Impacts of Leisure Activity Noise Levels - A Revised Case Study

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Abstract: An article originally published in the International Journal of Industrial Ergonomics in 1991 discussed the effects of damaging noise levels exposed during the leisure time of industrial workers. With a noise level change preferences, this study was designed to work in collaboration with a 2013 study (Claire Drummond, 2013) which began the groundwork of measuring and examining the consistency of the data collected in 1990. Attributed to an increase in popularity of electronic music and improved digital sound equipment, indoor leisure environment sound levels have increased since the original study. The purpose of this study is to expand the collection of data on exposure levels in current leisure activities reported in the 2012 study to enhance the statistical significance that levels are indeed higher than the noise level preferences and tolerances specified by the Occupational Health and Safety Administration (OSHA) and International Standards Organization (ISO) guidelines. With strenuous legal standards, industries have taken substantial steps to follow the OSHA and ISO recommended guidelines; however, places of leisure such as bars, movie theaters, churches, and sporting events are not required to adhere to the same standards. The noise data was collected using a Quest SPL (2800) calibrated dosimeter. This device is a great improvement from the GenRad Sound Level Meter originally used in the 1990 study for the fact that the Quest SPL (2800) gives a complete printout at the end of a data run that takes in account the duration and average dose of noise exposure run as well as average and peak noise levels. The GenRad device was limited to measuring low and high noise level readings. Average leisure noise levels by category were as follows: peak levels in a sample of thirty-nine leisure activities: churches and concerts (118.06 dB (σ = 2.62 dB)), bars (117.48 dB (σ = 9.32 dB)), and sporting events (122.99 dB (σ = 10.97 dB)). Following the OSHA and ISO standards, any exposure noise level over 115.00dB exceeds the recommended allowance. Adult industrial workers exposing themselves to these levels after an eight hour workday in an OSHA-controlled environment are exceeding the allowable exposure. Industrial business are spending large sums of money to make sure they are in compliance with OSHA standards yet their employees are potentially permanently damaging hearing due to their choice of leisure activity. These individuals are thus increasing their risk of a permanent threshold shift. As a side observation to the adult exposures, many parents had their children under the age of 4 in attendance at the high level peak level leisure activities. Hearing is fully developed at birth, but extended exposure times to high peak noise levels can cause an earlier permanent threshold shift in children or permanent hearing loss at a younger age.

1. Introduction

With the standard work day in the United States being eight hours, it is also the industry standard for industrial ergonomics (Konz and Johnson, 2004). The work environments of certain industries require employees to be exposed to damaging noise levels for eight of every twenty-four hour day. Until recent years, hearing loss and impairment has not been the focus of job safety research. Companies with industrial environments spend millions per year on liability costs related to the hearing loss. Yet there has been no evidence to firmly prove the root of hearing loss to the workplace. Noise research completed by organizations like the Occupational Health and Safety Administration (OSHA, 2011) and the International Standards Organization (ISO) brought to light the possibilities of hearing damage from excessive noise levels in the work place. This study, an updated version of the article based on, "Impacts of leisure activity noise levels on safety procedures and policy in the industrial environment" (Brown and Yearout, 1991), which took an adverse approach to all previous studies and looked at the remaining sixteen hours of the day: leisure settings. Comparing data gathered in leisure environments from the 1990, 2012 and 2014 studies, this case serves as validation that cumulative noise exposure is a major concern in regards to hearing loss and a permanent threshold shift.

The Occupational Health and Safety Act of 1970 developed the first legislation to police all components of working environments which opened the doors of OSHA and the National Institute for Occupational Safety and Health (NIOSH). Table 1 displays the OSHA standards for exposure time to equivalent noise exposure levels (Asfahl, 1991). Throughout this study noise level measurement was done using the decibel, which is a measure of sound-pressure intensity (Asfahl, 1991). OSHA provides the following example to demonstrate how allowable exposure equates to damage: *OSHA allows 8 hours of exposure to 90dB but only 2 hours of exposure to 100 dB sound levels. NIOSH would recommend limiting the 8 hour exposure to less than 85 dB. At 100 dB NIOSH recommends less than 15 minutes of exposure per day.* Table 1 demonstrates

Table 1. Maximum daily noise exposure OSHA &
American Congress of Governmental Industrial Hygienists (ACGIH)

Duration/Day (Hours)	**OSHA**	**ACGIH**
16	85dB	80 dB
8	90 dB	85 dB
4	95 dB	90 dB
2	100 dB	95 dB
1	105 dB	100 dB
0.5	110 dB	105 dB
0.25	115 dB	110 dB
0.125	___	115 dB

the OSHA and American Congress of Governmental Industrial Hygienists (ACGIH) policies that show exposure levels with their allotted exposure times. Both standards focus on cumulative noise exposure during the work day and do not take into account noise exposure off-the-clock in leisure settings. With noise data being logarithmic rather than linear, extended exposure times greater than eight hours, whether for work or leisure, increase one's risk for a permanent threshold shift (loss of the ability to transmit sound waves at specific frequencies to the brain).

Excessive noise exposure and its relation to permanent hearing damage have been studied since the early 1970s with the emphasis of this research in industrial work places. However, in recent years the attention has shifted to the leisure activities completed during free time. The strict regulation put into effect by OSHA that sets the standard for noise safety in industrial work environments is not required in places of leisure. It is a requirement for companies with manufacturing settings to not only educate on the risks of excessive noise exposure, but also provide personal protective equipment for employees. A recent theory, known as the social noise phenomena, says that noise in social settings consistently exceeds comfortable levels (Calvert and Clark, 1983). This theory coincides with, "High levels of noise allowed young people to interact with members of the opposite sex in an environment which does not require the use of extensive social skills" (Shirreffs, 1971). Steven Konz (1987) described the effects of loud noise in the organ of the Corti, which has about 30,000 hair cells. As a wave goes through the tympanic chamber it deflects the vestibular membrane down into the tympanic chamber. The hair cells are supported at both ends, so the hair cells (figure 1) send out an electric pulse which goes to the brain by way of the cochlear nerve. Nerve loss in the inner ear is rarely curable. Nerve loss is very commonly caused by loud noise." Stephan Konz used an allegory to describe this induced loss as, "Walking on the Grass"

> *"When one walks across a finely manicured lawn, the grass by the weight of the foot-step is forced to lie down. Immediately the grass begins to stand back up. However if continues repeatedly without allowing recovery time, the grass dies and leaves a permanent worn path."*
>
> *(Stephan Konz)*

The hairs in the Corti respond to loud noise in the same manner as the grass. When the hair cells die and cannot be replaced a permanent threshold shift occurs.

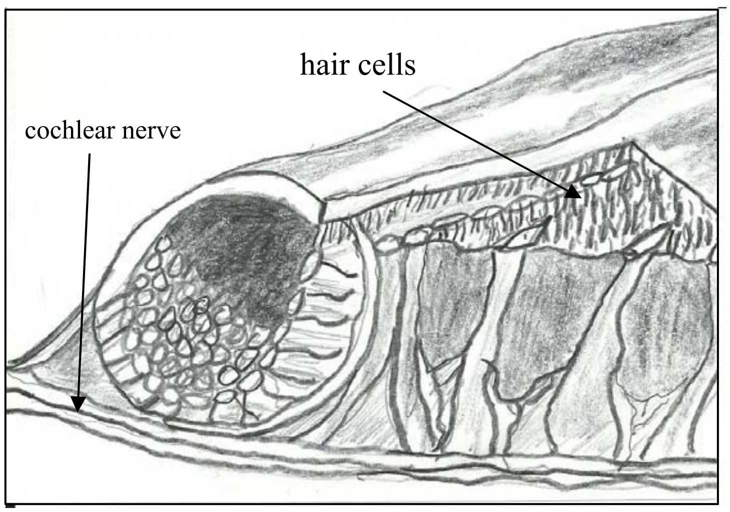

Figure 1. Cross Section of the Corti (Yearout 2014)

This study was designed to expand the proceedings article from the 2nd ANNUAL World Conference of the Society for Industrial and Systems Engineers (Drummond, Lee, Parsons, Patch, and Yearout, 2013) by completing noise data collection in varied social and leisure settings (Brown and Yearout, 2012). For data collection, leisure settings were categorized into the following: bars, churches, and sporting events. Each of these categories were further sub-categorized: bars were divided into 21-30 age bars and 30+age bars (this subset was based on the targeted customer from marketing strategies and offered products); churches were sub-divided into contemporary churches/concerts and traditional churches; and sporting events were sub-divided into men's basketball and women's volleyball. Additional data was gathered from seven movies to further strengthen data of leisure settings. During a 2012 observation of an industrial manufacturing plant, peak sound levels averaged at 119.90 dB with a standard deviation of 3.27 dB (Lane, Barrow, and Yearout, 2012). An examination of the 2012 and 2014 combined leisure noise data shows individual peaks over 127 dB and as high as 146 dB. As seen in Table 1, All noise below 85 dBA is assumed to have 0 effect. Beyond 115 dBA, 0 exposure is permitted (Konz and Johnson, 2004). Through the collection of data from leisure settings known to have excessive noise levels and extended exposure time, this study's motivation is to inform on risks of this common issue.

2. Methodology/ Experimental Protocol

The combination of the 2012 and 2014 data sets produced fifty-three leisure activity data points which can be divided into the following categories: twelve (12) 21-30 age bars, five (5) 30+ age bars, eleven (11) contemporary churches, seven (7) traditional churches, seven (7) men's basketball games, five (5) women's volleyball games, and six (6) movies. The combined data set was gathered from September 28, 2012 to March 2, 2014 with all data collected in Western North Carolina. All noise samples were taken using the Quest Electronic Micro-15 Permissible Noise Dosimeter (Figure 2) which measures peak (the highest peak sound level during the run) and 3dB SEL (the integrated average sound level measured in decibels with a 3dB exchange rate, no time constant, and no threshold). The Micro-15 Dosimeter was calibrated before each run to ensure complete accuracy of the collected data. The 2012 data was gathered with the Micro-15 Dosimeter concealed within a clutch purse, with the microphone clipped as close to ear level as possible to mimic actual sound exposure. All 2014 data was gathered with the Micro-15 Dosimeter tucked in the pocket of the experimenter's pants with the microphone being clipped to the lapel of the shirt collar. For each run, the Micro-15 Dosimeter provided an accurate run-time which could be reutilized as the "exposure time" of the particular data point. Each run was recorded in an electronic notepad within the experimenter's cell phone and were later transferred to Microsoft Excel.

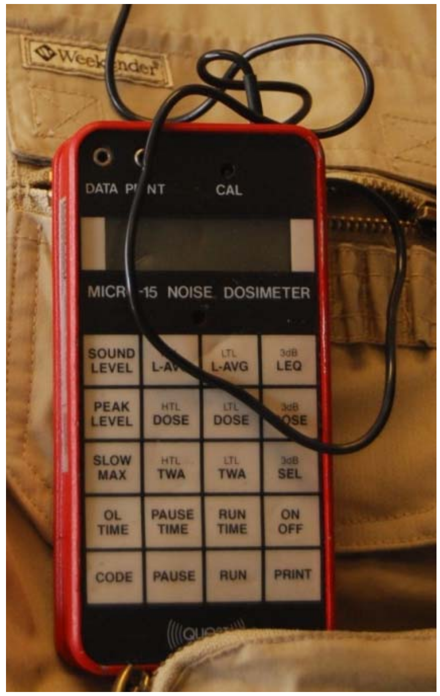

Figure 2. Quest Electronic Micro-15 Noise Dosimeter

In noise data, decibels are logarithmic and not linear; each data point had to be analyzed by a normality test to ensure they could be compared with one another. This task was completed using two separate strategies to ensure and verify the process. The first method required that all data points be converted to natural logs (LN). Afterward, Levene's test for homogeneity was used at a statistical significance of $\sigma = 0.05$ to check the normality and homogeneity of both the raw data and the natural logs. The Messy Data Assistant computer software program (Barger, Lisnerski, Yates, and Yearout 1999) was used to directly compare raw data from the 1990 and 2014 studies to prove the increase of overall leisure noise levels were statistically significant. This program allows experimenters to evaluate homogenous and heterogeneous data at a set confidence level and specifically addresses the small sample sizes and considerable variations (Milliken and Johnson, 1984) of the two studies. Messy Data Assistant required the total number of groups to be compared, an eight character name of each group, the number of samples in each group, the sample mean of each group, and the standard deviation of each group.

Satterwaite's Approximation method and Bonforoni Intervals were used to analyze the data at a statistical significance level of $\sigma = 0.05$. The results of this analysis technique produced an output containing that contained the corrected degrees of freedom and calculated t-value for a linear combination of group means ($\mu_1 - \mu_2 = 0$).. Since comparisons were only made between two groups and not multiple groups, Bonforoni's adjustment for pair-wise error rate had no effect.

3. Results

The mean for all data point from the 2012 and 2014 study was 117.95 dB, with a standard deviation of 8.54 dB. The sample size, mean, and standard deviation of each sub-category can be seen in Table 2. The mean of 117.95 dB is a significant increase from the 1991 mean level (Brown and Yearout, 1991) which was 99.4 dB.

Table 2. Peak & 3db SEL Noise Levels in 2014 for Leisure Activities (Sub-Categories)

	Sample		Peak		3dB SEL	
Category	Sub-Category	(n)	(mean)	(s)	(mean)	(s)
Bar	21-30	12	119.50	9.556	127.023	6.925
Bar	30+	5	112.64	7.382	118.754	0.928
Church	Contemporary	11	118.06	2.616	125.975	11.109
Church	Traditional	7	111.19	5.685	112.734	2.544
Movie	N/A	6	116.90	8.725	116.423	7.059
Sports	Men's Basketball	7	128.60	10.725	130.353	8.113
Sports	Women's Volleyball	5	115.13	5.107	124.058	3.248

4. Analysis

The noise data results of each category (bars, churches, sports, and movies) are illustrated in Table 3. The main note to make from Table 3 is the order in which these leisure activities rank from least loud to most loud: movies, bars, churches and sporting events. A combined mean of all noise samples from the 2012 and 2014 studies was 18.55 dB higher than the leisure noise mean recorded in the 1990 study. For the purpose of comparison, Table 4 displays the noise level, increase and the significance of the increase between the 1990 study and the 2014 study. Within the table, discotheques and bars as well as concerts and contemporary churches (containing concert style environments) were compared. The most notable increase in noise level is the 17.98 dB jump in decibels in bars from 1990 to 2014. Concerts and contemporary churches saw an increase of 8.46 dB from 1990 to 2014 (Figure 3 and Table 4). It is important to consider that since noise data behaves logarithmically, a one decibel increase is in reality like making a three decibel jump because of sound force. As noise levels increase the sound force intensity increases in logarithmic behavior. Sound force has a more detrimental affect on the permanent threshold shift of the human ear because of its fierce effect on the auditory components. A real-life analogy would be to visualize the effect of sound force is to think about the damages of traffic collision between two compact automobile or a collision between one compact automobile and an eighteen-wheeled semi-truck. The collision between the car and semi will have considerably more damage than the later because of the greater amount of force the semi-truck exerts.

The analysis results were highly statistically significant. For Discotheques and Bars the comparison was a corrected degrees of freedom of 17.86 degrees of freedom and a t-value of 7.738. For Concerts and Contemporary Churches the comparison was found to have 19.73 corrected degrees of freedom and a t-value= 8.996.

Table 3. Peak and 3db SEL Noise Level for 2014 Leisure Activities (Categories)

Category	Sample (n)	Peak (mean)	Peak (s)	3dB SEL (mean)	3db SEL (s)
Bar	17	117.48	9.32	124.59	6.95
Church	18	118.06	2.62	120.83	10.91
Sports	12	122.99	10.97	127.73	7.09
Movie	6	116.90	8.73	116.42	7.06

Table 4. Comparison of 1990 to 2014 Noise Data

Category	1990 peak (mean) dB	1990 peak (s) dB	2014 peak (mean) dB	2014 peak (s) dB	Difference	Significance
Discotheques/Bars	99.5	5.90	117.48	9.316	17.98	Highly Significant; p = 0.001
Concerts/Contemporary Churches	109.6	5.00	118.06	2.616	8.46	Highly Significant; p = 0.001

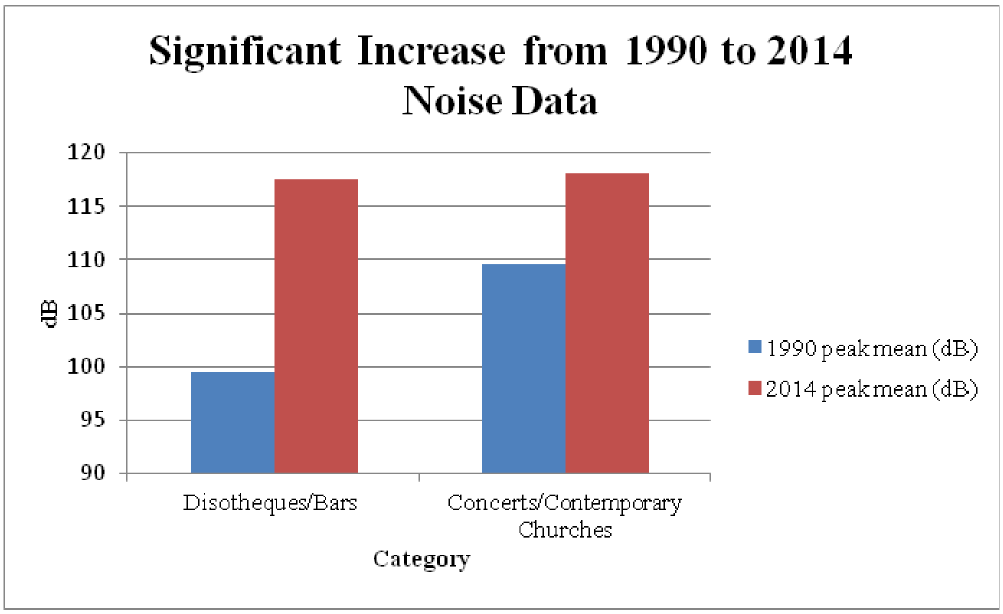

Figure 2. Significance Levels between 1990 and 2014 Data

Both groups were evaluating using the Standard t-Table and both produced p values = 0.001. In simpler terms, both groups had overall mean peak sound level increases that were considered to be 99.9% significant.

5. Discussion

Noise is a basic part of daily life; Without proper awareness of its dangers and protection techniques those exposed are at risk of permanent damage. A single acute exposure of exceedingly high noise levels has the potential to shift the auditory threshold (permanent hearing loss) (Ashfahl, 1995). Table 1 displays the regulations around sound exposure from the Occupational Health and Safety Administration (OSHA) and American Congress of Governmental Industrial Hygienists (ACGIH). Using these regulations and comparing them to the collected data, it would be recommend that attending contemporary church worship and visiting bars should not exceed a fifteen- minute duration. This stipulation only stands true if the individual has no other accumulated noise exposure during the same day. In a 1990 study by Brown and Yearout, it was observed that employees who work in noisy environments tend to participate in equally noisy leisure activities. It has been further studied that, often, noise incurred at work is inescapable and can actually encourage leisure activities with higher noise levels. A study with Finland's military personnel showed that individuals who worked in places with inescapable noise were more likely to choose leisure activities with higher noise levels. The study evaluated the leisure activities of personnel who worked in positions associated with noise including: cannons, mortars, rocket propelled grenades (RPGs), missiles, and rockets. It was concluded that one in five of the surveyed individuals was at were at a high risk of experiencing hearing loss during leisure-time activities (Jokitulppo and Toivonen, 2008). In addition, studies have been conducted in dangerous noise levels in movie theaters. A 1997 study by Osbourne, Yearout, and Lisnerski showed that 88% of movie-goers preferred louder noise levels at movie theaters. Additional studies have shown strong correlations between age and gender and the desired noise level. The trend that loud music in social settings is preferred by young people because it allows social interaction without meaningful conversation is known as the, "Social Noise Phenomena."

6. Conclusion

As mentioned in the introduction, this work is intended to expand the data collection from 2012 study with intentions of proving statistical significance of the findings. Organizations like OSHA and ISO provide education, policies, and noise level protection for industrial work environments. However, the places where millions of Americans choose to spend their leisure time have no governing body to regulate ergonomics. Since the original 1990 study, the exponential rate of technological development has driven down the price of powerful digital sound equipment which can partially explain the significant peak decibel increases over the past twenty-five years. This study supports the research in which younger generations openly welcome excessive noise levels because of the social benefit more formally known as the social noise phenomena. The lack of proper education regarding the permanent effects of loud noise exposure and proper hearing protection techniques is a shortcoming nationwide.

Workers who are exposed to noises within the regulatory guidelines for eight hours and then are exposed to additional hours of unacceptable leisure noise levels are at risk for permanent threshold shift. The natural tendency is then to place blame on the workplace and not on leisure actives for any hearing loss. The fact is that unsafe noise levels experienced daily should be avoided for any duration. The time has come for the proper health hazard implications to be addressed in both regulation and education. Following the lead by advocates and sponsors of some leisure activities such as shooting, motorsports, woodworking, and landscaping efforts to educate, warn, and provide protection for some of the unregulated activities that have significantly increased over the period of time examined.

7. References

Brown , Pamela J., and Robert D. Yearout (1991). Impacts of leisure activity noise levels on safety procedures and policy in the industrial environment. *International Journal of Industrial Engineering*, 1991; 7: 341-346.

Barger, Renee M., Donald Lisnerski, George Yates, and Robert Yearout (1999). A methodology for appropriate testing when data are heterogeneous. *International Journal of Industrial Ergonomics,* 1999; 24: 129-134

Calvert, D.R., and Clark, W.W. (1983). The social noise phenomenon. *Newsnotes, Central Institute for the Deaf.* 1983.

Drummond, Claire, Jimin Lee, Donna Parsons, Steve Patch, and Robert Yearout (2013) Impact of Leisure Activity Noise Levels, Revised (A Case Study). *The 2nd Industrial and Systems Engineering World Conference, Las Vegas, NV, USA*

Jokitulppo, Jaana, and Lt Col Markku Toivonen (2008). Military and Leisure-Time Noise Exposure and Hearing Thresholds of Finnish Conscripts. *MILITARY MEDICINE*. 2008; 173. 9: 906-912. Retrieved from http://0-ehis.ebscohost.com.wncln.wncln.org/ehost/detail?vid=2&hid=23&sid=100b6e49-cdce-4053-89a7-6ff02cf37e55@sessionmgr4&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ.

Konz, Stephan, *Work Design, Occupational Ergonomics*. Hoboken NJ, John Wiley and Sons, 1985.

Konz, Stephan, and Steven Johnson. *Work Design, Occupational Ergonomics*. Scottsdale, AZ: Holcomb Hathaway Publishers, Inc., 2004.

Milliken, G. and Johnson D. *Analysis of Messy Data, Designed Experiment. Vol. 1.* London: *Lifetime Learning,* 1984.

Lane, Mitch, Barrow, Kate, and Yearout, Robert (2012). A Systematic Methodology to Ensure OSHA Noise Level Compliance When Production Processes are Changed (A Health & Safety Case Study). *Proceedings of the 1st Annual World Conference of the Society for Industrial and Systems Engineering.* 2012: 167-181.

Osborne, K., Yearout, R.and Lisnerski, D. (1997). Excessive Noise Levels that Enhance Special Effects, Are You Aware? *Advances in Occupational Ergonomics and Safety*. 1997; 2:513-516.

Shirreffs, Janet H. Ph.D. (1971). Recreational Noise: Implications for Potential Hearing Loss to Participants. *Journal of School Health*. 1971; XLIV. 10: 548-550.

United States, (2011, November). Occupational Safety & Health Administration. Occupational Noise Exposure. Retrieved from http://www.osha.gov/SLTC/noisehearingconservation/.