# CHARACTERIZATION OF 24-HOUR NOISE EXPOSURES AMONG U.S. NAVY NIMITZ CLASS AIRCRAFT CARRIER PERSONNEL NOT ENROLLED IN THE HEARING CONSERVATION PROGRAM


by

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Thesis submitted to the Faculty of the
Preventive Medicine and Biostatistics Graduate Program
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UNIFORMED SERVICES UNIVERSITY, SCHOOL OF MEDICINE GRADUATE PROGRAMS
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March 1, 2017

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**MARIA K. MAJAR, MS**
**NICHOLAS C. SCHAAL, PhD**

**SUBJECT:** Appointment to the Final Master's Examination Committee for Kevin D. Lange

In accordance with the School of Medicine Graduate Program Guidelines, you are formally appointed to the Final Examination Committee of Kevin D. Lange, Master of Science in Public Health student in the Department of Preventive Medicine & Biostatistics.

This Committee will evaluate the scope and qualities of the student's Dissertation and certify the document's acceptability.

In addition, the Committee will conduct an Oral Examination of the student's scientific knowledge, as well as his knowledge/ understanding of his thesis research project and Dissertation. This Examination constitutes the Private Defense.

The Private Defense for Kevin D. Lange will take place on Thursday, March 23, 2017 at 1:30 PM, in AFRRI OEHS Conference Room 3176H.

Dr. Mary T. Brueggemeyer is appointed Chair of the Examination Committee. Dr. Brueggemeyer will oversee the Examination. Passage of the Private Defense will be by majority vote. If corrections to the Dissertation are needed, the Chair may oversee this process and sign-off after the corrections are made.

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GEO thanks you in advance for your participation in the SOM Graduate Program process.

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Gregory P. Mueller, Ph.D.
Associate Dean for Graduate Education

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DISSERTATION APPROVAL FOR THE MASTER IN SCIENCE IN PUBLIC HEALTH DISSERTATION IN THE DEPARTMENT OF PREVENTIVE MEDICINE AND BIOSTATISTICS

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THESIS AND ABSTRACT APPROVED:

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FINAL EXAMINATION/ PRIVATE DEFENSE FOR THE DEGREE OF MASTER OF SCIENCE IN PUBLIC HEALTH IN THE DEPARTMENT OF PREVENTIVE MEDICINE AND BIOSTATISTICS

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Time: 1:30 PM

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DECISION OF EXAMINATION COMMITTEE MEMBERS:

| | PASS | FAIL |
|---|---|---|
| Mary T. Brueggemeyer, MD, MPH, Col<br>DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS<br>Committee Chair | X | |
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# DEDICATION

I would like to dedicate this thesis to all my family and friends who helped me throughout my 2 years here at USUHS. Words cannot express my gratitude for being there for me when I needed advice and to help me find my way back when I found myself led astray.

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To Aunt Steph and Uncle Floyd., I will always claim you as my second parents. Despite your reasons for being at Walter Reed and spending so much time recovering from your treatment in the Fischer House you were always there for me. I sincerely appreciate both of you for taking the time to check up on me and make sure I was doing well. Bowling alley pizza and good conversation will always hold a special place in my heart thanks to you two.

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Kevin D. Lange

April 6th, 2017

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# ABSTRACT

Characterization of 24-Hour Noise Exposures among U.S. Navy Nimitz Class Aircraft Carrier Personnel Not Enrolled in the Hearing Conservation Program

Kevin D. Lange, Master of Science in Public Health, 2017

Thesis directed by: Captain Maria K. Majar, Assistant Professor, Department of Preventive Medicine and Biostatistics, Occupational and Environmental Health Sciences Division

**Background**: Personnel working in an operational shipboard environment on a U.S. Navy aircraft carrier are exposed to a variety of noise hazardous equipment and hazardous noise from flight deck operations. While at sea, work shifts commonly exceed standard 8-hour shifts, reaching durations of 12 hours or more. Personnel with noise exposures less than 85 decibels "A" weighted (dBA), may be at high risk of noise exposure because areas designated for sleeping and relaxation may be adjacent to shipboard noise hazardous operations. The objective of this study was to characterize 24-hour noise exposure profiles for U.S. Navy Nimitz class aircraft carrier personnel not enrolled in the Department of Defense (DoD) Hearing Conservation Program (HCP).

**Methods**: A total of 45 noise dosimetry samples were collected from personnel not included in the DoD HCP during 24-hour periods while at sea during airwing carrier qualifications. Noise measurements were compared to the EPA 24-hour 70 dBA environmental exposure recommendation. Four homogenous exposure groups (HEGs) were created based upon departmental assignment and task and included: Administration/Religious Ministries/Legal/Training, Combat Systems/Operations, Medical/Dental, and Supply. HEGs were then analyzed and compared to determine if there were significant differences between 24-hour noise exposures between HEGs.

**Results**: A total of 97.8% of the noise dosimetry samples exceeded the EPA environmental noise recommendation of 70 dBA. Combat Systems/Operations had significantly higher noise exposures than Medical/Dental (p=0.014) and Supply (p=0.04) with an overall mean noise exposure of 79.6 dBA. Personnel assigned to work spaces directly below the flight deck had significantly higher average noise exposures compared to personnel working on lower decks.

**Conclusion**: Results of this study suggest measuring noise over a full 24-hour shift rather than an 8-hour shift may better characterize U.S. Navy aircraft carrier personnel noise exposures when personnel are working and living in close proximity. Future studies should improve process understanding of department/division assignment and primary work locations for determining personnel at greatest risk of hazardous noise exposure.

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# CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

## Statement of Purpose

The objective of this study was to characterize 24-hour noise exposure profiles for United States (U.S.) Navy aircraft carrier personnel not historically enrolled in the Department of Defense (DoD) Hearing Conservation Program (HCP).

Results from this research will be compared to Environmental Protection Agency (EPA) recommendations for 24-hour environmental noise exposures. EPA environmental noise exposure recommendations could potentially be utilized to characterize and support judgment of noise exposures and inclusion into the DoD HCP, establish priority for military occupational health professionals, and aid in the implementation of engineering controls for the purposes of hazardous noise mitigation.

## Background and Significance

Occupational noise induced hearing loss is the most prevalent work-related injury in the United States (23). Hearing loss is the third most common chronic physical condition in the U.S., behind hypertension and arthritis (18). An estimated 30 million workers are exposed to hazardous noise annually (23) and $242 million per year is spent on hearing loss disability according to the National Institute for Occupational Health and Safety (NIOSH, 2016). Tinnitus and occupational hearing loss are the respective number 1 and 2 causes of disability compensation claims at the close of fiscal year 2015 with approximately 2.4 million combined compensation recipients as reported by Veterans Benefit Administration (29). Occupational hearing loss develops over a long period of time and is typically irreversible.  Prevention, early detection, and intervention efforts are critical to limit potential hearing loss.

***Sensorineural Hearing Loss***

There are three main types of hearing loss: conductive, sensorineural, and mixed. Sensorineural hearing loss is the most common type of hearing loss, and is caused by damage to the receptor hair cells in the cochlea or to the primary auditory nerve.  Noise induced hearing loss (NIHL) from continuous noise may result from accumulated mechanical trauma or due to metabolic exhaustion (19).

Animals exposed to impulse noise exhibit anatomic changes such as distorted stereocilia, edema of the stria vascularis, and rupture of the Resissner membrane (Mathur, 2016).  Temporary threshold shifts (TTS) are anatomically correlated with a reduction in stiffness in outer hair stereocilia, while permanent threshold shifts are associated with loss of stereocilia and stereocilia fusion (Mathur, 2016).  The loss of stereocilia can result in hair cell death, loss of primary auditory nerve fibers, and functional disruption of the Organ of Corti (19).

Both acute and chronic exposures to hazardous noise can cause hearing loss; however, it should be noted that acoustical trauma is caused by impulse noise.  Acute acoustic trauma exposures in excess of 140 decibel A-weighted (dBA) can stress and tear membranes and cause cell wall stretching beyond normal ear tissue elasticity and ultimately result in permanent hearing loss (31).  The cochlea receptor hair cells transmit mechanical motion caused by sound pressure waves into action potentials (6).  Repeated chronic exposure to high intensity noise can overstimulate cochlea receptor hair cells potentially causing structural damage (6).  Once damaged these receptor hair cells are usually incapable of self-repair and hence sensorineural hearing loss is normally permanent (20).

Acute and chronic exposures to hazardous noise can cause a variety of auditory and non-auditory health effects. Exposures to environmental and occupational noise at high enough intensities can cause NIHL and tinnitus but is also associated with: annoyance, impairment of cognitive performance in children, hypertension, heart disease, and sleep disturbances (4). The main consequence of hearing impairment is permanent hearing loss and the inability to understand everyday conversations. (25). Additionally, hearing impairment can hinder cognitive performance and negatively impact attention required to perform tasks (25).

The tissues and cells of the inner ear are in a constant state of repair following noise exposures. Ear cell recovery is dependent on the magnitude of damage inflicted by noise exposures (5). Exclusion from noise of sufficient intensity and duration to cause damage to inner ear cells to allow for recovery of these cells is deemed auditory rest (9). Federal regulations for noise exposure levels are based upon 16 hours of auditory rest between occupational noise exposures while chapter B4 of OPNAV 5100.19 series states that an auditory rest period of 14 hours is usually enough time to recover from a significant threshold shift (STS) (9).

### *NIHL and Hearing Conservation*

Occupational NIHL is defined as hearing loss primarily attributed to work-related exposures to hazardous noise (23). While nonmodifiable, age is also a risk factor in the development of NIHL (7). In the past decade, NIHL is increasing in prevalence among children and young adults (7).

The purpose of HCPs is to prevent NIHL, but the existence of an occupational HCP does not guarantee NIHL prevention amongst employees (22). There are seven basic components of a hearing conservation program: engineering and administrative controls, noise exposure monitoring, education and motivation, audiometric evaluation, record keeping, program evaluation, and use of hearing protective devices (22).

Per the OPNAV 5100.23 series, the goal of the Navy HCP is to not only prevent occupational hearing loss but to also ensure auditory fitness in military and civilian personnel. Medical surveillance programs are designed to prevent, identify, and treat occupational injuries and illnesses. Noise exposure assessments are conducted to determine personnel at risk of noise induced hearing loss and to recommend these individuals for inclusion into the HCP. Noise controls and the HCP contribute to operational readiness by preserving and optimizing auditory fitness in Navy personnel (9).

The most effective means of preventing NIHL is to utilize engineering controls to isolate or reduce the noise hazard. This can be accomplished by substituting hazardous noise producing equipment with quieter technology, isolating hazardous noise producing equipment from the worker, reducing vibration whenever possible, using sound dampening or noise mitigation materials near hazardous noise producing equipment, and ensuring routine maintenance. Engineering controls are the most desirable amongst the hierarchy of controls; however, these controls may be impractical and difficult to implement due to lack of cost-effectiveness, lack of enforcement, and management safety culture (27). Hearing protective devices are the last resort in the hierarchy of controls if engineering and administrative controls are not feasible. Hearing protection use may be a temporary solution to prevent or limit NIHL if use is carefully planned, evaluated, supervised, and used consistently (27).

***Regulations and Standards***

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) is 90 dBA as an 8-hour time TWA. Hearing conservation program implementation is required when 8-hour TWAs exceed 85 dBA (23). The American Conference of Governmental Industrial Hygienists (ACGIH) and NIOSH have recommended an occupational exposure limit of 85 dBA as an 8-hour TWA.

Despite wide acceptance that prolonged exposure to hazardous noise can cause permanent hearing loss there is little governmental regulation on environmental and recreational noise exposures (5). The Occupational Safety and Health Administration (OSHA) regulates occupational noise exposures; however, OSHA's PEL for hazardous noise was not developed to prevent adverse hearing effects in longer than 8-hour work shifts or in cases where the employee rests/sleeps near an individual's work space. Although specific source or task based industrial hygiene worksite assessments of hazardous noise generators provide information useful for characterizing risk; such assessments provide limited information about the cumulative 24-hour noise exposures.

A 1974-1975 U.S. Environmental Protection Agency (EPA) progress report (12) recommended an environmental exposure limit of 70 dBA averaged over a 24-hour period for environmental noise. The 70 dBA EPA recommendation was designed to protect 96% of the population from developing NIHL. ACGIH recommends a threshold limit value (TLV) of 80 dBA for 24-hour exposures. The TLV recommendation is based on the assumption that there will be time away from the workplace to rest and sleep after exposure; however, when an employee's work and living spaces are close proximity, ACGIH recommends that background noise levels be at or below 70 dBA (2).

The Department of Defense Instruction (DoDI) 6055.12 articulates DoD policy, assigns responsibilities, and procedures for the establishment of a HCP to protect personnel from NIHL associated with operational and occupational-related noise exposure (8). Additionally, DoDI 6055.12 requires all DoD components conducting occupational and combat operations to establish and maintain an adequate HCP. Furthermore, an aim of the instruction is to reduce operational noise exposure to DoD personnel whenever possible to enhance mission readiness and safety (8).

The U.S. Navy supplements DoDI 6055.12 in order to provide a safe and healthy workplace for all Navy personnel in afloat and ashore environments with OPNAV Instructions 5100.19E and 5100.23G respectively (9). These instructions provide policy and outline responsibilities for the proper implementation and execution of the Navy Occupational Health and Safety Program for the entire operational and administrative chain of command. Industrial hygiene surveys do not recommend HCP/medical surveillance when personnel are not routinely exposed to hazardous noise. The purpose of noise monitoring is to identify noise hazardous environments that may produce noise induced hearing loss. Aircraft carrier medical surveillance programs may vary individually; however, HCP recommendations are based upon noise dosimetry for a particular departmental task. Noise exposure monitoring may not have been conducted when a risk assessment is performed and the exposure is controlled to less than 85 dBA.

The Navy occupational exposure limit as established by OPNAV 5100.23 series and 5100.19 series is 85 dBA TWA. An employee should not be exposed to a cumulative sound level above 85 dBA for an 8-hour work shift. Therefore, DoD employees should be included in the HCP when their 8-hour TWA exposure is at or above 85 dBA. Additionally, employees should also be enrolled into the HCP if an impulse sound pressure level reaches or exceeds 140 dB at any point in an 8-hour work shift.

In addition to the 85 dBA TWA, the DoD employs an exchange rate of 3 decibels and is viewed as more stringent than the 5 dB exchange rate enforced by OSHA in the general industry noise standard (5). An exchange rate (also doubling rate) is the increase or decrease in decibels corresponding to twice or half the noise dose respectively. Exchange rate can be viewed as an equal energy balance between the sound pressure level in dB and the allowable exposure duration in hours (23). In steady-state exposures, the two exchange rates produce identical measures of exposure, whereas variable noise exposures produce larger differences between the two exchange rates. Table 1 displays the effects of OEL selection and exchange rate on allowable exposure duration at specific noise levels.

Table 1. Summary of Exposure Level and Exchange Rate on Allowable Exposure Time

| **Exposure Level 85(dBA) Criterion ER=3** | **Allowable Exposure Time (Hours)** | **Exposure Level 85 (dBA) Criterion ER=5** | **Allowable Exposure Time (Hours)** |
|---|---|---|---|
| **85** | 8 | 85 | 8 |
| **88** | 4 | 90 | 4 |
| **91** | 2 | 95 | 2 |
| **94** | 1 | 100 | 1 |
| **97** | 0.5 | 105 | 0.5 |

BUMED NOTICE 6260, released 9 May 2016, provided interim HCP guidance clarifying select elements within the program. The notice is applicable to both operational and shore based industrial hygiene (IH) offices. The Navy and Marine Corps Public Health Center (NMCPHC) defines routine exposures as > 85 dBA for $\geq$ 2 days per month for HCP placement parameters. However, BUMED notice 6260 recommends that all personnel routinely exposed to noise in excess of the OEL of 85 dBA, and other specific at risk personnel must be enrolled in the HCP.

***Noise Exposure Monitoring***

As with any health hazard, it is important to identify the health hazard and characterize the hazard accurately so control efforts can be directed as appropriate. Noise exposure monitoring has many purposes to include: determining whether noise is hazardous or not, evaluation of specific processes and noise sources to prioritize appropriate control, documenting employee noise exposures, identifying employees that must be included in the HCP, and evaluating hazardous noise control efforts.

Occupational noise exposure monitoring data typically consists of personal noise dosimetry or area monitoring. Noise dosimetry is a form of personal sampling, and involves placing the dosimeter on the worker to determine personal noise dose for a particular work shift or sampling period. Dosimeters can be used to ensure compliance with the federal OSHA noise standard or other relevant professional recommendations. The noise dosimeter measures and stores sound pressure levels and integrates them over time.

Noise dosimetry involves placing noise monitoring equipment on the worker's lapel or belt with the microphone placed near an employee's hearing zone to monitor an employee's noise exposure over a work process or shift. The hearing zone is defined as a spherical 30-cm radius around an individual's head (5).

In most workplaces, measuring the exposures of every individual worker would not be effective or possible. A strategy for conducting a comprehensive exposure assessment is to assemble workers believed to have similar or "homogenous" exposures into a group. Stratifying workers allows for effective allocation of resources but still provide adequate characterization of a hazard to a similar group of workers (14). Grouping similar individuals can be done by observation, process, job, task, and/or sampling results (14). Once several measurements have been collected, an industrial hygienist can estimate TWAs for a particular grouping of a department or shop using statistical analysis. Noise dosimetry measurements are used to classify the noise hazard as acceptable, unacceptable, or uncertain. Hazard classification results determine necessary engineering controls to mitigate the hazard, and determine if noise exposure warrants inclusion of personnel into the HCP.

Per 29 CFR 1910.95, noise dosimeters are to be set to particular parameters (criterion, exchange rate, weighting filters, etc.) compare to the OSHA noise standard. Federal OSHA utilizes a criterion level of 90 dBA, exchange rate of 5 dB, and a dosimeter threshold levels of 80 dBA for hearing conservation compliance and 90 dBA for permissive exposure limit compliance. NIOSH and ACGIH have recommended different parameters for occupational exposures based upon peer reviewed literature, toxicological, and epidemiological data. These parameters can be selected by the industrial hygienist to match the relevant standard or organizational exposure limit. Lowering of the threshold or criterion levels allows for facilitating identification of employees for HCP inclusion when parameters differ from OSHA dosimeter recommendations, such as when targeting lower risk populations below OSHA or regulatory exposure limits. According to OSHA, the threshold level is the A-weighted sound level at which noise measurements are integrated into the computation for a measured dose in a noise exposure, whereas sound level measurements below a set threshold would not be included in the noise dose computation (24). Noise dosimeters utilize frequency selective weighing filters, most commonly A, B, C; that are derived from Fletcher-Munson curves that characterize human perception of pure tones of different frequencies (5). These weighting scales have been investigated thoroughly in peer reviewed literature and; while not without controversy, widely accepted that A weighting gives a better estimation of threat to hearing than B-weighting or C-weighting because it de-emphasizes noise intensities at low (5). Similar contention exists amongst selection of a 3 dB exchange rate and a criterion of 85 dBA; however, currently NOISH and ACGIH recommend the use of those parameters (5).

Noise dosimetry within the Navy focuses on measuring noise exposures as an 8-hour TWA during on-duty shifts. These personnel are identified by noise exposure assessments documented in baseline and periodic IH surveys. Ultimately, noise exposure monitoring is conducted to determine inclusion into the HCP. Operational or deployed IH offices followed OPNAV 5100.19 series guidance of including personnel into the HCP who are routinely exposed to hazardous noise in excess of Navy occupational exposure limits based upon 8 hour-TWA for personal noise exposures. Routinely exposed is defined by OPNAV 5100.19 series as exposures of sufficient intensity and duration in noise hazardous areas or in the vicinity of hazardous noise producing equipment where it can be reasonably expected that those exposures will result in a loss of hearing sensitivity. This method of conducting noise dosimetry over an eight-hour shift then comparing the result to the 85 dBA OEL as a basis for HCP inclusion follows OSHA regulation and private industry recommendations for 8-hour work shifts.

***Military Health Relevance***

U.S. Navy aircraft carriers are the centerpiece of Naval Forces and are essential in supporting the launching and recovery of aircraft that engage in attacks on airborne, afloat, and ashore targets that threaten free use of the sea (11). Each of the 10 Nimitz class aircraft carriers is designed for approximately 50 years of service and supports approximately 60 aircraft when the air wing is operational. The crew of an aircraft carrier consists of personnel assigned to ship's company with approximately 3,000-3,200 when underway (11).

Aircraft carriers operate on a 32-month cycle. During this cycle, ships require continuous and regularly scheduled maintenance, while the crews require lengthy training to achieve and sustain standards set for readiness levels. The length of training, readiness deployment, and maintenance cycle varies among individual Nimitz class aircraft carrier; however, a ship may be deployed or conducting humanitarian aid, conducting shipyard or pier side maintenance, or in a non-deployed status but capable of providing surge assistance. Personnel typically work 12 hour shifts in their respective work spaces while underway, while the other 12 hours is considered off-duty time. During off-duty time, personnel remain on the ship but are usually free to spend most of that time in their berthings (sleeping areas), mess decks (eating area), libraries, college classes, or spaces utilized for recreational physical training (on-board gyms).

Due to the amount of high intensity noise exposures from a wide variety of shipboard-specific operations during routine operations and maintenance periods, noise induced hearing loss is the number one occupational health hazard in the Navy (10). Tinnitus and NIHL have been reported in military personnel who are routinely exposed to occupational hazardous noise (16) and are the number one and number two sources of Veteran's Administration claims for the year 2015 (29) respectively. Noise induced hearing loss is often accompanied by tinnitus with abnormal loudness perception and distortion. Additionally, prolonged exposure to hazardous noise can cause temporary or permanent threshold shifts, reduction in speech audibility, miscommunication, sleep and cardiovascular disturbances, impaired task performance, and decreased quality of life. Hearing acuity is a vital component of a military service-member's effectiveness. Tinnitus and NIHL can negatively impact mission readiness by impairing individual acoustical cues and communication signals (31).

Although NIHL is 100% preventable, once acquired it is permanent and irreversible [NIOSH 1998]. Understanding and minimizing the risks associated with noise exposures are the keys to preventing NIHL. Understanding the noise sources that may affect workers has historically been limited to noise dosimetry measurements while on-duty during 8-hour shifts. Characterizing only on-duty noise exposures may underestimate exposure since on-duty time may last 12-hour shifts and since off-duty time may also involve hazardous noise exposures with little opportunity for auditory recovery. Occupational noise exposure standards are based on a traditional 8-hour workday with the assumption that the remaining 16 hours for auditory recovery. Not only do operational commitments frequently require longer working hours of aircraft carrier personnel, but there are a limited number of spaces where sailors can spend their off-duty time. Often during routine operations berthing, mess deck, and gym spaces intended to provide respite from the work area may also be noise hazardous. This situation limits the opportunity for auditory recovery in accordance with occupational noise standards.

The shipboard environment throughout an entire day, whether at sea or in port on-duty, provides the potential for a sailor to be exposed to significant noise over a 24-hour period with very little opportunities for auditory rest. Therefore, noise data over a 24-hour exposure period is necessary to more accurately characterize noise exposure to aircraft carrier personnel. This full noise characterization could also facilitate prevention efforts, as well as employee education resulting in a more effective HCP. Incidental and non-routine noise exposures < 85 dBA as an 8-hour TWA have not historically been recommended for inclusion into the HCP. Therefore, reliance on only 8-hour TWAs when making HCP enrollment decisions may be missing a portion of the population that may still be at risk of hazardous noise exposures during off-duty hours when assigned to an operational aircraft carrier and underway.

***Literature Review***

Although many studies have examined 24-hour noise exposures in environmental or recreational settings, noise exposures during routine aircraft carrier operations, and 24-hour noise dosimetry on aircraft carrier personnel is limited. Most noise studies focus on an 8-hr shift lengths. Table 2 is a summary of the relevant studies.

Studies by Yankaskas (30) and Aubert (3) used sound level meters to conduct area noise measurements to investigate hazardous noise exposures based upon personnel being in the vicinity of hazardous noise producing equipment. Yankaskas et al (1999) utilized Type 1 sound level meters to assess noise measurements beneath the flight deck during carrier qualifications. Flight deck sound level measurements were compared in real time to sound measurements in spaces directly below the flight deck. The average difference between flight deck and 03 spaces were approximately 30-40 dBA and the average daily flight ops length was approximately 14 hours. Sound level measurements ranged from 60-100 dBA in the 03 spaces during flight ops intermittently. This study suggests sailors may be exposed to hazardous noise in areas directly adjacent to the flight deck. This study did not use personal noise dosimetry on personnel occupying these spaces. The average work day for personnel included in the study was 15 hours and the other 9 hours were assumed to be rest.

A 2004 study by Kock et al. attempted to characterize 24-hour noise exposures in 10 high risk industries in Denmark (15). Full shift noise dosimetry was conducted, and recreational time off was captured in this study as well. The study researchers used type II dosimeters and programmed the noise dosimeters to sample sound pressure levels every 5 seconds with A-weighting, no threshold, criterion level of 85 dBA, and an exchange rate of 3 dB. The average overall occupational exposure was 83.7 dBA, 75.6 dBA during recreational activities, and 69.2 dBA while sleeping. In these high-risk occupations in Denmark, nearly 50% of all samples exceeded the criterion of 85 dBA.

Neitzel et al. conducted a 24-hour noise characterization study involving noise exposures of commercial fisherman onboard a combination catcher/processer vessel at sea (21). Noise exposures were assessed using dosimetry, sound level mapping, and a self-reported activity log. Additionally, length of hearing protective device wear was utilized to calculate effective protection in personnel. 24-hour noise measurements were compared to OSHA (OEL=82 dBA, ER= 5), U.S. Coast Guard (24-hour= 82 dBA, ER=5), NIOSH (24-hour = 80 dBA, ER=3), and the International Maritime Organization (24-hour= 80 dBA, ER= 3) occupational exposure limits for 24-hour duration exposures. One hundred percent of unadjusted Leq measurements exceeded 80 dBA, when factoring hearing protection use, half of the workers still had 24-hour exposures above 85 dBA. The results of this survey indicate fisherman on catcher/processor vessels are at risk for NIHL.

A study by Abdus-Salaam (1) focused on 24-hour noise dosimetry (on/off duty) of aircraft carrier aviation rated personnel who had a high risk of hazardous noise exposure and were included in the HCP (1). The objective of the study was to determine the extent that off duty noise contributed to 24-hour noise exposures. 59 sailors from primarily aviation rates participated in the study, although 17 of the 24-hour noise measurements were collected from non-aviation rates. The average noise exposure for the volunteers was 93 dBA. Approximately 70% of the participants' off-duty noise exposures were at or above 70 dBA. Results of this study suggest that personnel who work/live near hazardous noise areas exceed 24-hour exposure limits. Additionally, adequate hearing recovery may not occur during off duty time as all hearing recovery areas exceeded the 70 dBA threshold for auditory recovery over a 24-hour period. Compartments that can be used for hearing recovery are designed to be <70 dBA per OPNAV 5100.19 series, and include the following living spaces: berthings and staterooms, recreational areas, lounges, and wardrooms/crew mess decks.

Table 2. Investigating 24-hour Noise Dosimetry among Naval Personnel – Summary of Relevant References

| **Author (Publication date)** | **Aircraft carrier during routine operations** | **24 Hour Dosimetry** | **Population** |
|---|---|---|---|
| **Yankaskas et al (1999)** | X | Area monitoring | Aviation |
| **Kock et al (2004)** | -- | X | -- |
| **Neitzel et al (2006)** | -- | X | -- |
| **Virji et al (2009)** | X | -- | -- |
| **Aubert et al. (2011)** | X | Area monitoring | Aviation |
| ***Salaam (2014)** | X | X | Aviation |

*USUHS MSPH student thesis.

### *Research Question & Specific Aims*

**Research Question**: Are U.S. Navy aircraft carrier personnel not enrolled in the DoD Hearing Conservation Program exposed to non-routine hazardous noise that exceeds the EPA 24-hour exposure limit?

**Objectives:**

1. Characterize personal 24-hour noise exposures to determine if exposures exceed the EPA 24-hour OEL in personnel not historically enrolled in the Hearing Conservation Program during routine carrier operations.

   -Specific Aim: Place noise dosimeters on study volunteers while they go about normal duties.

   -Specific Aim: Collect dosimeters, department/rate, and download 24-hour dosimetry results to analyze via data management software for further analysis.

2. Compare 24-hour personal noise exposures among selected aircraft carrier departments to determine if there are differences between non-HCP HEGs.

# CHAPTER 2: MATERIALS AND METHODS

Full day (24-hour) noise exposures profiles were measured during routine Nimitz-class aircraft carrier operations and analyzed to determine if 24-hour noise exposures (occupational, environmental, and incidental noise) exceeded 24-hour EPA environmental noise exposure recommendations. Additionally, homogenous exposure groups (HEGs) were created from shipboard departments and compared to determine if there were differences between HEGs. This was accomplished via measurement of 24-hour personal noise profiles of personnel not traditionally enrolled in the DoD HCP onboard a U.S. Navy Nimitz-class aircraft carrier. Personnel working in Departments or Divisions that were not recommended to be placed into the HCP according to the most recent periodic industrial hygiene survey were considered for inclusion in this study.

Naval Air Force U.S. Atlantic Fleet (COMNAVAIRLANT), Norfolk Virginia, approved this study. Noise dosimeters were placed on the belt or lapel of volunteers, and the microphone was shoulder mounted. Little interference with study participant's duties was anticipated. This study was deemed non-human use research, exempt from further review, after the study protocol was reviewed by the Uniformed Services University of the Health Sciences (USUHS) Institutional Review Board (IRB) Human Research Protection Program Office (#G18789). Additionally, no identifiable information was collected in connection with the use of the dosimeter.

This study was conducted 29 November to 9 December onboard CVN 73 USS GEORGE WASHINGTON (Nimitz Class aircraft carrier) during a routine underway with flight operations (fixed and rotary wing) in the Atlantic Ocean. The mission for this underway involved Fleet Replacement Squadron Carrier Qualifications (FRSCQs) where new pilots are trained and qualified to conduct operations at sea including the launch and recovery of aircraft. Flight operations typically lasted 12 hours and included the following aircraft: F/A 18 C/D, F/A 18 E/F (Super Hornet), EA-18G (Growler), E-2C, C-2A (COD), and MH60S. Other major evolutions occurring during this study included: General Quarters (1 night), man overboard drills, burial at Sea, daily Foreign Object Damage (FOD) walk-downs in the hangar bay and on the flight deck, damage control and material condition training, material condition hour, and nightly propulsion plant drills.

Each morning upon completion of a 24-hour sampling period, 3M™ NoisePro DLX (Oconomowoc, WI) and Edge eg5 (Oconomowoc, WI) personal noise dosimeters were retrieved from study participants and post-calibrated in the field to verify the dosimeter was still functioning appropriately. Data from the personal noise dosimeters were then downloaded and saved into the Detection Management Software wirelessly via the ACTiSYS Infrared (IR) wireless interface. All results were exported to Microsoft Excel for data compilation and storage. All statistical analysis was conducted using SPSS version 24.

***Study Participation***

Previous studies focused on personnel working in or near noise hazardous spaces; however, some of the study participants were assigned to departments and/or shops where 8-hr TWA noise exposures were < 85 dBA. This study focused on participants from those departments and work-centers not typically included in the DoD HCP, while personnel from departments and work-centers traditionally enrolled in the DoD HCP were specifically excluded from this study.

Potential participants were identified by reviewing and analyzing the ship's periodic industrial hygiene (IH) survey which includes historical noise dosimetry and medical surveillance recommendations. Historical noise dosimetry within the defined population was limited, therefore medical surveillance recommendations within each department were analyzed to determine personnel enrollment in the hearing conservation program. Department heads, division officers, and divisional chief petty officers were contacted and requested to solicit participants for the study.

Each participant was asked prior to the start of 24-hour noise dosimetry if they were enrolled in the HCP or were required to perform annual audiograms. Study participants were briefed on the purposes of the study, dosimetry basics, and how to appropriately don, doff, and take care of the dosimeter. Study participants were requested to carry about their normally assigned duties while wearing the noise dosimeter; to not shout into, blow, or tap the dosimeter microphone intentionally and to avoid incidental contact if possible. To prevent damage to the noise dosimeters during a General Quarters drills (all were participants from medical/dental), the researcher collected dosimeters from study participants until conclusion of the drill. The dosimeters were then placed back on study participants.

***Sample Size Determination***

Prior to the underway and with consultation from the USUHS Biostatistics Consulting Center, 12-15 individuals per HEG would be required in order to see a difference between groups of approximately 7 decibels based upon the average standard deviation in a previously conducted and similar study (1).

Additionally, Leidel et al. (1977) created a sampling size strategy guide required to attain a 95% confidence level that the sampling strategy will include at least one or more employees with the highest exposure based upon the size of the group to be sampled (Table 3). While each Nimitz class aircraft carrier department varies in size, 12-14 samples per homogenous exposure group (HEG) is ideal.

Table 3: Sample Size Needed to Ensure 95% Confidence Level that the sample will include one or more observations for employees with exposures in the top 20% of the Distribution (17)

| | **Required Number of Employees** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7-8 | 9-11 | 12-14 | 15-18 | 19-26 | 27-43 | 44-50 | 51-∞ |
| **Required # of samples** | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 14 |

### *Homogeneous Exposure Groups*

Four broad homogenous exposure groups (HEG) of non-HCP enrolled personnel were created based on observation and task due to departmental and divisional assignment (Table 4 below). Three of the four HEG's included Departments with HCP recommendations; however, most personnel in the department were not enrolled and divisions without HCP recommendations were selected. Divisions that had personnel in the HCP or recommendations from the IH survey were excluded from the department entirely.

Table 4: Homogenous Exposure Group (HEG) and Selected Departments

| **HEG 1** | **HEG 2** | **HEG 3** | **HEG 4** |
|---|---|---|---|
| **Admin, CRMD, Legal, Training** | Combat Systems, Operations | Medical, Dental | Supply |

CRMD= Command Religious Ministries Department

In large departments, such as Combat Systems (HEG 2) CS1-CS6 divisions and Supply (HEG 4), S3/S8A divisions were selected due to no personnel being recommended for HCP inclusion. While small departments such as HEG 1 (administrative) and HEG 3 (Medical/Dental) contained task based HCP recommendations for personnel, these individuals were easily identified and excluded from the study population.

It was the original intention of the researcher to collect 12-15 samples per HEG with a goal of 4 HEGs; however due to operational constraints of the ship's schedule and equipment challenges, two days of sampling originally accounted for in the sampling plan for this study were not conducted and a total of 47 samples were collected (9-13 samples per HEG).

***Noise Dosimetry Measurements***

Two different types of noise dosimeters for a total of 14 dosimeters were used during this study: (10) 3M™ Quest Technologies NoisePro DLX and (4) 3M™ Quest Technologies The Edge eg5. An acoustical calibrator, 3M™ QC-10, was utilized for field calibration prior to and after conducting noise dosimetry. QC10 noise calibrator parameters are factory set at 114 dBA and 1,000 Hertz to ensure that lab calibrated noise dosimeters are within calibration for field use. Dosimeters were calibrated pre/post data collection and prior to the start of the next 24-hour noise dosimetry samples.

Both types of noise dosimeters and the acoustical calibrator were laboratory calibrated annually in keeping with OSHA Hearing Conservation Amendment and manufacturer guidelines. In keeping with routine noise dosimetry protocols, noise dosimeters were adjusted as needed to match the 114 dB acoustical calibrator output prior to sampling. If pre and post calibration exceeded 1 dB difference, results would have been of questionable validity. All pre and post calibration were within 1 dB differences.

Appendix I of the OSHA Hearing Conservation Amendment and American National Standards Institute (ANSI S1.25-1991) set specific requirements for noise dosimeter characteristics (5). As mentioned previously, specific noise dosimetry sampling parameters are set by OSHA and Navy regulation; however, for the purposes of characterizing 24-hour noise exposure for "lower risk" personnel (defined as individuals with 8-hour noise exposures < 85 dBA), certain noise dosimeter parameters were adjusted to meet the needs of this study. Noise dosimeters were set as follows: Criterion Level= 70 dBA, Exchange Rate= 3 dB, and Threshold= 60 dBA.

In the field, AA batteries for NoisePro DLX models were replaced after each 24-hour noise dosimetry sampling. The Quest Edge eg5 dosimeters models operate on rechargeable lithium batteries, and were capable of a full recharge in approximately 4 hours. The Edge eg5 could only be used once per 24-hour sampling period due to its 40-hour maximum battery life (manufacturer), and the recharge time for the Edge5s was approximately 4 hours. Noise dosimetry using the Edge eg5 dosimeters was conducted every other day in order for Edge5's to charge and to download the dosimetry results and to be available to issue for the next 24-hour sampling period.

All NoisePro DLX dosimeters require the body of the dosimeter to be belt mounted as seen in figure 1 below.

Figure 1: NoisePro DLX Belt Placement

The microphone is then secured to the uniform of the participant and is placed in the individual's hearing zone as seen in Figure 2.

Figure 2: NoisePro DLX Hearing Zone Placement

The Edge eg5 model dosimeters are smaller and the entire body of the instrument and microphone can be attached to an individual's collar as seen in figure 3.

Figure 3: The Edge eg5 Hearing Zone Placement

***Average Sound Level***

OSHA utilizes the 8-hour Time Weighted Average (TWA) for regulatory and compliance purposes. A TWA is an hour 8-normalized measurement and doesn't represent average sound level for any period (5). The average sound level ($L_{avg}$) is often used for characterizing time-varying sound levels for time periods greater than 8 hours during an exposure period ((5). Since this characterization utilized a threshold of 70 dBA the average sound level or $L_{avg}$ will be used vice equivalent sound level.

***Threshold Effect***

Quest NoisePro™ DLX dosimeters are capable of measuring a threshold of 60 dBA, while The Edge™ eg5 dosimeters are only capable of setting the threshold to 70 dBA. The difference between the two dosimeter thresholds was not noticed until the conclusion of data collection during the underway. Internal circuits in the noise dosimeter exclude measured sound levels below the appropriate threshold setting, which affects noise exposure doses and average sound levels; therefore in comparing noise dosimetry during data analysis, one must be aware that data collected with differing thresholds cannot be directly compared (26) . Noise dosimetry measurements with the NoisePro™ DLX had to be mathematically adjusted by DMS to compare results with two different thresholds using the following equation to verify results with 3M™ Detection Management Software "What if" Data Panel function (Figure 4). The "What If" Data Panel allows the user to recalculate data by changing parameters. The "What if" Data Panel operates in accordance with specification for noise dosimeters ANSI 21.25. In altering the threshold parameter for NoisePro DLX dosimeters to match The Edge eg5 dosimeters, the "What If" Data Panel no longer factors in sound pressures below the new parameter of the 70 dB threshold in the dose %, $L_{avg}$, or TWA calculation.

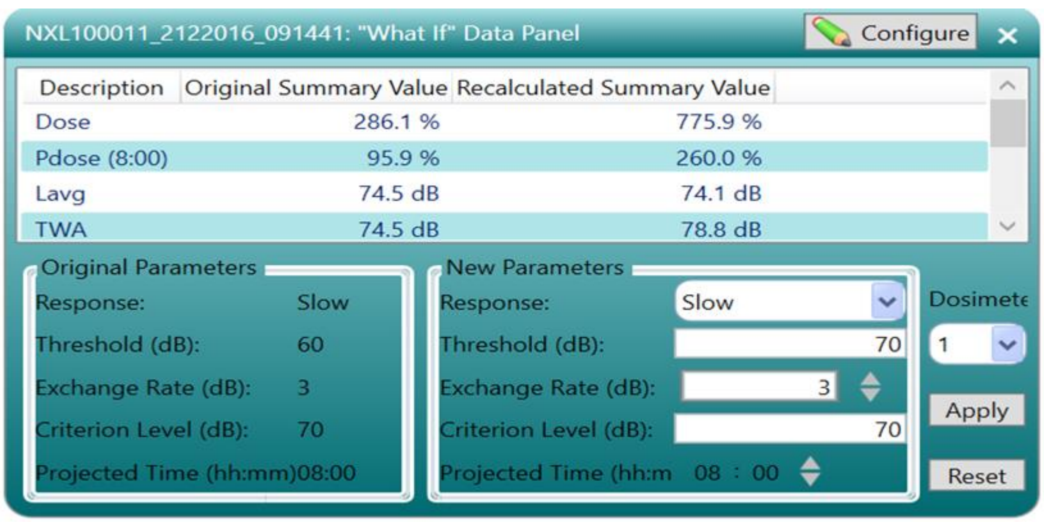


Figure 4: 3M™ Detection Management Software: What If Data Panel

***Noise Measurement Data Download***

While noise dosimeters offer Sound Level Meter (SLM) capabilities and can be read directly from the display screen and recorded manually for individual sampling data, several accessories aid in the collection and analysis of noise dosimetry data. An activity form (Figure 5) was created with slight modifications utilizing MAJ Raushan Salaam's field tested activity form. The activity form was used primarily for sample tracking purposes but was also used to match noise measurements with activity throughout day in the event an unexplained result occurred.

| **Activity**<br><br>Please include the following to describe what you were doing during the timeframe:<br><br>Work task description<br><br>Major noise sources<br><br>Breaks/Eating/ Sleeping/other | **0600-1200** | **1200-1800** |
|---|---|---|
| **Activity**<br><br>Please include the following to describe what you were doing during the timeframe:<br><br>Work task description<br><br>Major noise sources<br><br>Breaks/Eating/ Sleeping/other | **1800-0000** | **0000-0600** |

DEPT:____________________ DIV:____________________

RATE____________________ RANK____________________

Date and time dosimeter started:____________________

Sample ID:______________________________

Figure 5: Activity Form adapted from (1)

A personal computer with Windows 10 software, 3M™ Database Management Software (Version 2.9.159.0), and ACTiSYS Infrared (IR) wireless interface with driver (ACT-IR424UN Version 1.0.0), and an activity tracking form. The 3M™ DMS is a desktop based software that allows for the storage and analysis of data collected by noise dosimeters. The features primarily used for this study were instrument configuration and advanced report generation. The software provides a summary data panel with useful information pertinent to this study to include: runtime, Dose %, $L_{avg}$, and TWA.

A PC preloaded with 3M™ DMS software and an infrared USB data-transfer cable was used to download the data from the NoisePro DLX dosimeters, while the Edge eg5 type dosimeters were downloaded to DMS via a dual use charging/downloading docking station. Once each dosimeter sample session had been stopped at approximately 24 hours and was added to the DMS database, each sample was reviewed under the “Data Finder” tab to ensure approximately 24 hours of sample data was collected. The time-history for each sample’s data log should display a total of approximately 1,440 1-minute sound pressure level averages. The 24-hour $L_{avg}$ exposure results were directly exported from DMS to Excel spreadsheets for data compilation and initial analysis.

A sampling log was created that included the following information: sample date, noise dosimeter serial number, HEG, date, department, rank, total sampling time, and any other observations during sampling event pertinent for data analysis. Other pertinent information included time dosimeter was taken off for personal matters and included artifacts such as microphone tapping. The sampling log was used to pair a particular sample with the noise dosimetry data found in DMS.

***Statistical Analysis***

SPSS (version 24) software was used for data analysis. Descriptive statistics were used to characterize the exposure and compare noise measurements to EPA 24-hour environmental exposure recommendations. The data was analyzed visually using a histogram, boxplot, and a normal Q-Q plot to determine if the data followed a normal distribution. To determine if there was a statistically significant difference between homogenous exposure groups (α: 0.05), nonparametric analysis using the Welch T-test and Post Hoc analysis using the Dunnett T3 were conducted due to a lack of homogeneity of variance and to determine differences between HEGs respectively.

# CHAPTER 3: RESULTS

***Results of Personal Noise Dosimetry by HEG***

Overall, 47 noise dosimetry samples were collected during the routine underway; 1 noise dosimeter did not yield noise measurements, and 1 sample was identified as an outlier. The dosimeter that did not yield data was pre/post calibrated appropriately and no cause for the lack of data in that one sample was determined. Therefore, the dosimeter was utilized throughout the rest of the sampling period. Table 5 displays $L_{avg}$ results for selected HEGs respectively: HEG 1 (Admin, CRMD, Legal, Training), HEG 2 (Combat Systems, Operations), HEG 3 (Medical, Dental), and finally HEG 4 (Supply).

Table 5: Lavg Results for HEGs

| HEG 1 ADMIN, CRMD, LEGAL, TRAIN (dBA) | HEG 2 Combat Systems, OPS (dBA) | HEG 3 MED/DENT (dBA) | HEG 4 SUPPLY (dBA) |
|---|---|---|---|
| 74.8 | 78.5 | 73.7 | 70.9 |
| 72.3 | 75.4 | 71.2 | 75.4 |
| 84.1 | 77.6% | 76.8 | 74.1 |
| 82.4 | 80.5 | 75.9 | 75.9 |
| 71.6 | 82.8 | 76.2 | 76 |
| 78.6 | 83.5 | 76.7 | 75.1 |
| 76.8 | 77.1 | 73.0 | 70.1 |
| 71.3 | 82.3 | 75.9 | 78.6 |
| 87.6 | 85.7 | 72.9 | 76.5 |
| 80.8 | 80.7 | 74.2 | |
| 75.7 | 71.0 | 77.1 | |
| 69.2 | | 75.1 | |
| 74.4 | | | |

Objective 1: Characterize personal 24-hour noise exposures to determine if exposures exceed EPA 24-hour OEL in personnel not historically enrolled in the Hearing Conservation Program during routine carrier operations.

All but 1 (97.8%) of the 45 noise dosimetry samples exceeded 24-hour EPA environmental noise recommendations of 70 dBA. The overall mean value of the noise dosimetry samples was 81.3 dBA, ranging from 74.1 dBA-87.6 dBA, with a standard deviation of 4.3 dBA. Sample #47 was identified as an extreme outlier and was excluded from statistical analysis as discussed later in this chapter. Descriptive statistics of noise measurements is provided in Table 6.

Table 6: Descriptive Statistics of Noise Measurements

| # of Samples | Mean (dBA) | Std. Error of Mean (dBA) | Std. Deviation (dBA) | Range (dBA) | Min. (dBA) | Max. (dBA) |
|---|---|---|---|---|---|---|
| 45 | 76.5 | 0.6 | 4.3 | 18.4 | 69.2 | 87.6 |

The histogram is a numerical graph that plots observed values (X-axis, in dBA) against their frequency of occurrence. Histograms provide a general shape of the data or its distribution, additionally histograms provide some insight into amount of variability or spread of the data. The histogram (Figure 6) appears to be relatively symmetric and normally distributed. Variability in the data is discussed further in the limitations section.

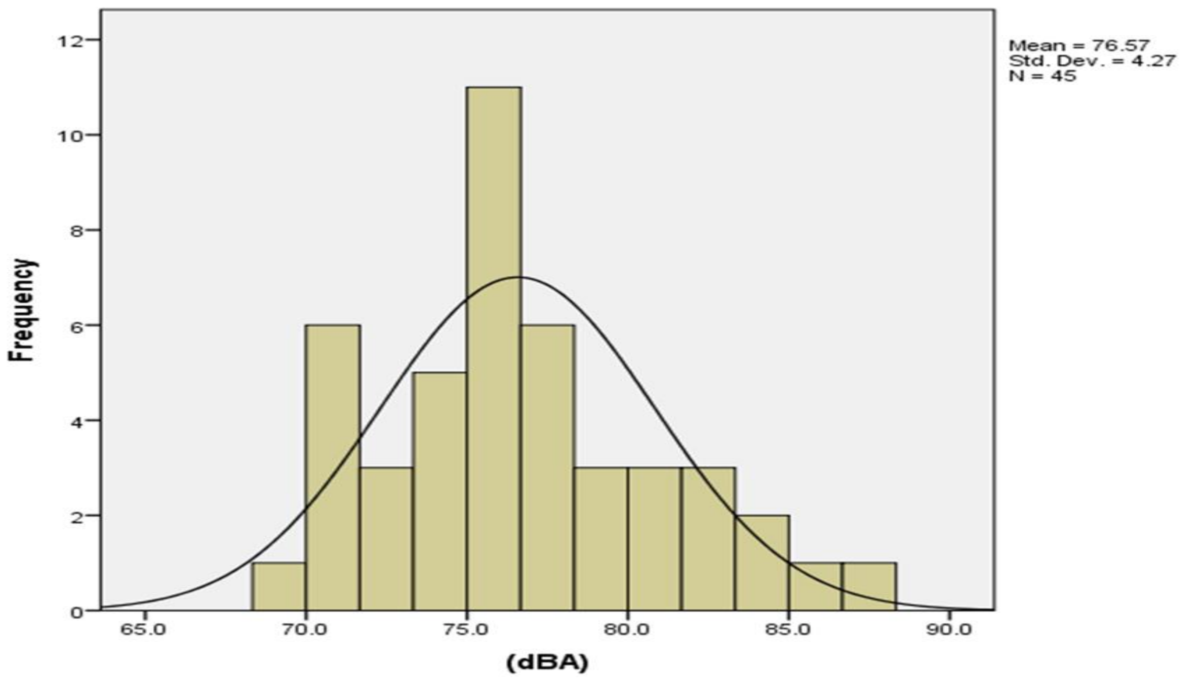


Figure 6: Histogram of Lavg Data

The Quarter-Quantile (Q-Q) Plot (Figure 7), is another graphical tool used to aid in the assessment of whether or not a set of data is normally distributed. While interpretation of the Q-Q Plot is somewhat subjective, it allows for further visual interpretation of normality. The Q-Q Plot displayed as figure 6 appears to follow normality as it does appear that all the dependent variable data points fall on/about a straight line.

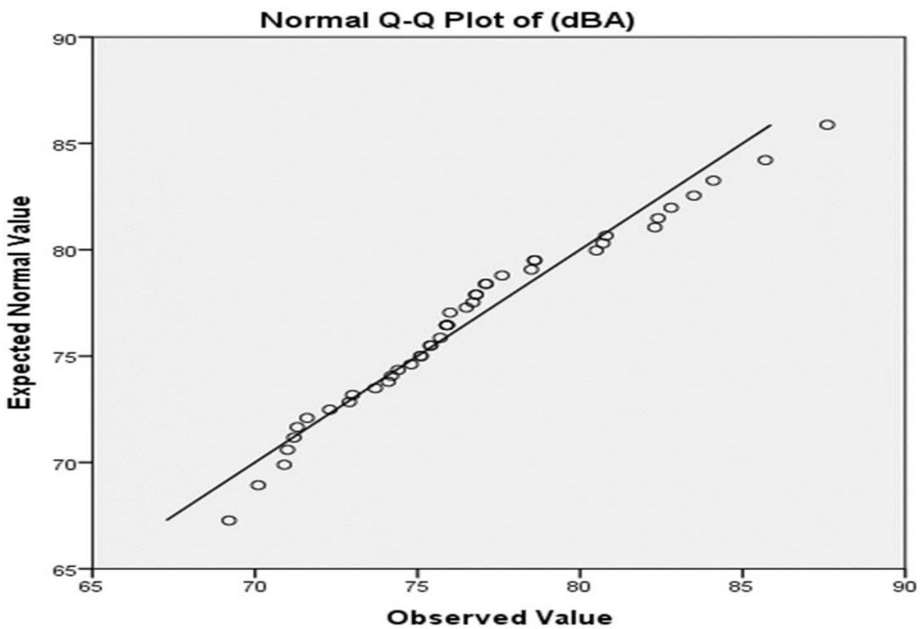


Figure 7: Quarter-Quantile (Q-Q) Plot

The boxplot (Figure 8), or box and whisker plot, is a graphical tool which shows numerical data with quartiles. The median is displayed with a horizontal line inside the box, the interquartile range (IQR) as the length of the box itself, and the whiskers are the lines which extend from the box. The whiskers represent variability outside of the quartiles, while the interquartile range represents variability by dividing the data into quartiles ($25^{th}$ and $75^{th}$).

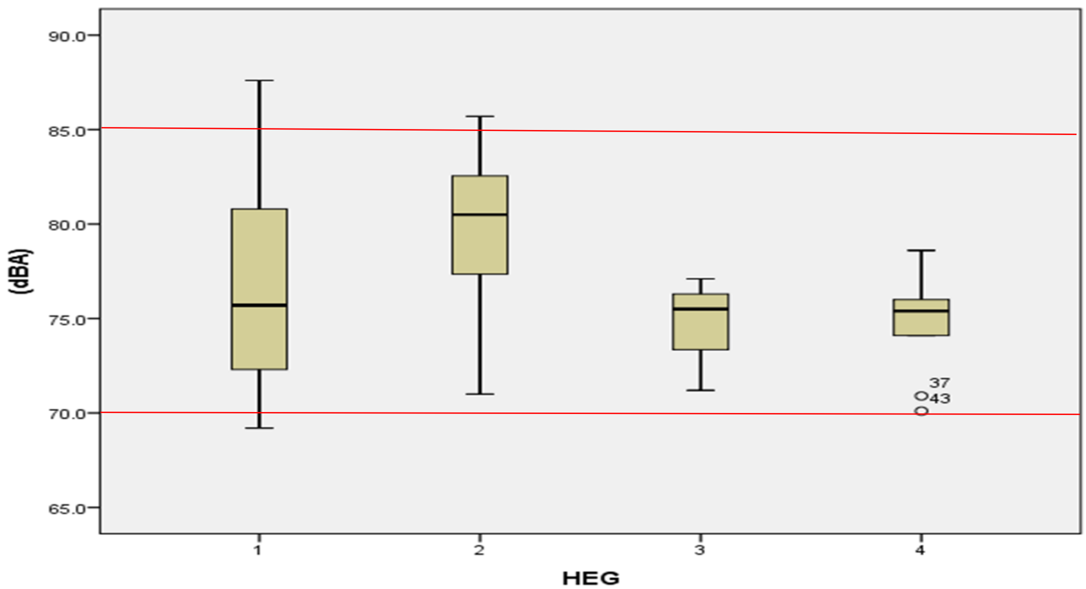


Figure 8: Boxplot of dBA Values According to HEG

Data points on either side of the boxplot that are greater than 1.5 times the IQR are considered outliers (depicted in figure 7 as a hollow circle), and those data points on either side of the boxplot greater than 3 times the IQR are known as extreme outliers. One sample from HEG 4 (Supply Department) was identified as an extreme outlier during the boxplot visual analysis for normality, and two samples in HEG 4 were identified. The two outliers in HEG 4 (Supply Department) were not analyzed for exclusion after consultation with field notes did not review intentional data tampering as was the case with the extreme outlier. The Grubbs Test is a quantitative test that is used to test single data points to determine if an outlier can justifiably be eliminated during data analysis.

Grubbs Test

$H_0$ = There are no outliers in the data

$H_a$ = The maximum value is an outlier

Equation 1: $$G = \frac{Y_{\max} - \bar{Y}}{s}$$

$$G = \frac{92.7 - 76.9}{4.8} = 3.3$$

DF= N-2= 44

Critical value for an upper one-tailed test at $\alpha = 0.05 = 2.9$

Critical region: Reject H0 if $G > 2.9$

Reject the null hypothesis. Maximum value is in fact an outlier at the 0.05 significance level.

The Grubbs test (Equation 1) identified the maximum value of 92.7 dBA as an outlier, while the two other data points in HEG 4 were not analyzed due to being within 1.5 times the IQR. Additionally, the participant stated that the dosimeter had been tampered. Thus, all further statistical analysis excluded the data point. Results and conclusions drawn from the data will be based on data with the outlier removed.

Descriptive statistics of each HEG (Table 7) were calculated using SPSS version 24. HEG 2 had the highest mean exposure of the four HEGs, while HEG 1, HEG 3, HEG 4 had similar mean exposures. HEG 2 also had the highest minimum noise measurement while HEG 1 had the highest noise maximum measurement.

Table 7: Summary Table of Lavg Noise Data

| | HEG 1 (ADMIN, CRMD, LEGAL, TRAIN) | HEG 2 (Combat Systems, OPS) | HEG 3 (MED/DENT) | HEG 4 (SUPPLY) |
|---|---|---|---|---|
| Mean (dBA) | 76.9 | 79.6 | 74.4 | 74.8 |
| Minimum (dBA) | 69.2 | 71.0 | 70.6 | 70.1 |
| Maximum (dBA) | 87.6 | 85.7 | 77.1 | 78.8 |
| LCL (dBA) | 73.6 | 76.7 | 73.0 | 72.7 |
| UCL (dBA) | 80.2 | 82.4 | 75.8 | 76.9 |

Objective 2: Compare 24-hour personal noise exposures among selected aircraft carrier departments to determine if there are differences between non-HCP HEGs.

***ANOVA***

Assumptions associated with Analysis of Variance (ANOVA) includes normally distributed data and equal variance between groups (homogeneity of variance). Outliers were examined prior to ANOVA and the other assumption of independence of case were met during the design phase of the study. Each HEG consisted of different individuals and each individual was measured once.

$H_0$: Means of all HEGs are equal

$H_a$= Means of HEGs are not equal

Test of normality: the Shapiro-Wilk test yielded p-values for HEG 1 (Admin, CRMD, Legal, Training) = .720, HEG 2 (Combat Systems, Operations) = .892, HEG 3 (Medical, Dental) = .379, and HEG 4 (Supply) = .381. The null hypothesis cannot be rejected and therefore the data comes from a normal distribution.

Test of homogeneity of variances: The Levene's Test of Equality of Variances was performed to determine homogeneity of variance and yielded a p-value of 0.017, we fail to reject the alternative hypothesis and the assumption of homogeneity of variance is violated.

The Welch T-Test was used to test the hypothesis that there is equal variance among group means because the data failed the Levene's Test of Equality of Variances. The Welch test is robust to violations of homogeneity of variance in that the Welch's t-test maintains type I error rates close to nominal for unequal variances and sample sizes. The result of the Welch T-Test was statistically significant (p-value= 0.013), or the means of the HEGs are not equal. Post Hoc analysis was then conducted to determine differences between the HEGs.

***Post Hoc Analysis***

The Dunnett T3 test is a method to be used when comparing groups of unequal size, unequal variances, small sample sizes, and when it is essential to maintain significance across multiple tests.

The results of the Dunnett T3 Test (Table 8) can be seen on the page below. There were statistically significant differences between HEG 2 and HEG 3 (significance= 0.014, lower bound= 0.898, upper bound= 9.361), and between HEG 2 and HEG 4 (significance= 0.04, lower bound=0.162, upper bound= 9.347). HEG 2 had the highest mean exposure of all the HEGs and was comprised of individuals in Combat Systems and Operations. HEG 2 included participants with work spaces located exclusively on the 03 level, or the level directly below the flight deck. HEG 3 was comprised of Medical and Dental department participants whose work spaces were located on the $2^{nd}$ deck. HEG 4 was comprised of individuals whose work spaces were primarily located on the 03 level but also included individuals on the 02 and below.

Table 8: Dunnett T3 Post Hoc Analysis

**Multiple Comparisons**

Dependent Variable: (dBA)
Dunnett T3

| (I) HEG | (J) HEG | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -2.6622 | 1.9853 | .698 | -8.369 | 3.045 |
| | 3 | 2.4673 | 1.6584 | .601 | -2.460 | 7.395 |
| | 4 | 2.0923 | 1.7880 | .804 | -3.127 | 7.312 |
| 2 | 1 | 2.6622 | 1.9853 | .698 | -3.045 | 8.369 |
| | 3 | 5.1295* | 1.4109 | .014 | .898 | 9.361 |
| | 4 | 4.7545* | 1.5612 | .040 | .162 | 9.347 |
| 3 | 1 | -2.4673 | 1.6584 | .601 | -7.395 | 2.460 |
| | 2 | -5.1295* | 1.4109 | .014 | -9.361 | -.898 |
| | 4 | -.3750 | 1.1162 | 1.000 | -3.719 | 2.969 |
| 4 | 1 | -2.0923 | 1.7880 | .804 | -7.312 | 3.127 |
| | 2 | -4.7545* | 1.5612 | .040 | -9.347 | -.162 |
| | 3 | .3750 | 1.1162 | 1.000 | -2.969 | 3.719 |

*. The mean difference is significant at the 0.05 level.

# CHAPTER 4: DISCUSSION

The current investigation targeted individuals assigned to U.S. Navy Nimitz class aircraft carriers that are normally not included in HCPs due to noise exposures less than 85 dBA. Results of this study indicate that individuals were exposed to noise levels less than 85 dBA as an 8 hour TWA, however a risk still may be present due to noise exposure above EPA recommendations of 70 dBA for a 24-hour period. Studies by Yankaskas et al and Aubert et al. suggest personnel adjacent or below the flight deck on the 03 level during flight operations are potentially exposed to hazardous noise (up to 100 dBA). This study had a mean noise exposure level of 76.5 dBA compared to a mean noise exposure level of 93 dBA in the study by Salaam (2014). The target population for this study was individuals with an 8-hour TWA <85 dBA while the Salaam study focused on aviation personnel. Mean results from this study were well below the mean results in the Neitzel et al study in the catcher/processor ships and the IMO occupational exposure level of 80 dBA; however, the U.S. Coast Guard recommends HCP implementation at 77 dBA (13).

Currently, personnel assigned to aircraft carriers are placed into the DoD HCP when noise exposures reach 85 dBA or greater based upon an 8-hour 85 dBA TWA. The 8-hour TWA assumes 16 hours of rest for hearing recovery. A previous study by MAJ Salaam indicate that hearing recovery areas (berthing and recreational) on Nimitz class aircraft carriers are above recommendation for hearing recovery areas. A 12-hour shift for personnel not included in the HCP is spent primarily in administrative work areas near where flight ops are occurring. The other 12 hours are spent in an off-duty status and are spent resting/relaxing in spaces designed for eating, exercising and recreational purposes. Personnel may not be getting adequate hearing recovery during off-duty hours due to their close proximity to flight ops and hazardous noise producing equipment, therefore utilization of an 8-hour TWA for occupational exposures for determination of HCP inclusion may not be include all individuals with potential for NIHL. Currently there is no specific regulatory occupational exposure limit for 24-hour exposures or for occupational noise exposures without hearing recovery. The EPA 70 dBA recommendation for 24-hour environmental noise exposures to the general public may be an appropriate measure since it was designed to protect 96% of the population from developing NIHL and to protect the general public against the other health effects caused by nuisance noise exposure (EPA, 1976).

This study involved the creation of four HEGs based upon departmental assignment and task to determine if there were significantly different noise exposures between the HEGs. Personnel assigned to HEG 2 (Combat Systems, Operations) had significantly higher noise exposures from HEG 3 (Medical, Dental) and HEG 4 (Supply) respectively, which suggests that primary location of office space may be an appropriate measure for HEG placement in future noise dosimetry studies. These findings suggest personnel adjacent or below the flight deck during flight operations are potentially exposed to hazardous noise (up to 100 dBA), especially directly below the flight deck on the 03 level. Additionally, HEG 1 had significant variability when compared to the results of the other three HEGs suggesting further segmentation of the HEG may be appropriate. High variability is frequently present in occupational exposure studies due to variability throughout the day, between days, between seasons, and differences between workers and processes (28). When characterizing worker exposures, high variability can be present even if the assessor took a statistical approach when creating exposure groups (28). HEG 1 was a collection of primarily administrative personnel in multiple departments. Individuals in CRMD and Training (HEG 1) were in a work space adjacent to a flight deck access hatch on the 03 level and in an office space on the 02 level respectively. Both Departments had noise exposure profiles that were higher than administration and legal departments who were also in HEG 1.

# CHAPTER 5: CONCLUSION

The results of this study indicate that the 24-hour noise exposures of personnel not enrolled in the HCP and with 8-hour TWA noise exposures <85 dBA were found to be in excess of 24-hour EPA environmental noise recommendations. The 24-hour EPA environmental noise recommendation may be a more appropriate exposure limit of evaluating cumulative noise exposures as it was designed to protect 96% of the general population and it assumes no auditory rest periods. The study also indicated that 24-hour noise exposures on the 03 level were higher than noise exposures on lower decks. Studies completed on aircraft carrier aviation personnel and workers on commercial fishing vessels support these findings. Controlling noise exposures can be achieved by a combination of engineering, administrative, or hearing protection. Engineering controls are the most desirable method to control noise exposures and should be utilized whenever economically practical. Hearing protective devices are available onboard and can be worn be personnel in close proximity to the flight deck during flight operations.

***Limitations***

The current investigation was limited by several factors that must be acknowledged. Systematic and random error could have significantly affected exposure monitoring results by introducing bias.

Study participants were not randomized, personnel were -selected from the HEG/Department/Division of interest which introduces potential for selection bias. Participant's noise exposure may be different from exposures in personnel that did not choose to participate in the study.

Prior to data collection, the estimated sample size to achieve 80% power at 95% confidence for each HEG was calculated to be 12-15. However, due to operational commitments, two sampling days were not captured in this study which resulted in HEGs having unequal sample sizes and two HEGs with less than the desired 12 samples. Time required to complete the desired sampling plan should be considered in future studies and when scheduling underway evolutions to collect samples.

Quest NoisePro™ DLX dosimeters are capable of measuring a threshold of 60 dBA, while The Edge™ eg5 dosimeters are only capable of setting the threshold to 70 dBA. To establish consistency between the dosimeters a threshold of 70 dBA was used. This decision was made based upon the Lavg reading differing up to 1 dBA when corrected to 70 dBA.

Each participant was briefed on proper care of the noise dosimeter and microphone. Additionally, participants were asked after the study if the microphone had been intentionally blown on, tapped, or otherwise artificially influenced. Several participants stated that fellow sailors had induced artificial inputs or expressed the difficulty in inadvertently hitting the microphone. While artificial influence of noise dosimetry measurements is not typically a significant issue when utilizing OSHA noise exposure criteria; studies suggest that data contamination is more of a concern when ACGIH noise criteria is utilized and could result in 1-3 dB increase during 8-hour noise measurements (5). As this study attempted to characterize lower risk individuals (defined as individuals with 8-hour noise exposures < 85 dBA), criterion and threshold levels were lower than ACGIH criteria and least 1-3 dB or more may be attributed to contamination.

### *Future Research*

Since personnel onboard U.S. Navy Nimitz class aircraft carriers work and live in the same area, they potentially do not receive adequate auditory rest from occupational exposures and environmental noise exposures. While there is no a joint occupational and environmental noise exposure standard for individuals, the EPA does recommend 70 dBA as an appropriate parameter to evaluate 24-hour environmental noise exposures for the general population. The results of this study support further investigation in personnel not traditionally included in the DoD HCP on Nimitz class aircraft carriers. These personnel may be chronically overexposed to hazardous noise in a 24-hour period and there is potential for hearing loss in this group. Future noise dosimetry studies should focus on grouping HEGs according to location of work spaces (by deck) instead of by task or departmental assignment. Future studies could also investigate hearing loss risk for personnel with 24-hour noise exposures exceeding the 70 dBA EPA recommendation that also have 8 hour TWA exposures less than 85 dBA. Personnel with work spaces on the 03 and 02 levels may have higher overall 24-hour noise exposures than personnel below the 02 levels and these personnel should be targeted for future noise dosimetry studies on personnel not enrolled in the HCP. Prior to DoD or BUMED level policy changes to reflect 24-hour noise exposures above a particular occupational exposure limit, future studies should be done to determine if there is hearing loss among individuals that are below an 85 dBA TWA but above the EPA 70 dBA exposure limit. Hearing protection devices are the last step in the hierarchy of controls and are to be utilized when engineering and administrative controls cannot be implemented to control an identified hazard. The results of this study do not suggest that individuals on the 03 level need to wear hearing protection for the duration of flight operations.

This research will increase our understanding and provide descriptive information which may potentially reveal additional opportunities for targeted noise control and hearing conservation efforts.

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