It is hypothesized that the Bayesian statistical framework used along with 0 dB noise monitoring might select different groups for inclusion into hearing conservation than what the US Army method using noise monitoring at 80 dB might select.

nterpretation of the sample 90th percentile and the 75% Upper Confidence Limit				Severity Rating	Certainty Level
90^{th} percentile <	50%	75%UCL ≤	50%	2	High Certainty
90^{th} percentile <	50%	75%UCL≤	100%	2	Medium Certainty
90^{th} percentile <	50%	75%UCL >	100%	2	Low Certainty
90^{th} percentile <	100%	75%UCL ≤	100%	3	High Certainty
90^{th} percentile <	100%	75%UCL ≤	200%	3	Medium Certainty
90^{th} percentile <	100%	75%UCL >	200%	3	Low Certainty
90^{th} percentile >	100%	75%UCL ≤	200%	4	High Certainty
90^{th} percentile >	100%	75%UCL ≤	400%	4	Medium Certainty
90^{th} percentile >	100%	75%UCL >	400%	4	Low Certainty

Table 1: Severity Rating Determination Chart Based on Statistics Using the US Army Statistical Method

	Threshold Level	Criterion Level	Exchange Rate	Upper Tolerance Limit/Confidence	Percentile Fraction	Rating System		
US Army TG 181	80 dB	90 dB	5 dB	90/75	90	2:No HCP Needed	3:HCP Inclusion	4:HCP + Hearing Protection
Bayesian Methods	0 dB	90 dB	5 dB	95/95	95	0-2:No HCP Needed	3:HCP Inclusion	4:HCP + Hearing Protection

Table 2: Criteria for Two Noise and Hearing Conservation Program (HCP) Selection Methods

LITERATURE REVIEW

An extensive review of available literature yielded a range of studies available on noise dosimetry and hearing conservation programs. However, a limited amount of information is available on the effects of moderate noise exposures, alternative noise monitoring thresholds, or Bayesian techniques for environmental or occupational exposure categorization.

Noise Exposure and Associated Effects

Attempts to quantify the severity of workplace noise exposure and any damaging effects it might have on the worker has resulted in a wide variety of research available for review. One occupation where hearing loss is recognized as an issue is farming and agriculture. A study of farmers in New Zealand in 2004 attempted to characterize the types and intensities of exposures found so that the risk of hearing loss could be better understood. The exposures found at the 60 participating farms had average noise ranges between 84.8 dBA and 86.8 dBA (McBride et al, 2004). It was also found that operating heavy farming machinery without enclosed cabs was an important risk factor to the increased risk of hearing loss (McBride et al, 2004).

Another area where literature on noise exposure was readily available is transportation. A study of noise exposure in Chicago authority train noise exposure found that passengers riding the trains could be exposed to levels averaging from 76.9d dBA to

88.9 dBA, with higher levels being reported during portions of the route that went through tunnels (Phan et al, 2017). It was found that train operators had the potential for exposures higher exceeding 85 dBA, especially when operating the trains with cab windows open. In as study of New York City's mass transit systems, it was found that levels inside the vehicle of subway cars averaged 79.3 dBA and were 81.1 dBA on platforms. Lower average levels were recorded for busses, 75.5 dBA inside the bus and 76 dBA on the platform, and for the ferry, 77.7 dBA inside and 72.9 dBA at the terminal (Nietzel et al, 2009). Peak levels were found to 102.1 dBA for the subway, 101.6 dBA for the bus, and 89.9 dBA for the ferry.

In the music industry, many professional performers have an increased risk of excessive noise exposure. In a study of professional pop, rock, and jazz artists a positive correlation was found between the exposure to amplified music and hearing thresholds in the 3-6 kHz range as well as a relationship between the number of years performing and hours per week spent practicing and performing (Halevi-Katz et al, 2015). A study of the noise exposure to symphonic orchestra musicians found that brass, woodwind, and percussion and timpani musicians are exposed to noise levels about 85 dBA, with peak levels for percussion members up to 135 dBA (Rodrigues et al, 2014). Location and repertoire also had an effect of up to 3 dBA in the noise exposure. In addition to this, the study points out that professional musicians do not fall under any regulatory guidelines and are often neglected from hearing conservation issues (Rodrigues et al, 2014). A study of musicians' exposure during rehearsal and performance times found ranges from 84.3 dBA to 90.4 dBA during one 2-hour rehearsal and from 94.0 dBA to 102.8 dBA during one 4-hour performance (McIlvane et al, 2012).

While noise induced hearing loss is a major concern for occupational hygienists and environmental researchers, it is not the only issue that could arise from exposure to moderate and excessive noise levels. One issue, noted in a study noted that for noise exposes workers, a ringing in the inner ear known as tinnitus can also accompany hearing loss. Approximately 40% of the 145 firefighters and 769 operating engineers involved in the study reported tinnitus while 34% of firefighters and 59% of operating engineers had nearing loss at noise-sensitive frequencies (4-6 kHz) (Hong et al, 2016). The study also found that high frequency hearing loss and hearing impaired status increased the likelihood of reporting having tinnitus, and that high frequency and low frequency hearing loss along with hearing impaired status doubled the likelihood a worker would also have tinnitus (Hong et al, 2016).

Occupational settings are not the only source of potentially hazardous noise, and one study reported that exposure to traffic noise had adverse effects on the metabolic system. In a comparison of waist circumference, a 0.21 cm increase in waist circumference was seen for every 5 dBA increase in environmental noise. Increased odds of having larger waist-hip ratios and central obesity levels when exposed to railway and aircraft noise in addition to road traffic (Pyko et al, 2015).

A study reviewing research in Sweden found a 30% risk increase in self-reported hypertension with every 5 dBA increase in environmental noise exposure due to traffic, and an assessment of cumulative incidence of hypertension found a 1.10 relative risk increase for every 5 dBA increase (Bluhm et al, 2011). A study using data from the RECORD study focused on the potential risk of cardiovascular disease caused from living in areas with increased noise from road, rail, and air traffic. The study found an increased risk of high systolic and diastolic blood pressure associated with road, rail, and air traffic noise when exposed at the workplace and for neighborhoods near the air and train terminal locations. No significant relationship was found in participants who lived in neighborhoods located further away from the traffic noise (Meline et al, 2015).

Almost any type of industry can experience excessive noise exposures. Many of the more concerning industries, based on the literature search, are transportation, manufacturing, agriculture, and musicians. These occupational groups are among those occupational and environmental exposures that are to be analyzed in the following study. The studies discussed above help to give an understand of the wide variety of occupations which might experience excessive noise exposure, but are simply attempts to quantify the noise exposure. In the study at hand, not only will the noise exposure be quantified, but it will also attempt to explain how certain noise exposed groups might be classified into hearing conservation programs because of those exposures.

Moderate Noise Exposure Effects.

One aspect of interest for this study is the effect of moderate noise levels, ranging from about 60 dB to 79 dB, on exposure estimation and hearing loss. A few studies are available where the focus of determining risk associated with these noise levels. In 1994, an analytical review study was conducted using data from the NIOSH Occupational Noise and Hearing Survey, which was collected during the years 1968-1972 (Lempert et al, 1973). The data used was of special interest since it was collected before hearing protection was widely used in the United States, and investigators did not report any participating companies had policies requiring the use of hearing protection, nor did they report mass use of hearing protection in the companies surveyed (Lempert et al, 1973).

The NIOSH study compared a group of higher noise exposed workers and logistic regression models were used to analyze the data, and controlled for age and duration of exposure. The final best fitting model yields an excess risk estimate range of 1.2 for exposure sound level of 80 dB, up to 44.0 for 100 dB (Prince et al, 1994). Between the best fitting model and the various other models used to analyze the data, there is a great deal of variation in the excess risk estimates (especially at 85 dB and lower), a fact which the author credits to not having data at lower sound levels (Prince et al, 1994). While this article is unable to estimate the risk levels at, or interpret data for, noise exposures below the 80 dB monitoring threshold, it does well to set up a scenario to warrant the use of noise monitoring data below 80 dB to create a more accurate assessment of the excess risk estimate of hearing damage due to excessive noise exposures.

A study done through the Yale University School of Medicine and Occupational and Environmental Medicine Programs in 2006 builds on the findings of the previously discussed reevaluation of the NIOSH Occupational Noise and Hearing Survey data done many years earlier. The study participants were chosen if they had at least three audiograms between 1990 and 1996 and at least five audiograms after 1996 with the last test occurring 8-12 years after the initial audiogram, yielding a study total of 6217 workers (Rabinowitz et al, 2006). The range of calculated equivalent exposures ranges from ≤77 dB to ≥94 dB (Rabinowitz et al, 2006). The study compares the hearing loss rates of all workers to workers ≤35, as well as observed hearing loss rates to the American National Standards Institute (ANSI) expected rates. Workers in both the 'all ages' group and the '35 and younger group' had an annual rate of hearing loss (dB/year) of less than 1.0 for all decibel ranges measured, and a decrease in hearing loss rates with increase in Leq noise exposure. When comparing the ANSI expected rate of hearing loss (white males only) to the observed rates, lower dB level ranges agreed relatively closely and remained around 1.0, where the higher dB level range rates deviated with ANSI expected rates curving upwards over 1.0 and observed rates curved downward near 0.7 (Rabinowitz et al, 2006). While monitoring is not explicitly performed at a 0 or very low dB threshold, the study's noise risk estimates based on the exposure estimate averages (Leq) begin to help demonstrate the impact of noise exposures below the 80 dB threshold.

In 2014, a second study was conducted by Rabinowitz et. al. on the dose response relationship of in-ear occupational noise exposure and hearing loss. The study followed members of an aluminum company's hearing conservation program, including a group who had mandatory daily exposure monitoring due to an audiometric shift of 5 dB from baseline in the normal hearing range (2-4 KHz). Measurements were taken on individuals having three audiograms over at least three years since being placed into monitoring, and used a microphone fitted inside of the worker's hearing protection for an in-ear exposure (Rabinowitz et al, 2013). The study showed that most exposures measured under the hearing protection were well below 85 dB. It also found that there was no significant relationship between these exposures and hearing loss due to occupational noise in the frequencies screened for. These measurements were taken at an 80 dB floor, and the author suggests using a lower threshold for noise monitoring could add some significance to the findings, as well as using more advanced dosimeters which could record a detailed dosimetry data log (Rabinowitz et al, 2013).

A study conducted in 2013 uses mice to test the physiological, psychological, and behavioral effects of chronic moderate noise exposure. The investigator mirrors the daily sound exposures as they might occur to a worker: louder levels of 70 dBA to 85 dBA for 6 hours (work exposure) and lower levels of 32 dBA to 35 dBA during the remainder of the day. Compared to control rats, exposed at 32 dBA to 35 dBA for the entire day, the test rats showed significant higher corticosterone levels, changes to adrenal makeup, oxidative stress and injury to cardiac cells, and inflammation in thyroid cells (Gannouni et al, 2013). While the subjects in this study are not human, similar results would be expected in human systems.

While the Prince et al study and the Yale study do not necessarily use noise monitoring below 80 dB, they set up a scenario that warrant for the use of monitoring below the current established threshold to determine a more accurate risk assessment of hearing damage at moderate noise exposures. While the study at hand is not aiming to determine the risk of hearing damage at lower decibel levels, it is aimed at determining the difference of the exposure estimate, which could eventually lead to a study as suggested by Prince et al.. The Yale study also brings about an important idea that much higher noise levels workers cause less hearing damage, which is likely due to workers wearing hearing protection at higher levels removing the hearing protection in areas where noise is below ‘required’ level. This idea is again an important reason to introduce lower level thresholds for noise monitoring. The second Yale study, while not necessarily directly related to the subject of 0 dB threshold dosimetry as it relates to determining hearing conservation, does bring up the ideas of monitoring at a lower threshold and determining exposure profiles accordingly to assess risk for hearing loss.

Dosimetry

One study conducted in 1994 in association with the Mine Safety and Health Administration (MSHA) aimed to determine the effect of threshold on noise dosimeter measurements. The article states that the concept of a threshold implies that exposure to sound above the level is potentially damaging but sound below the threshold abruptly becomes nonhazardous, but there is no published evidence exists to prove this theory (Seiler et al, 1994). The study uses a high threshold level (HTL) of 90 dB and a low threshold level (LTL) of 80 dB with an exchange rate of 5 dB along with six sets of exposure scenarios to demonstrate the relationship between the threshold used and the resulting dose. The resulting exposures (calculated in % dose) were 0% for any exposure under the lower threshold. When scenarios used multiple ranges of sound levels, including levels falling between the two threshold levels, the percent dose showed the greatest difference, but for ranges above both the lower and higher threshold level, the resulting percent doses did not differ (Seiler et al, 1994). A field study was done following the simulated experiment, which monitored 2631 workers and saw a difference in dose of 20.1% using the same 80 and 90 dBA threshold levels and 5dB exchange rate.

The MSHA study sufficiently demonstrates the concept of a threshold and its effect on data collected by an occupational or industrial hygienist. Unlike the current study, it does not investigate the relationship between lower level threshold and percent dose nor does it utilize collected data for statistical analysis in the determination of hearing conservation program participation. The study does, however, make a valid point surrounding the concept of the threshold: that because it is assumed that no damage occurs below that specified level, does not necessarily mean that is absolute fact. This remark reaches beyond the aim of this study, but would likely be a possible future study, should more occupational hygienists begin collecting full exposure profiles using no threshold for noise measurement.

A more recent study conducted by researchers in Australia, aimed to quantify the difference between exposure dose as it relates to regulatory threshold levels. The paper outlines many different regulations for noise monitoring around the world. A summary of the standards used in this study and their measurement specifics can be found below in Table 3. The study follows a similar format to the MSHA study from 1994, where first a simulated exposure conducted in a laboratory is done, followed by a real-world scenario test. The OSHA PEL, which is mainly used to support the need for machinery modifications and other engineering controls to reduce noise, had the lowest result and NIOSH had the highest result (Tingay et al, 2014). The second test was performed using two channels of a noise dosimeter: 3 dB exchange, no threshold, no time weighting and 80 dB criterion level vs 5 dB exchange, 80 dB threshold, slow time weighting, and 90 dB criterion level. The first channel reported an exposure of 511% dose while the second reported a dose of only 75%, despite having the same source (Tingay et al, 2014). It is not known here if the difference is caused by the exchange rate or the use of a lower threshold.

A similar study published by the German Acoustical Society looks into the effects of various thresholds and exchange rates as they relate to various occupational regulatory standards. It describes the applicability of using dual or multi-channel dosimetry in situations where multiple governing bodies may have domain over a singular facility. It examines the potential error which might be cause by the dual channel dosimetry, since the channels use the same hardware but might process the data differently for each channel (Imtiaz et al, 2016). The investigator uses simulated dose tests from the ANSI standard S1.25 which was written in 1991, but reaffirmed in 2007 (ANSI, 1991) and mathematical modeling tools. Some variation was found between the computed exposure to the ideal values, but not significant enough difference to be outside the acceptable range set by ANSI for any of the tested settings (Imtiaz et al, 2016).

While the two studies above aimed to demonstrate the differences between a variety of various thresholds and exchange rate settings for dosimetry, the exchange rate issue is beyond the scope of the study at hand. This is mainly because it is easy to quantify how the exchange rate can affect the calculated exposure dose, but the threshold setting is rarely ever investigated on its own. The study from the German Acoustical Society does a similar investigation into dosimetry functioning using different settings and how they may affect the accuracy of exposure estimations when used along with a dual channel function.

Standard	ISO	OHSA HC	OSHA PEL	NIOSH	DOD USN
Threshold	none	80 dB	90 dB	80 dB	90 dB
Exchange Rate	3 dB	5 dB	5 dB	3 dB	5 dB
Criterion Level	85 dB	90 dB	90 dB	85 dB	85 dB
Criterion Time	8 hrs	8 hrs	8 hrs	8 hrs	8 hrs
Time Weighting	none	slow	slow	slow	slow

Table 3: Summary of Various International Noise Standards and their Criteria for Measurement Used in the Tingay Study

Bayesian Techniques for Exposure Categorization

Even though Bayesian statistics is not a new concept, it has seen little use in the occupational setting. This issue is likely due to lack of acceptable programs to perform the statistical functions involved in these methods. A few new programs are available to allow occupational hygienists to use the statistical method to determine exposure severity. A study done through the Fudan University's School of Public Health in China uses a Bayesian modeling method to estimate exposure of Benzene in a rubber manufacturer (Yonghua et al, 2009). The study uses a mathematical framework built using the characteristics of the pollutant combined with parameters based on historical working conditions (the prior distributions) and estimated variance of historical data (likelihood distribution), and updated the prior distribution with historical data to produce a posterior distribution. This is much like many Bayesian models seen for estimating exposure means for airborne toxics. The author recommends a Bayesian method such as described for its inherent ability to combine measurements, expertise, and mathematical modeling to estimate exposure levels (Yonghua et al, 2009).

A different study uses an analytical tool called Advanced REACH Tool (ART), which is a higher tier exposure tool that combines disparate sources of information within a Bayesian statistical framework (McNally et al, 2009). The tool uses both conventional Bayesian analysis, which combines experimental data with parameters through the likelihood distribution and updates the prior distribution using those measurements, as well as a model which uses available exposure measurements from other scenarios and are similar to the assessment scenario. The study uses simulated data and experimental inhalation estimate data to evaluate the models. The author of this paper mentions the method by Hewett et al, which will be utilized in the current study, but thinks that the ART tool may more practical since it more easily allows users to input prior data or expert beliefs.

A study outlining a Bayesian hierarchical framework by Banerjee et al again uses the framework of prior, likelihood, and posterior distributions to use in occupational hygiene decision making. This method implements the AIHA exposure banding models which are of interest for use in the study at hand. The method implements two different models to estimate the area concentrations of airborne toxics, something not of interest in the study at hand since it is attempting to estimate noise exposure (Banerjee et al, 2014). However, a similar mathematical model for the Bayesian framework will be used in this study. The Bayesian hierarchical framework model can be easily modified based on the validity of the occupational hygienists judgement and the historical data available to construct prior distributions (Banerjee et al, 2014). For this reason, it is a useful tool to accurately estimate exposures.

These studies show that the Bayesian methods available yield valid results for exposure rating. As seen in the above studies, Bayesian tools in this setting are predominately used for determination of occupational risk from air exposure monitoring, while the study at hand is investigating new methods for statistical determination of employee exposure to noise. This study attempts to present Bayesian modeling tools as a valid means for estimating noise exposure and classifying worker groups into one of three predetermined hearing conservation program categories. Similar to the Yonghua et al, McNally et al, and Banerjee et al studies, the study at hand will use a method which incorporates historical data into the prior distribution to estimate the exposure but will also include a method where no prior information is included (generic priors) and relate the results of the estimations to an exposure banding model discussed previously in the introduction to this paper.

Statement of Problem and Its Relevance

Occupational noise and noise induced hearing loss is a well-known issue in today's working world. It is estimated that 26 million Americans aged 20-69 have hearing loss that could have been caused by exposure to excessive noise in the workplace (NIH, 2015). In 2007, there were approximately 23,000 reported cases of occupational hearing loss (CDC, 2015). The United States occupational regulatory agency, OSHA, recognizes this risk and sets standards for employers in noise hazardous industries to monitor noise and implement controls to reduce the noise levels in hopes to prevent hearing loss. Once the standard was set, little revision has been done, especially involving the threshold (minimum noise level picked up) of 80 dB. Literature shows that, while much research has been done to characterize the nature of noise and extent of damage in certain industries and investigations into the effect of different regulatory standards for noise measurement affect the exposure estimate, little research has been done investigating using 0 dB dosimetry in the occupational setting. Additionally, there are many statistical methods used to interpret data collected which could be used to evaluate the effects of lower threshold noise monitoring on how workers are included into hearing conservation.

PURPOSE OF THE STUDY

The purpose of this study is to evaluate the difference in exposure dose estimates using what is called dual channel noise monitoring with a 0 dB or negligible threshold level compared to the standard threshold level of 80 dB. The data will be analyzed using a validated method for determining hearing conservation participation of worker groups against newer models using Bayesian statistical tools. Additionally, the study aims to determine if there are any effects on the measurement sensitivity of the microphone or data logging capabilities of the integrator due to using the 0 dB threshold or dual channel dosimetry.

To make a comparison between the two distinct measurement thresholds and the statistical methods in question, the experiment was designed to simultaneously measure noise at 1 second intervals using both 0 dB and 80 dB threshold levels. This process utilized a function on the dosimeter that is referred to as dual channel dosimetry and allows to the device to measure and integrate the noise levels at different threshold settings and produce a percent dose value for each setting. Laboratory simulations of various noise exposures were measured to a random iteration and the data for the two thresholds was analyzed side by side using the US Army TG 181 validated method and two Bayesian statistical tools. It is expected that there will be some variations between using the two different measurement techniques on the resulting exposure estimate, and therefore reveal variations in the worker groups included into hearing conservation using the different statistical methods with data from either threshold, but between the data using a singular threshold when computed using different thresholds.

METHODS AND MATERIALS

This study has two components. The first component of this study will evaluate differences in outcome for similar exposure groups (SEG) classification into hearing conservation programs using three statistical methods using the percent dose calculated from 80 dB threshold and 0 dB threshold monitoring. To evaluate the differences between using an 80 dB threshold and 0 dB threshold for noise monitoring and the differences in the effect on hearing conservation program selection using the Bayesian techniques and the validated Army TG 181 method, exposures will be simulated in a laboratory setting. Dosimeters with dual channel functionality, which can simultaneously monitor at multiple threshold, criterion level (maximum exposure level), and exchange rate, are set up to record the sound level in time weighted average and percent dose. The second component of the study involves using a set up of three dosimeters to determine if the use of dual channel dosimetry or 0 dB threshold noise has any effect on the accuracy of the exposure estimates.

Sampling

Noise samples for this study are taken in a small classroom on the laboratory floor of a school building. The background noise of the room is measured before beginning the sampling series and is found to be 46 dB. This background level will be picked up and incorporated into the final measurement by the 0 dB threshold monitoring and contribute a small amount to the overall dose should the simulated exposure level drop below the room background. Since the background levels of any area be integrated in real time exposure monitoring at 0 dB, this is not considered to influence the results of the analysis. Special care is taken to ensure that no occupants are in the building so that outside interruption of the noise sampling does not occur.

Measurements for this study are taken using either a Larson Davis 706 Spark Blaze, PCB Piesotronics, Utah, US, or Cirrus doseBadge CR 110A, Cirrus Research, United Kingdom, for the sample. The dosimeters are set to measure on dual channel functions where the first channel records noise at a 0 dB threshold and calculates a dose using a 90 dB criterion level, and 5 dB exchange rate and the second channel records noise at an 80 dB threshold and calculates a dose using a 90 dB criterion level and 5 dB exchange rate. The criterion level is the occupational exposure limit and is considered 100% dose and the exchange rate represents a doubling of the dose for every 5 dB above the criterion level (or halving of the dose for every 5 dB below the criterion level). This simplified formula is the basis on how the equipment calculates the percent dose used for analysis. Slow detector rate of 1 second, which refers to a time constant in the calculation of the overall TWA of percent dose, and dBA weighting are used for all measurements taken. For the remainder of this paper, dB is used as the noise measurement and should be assumed that A weighting is used unless otherwise noted.

Twelve different similar exposure groups are generated for the study using sound clips of various work equipment, tools, music, or vehicle noises. While some of the clips for the groups could have overlapping elements i.e. construction and power tools, but the groups are distinguished by the search term and title of the sound clip. The clips used for the trial were obtained using videos and sound recordings downloaded from an internet site, Youtube. For each exposure group, the clips ranged from a few minutes to about an hour each, and enough clips were accumulated that there was 10-15 hours of play time. The same set of clips was used for each sample in the exposure group, but were shuffled at random to allow for some variation in the results. The sound clips are played from the playlist over the course of the sampling time through a speaker. The noise measurements will run anywhere from 6.5 hours to 10 hours, and are set using an 8-hour time criterion for data collection. It is of interest to create as realistic measurements as possible, so attempts are made to quantify the exposure levels by adjusting the loudness of the noise source to the average range for the groups, and adjusting the volume on the speaker ±5dB between each sampling event for a group to increase the variation in the results for analysis purposes. This is verified using a sound level meter to determine the decibel level at the beginning of the sampling event. The Larson Davis dosimeters can be set up on a timer, which can guarantee an exact 8-hour measurement time-the most desirable for collecting data since most employee exposure monitoring is done on 8-hour work day shifts, but the doseBadge models do not have that capability so the time of the samples collected using varies greater when using those units. The dosimeters are calibrated pre- and post-sampling to 114.0 dB, using preset calibrators provided by the manufacturer for either of the units. For the Larson Davis Spark units, a calibration offset of 0.5 dB for pre-or post-calibration is considered to fall within acceptable error, as well as a 0.5 dB difference from the pre-calibration to the post calibration, per the manufacturer's instructions (Piesotronics, 2013). Any deviations greater than this, and any deviations of 0.5 dB or more between pre-and post- calibration of the series samples for the second part of this study, will cause the sample to be voided. DoseBadge calibration automatically sets to 114.0 dB, so no variations are seen with this model (Cirrus, 2013).

The ANSI standard S1.25 for assessing integrator functioning with varying dosimeter threshold tolerances is specific only to thresholds above a zero or non-existent threshold, so they are not able to be used in this study (ANSI, 1991). So, a trial is set up where three dosimeters, two single channel at 80 dB or 0 dB and one dual channel at 80 dB and 0 dB. The noise dosimeters are set up 20 inches from the noise source on a separate structure to ensure that vibrations do not interfere with the microphones or equipment and to allow the sound wave to level out to reduce potential minute variations in sampling. When multiple dosimeters are used in the cases where the dual channel functionality is to be examined, the dosimeters are suspended from an above cabinet in a triangular pattern with the noise source in the center. The distance from the center of the noise source is measured each time to ensure equal spacing so that no differences occur in the readings.

Ln statistics of the noise data captured by the dosimeter, generated automatically by the noise monitoring equipment, will be used as an indicator to measure the variation, if any, between the three dosimeters used for the second part of this study. The Ln statistics of L10, L50, L70 and L90 are a percentile for the data, but are calculated logarithmically as another method of interpreting the results and handling the logarithmic nature of noise. The Ln statistics are used to understand in greater detail the complex variations which might occur over the course of a noise sampling period. From the statistics, we can gather the level that is exceeded for a certain percentage of time. For example, L50 represents a dB level that was at least above the given level for 50% of the sampling time (Piesotronics, 2013). The greater the consistency between the Ln statistics of the three dosimeter outputs, it can be assessed that there is little of no variation between the measurement thresholds and the accuracy of the measurements remains intact.

Informative Prior Bayesian Data

Three components of the prior data are needed for the informative prior Bayesian method of Quick et al (2017): prior sample size, nθ, prior geometric mean, GMθ, and prior geometric standard deviation, GSDθ. For prior sample size in this study, a constant of 3 is used for all the calculations. This is because the smallest sample size of the current data is 3 and it is necessary to have the sample size of prior data be the same or smaller so that the algorithm assigns equal or more weight to the current data (Huynh et al, 2015). Since geometric standard deviation is typically a small figure, a neutral estimate of 2 is used for the prior data for all data sets since this is approximately the median GSD used in the IHDA Bayesian method of generic priors, where the prior GSD is constructed based mathematically from the current data (a more statistically sound approach would be to use a GSD based on prior data, but here none was available). For the geometric mean, data is found using published data from studies done regarding the type of exposure for the simulated trials and converted to a percent dose to be consistent with data found in the simulation. The prior GM for 'kitchen' is found using data from a study on hospital restaurants, where the average time weighted average using OSHA PEL standards for measurement for the entire location is converted to a percent dose of 5.8 (Achutan, 2009). For 'auto shop' the average time weighted average found in a study on hazards in automotive repair shops is converted to a percent dose of 27 (Loupa, 2013). A study of professional pop and rock musicians yields a percent dose of 248 for ‘rock music’ (Halevi-Katz et al, 2015), a study of discotheques (European clubs) is used for ‘rap music’ and the percent dose that will be used is 87.1 (Lee, 1999), and gospel music prior data is found from a study of classical musicians and is 33.4 (McIlvane et al, 2012). For the ‘animals’ group, a study of noise levels on farms is used and the percent dose is converted from the average time weighted average found, and is 55.9 (McBride et al, 2003). A study evaluating hazards in construction that focused on equipment operators yielded a percent dose of 75.2 (Houg, 2005) which will be used as prior data for the ‘construction’ exposure group. For ‘trains’ a study on the average exposure to on board locomotives was used for the prior data and the percent dose is 30 (Seshagiri, 2003). For ‘traffic’, a study of ambient noise in urban areas was used to find a percent dose of 78 for the prior data (Neitzel et al, 2009). For ‘alarm + horn’, an average car horn, alarm clock, and ambulance siren were taken using data from the Center for Hearing and Communications list of common environmental noise data and the percent dose was calculated from that to be 114. The same database was used for ‘vacuum + fan’ and the percent dose was found to be 8.2. For ‘weather’ data was obtained from Lightning Safety (Science of Thunder, 2017) on the sound level of lightning, and the number of times lighting strikes during a storm using data from Weatherunderground.com was used to calculate a rough TWA which was converted to a percent dose of 106.

RESULTS

For the pre-defined twelve groups, sample numbers ranged from 3-12 samples per group. Since a minimum of three data points are suggested for the US Army TG 181 statistical method (US Army, 1999), all exposure groups had a minimum of three noise samples; however, some variation was allowed so that the data more closely model real occupational sampling data, which can have any number of samples. Since the noise simulations were taken using prerecorded clips of noise sources, the number of clips dictated the number of samples taken in attempt to reduce the amount of repetition in the results. The results were graphed for the dataset as a whole and found to be distributed in a lognormal manner. This is a typical finding in exposure monitoring and will not affect the outcome of the analysis to come.

The magnitude of the effects of using the 0 dB threshold noise monitoring on the estimated exposure dose varied from group to group. The group having the smallest difference in percent dose from using the 80 dB monitoring and the 0 dB monitoring was trains, where the range of 80 dB percent dose results was 6.1 to 87, with an average of 29.8 and the range of 0 dB percent dose results was 12 to 89.9 with an average of 36.4. The group with the larges difference in percent dose from using the 80 dB monitoring and the 0 dB monitoring was rap, where the range for 80 dB percent dose results was 16 to 49.8, with an average of 32.4 and the range of 0 dB percent dose results was 37.6 to 137, with an average of 68.8. Full detailed statistics for the exposure group data at 80 dB threshold can be found below in Table 4 and for the exposure group data at 0 dB threshold can be found in Table 5.

The group with the greatest number of samples of 12, classic rock, was also one of the louder groups, with a mean percent dose of 82.9 for 80 dB monitoring and 117 for 0 dB monitoring. One of the groups having a smaller number of samples, kitchen, had four samples. The mean percent for the 80 dB results was 3.2 and was 12.6 for the 0 dB monitoring results. The GSD for the 80 dB results was 14.6 and for 0 dB was 2.32. This was a sign of an anomaly in the data, and after inspection and removal of an extreme outlier, the issue was resolved and the GSD was 1.8 and 2.03 for 80 dB results and 0 dB results, respectively. Another smaller group, fan + vacuum had anomalies in the range of GSD between the 80 dB results and 0 dB results, where the 80 dB results had a GSD of 14.7 and the 0 dB results had a GSD of 2.94. There were no noticeable outliers in this group and removal of any sample data did not remedy the extreme difference, so likely it is due to the amount of variability between the sample data since in both cases the standard deviation was higher than the data obtained. Weather, with a sample size of 7, had a similar anomaly with the GSD, where the 80 dB percent dose resulted in a GSD of 2.74 and the 0 dB percent dose resulted in a GSD of 1.9. Typically, the GSD would be expected to be lower for the group with smaller data points, but it seems that the variation between the data is greater for 80 dB than it is for 0 dB in these cases.

	Classic Rock	Rap	Gospel	Weather	Kitchen	Trains	Traffic	Const.	Auto Shop	animal	Alarm horn	Fan + vacuum
n	12	6	3	7	4	8	4	5	9	4	3	4
min	15.4	16	13	2.6	1.4	6.1	3	7	9	9.5	22	2
max	315	49.8	34	49.8	5.6	87	41	172	163	27.8	118	119
median	58.9	30	32	18.6	4.5	13.4	10.9	38	54.8	10.3	110	17.3
mean	82.9	32.4	26.3	20.4	4	29.8	16.4	71	68.1	14.5	83.3	38.8
SD	80.9	11.6	11.6	16.3	1.85	29.1	16.8	73	54.8	8.89	53.2	54.3
GM	61.5	30.6	24.2	14.3	3.54	20	11	38	46.6	12.9	65.8	14.7
GSD	2.16	1.47	1.71	2.74	1.8	2.57	2.91	3.95	2.7	1.67	2.58	5.79
75/90 UTL	214.29	53.95	53.32	49.54	7.91	80.43	52.26	214.71	161.28	33.45	216.31	154.71
X90	165	50.2	48.2	51.9	34	67	43.2	221	170	24.9	222	139

Table 4: Statistics for Percent Dose Results for 80 dB Threshold Channel of Dual Channel Noise Monitoring

	Classic Rock	Rap	Gospel	Weather	Kitchen	Trains	Traffic	Const.	Auto Shop	Animal	Alarm horn	Fan + vacuum
n	12	6	3	7	4	8	4	5	9	4	3	4
min	31.5	37.6	16	14.5	7	12	16	19	13.8	14.2	37	13
max	519	137	59	58.3	34.1	89.9	53	344	187	32.1	122	138
median	79.9	44.4	36	24.4	9.35	19.3	23	40.7	62.5	20.3	117	27.1
mean	117	68.8	37	33.1	14.9	36.4	28.8	126	80.5	21.7	92	51.3
SD	136	43.4	21.5	16.7	12.8	29.5	16.5	144	60.7	8.61	47.7	58.9
GM	82.2	59.3	32.4	29.6	12	27.9	25.9	66.5	58.4	20.5	80.9	32.3
GSD	2.18	1.77	1.9	1.67	2.03	2.13	1.66	3.68	2.5	1.49	1.97	2.94
75/90 UTL	337.48	149.51	90.81	63.02	36.67	87.76	63.99	408.17	183.76	40.09	211.44	176.9
X90	223	124	75.4	57	27.4	73.6	49.7	353	189	34.1	193	129

Table 5: Statistics for Percent Dose Results for 0 dB Threshold Channel of Dual Channel Noise Monitoring

Comparison

Multiple comparisons are done using the percent dose for 80 dB threshold monitoring and 0 dB threshold monitoring with the US Army statistical method, IHDA Bayesian tool, and Informative Priors Bayesian technique. First a comparison of the hearing conservation inclusion results for each statistical method performed with both 80 dB threshold data and 0 dB threshold data will be done, then a comparison of inclusion using statistical methods comparing the same threshold data will be done, and finally, the hearing conservation inclusion outcome using different statistical methods will be cross compared using 80 dB or 0 dB threshold data will be done (i.e. 80 dB threshold and US Army method vs 0 dB and Bayesian methods and vice versa).

Inclusion into hearing conservation for the US Army method is determined using a severity rating discussed in the introduction calculated using the 90th percentile and 75% UTL from the data in tables 4 and 5 above. For the Bayesian methods, severity rating distributions are calculated using either IHDA software or code for informative priors. The distributions for 80 dB data and 0 dB data using the Informative Priors Bayesian methods can be seen in tables 6 and 7 below, respectively. The distributions for 80 dB data and 0 dB data using the IHDA Bayesian method can be seen below in figures 1a-12b. In both situations, the severity rating with the highest distribution is the one selected for the hearing conservation inclusion category.

	80 dB Distribution				
	0	1	2	3	4
alarm/horn	0	0.0001	0	0.0056	0.9943
animals	0	0.0001	0.169	0.4466	0.3843
auto shop	0	0.0001	0	0.074	0.9925
classic rock	0	0.0001	0.0075	0.5395	0.4529
construction	0	0.0001	0	0.0159	0.984
fan/vacuum	0	0.0001	0.1452	0.4693	0.3854
gospel	0	0.0001	0.1286	0.5878	0.2835
kitchen	0	0.0802	0.717	0.0325	0.0095
rap music	0	0.0001	0.0108	0.5523	0.4368
traffic	0	0.0001	0.0063	0.1551	0.8385
trains	0	0.0001	0.0205	0.494	0.4854
weather	0	0.0001	0.002	0.1052	0.8927

Table 6: AIHA Exposure Control Banding Distribution for Informative Prior Method, 80 dB Data

	0 dB Distribution				
	0	1	2	3	4
alarm/horn	0	0.0001	0	0.0027	0.9972
animals	0	0.0001	0.1384	0.531	0.3305
auto shop	0	0.0001	0	0.0019	0.998
classic rock	0	0.0001	0	0	0.9999
construction	0	0.0001	0	0.0019	0.998
fan/vacuum	0	0.0001	0.0913	0.5286	0.38
gospel	0	0.0001	0.0238	0.5363	0.4398
kitchen	0	0.0003	0.8351	0.363	0.00284
rap music	0	0.0001	0	0.0226	0.9979
traffic	0	0.0001	0.0063	0.1551	0.8385
trains	0	0.0001	0.0075	0.5394	0.4529
weather	0	0.0001	0.0022	0.369	0.6287

Table 7: AIHA Exposure Control Banding Distribution for Informative Prior Method, 0 dB Data

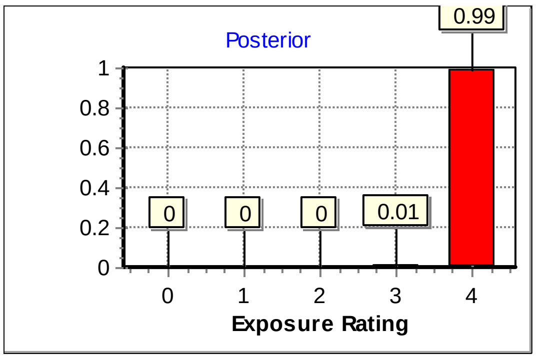

Figure 1a: Alarm + Horn Distribution, 0 dB

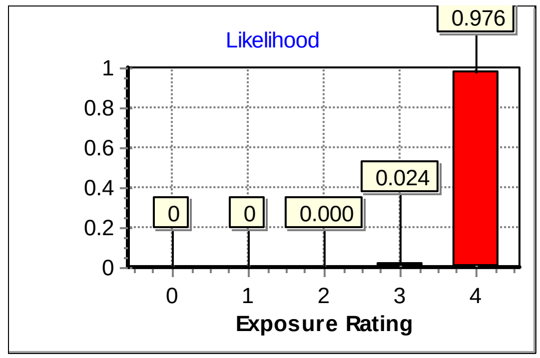

Figure 1b: Alarm + Horn Distribution, 80 dB

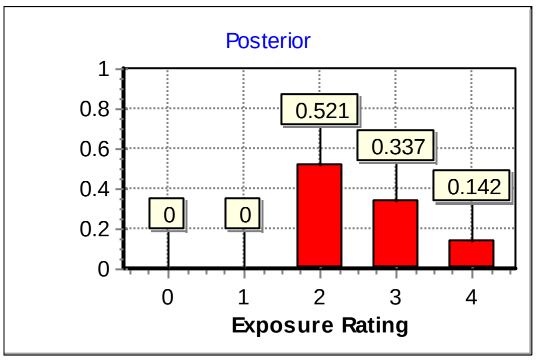

Figure 2a: Animals Distribution; 0 dB

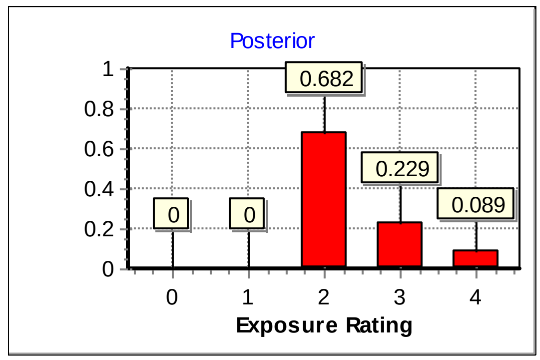

Figure 2b: Animals Distribution, 80 dB

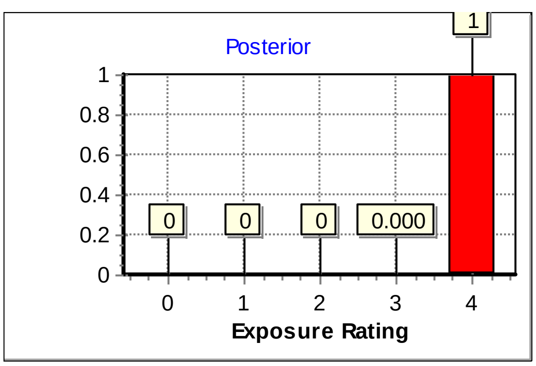

Figure 3a: Classic Rock Distribution; 0 dB

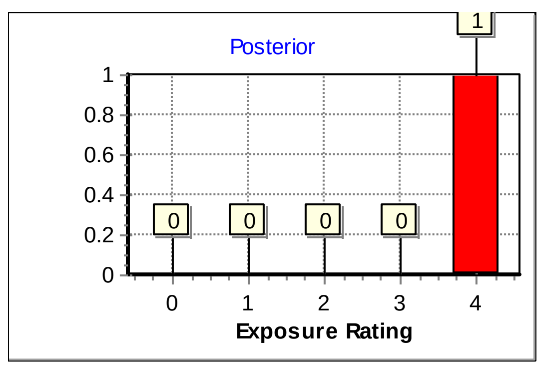

Figure 3b: Classic Rock Distribution; 80 dB

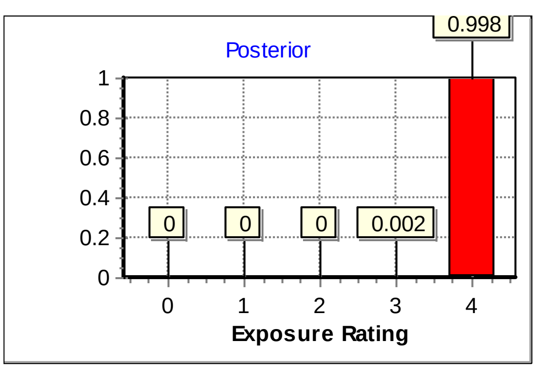

Figure 4a: Construction Distribution; 0 dB

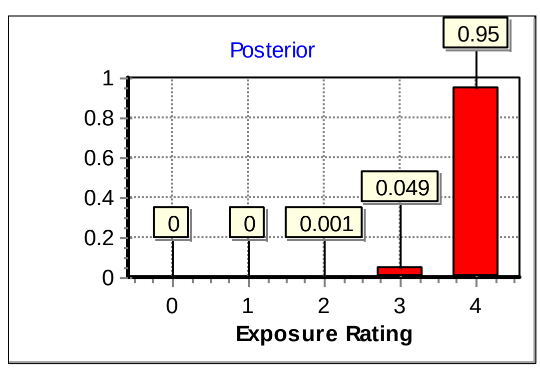

Figure 4b: Construction Distribution; 80 dB

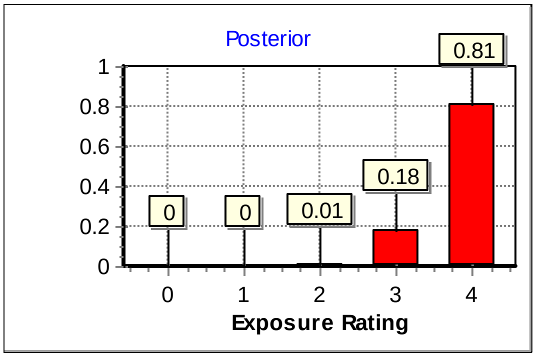

Figure 5a: Fan + Vacuum Distribution; 0 dB

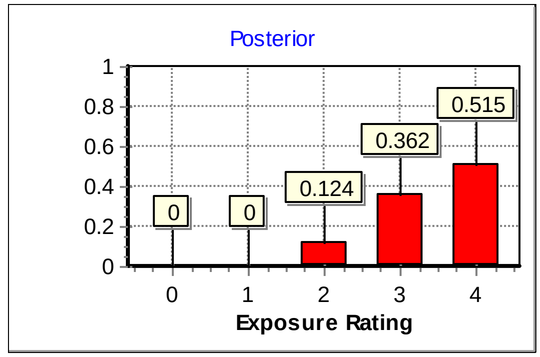

Figure 5b: Fan + Vacuum Distribution; 80 dB

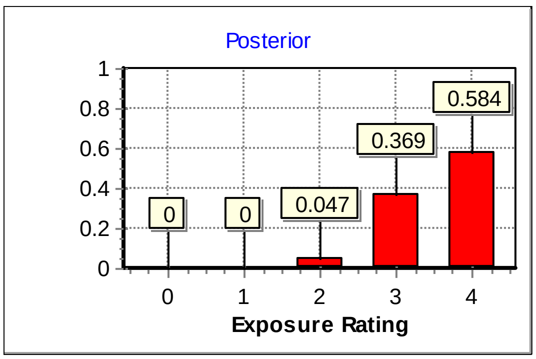

Figure 6a: Gospel Distribution; 0 dB

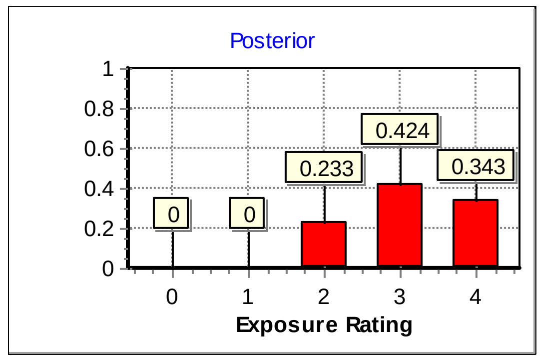

Figure 6b: Gospel Distribution; 80 dB

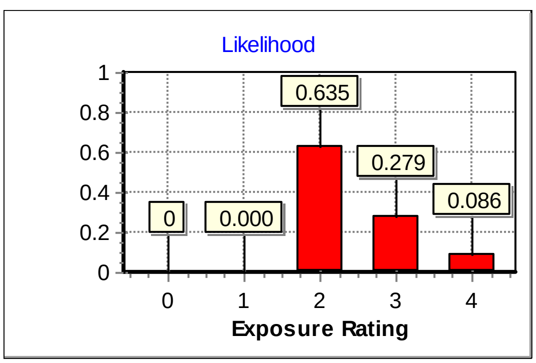

Figure 7a: Kitchen Distribution; 0 dB

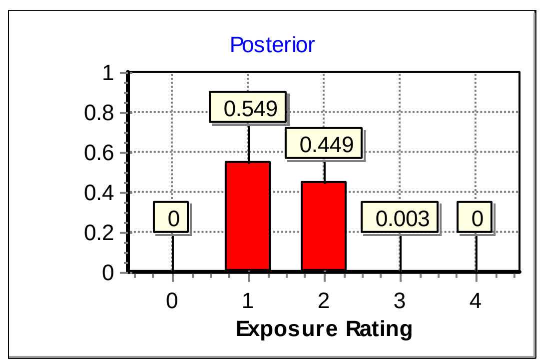

Figure 7b: Kitchen Distribution; 80 dB

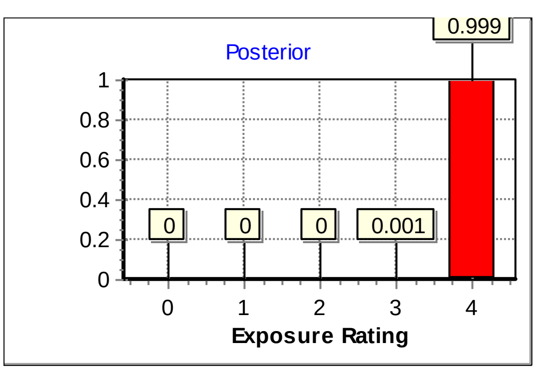

Figure 8a: Auto Shop Distribution; 0 dB

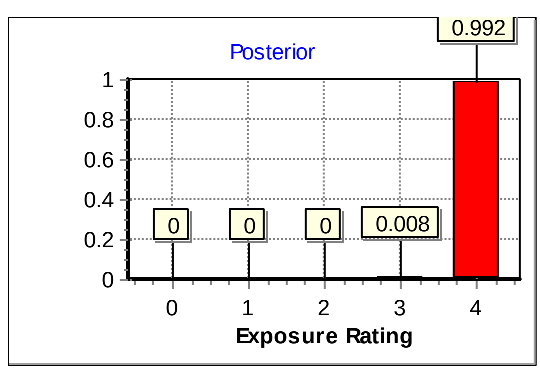

Figure 8b: Auto Shop Distribution; 80 dB

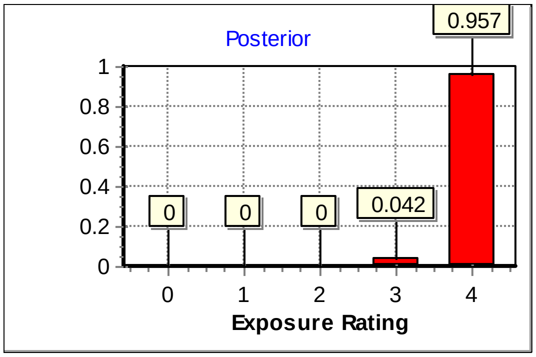

Figure 9a: Rap Music Distribution; 0 dB

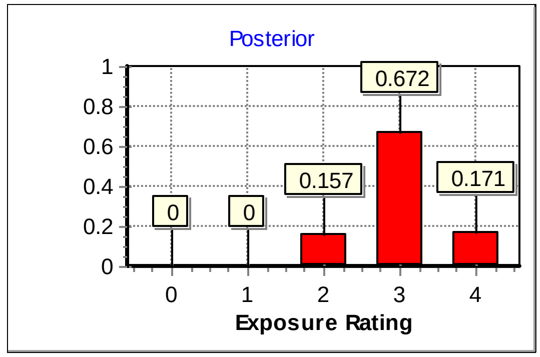

Figure 9b: Rap Music Distribution; 80 dB

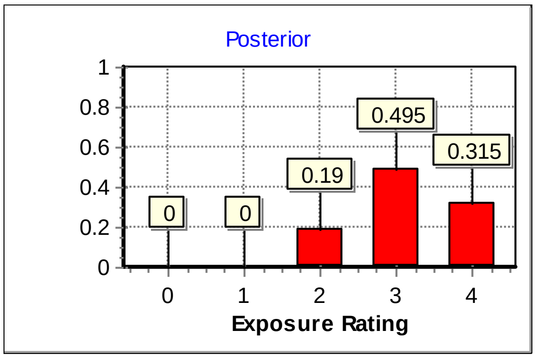

Figure 10a: Traffic Distribution; 0 dB

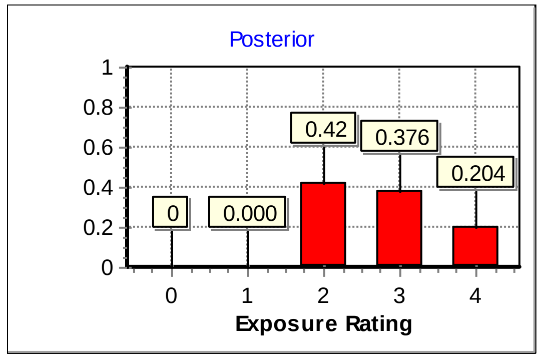

Figure 10b: Traffic Distribution; 80 dB

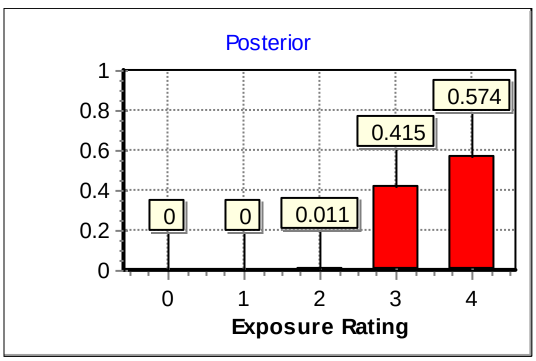

Figure 11a: Trains Distribution; 0 dB

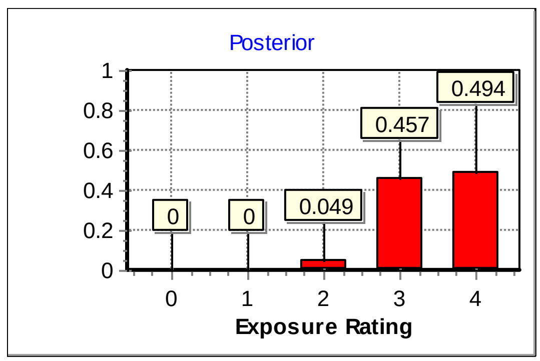

Figure 11b: Trains Distribution; 80 dB

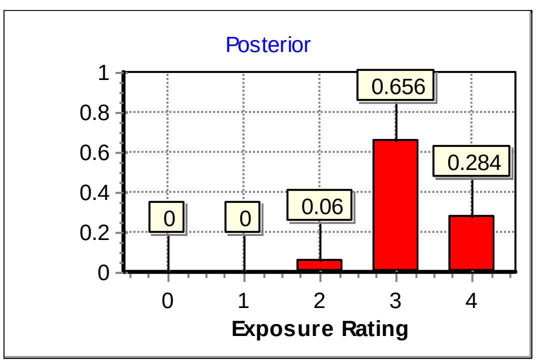

Figure 12a: Weather Distribution; 0 dB

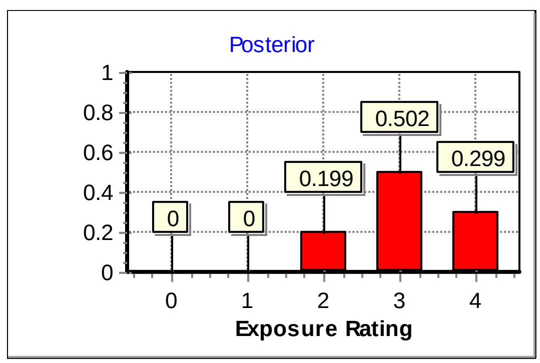

Figure 12b: Weather Distribution; 80 dB

If a comparison is done between the two thresholds using the same statistical method, it can help to see how exactly the threshold effects the outcome of the exposure estimate. For the US Army method, only one category, rap, changed severity rating from a 2 using 80 dB threshold data to a 3 using 0 dB threshold data, while all others remained the same. Using IHDA, gospel and rap changed from a severity rating of 3 using 80 dB threshold data to a 4 using 0 dB thresholds data and traffic changed from a severity rating of 2 using 80 dB threshold data to a 3 using 80 dB threshold data. It can be seen in figures. Above, Figures 6a and 6b correspond to the distributions for rap, Figures 9a and 9b correspond to the distributions for gospel, and Figures 10a and 10b correspond to traffic. Most of the distributions for the groups that did not change were similar for the two threshold levels. When using the Informative Priors Bayesian method, animals, classic rock, and rap changed, moving from a category 3 severity rating to a category 4 severity rating for 80 dB and 0 dB thresholds, respectively. Again, here, the distributions for groups that did not change remained similar between the two measured thresholds. See Tables 4 and 5 to compare the distributions for the exposure groups using the Informative Priors Bayesian method for both thresholds.

The severity rating results for each statistical method by threshold are shown in Table 5. When comparing the US Army method with the two Bayesian methods using 0 dB threshold data, similar results as the above comparison are seen. Most the groups remained at the same severity rating category when using 0 dB threshold data and when using 0 dB data for each statistical method. Six groups did see change from one severity rating into another: animals went from a severity rating of 2 using the US Army method and IHDA methods to a severity rating of 3 using the Informative Priors method; fan +

vacuum went from a severity rating of 4 using both the US Army method and IHDA method to a severity rating of 3 using the Informative Priors method; gospel went from a severity rating of 2 using the US Army method, to a severity rating of 3 using the Informative Priors method, to a severity rating of 4 using the IHDA method; traffic went from a severity rating of 2 using the US Army method to a severity rating of 3 using the IHDA method and to a severity rating of 4 using the Informative Priors method; trains went from severity rating of 3 using the US Army method and the Informative Priors method to a severity rating of 4 using the IHDA method; and weather went from a severity rating of 3 using the US Army and IHDA methods to a severity rating of 4 using the Informative Priors method.

In a comparison of severity rating outcomes using 80 dB threshold data analyzed using all three statistical methods, five groups remained unchanged between the methods and seven group had changes. Animals went from a severity rating of 2 using the US Army method and IHDA methods to a severity rating of 3 using the Informative Priors method; classic rock and fan+vacuum went from a severity rating of 4 using the US Army and IHDA methods down to a severity rating of 3 using the Informative Priors method; gospel went from a severity rating of 2 using the US Army method to a severity rating of 3 using both Bayesian methods; traffic went from a severity rating of 2 using the US Army and IHDA methods to a severity rating of 4 using the Informative Priors method; trains went from severity rating of 3 using the US Army method to a severity rating of 4 using both Bayesian methods; and weather went from a severity rating of 3 using the US Army and IHDA methods to a severity rating of 4 using the Informative Priors method.

Comparison of results obtained using 80 dB threshold data analyzed using the US Army method against 0 dB threshold data analyzed using Bayesian Methods showed six groups that did not change severity rating between thresholds and corresponding analytical methods. Six groups did change: animals changed severity ratings from 2 using the US Army and IHDA methods to 3 using the Informative Priors method; fan+vacuum changed severity ratings from 3 using Informative Priors to 4 using IHDA and US Army methods; gospel changed severity ratings from 2 using the US Army method, to 3 using Informative Priors, to 4 using IHDA; rap changed severity ratings from 3 using the US Army method to 4 using both Bayesian methods; traffic changed severity ratings from 2 using the US Army method, to 3 using the IHDA method, and to 4 using the Informative Priors method; trains changed severity ratings from 3 using US Army and Informative Priors to 4 using IHDA methods; and weather changed severity ratings from 3 using the US Army and IHDA methods to 4 using the Informative Priors method.

Much more variation was seen through the comparison of results obtained using 80 dB threshold data analyzed using Bayesian methods against 0 dB threshold data analyzed using the US Army method. Five groups had the same severity rating between the two thresholds and corresponding analytical methods. Seven groups did see change: animals changed severity ratings from 2 using the IHDA and US Army methods to 3 using the Informative Priors method; classic rock and fan+vacuum changed severity rating from a 3 using the Informative Priors method to a 4 using the US Army and IHDA methods; gospel changed severity ratings from 2 using the US Army Method, to 3 using both Bayesian methods; rap changed severity ratings from 3 using both Bayesian methods to 4 using the US Army method; trains changed severity ratings from 3 using the

US Army and Informative Priors methods to 4 using IHDA method; and weather changed severity ratings from 3 using the US Army and IHDA methods to 4 using the Informative Priors method. A detailed chart of the ratings and interpretations used to compare hearing conservation program inclusion outcomes can be seen below in Table 8.

	80 dB Threshold Data			0 dB Threshold Data		
	US Army	IHDA	Inf. Priors	US Army	IHDA	Inf. Priors
Alarm + Horn	4-medium; HCP +	4-high; HCP +	4-high; HCP +	4-medium; HCP +	4-high; HCP +	4-high; HCP +
Animals	2-high; NO	2-medium; NO	3-medium; HCP	2-high; NO	2-medium; NO	3 medium; HCP
Auto Shop	4-high; HCP +	4-high; HCP +	4-high; HCP +	4-high; HCP +	4-high; HCP +	4-high; HCP +
Classic rock	4-medium; HCP +	4-high; HCP +	3 medium; HCP	4-medium; HCP +	4-high; HCP +	4-high; HCP +
Construction	4-high; HCP +	4-high; HCP +	4-high; HCP +	4-low; HCP +	4-high; HCP +	4-high; HCP +
Fan + Vacuum	4-high; HCP +	4-medium; HCP +	3 medium; HCP	4-high; HCP +	4-high; HCP +	3 medium; HCP
Gospel	2-medium; NO	3-medium; HCP	3 medium; HCP	2-low; NO	4 high; HCP +	3 medium; HCP
Kitchen	2-high; NO	2-medium; NO	2-high; NO	2-high; NO	2-medium; NO	2-med; HCP
Rap	3-high; HCP	3-medium; HCP	3 medium; HCP	4-high; HCP +	4-high; HCP +	4-high; HCP +
Traffic	2-medium; NO	2-medium; NO	4-high; HCP +	2-low; NO	3-medium; HCP	4-med; HCP +
Trains	3-high; HCP	4-medium; HCP +	3 medium; HCP	3-high; HCP	4-medium; HCP +	3 medium; HCP
Weather	3-high; HCP	3-medium; HCP	4-medium; HCP +	3-high; HCP	3-medium; HCP	4-med; HCP +

Table 8: Full Comparison of Each Statistical Method Used to Determine Hearing Conservation Inclusion for Both 80 dB and 0 dB Threshold Noise Monitoring. Color blocks represent cross comparison of threshold data and statistical method; NO represents an SEG not being included in HCP, HCP represents an SEG being included in HCP, and HCP + represents an SEG being included in HCP and using hearing protection as well

Effect of Dual Channel Capability on Exposure Estimate Accuracy

Studies were also done to determine if using 0 dB threshold settings or dual channel functionality had any effect on the accuracy of the exposure estimate. Ln statistics, which are generated automatically by the equipment, for each sample are analyzed to determine the severity of the variation to greater extent. Based on a basic first assessment of the data from the three settings used for this portion, some minor variations were found for each of the samples. When the variation occurred, usually there was between 0.5 dB and 5.5 dB of change for the largest gaps between all three dosimeter outputs. From 0 dB to 80 dB to 0 + 80 dB dosimeter outputs, the difference ranged from 0.5 dB to 2 dB. Most the groups' overall variation of Ln statistic was between 2 and 4 dB, and one group saw an overall variation of 1 dBA for Ln statistic values. Only three groups had a maximum overall change in Leq between the groups greater than 5 dB, the highest of which was 8 dB. A table containing the Ln statistic values can be seen below in Table 9. Standard deviations were calculated for the differences in the data of the three-way analysis and can be seen in Table 12 below. These numbers remained relatively small and ranged from 0.28 to 4.25. Graphical data of the noise logs were also reviewed as well, and showed no major anomalies between the three data outputs. In the graphs, the column titled '80 dB threshold' refers to data taken from using a singular channel of noise monitoring at 80 dB, the column titled '0 dB threshold' refers to data taken from using a singular channel of noise monitoring at 0 dB, and the column titled 'Dual Channel' refers to data taken using dual channel noise monitoring at both 80 dB and 0 dB thresholds.

		80 dB Threshold	0 dB Threshold	Dual Channel		
	Leq (dBA)				Mean	Standard Deviation
Traffic	L10	88.5	88.5	91.5	89.50	1.73
	L30	87	87.5	90.5	88.33	1.89
	L50	86	86.5	86.5	86.33	0.29
	L70	85	85	86.5	85.50	0.87
	L90	83	83	86	84.00	1.73
Classic rock	L10	90.5	91	91	90.83	0.29
	L30	89.5	90	89.5	89.67	0.29

	L50	88	88.5	88.5	88.33	0.29
	L70	85	85.5	85.5	85.33	0.29
	L90	66.5	66.5	64.5	65.83	1.15
Animals	L10	84	84.5	90.5	86.33	3.62
	L30	76.5	77	83	78.83	3.62
	L50	66.5	67	70	67.83	1.89
	L70	66.5	66.5	64.5	65.83	1.15
	L90	66.5	66.5	64.5	65.83	1.15
Alarm + Horn	L10	98	98	99	98.33	0.58
	L30	92.5	91	93.5	92.33	1.26
	L50	65	66	66.5	65.83	0.76
	L70	64.5	66	66	65.50	0.87
	L90	64.5	66	66	65.50	0.87
Gospel	L10	92.5	88	90.5	90.33	2.25
	L30	86	83	85	84.67	1.53
	L50	76	74	77.5	75.83	1.76
	L70	74.5	72	73	73.17	1.26
	L90	66.5	66.5	65	66.00	0.87
kitchen	L10	73.5	74.5	72.5	73.50	1.00
	L30	69.5	70.5	68.5	69.50	1.00
	L50	68	68.5	67	67.83	0.76
	L70	66.5	67	65.5	66.33	0.76
	L90	65	65	63	64.33	1.15
Auto Shop	L10	91.5	92.5	91.5	91.83	0.58
	L30	91	92	90.5	91.17	0.76
	L50	66.5	64.5	66.5	65.83	1.15
	L70	66.5	64.5	66.5	65.83	1.15
	L90	66.5	64.5	66.5	65.83	1.15
Rap Music	L10	87	95	88.5	90.17	4.25
	L30	85.5	93	87	88.50	3.97
	L50	84.5	91.5	85.5	87.17	3.79
	L70	83.5	90.5	84.5	86.17	3.79
	L90	81.5	88	82	83.83	3.62
Traffic	L10	87	95	88.5	90.17	4.25
	L30	85.5	93	87	88.50	3.97
	L50	84.5	91.5	86	87.33	3.69
	L70	83.5	90.5	85	86.33	3.69
	L90	81.5	88	83	84.17	3.40
Weather	L10	85	88.5	88.5	87.33	2.02
	L30	82.5	85.5	86.5	84.83	2.08
	L50	80	84	85	83.00	2.65
	L70	78	81.5	82.5	80.67	2.36

	L90	75	72	71	72.67	2.08
Fan + Vacuum	L10	92.5	88	90.5	90.33	2.25
	L30	86	83	84	84.33	1.53
	L50	76	74	75.5	75.17	1.04
	L70	74.5	72	73	73.17	1.26
	L90	66.5	66.5	65	66.00	0.87
Trains	L10	85	84.5	84	84.50	0.50
	L30	80	80	79.5	79.83	0.29
	L50	73	73	72.5	72.83	0.29
	L70	70.5	70.5	70	70.33	0.29
	L90	63	64	64.5	63.83	0.76

Table 9: Ln Statistics Summary of 3-way Noise Monitoring Comparison

DISCUSSION

Monitoring noise at a 0 dB threshold created a range of differences between the measured exposure dose as compared to the standard 80 dB threshold level. When using statistical methods to determine the effect of these exposure estimates on the inclusion of worker groups into hearing conservation, the effect seen from this difference was widely different between methods. In the above analysis, a severity rating is used, and the higher the rating, the more involved a group will be in hearing conservation. From the above analysis, the US Army TG 181 + 80 dB threshold monitoring method is, in several cases, slightly less protective compared to either of the Bayesian methods used with 0 dB threshold or 80 dB threshold noise monitoring. This is not always the case, since the Informative Priors method sometimes rates a group lower than either of the other two methods. Another interesting finding is that between the two different comparisons of threshold/statistical method, many of the groups followed the same pattern for which methods saw a change in severity rating. For example, all five groups that did not see any change between 0 dB + Bayesian and 80 dB + US Army were the same five that did not see change for the inverse comparison.

There showed to be more variations between the results of hearing conservation selection when comparing the 80 dB threshold + IHDA method to the 0 dB threshold + US Army method. Looking at the different statistical methods for 80 dB threshold and/or 0 dB threshold, the US Army was the most exclusionary for both thresholds, the

Informative Priors Bayesian method was more protective for some SEG's, and the IHDA Bayesian method was generally the most protective.

Some of the SEG's saw a less protective outcome using IHDA + 80 dB data compared to the Army Method + 0 dB, due to the fact that the 0 dB threshold monitoring created a higher exposure estimate. Since for most of the SEG's, the IHDA analysis of 80 dB data was more protective than the Army method analysis of 0 dB data, the statistical method has an influence on how the data is interpreted and variations are not solely caused by the exposure estimate. Since the IHDA method uses a range of GSDs for the data sets between 1.05 and 5, the program may estimate the exposure lower than when consistently using the approximate median GSD of 2 in the Informative Priors method, which is one explanation for the reason for the deviation between the to Bayesian methods.

When comparing the results of using a singular statistical method with both monitoring thresholds, there was more consistency seen that originally expected, despite the amount of variation between the dose from using the two different thresholds. Generally, the groups remained the same for both thresholds, except for a few increasing in severity for the 0 dB results. This further shows that, while the exposure estimate does have bearing on the results of how an SEG is included or excluded into hearing conservation, the statistical method has some effect on the outcome too. Since Bayesian statistics utilize the geometric mean and geometric standard deviation, which is better suited to lognormal distributions found in exposure monitoring, this may be one reason the statistical model used has so much impact on the outcome of hearing conservation inclusion.

For the analysis concerning determining the effect of the 0 dB threshold monitoring setting and dual channel capabilities on the microphone sensitivity and/ or the data logging capabilities, there was some small discrepancies found when comparing data outputs for the three monitoring settings used. The larger the difference between percent dose between the 80 dB threshold and the 0 dB threshold for both singular channel monitoring and the dual channel option, the more variation between the Ln statistics. This could mean that there are some minute occurrences when using one or both functionalities. Since most of the differences were less than 5 dB from the largest to smallest Leq statistic-and none of the variations in the percent dose data used would have caused inconsistencies at major OEL levels (i.e. 50% dose or 100% dose), it is unlikely that this would have affected the outcome of the statistical analysis. Additionally, since the variations were all small, it is most likely that there is no major effect of the use of 0 dB threshold or dual channel functionality on the noise measuring device. Likely, some of the more minute differences could have been caused by small errors of a few millimeters in the location of the microphone between the center of the noise source. It is also possible that the age of the equipment could have caused some of these more minor errors. The Larson Davis Spark units used to assess this difference are some of the earlier models that have multi-channel capabilities and allow for 0 dB threshold monitoring at 1 second intervals, so despite regular manufacturer calibrations and pre/post calibrations during the study, some minor age related effects could have occurred. It should be noted that, when variation occurred for noise monitoring results in the comparison, the dual channel monitoring results for % dose were used to maintain consistency across all noise data.

Overall, the use of the US Army along with the prescribed 80 dB threshold noise monitoring was the least protective method, often estimating exposures as less hazardous than using the US Army method with 0 dB threshold noise monitoring or the Bayesian statistical methods with 80 dB or 0 dB noise monitoring. The most protective method IHDA used with 0 dB noise monitoring data. Using informative priors excluded some similar exposure groups when the other two methods did not, but generally higher ratings were seen using that method. While the US Army method was established to rule out worker groups from hearing conservation to be more feasible in the inclusion of the program, the Informative Priors Bayesian method may rule out similar exposure groups that the US Army method deems overexposed, while either Bayesian methods may include groups that the US Army method neglects to determine are overexposed. The use of 0 dB threshold noise monitoring with the IHDA software might be the best tool to use, since it is always better to be more protective when concerned with the hearing of workers exposed to noise.

It should be noted that, despite efforts to validate the noise levels according to values found in literature for each SEG, it was difficult to produce levels which might reflect the true exposure levels of each category with one hundred percent accuracy. If this experiment had been conducted in an occupational setting for a given exposure group, the data collected might differ slightly from what is seen in the study. However, since there is naturally variation in occupational noise exposure monitoring of any kind has, this is not seen as a limiting factor for the study, since the focus of the study was to evaluate how the different noise monitoring thresholds and statistical methods might affect hearing conservation program participation for different SEG's.

A limitation of this study was the investigation into only the use of 0 dB threshold and not using different exchange rates or criterion levels, like the NIOSH suggested 85 dBA criterion and 3 dB exchange rate. The research was conducted this way to be consistent with a previous data analysis which was performed using industry data taken using 0 dB threshold with the standard 5 dB exchange and 90 dB criterion level. While it could be hypothesized that the effect of these alterations to the noise monitoring criteria would create a greater resulting exposure estimate which would prove to be more protective using either statistical method, it was not of specific interest of this study to investigate the use of these settings. Future research could be done in order to quantify the difference between that noise monitoring method and the two used in this study and to compare the outcomes of using a 3dB exchange rate and 85 dB criterion level with the statistical methods discussed in the study and their effect on hearing conservation program inclusion.

CONCLUSIONS

Excessive noise in the workplace is a global problem for industry. Noise induced hearing loss as a result of this noise exposure is one of the most frequently reported occupational injury claims, and can end up costing the affected person and their employer millions over the course of their lifetime. While the problem is widespread, hearing loss can be prevented using hearing conservation programs and employee exposure monitoring. Currently, there are methods in place to help interpret gathered exposure data in order to classify worker SEGs into hearing conservation programs, but many of those methods are older and there are updates in noise monitoring technology and statistical methods that can help an employer make a more informed decision.

The purpose of this study was to quantify the effect of a lower threshold used for noise monitoring determine how newer Bayesian statistical methods influenced the outcome of categorization of worker SEG's into hearing conservation programs compared to a proven statistical model. Little data was available prior to this study showing the effect of a 0 dB or no threshold on exposure estimates, nor was there much information on the use of Bayesian tools in occupational exposure estimations-especially noise data. Results from a preliminary data analysis study that utilized new technology- known as dual channel dosimetry- to monitor levels simultaneously at two different thresholds showed results that warranted further research. Many of the worker groups in that study stayed the same using both the older statistical method with the standard monitoring level and the new statistical method with a lower monitoring threshold, but some groups did change between the two methods. Further investigations were warranted, which is the basis of this study.

Exposures that had low variability throughout the SEG remained in the same category, especially those where most the exposures recorded were at either the higher end or the lower end of the spectrum. The Bayesian statistical models are formulated in ways that handle exposure data more effectively than traditional statistics. This may be the reason that Bayesian models were more conservative in some estimates despite using more strenuous limits, compared to the US Army method. Additionally, the Informative Priors Bayesian method used in this study uses parameters specific to the exposure data that creates a more precise model with which results are based on. The Informative Priors Bayesian method produced results that varied greatly from the other two methods and ruled out groups that the others did not rule out from hearing conservation and included groups into hearing conservation that the others did not. Contrary to what was stated in literature about using a threshold below 80 dB for noise monitoring, there was little scatter in the results of the analysis using 0 dB percent dose with the US Army statistics. In fact, the methods seemed to be more consistent than was expected at the start of the study.

In addition to the study at hand further investigating the use of new technologies on the results of exposure monitoring and statistical modeling, it was also an aim of this study to evaluate the use of the dual channel function and 0 dB threshold on the data output by the dosimeter. While there were some minor discrepancies in the data, it is not thought to be drastic enough to be a result of impaired data logging or microphone abilities. Likely, it is simply due to minute anomalies in the sound waves or spacing issues, since despite best efforts to ensure the spacing was always exactly the same from the center of the source it is impossible to be 100% accurate in that endeavor.

Overall this study showed results that may be helpful in furthering the spread of 0 dB or minimal threshold noise monitoring technologies throughout the industrial hygiene and occupational health and safety profession. Since it is not currently a widely-used tool, there is little data out there to be examined. With the current noise monitoring methods in place, an employee could be exposed to a noise range of 79.999 dB for an entire day, but the resulting perceived exposure would be minimal. Currently the assumption is that noise exposures below 80 dB can only have some health effects on extra auditory systems, but it is also possible that moderate noise levels can also cause some hearing damage as well, especially in susceptible populations. Should an expansion in the use of the 0 dB threshold technology occurs, more studies on the effects of these noise ranges on both hearing and physiological effects could be possible.

The use of Bayesian statistical tools, like the ones seen in this study are not limited to the determination of hearing conservation in occupational settings. It has already been shown that there is practical application of Bayesian statistics for other occupational exposure estimation scenarios. Since Bayesian statistics are better formulated to appropriately handle smaller data sets and lognormal data seen in occupational exposure monitoring, these tools could be applied to historical data from both occupational and environmental settings and used to determine risk estimates where there are limited estimates on the severity of a particular exposure.

Based on the amount of available literature on noise exposure, dosimetry methods, and occupational hearing loss, physical damage from noise that might cause hearing impairment or other physiological problems is a well-known issue not only in the occupational setting, but as a public health issue as well. When a person loses their hearing, it can be a costly issue for him or her and their employer paying for medical bills and hearing aids as a result. In addition to this, should hearing loss become severe enough, it could cause an otherwise perfectly healthy and capable worker to face loss of productive working years. This can be a costly economic issue for both the worker and employer. Since hearing loss is not reversible, and many cases of hearing loss are accompanied by tinnitus or ringing in the ear, hearing aids only offer so much help. When a worker loses hearing, his or her ability to continue to work and function at their full capacity are impaired and the consequences are unemployment or early retirement and the permanent dependence on health care and aides to complete daily tasks.

Since hearing loss is a preventable condition thanks to the use of exposure monitoring and hearing conservation efforts, it is necessary to stay as up to date and accurate with exposure estimates and decision modeling criteria for selection into hearing conservation. The study here gives data and analysis that might help to update regulatory standards and inclusion criteria which will help to decrease the number of reported cases when used properly. Additionally, epidemiological studies regarding the exposure to moderate Nosie levels to hearing as well as physiological responses such as oxidative stress and adrenal response. In regards to the study's limitation, additional studies could be done to determine how using other dosimetry settings, like the NIOSH recommendation, might also effect worker inclusion into hearing conservation using 0 dB monitoring and Bayesian statistical models.

REFERENCE MATERIAL

Noise and Hearing Loss Prevention (2016). National Institute for Occupational Safety and Health. Retrieved October 19, 2016, from http://www.cdc.gov/niosh/topics/noise/stats.html

OSHA 1910. 95 CFR Occupational Noise Exposure: Hearing Conservation Amendment (Final Rule). (1974) 48 Federal Register. Vol 1910.95, 19839738–9785.9785

OSHA Technical Manual. Section III Chapter 5: Noise. https://www.osha.gov/dts/osta/otm/new_noise/

Noise-Induced Hearing Loss. (2014). National Institute on Deafness and Other Communication Disorders, NIH. Retrieved October 19, 2016, from https://www.nidcd.nih.gov/health/noise-induced-hearing-loss

Hearing Conservation. (2002). Occupational Safety & Health Administration Online. Retrieved October 19, 2016, from https://www.osha.gov/Publications/OSHA3074/osha3074.html

US Army Center for Health Promotion and Preventive Medicine. (1999). Noise Dosimetry and Risk Assessment TG181 (Hearing Conservation and IH Field Services Programs). Aberdeen Proving Ground, MD.

American National Standards Institute (1991). S1.25: Specification for Personal Noise Dosimetry. Acoustical Society of America, New York, NY.

Prince, M., Stayner, L., Smith, R., Gilbert, S. (1994). A re-examination of risk estimates from the NIOSH Occupational Noise and Hearing Survey. *Journal for the Acoustical Society of America, 101(2), 950-963.*

Lempert, B., & Henderson, T. (1973). Occupational Noise and Hearing, 1968 to 1972: A NIOSH Study, 232,

Rabinowitz, P., Galusha, D., Dixon-Ernst, C., Slade, M., & Cullen, M. (2006) Do Ambient Noise Exposure Levels Predict Hearing Loss in a Modern Industrial Cohort? *Occupational and Environmental Medicine, 2007(64), 53-59.*

Seiler, J., & Giardino, D. (1994). The Effect of Threshold on Noise Dosimeter Measurements and Interpretation of Their Results. Mine Safety and Health Administration, US Department of Labor.

Rabinowitz, P., Galusha, D., & Dixon-Ernst, C. (2013). The Dose Response Relationship between in Ear Occupational Noise Exposure and Hearing Loss. *Occupational and Environmental Medicine, 70(10), 716–721.*

Tingay, J., & Robinson, D. (2014). A Practical Comparison of Occupational Noise Standards. *Inter.Noise.*

Imtiaz, A., Goulamhoussen, G. (2016). Digital Computation of Exchange Rates for Calculation of Dosage in Embedded Systems. *Inter.Noise, 3920-3928.*

Banerjee, S., Ramachandran, G., & Vadali, M. (2014). Bayesian Hierarchical Framework for Occupational Hygiene Decision Making. *Annals of Occupational Hygiene, 58(9), 1079–1093.*

Huynh, T., Quick, H., Ramachandran, G. (2014) A Comparison of the β-Substitution Method and a Bayesian Method for Analyzing Left-Censored Data. *Annals of Occupational Hygiene, 1–18.*

Quick, H., Huynh, T., and Ramachandran, G. (2017). A Method for Constructing Informative Priors for Bayesian Modeling of Occupational Hygiene Data. *The Annals of Work Exposures and Health, 61, 67-75.*

He, Y., Liang, Y., & Fu, H. (2008). Application of Bayesian Methods to Exposure Assessment of Area Concentrations at a Rubber Factory. *International Journal of Environmental Research and Public Health, 6, 222-234.*

McNally, K., Warren, N., & Fransman, W. (2013). Advanced REACH Tool: A Bayesian Model for Occupational Exposure Assessment. *Annals of Occupational Hygiene, 58(5), 551-565*.

Mohr, P., Feldman, J., Dunbar, J. (2000). The Societal Costs of Severe to Profound Hearing Loss in the United States. *International Journal of Technology Assessment in Health Care, 16(4):1120-1135.*

Carlin, B., Louis, T., (2008). *Bayesian Methods for Data Analysis, 3rd Edition.* Oxfordshire, United Kingdom: Taylor & Francis

Hewett, P. Making Accurate Exposure Assessment Decisions with Scarce Resources. Enterprise EHS Software Solution: Medgate, 25 May 2016. Webinar. 31 Oct. 2016.

Spark Noise Dosimeters and Blaze Software (2013). Spark 703+. PCB Piesotronics, Inc., Provo, Utah. University of Alabama at Birmingham, Birmingham, Alabama.

User Manual for the CR:110A doseBadge Personal Noise Dosimeter & RC:110A Reader Unit (2013). doseBadge 110A Personal Noise Dosimeter. Cirrus Research plc, Hunmanby, North Yorkshire, United Kingdom. University of Alabama at Birmingham, Birmingham, Alabama.

Achutan, C. (2009). Assessment of noise exposure in a hospital kitchen. *Noise and Health, 11(44), 145-150. doi:10.4103/1463-1741.53359*

Loupa, G. (2013). Case Study. Health Hazards of Automotive Repair Mechanics: Thermal and Lighting Comfort, Particulate Matter and Noise. *Journal of Occupational and Environmental Hygiene, 10(10), 135-146.*

Common Environmental Noise Levels. (2017). Center for Hearing and Communication. Retrieved March 17, 2017. http://chchearing.org/noise/common-environmental-noise-levels/

Houg, O. (2005). Hearing Loss Among Operating Engineers in American Construction Industry. *International Archive for Environmental Health. 78, 565-574.*

Humann, M. J., Sanderson, W. T., Donham, K. J., & Kelly, K. M. (2013). Task-based noise exposures for farmers involved in grain production. *Journal of Agricultural Safety and Health, 19(2), 101-n113. Retrieved from www.scopus.com.*

Lee, L. T. (1999). A Study of the Noise Hazard to Employees in Local Discotheques. *Singapore Medical Journal, 40(9), 571-574. Retrieved from www.scopus.com*

Rodrigues MA, Freitas MA, Neves MP, Silva MV. (2014). Evaluation of the Noise Exposure of Symphonic Orchestra Musicians. *Noise Health [cited 2017 Mar 17];16:40-6. Available from:* http://www.noiseandhealth.org/text.asp?2014/16/68/40/127854

Lightning. (n.d.). Retrieved March 17, 2017, from https://www.wunderground.com/resources/education/lightning.asp

Vavrek, J., Kithil, R., Holle, R., & Allsopp, J. (n.d.). The Science of Thunder. Retrieved March 17, 2017, from http://lightningsafety.com/nlsi_info/thunder2.html

McBride, D. I., Firth, H. M., & Herbison, G. P. (2003). Noise Exposure and Hearing Loss in Agriculture: A Survey of Farmers and Farm Workers in the Southland Region of New Zealand. *Journal of Occupational and Environmental Medicine*, 45(12), 1281-1288. doi:10.1097/01.jom.0000100001.86223.20

Neitzel, R., Gershon, R. R. M., Zeltser, M., Canton, A., & Akram, M. (2009). Noise Levels Associated with New York City's Mass Transit Systems. *American Journal of Public Health, 99(8), 1393-1399. doi:10.2105/AJPH.2008.138297*

Seshagiri, B. (2003). Exposure to Noise on Board Locomotives. *American Industrial Hygiene Association Journal, 64(5), 699-707. doi:10.1202/532.1*

McIlvaine, D., Stewart, M., Anderson, R. (2012). Noise Exposure Levels for Musicians During Rehearsal and Performance Times. *Medical Problems of Performing Artists, 27(1) 31-36.*

Halevi-Katz, D., Yaakobi, E., Putter-Katz, H. (2015). Exposure to Music and Noise-Induced Hearing Loss (NIHL) Among Professional Pop/Rock/Jazz Musicians. *Noise Health, 17(76) 158-164.*

Phan, L., Jones, R. (2017). Chicago Transit Authority Train Noise Exposure. *Journal of Occupational and Environmental Hygiene*

Rodrigues, M., Freitas, M., Neves, M., Silva, M. (2014). Evaluation of the Noise Exposure of Symphonic Orchestra Musicians. *Noise and Health,16(68) 40-46.*

Bluhm, G., Eriksson, C. (2011). Cardiovascular Effects of Environmental Noise: Research in Sweden. *Noise and Health, 13(52) 212-216.*

Meline, J., Van Hulst, A., Thomas, F., Chaix., B. (2017). Road, Rail, and Air Transportation Noise in Residential and Workplace Neighborhoods and Blood Pressure (RECORD Study). *Noise Health, 17(78) 308-319.*

Pyko A, Eriksson C, Oftedal B. (2015). Exposure to Traffic Noise and Markers of Obesity. *Occupational and Environmental Medicine,* ***72;****594-601.*

Gannouni, N., Mhamdi, A., Tebourbi, O. (2013). Qualitative and Quantitative Assessment of Noise at Moderate Intensities on Extra Auditory Systems in Adult Rats. *Noise and Heatlh,15(67) 406-411.*

ITRC (Interstate Technology & Regulatory Council). 2013. Groundwater Statistics and Monitoring Compliance, Statistical Tools for the Project Life Cycle. GSMC-1. Washington, D.C.: Interstate Technology & Regulatory Council, Groundwater Statistics and Monitoring Compliance Team. http://www.itrcweb.org/gsmc-1/

Sarwan, N. (2016, June 20). Bayesian Statistics Explained to Beginners in Simple English. Business Analytics. https://www.analyticsvidhya.com/blog/2016/06/bayesian-statistics-beginners-simple-english/.

Oestenstad, R., Norman, M., Borton, T. (2008). Efficacy of the US Army Policy on Hearing Conservation Programs. *Military Medicine, 173(10), 992.*

Hong, O., Chin, D., Phelps, S., Joo, Y. (2016). Double Jeopardy: Hearing Loss and Tinnitus Among Noise Exposed Workers. *Workplace Health and Safety, 64(6), 235-242.*