Noise at sea: Characterization of extended shift noise exposures among U.S. Navy aircraft carrier support personnel

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ABSTRACT
The purpose of this investigation was to characterize 12-hr on-duty, 12-hr off-duty, and 24-hr noise exposures among U.S. Navy aircraft carrier support personnel. Noise dosimetry samples were collected for 47 aircraft carrier support personnel while at sea during airwing carrier qualifications. Leq measurements during 12-hr on-duty, 12-hr off-duty, and over 24-hr periods were compared to Threshold Limit Values. Four similar exposure groups (SEGs) were created based upon departmental assignment and similarity of work tasks: (1) Administration/Religious Ministries/Legal/Training, (2) Combat Systems/Operations, (3) Medical/Dental, and (4) Supply. Equivalent sound level (Leq) measurements in decibels “A” weighted (dBA) were compared to determine significant differences between each group according to 12-hr on-duty, 12-hr off-duty, and 24-hr periods. Mean 24-hr noise levels ranged from 69–88 dBA with 22% exceeding the 80 dBA Threshold Limit Value. Twelve-hr on-duty noise levels ranged from 71–90 dBA with 17% exceeding the 83 dBA 12-hr on-duty Threshold Limit Value. Twelve-hr off-duty noise exposure ranged from 68–84 dBA with 95% exceeding the 70 dBA American Conference of Governmental Industrial Hygienists threshold classified as effective quiet to allow for temporary threshold shift recovery. Welch Analysis of Variance and Dunnett T3 post hoc tests revealed SEG 2 had significantly higher 24-hr noise exposures than SEG 3 (p = 0.019) and SEG 4 (p = 0.045). SEG 2 had significantly higher 12-hr on-duty noise exposure than SEG 3 (p = 0.030). One Way Analysis of Variance revealed no significant differences between 12-hr off-duty noise exposures according to SEG (p = .096). Some aircraft carrier support personnel had 12-hr on-duty and 24-hr noise exposures exceeding Threshold Limit Values with a large proportion exceeding the 70 dBA effective quiet limit during 12-hr off-duty periods. Results suggest personnel that are typically considered low risk for hazardous noise exposure (<85 dBA) during 8-hr shifts may have a greater risk of noise exposure when considering full 12-hr and 24-hr shifts when working and living in close proximity.

KEYWORDS
12-hr noise exposure; 24-hr noise exposure; auditory rest; effective quiet; hearing loss; noise dosimetry

Introduction
The National Institute for Occupational Safety and Health (NIOSH) estimates occupational hearing loss is one of the most common work-related illnesses in the U.S., with 22 million exposed to hazardous noise levels at work.[1] The Occupational Safety and Health Administration (OSHA) estimates $242 million per year is spent on hearing loss disability.[2] Occupational hearing loss and tinnitus were the two most frequently occurring service-connected disabilities within the DoD for fiscal year 2017.[3] Occupational hearing loss develops over a long period of time and is irreversible. Prevention, early detection, and intervention efforts are critical to limit hearing loss.

Auditory and non-auditory effects have been associated with noise exposure. Because extended work-shifts, work-shifts >8 hr, are common on aircraft carriers, personnel are at risk of developing Temporary Threshold Shifts (TTSs) even when 8-hr TWAs are less than 85 dBA. A previous investigation by Mills et al. found threshold shifts increased 1.7 dB for every 1 dB increase in noise level beginning at 74 dB at 4,000 Hertz (Hz), 78 dB at 2,000 Hz, and 82 dB at 500 and 1,000 Hz over an 8-hr shift.[4] After noise exposure ended, hearing acuity returned to within 5 dB of pre-exposure levels within 24 hr when personnel were provided auditory rest in effective quite areas.[4] Non-auditory effects such as perceived disturbance, annoyance, cognitive
impairment, sleep disturbance, and cardiovascular disease have been investigated and linked to noise exposure in past studies.\cite{5} Environmental noise exposure has been shown to increase the prevalence of coronary heart disease mortality.\cite{6} Studies investigating sleep quality due to air, rail, and traffic noise found subjectively reported decreases in sleep quality and gradual increases in fatigue for noise levels reaching 74 dBA.\cite{7} There are multiple consequences associated with noise exposure and hearing loss in an operational/military setting, particularly on an aircraft carrier. Personnel rely heavily on verbal and non-verbal communication in both industrial and training scenarios and includes being able to detect auditory cues, warnings, and signals as an element of situational awareness. Other consequences are related to conventional hearing protection usage which may compromise auditory perception, degrade signal detection, reduce speech communication abilities, and diminish situational awareness. These issues are applicable for aircraft carriers as personnel are expected to respond appropriately in a wide variety of emergency and non-emergency situations such as shipboard/flight deck firefighting or maintaining the situational awareness to avoid being struck by a moving aircraft, forklift, or other industrial equipment.

**U.S. Navy aircraft carriers**

In the U.S. Navy, one of the central functions of an aircraft carrier is to launch and recover (land) aircraft. There are 11 U.S. Navy aircraft carriers (10 are Nimitz class carriers); each capable of supporting approximately 60 aircraft and approximately 5,000 personnel. The primary source of hazardous noise exposure is from launching aircraft (take-off) and recovering (landing) aircraft for personnel working on the flight deck. There are numerous sources of noise on an aircraft carrier. Examples include jet engines (both on the flight deck and transmitted through the ship’s structure), machinery/equipment to support aircraft launch and recovery such as steam operated catapults, and machinery to operate the ship such as generators, air compressors, engineering plants, ship’s propellers. This list of noise sources is not exhaustive but provides examples of sources commonly found on an aircraft carrier. Noise is transmitted through the ship and may lead to exposures, both on-duty and off-duty for personnel located in offices, classrooms, recreational areas, religious worship spaces, mess (eating) spaces, recreational physical training areas (on-board gyms), and berthing (sleeping) spaces. Aircraft carriers are organized vertically according to numbered decks and levels (Figure 1). Figure 1 is not to scale and does not display all decks and levels but represents relative locations of each monitored area.

The lowest decks, generally below the 3rd deck, contain the engineering and propulsion plant used to generate power for the ship. Moving up the carrier vertically, some berthing spaces are located on the 3rd deck while medical, dental, and mess spaces (eating areas) are located on the 2nd deck. The next area up vertically is the main/hangar deck which is used to stow aircraft when not in use and to perform aircraft maintenance. Moving up further are flight deck machinery spaces, berthing areas, fitness areas, and other support functions such as Religious Ministries, Legal, and Supply departments, among others on the 01, 02, and 03 levels. Just above the 03 level is the flight deck where aircraft are launched (take-off) and recovered (land). The areas that are most affected by noise generated from flight operations are located directly below the flight deck on the 03 level and in spaces in close proximity to machinery.
Table 1. Summary of exposure duration noise standards (dBA) and exchange rates (dB).

| Standard                              | 8-hr | 12-hr On-Duty | 12-hr Off-duty | 24-hr | Exchange Rate |
|---------------------------------------|------|---------------|----------------|-------|---------------|
| Occupational Safety and Health Admin.  | 90   | 87\(^a\)      | N/A            | 82\(^a\)| 5             |
| Department of Defense                 | 85   | 83\(^a\)      | N/A            | 80\(^a\)| 3             |
| American Conference of Governmental Industrial Hygienists | 85   | 83\(^a\)      | 70\(^b\)       | 80    | 3             |

\(^a\)Exposure limit derived from 8-hr exposure limit and equal energy exchange rate
\(^b\)Defined as time away from the workplace in effective quiet to allow for temporary threshold shift recovery

Workers aboard operational aircraft carriers when at-sea commonly work a minimum of 12-hr shifts in their respective work spaces while the other 12-hr is considered off-duty time. There may be other work schedule configurations depending on department (e.g., personnel assigned to the flight deck may work 13–14-hr shifts) but 12-hr is the most common for most aircraft carrier personnel when at-sea. On an aircraft carrier, personnel working on the flight deck during flight operations (e.g., Air department), participating in aircraft maintenance activities (e.g., Aircraft Intermediate Maintenance department), or working in the engineering plants (e.g., Engineering department) are typically monitored in a Hearing Conservation Program (HCP) due to measured or anticipated exposures >85 dBA as an 8-hr TWA. Aircraft carrier support personnel are also assigned to aircraft carriers to provide a variety of support services to include professional/administrative duties. Support personnel are anticipated to have low noise exposures (<85 dBA) based on their work tasks. These groups include Religious Ministries, Medical, Dental, Media, Navigation, and Operations departments among others. During off-duty hours when an aircraft carrier is at-sea, personnel remain on the ship but are usually free to spend most of that time in their berthing, or at mess decks, libraries, classrooms, or spaces used for recreational physical training. These leisure areas are commonly located adjacent to flight deck operations and machinery capable of producing noise levels >85 dBA.

Regulations and standards

Table 1 displays a summary of exposure duration linked noise standards and associated exchange rates relevant for 8-hr and extended shift noise exposures. The OSHA permissible exposure limit (PEL) is 90 dBA as an 8-hr time weighted average (TWA). HCP implementation is required when 8-hr TWAs exceed 85 dBA. Despite recognition that prolonged exposure to hazardous noise can cause permanent hearing loss, there is little regulation governing environmental and recreational noise exposures.[8]

OSHA regulates occupational noise exposures for 8-hr shifts rather than exposure durations that include situations where the employee rests/sleeps near their work space for longer than 8-hr durations. The American Conference of Governmental Industrial Hygienists (ACGIH\(^a\)) indicates when workers are restricted for periods >24 hr to employer-controlled areas that serve as both workplace and living quarters, the average noise exposure over a 24-hr period should not exceed 80 dBA.[9] TLVs\(^a\) such as 85 dBA for 8 hr, 82 dBA for 16 hr, and 80 dBA for 24 hr are based on daily exposures where there will be time away from work in effective quiet areas (i.e., < 70 dBA) to rest and sleep after exposure and to allow recovery from any potential Temporary Threshold Shifts (TTSs) that may have developed.[9] The Department of Defense (DoD) and U.S. Navy standards require personnel to be entered in an HCP when routine occupational noise exposure is equal to or greater than 85 dBA as an 8-hr TWA with a 3 dB exchange rate (ER) with no additional consideration for on-duty durations longer than 8 hr or Occupational Exposure Limits (OELs) for off-duty periods.[10,11]

Noise monitoring metrics include $L_{avg}$ (average level), $L_{eq}$ (equivalent sound level), and TWA. $L_{eq}$ is based on a 3 dB ER and is used by agencies such as NIOSH while U.S. OSHA references $L_{avg}$ and a 5 dB ER. $L_{avg}$ and $L_{eq}$ with eventual comparison to equal energy-derived $L_{eq,ER}$ rather than the TWA, are appropriate metrics for extended work-shifts since the TWA is an 8-hr normalized measurement and does not represent exposures longer than 8-hr. The equal energy principle, using a 3 dB ER, indicates allowable exposure duration should be halved for every noise intensity increase of 3 dB. Regarding extended work-shifts, permissible noise exposure intensity should be reduced for exposure durations longer than 8 hr.

Background

Most noise studies have focused on 8-hr work exposures rather than examining both work and non-work 24-hr noise exposures that include environmental or recreational settings, particularly 24-hr noise exposures during routine aircraft carrier operations. A study by Yankaskas and Fast[12] used sound level meters to identify sound levels ranging from 60–100 dBA on the third level, the level immediately below...
the flight deck, during flight operations. Noise measurements for Norwegian Navy vessels such as mine vessels, frigates, coast guard, and coastal corvettes revealed mean A-weighted $L_{eq}$ values as high as 92.6 dBA during their 7-hr mean work shift for mine vessel electricians and as low as 65.9 dBA for navigators during their 13.7-hr mean work shift on coast guard vessels. Sailors may have varying noise exposures from their primary occupation and proximity to noise-hazardous areas not necessarily directly related to their occupation.

Study of noise exposures at-sea is also limited in civilian industries. All $L_{eq}$ measurements of 24-hr noise exposures exceeded the 80 dBA 24-hr TLV for a population of commercial fisherman onboard a combination catcher/processor vessel at sea for durations ranging from 13–18 days. A study of Danish personnel employed as seafarers and fisherman in the fishing industry from 1994–2003 while at sea for duty periods spanning days to months, found personnel working in the engine room had more frequent occurrence of hearing impairment compared to a non-seafarer Danish workforce (work shift and at-sea duration not reported). The results of these investigations suggest seafarers are at risk for Noise Induced Hearing Loss (NIHL) while at sea.

Continuous noise dosimetry supplemented with a time-activity log conducted during both occupational and non-occupational activities for such occupations as office workers, day-care workers, and military flight technicians revealed weekly exposures ranging from 76–81 dBA. While day-care workers had the highest daily exposures, flight technicians had the highest weekly exposures, with most weekly exposures exceeding 70 dBA. Office worker noise exposures were predominately non-occupational, while flight technician noise exposure was balanced between non-occupational and occupational activities. Characterization of 24-hr noise exposures during an on-duty work period, an off-duty recreational period, and while sleeping in 10 high risk industries in Denmark revealed average overall occupational exposures of 83.7 dBA, recreational activity exposures of 75.6 dBA, and 69.2 dBA when sleeping. These investigations suggest off-duty noise exposure may substantially contribute to overall noise exposure, specifically for occupations that traditionally are not entered in HCP due to 8-hr TWA exposures <85 dBA.

The purpose of this investigation was to characterize personal 24-hr, 12-hr on-duty, and 12-hr off-duty noise exposures among aircraft carrier support personnel, who were not included in an HCP and to determine if exposures exceed OELs during routine carrier operations. Additionally, the goal of the study was to compare 24-hr, 12-hr on-duty, and 12-hr off-duty personal noise exposures among selected aircraft carrier departments to determine if there were differences between similar exposure groups (SEGs).

**Methods**

**Method overview**

This investigation was conducted from November 29–December 9, 2016 onboard CVN 73 USS GEORGE WASHINGTON (Nimitz Class aircraft carrier) during routine Fleet Replacement Squadron Carrier Qualifications (FRSCQs) where new pilots are trained and qualified during the launching and recovering of aircraft. Flight operations typically lasted 12 hr 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. Flight operations were the primary noise source during this at-sea period but other noise sources/evolutions included emergency response drills (General Quarters), Man Overboard Drills, and nightly propulsion-plant drills. Aircraft carrier support personnel assigned to departments not enrolled in the DoD HCP and with noise exposures <85 dBA were specifically invited to participate in the study due to an expectation of substantial noise exposure. SEGs were created from selected shipboard departments and were compared to determine if there were differences between the groups.

**Study population**

Potential volunteers were identified by reviewing the aircraft carrier’s industrial hygiene survey report and selecting personnel in departments and work centers with measured 8-hr TWA noise exposures <85 dBA or anticipated 8-hr TWA noise exposures <85 dBA as validated with a written exposure evaluation. No departments or work centers meeting the low risk noise exposure previously discussed were excluded from the study, however, not all were represented due to volunteer interest and availability during the limited study timeframe.

Solicited participants were provided a briefing concerning the purpose and methods of the study, a worksheet to log their activities during the 24-hr monitoring period, were instructed to avoid tampering with noise dosimetry monitoring equipment, and were requested to perform their normally assigned duties.
During off-duty hours, participants were instructed not to remove the noise dosimeters unless showering or sleeping. While sleeping, participants were instructed to place the dosimeter in the sleep area or next to the sleeping area and as close as possible to the ear. The participants were also instructed not to cover the noise dosimeter microphone.

The study was approved by the Human Research Protection Program Office of Uniformed Services University of the Health Sciences (USUHS) and was classified as non-human subjects research. No identifiable information was collected in connection with the investigation. However, volunteers were provided a consent form approved by the USUHS IRB to document their voluntary participation in the study.

Four broad SEGs of non-HCP enrolled personnel were created using an observational approach considering location, task, division, and department assignment. Departmental composition of each SEG are provided in Table 2.

| SEG | Locations | Department | Description |
|-----|-----------|------------|-------------|
| 1   | Multiple (01, 02, 03 Levels) | Administrative | Computer, printer, and copier usage in support of customer service, accounting, public affairs, and personnel record management tasks |
|     |           | Religious Ministries | Provide ministry and spiritual counseling to include offering multiple denomination church services |
|     |           | Legal | Provide legal advice/assistance such as preparing wills, powers of attorney, and notary services |
|     |           | Training | Develop and provide training, manage training records |
|     | 03 Level | Combat Systems | Manage, repair, and use of communication equipment such as network computer systems, navigation equipment, and weapon systems |
|     |           | Operations/Intelligence | Support the aircraft carrier with weather forecasting, air traffic control, ship navigation/radar operations, and intelligence operations |
| 3   | 2nd Deck | Medical | Perform medical functions such as x-ray, pharmacy, preventive medicine, and sick-call functions |
|     |           | Dental | Conduct dental related processes such as dental cleanings, operations, dental x-ray, and equipment sterilization |
| 4   | Multiple (02 and 03 Level) | Supply | Provide financial functions to include handling money, shipping and receiving supplies, and managing the aircraft carrier’s post office |

**Activity logs/questionnaires**

Aircraft carrier support personnel were briefed on the purpose of the investigation, instructed to not tamper with noise dosimetry monitoring equipment, and provided an activity sheet/questionnaire to collect non-personally identifying information. The activity sheet/questionnaire was used to determine department, worker job title, work tasks, when and where a person spent their time during specific portions of the monitored period, and start and stop of on-duty and off-duty shifts. Personnel were instructed to fill out the activity sheets throughout their 24-hr monitoring period and to return to the location of dosimeter issue at the end of their 24-hr monitoring period.

**Materials**

Each participant wore either a 3M Quest Technology NoisePro DLX (Oconomowoc, WI) or 3M Quest Technology Edge eg5 (Oconomowoc, WI) personal noise dosimeter. The 3M Quest Technology NoisePro DLX was worn by each person on the belt and microphone shoulder mounted in the hearing zone. The 3M Quest Technology Edge eg5 was lapel-mounted in the hearing zone. Participants were requested to perform their normally assigned duties while wearing the noise dosimeter. During off-duty hours, participants were instructed not to remove the noise dosimeters unless showering or sleeping. While sleeping, participants were instructed to place the dosimeter in the sleep area or next to the sleeping area and as close as possible to the ear. The participants were also instructed not to cover the noise dosimeter microphone. Dosimeters were field pre-calibrated prior to the start of each 24-hr monitoring period and post calibrated at the end of each monitoring period with a 3M QC-10 field calibrator. The 3M QC-10’s parameters were factory set at 114 dBA and 1,000 Hertz.

Both the 3M Quest Technology Edge eg5 and NoisePro DLX personal noise dosimeters were set to slow response, dBA weighting, 3 dB ER, 70 dBA threshold level, and 85 dBA criterion level. The 70 dBA threshold was selected due to the anticipated noise levels measured among the low noise risk population. Noise dosimeter microphones and wind-screens were placed on the right shoulder. Noise levels were measured as a $L_{avg}/L_{eq}$ for the 24-hr exposure period representing the average sound level measured over the run time. Any sound below the 70 dBA threshold was not included in this average. $L_{avg}/L_{eq}$ differs from the TWA since TWA represents a constant sound level for an 8-hr duration that would result in the equivalent sound energy as the noise that
was sampled over the 8-hr period. The TWA is \( < \text{L}_{\text{avg}} \) during monitoring durations \(<8\) hr, the TWA = \( \text{L}_{\text{avg}} \) when the monitoring period = 8 hr, and the TWA \( > \text{L}_{\text{avg}} \) when monitoring duration is \( > 8 \)-hr. \( \text{L}_{\text{avg}} \) and \( \text{L}_{\text{eq}} \) are equivalent except \( \text{L}_{\text{eq}} \) is used in circumstances where the ER is set to 3 dB. Because \( \text{L}_{\text{eq}} \) is often used for characterizing time-varying sound levels for time periods greater than 8 hr during an exposure period using a 3 dB ER, this unit of measure was used in this investigation.

A personal computer with Windows 10 software (Microsoft, Redmond, WA), Database Management Software (DMS) (version 2.9.159.0, 3M), and ACTiSYS Infrared (IR) wireless interface with driver (ACT-IR424UN, Version 1.0.0, ACTiSys Corp., Fremont, CA) was used to download and save noise measurements from the noise dosimeters. The 3M DMS program and an infrared USB data-transfer cable were 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 hr and was added to the DMS database, each sample was reviewed under the “Data Finder” tab to ensure approximately 24 hr of sample data was collected. The minute-by-minute data logged sound pressure levels were exported from DMS to Excel spreadsheets. The downloaded noise data were isolated by 24-hr, 12-hr on-duty, and 12-hr off-duty according to each worker’s corresponding on-duty/off-duty start and stop times that were annotated on each questionnaire/activity sheet. The data-logged measurements were logarithmically added then averaged to determine each worker’s overall 24-hr, 12-hr on-duty, and 12-hr off-duty \( \text{L}_{\text{eq}} \) in dBA with a 3 dB ER.

### Statistical analysis

SPSS (Version 24, IBM Corp., Armonk, NY) was used for data analysis. Descriptive statistics were used to characterize noise exposures and compare noise measurements to OELs. Statistically significant differences between SEGs were assessed using an \( \alpha = 0.05 \). Parametric analysis was conducted with analysis of variance and post hoc tests for 12 hr off-duty noise exposures. Nonparametric analysis was conducted using the Welch T-test while Post Hoc analysis was conducted using the Dunnett T3 procedure due to some data failing the homogeneity of variance assumption and in order to determine differences between SEGs.

### Results

Overall, 47 noise dosimetry samples were collected during the underway/at-sea period. One sample, that was later determined to be an outlier, was removed due to equipment tampering and one sample was discarded due to noise dosimeter failure, leaving 45 noise dosimetry samples available for further 24-hr \( \text{L}_{\text{eq}} \) analysis. When assessing the 12-hr on-duty and 12-hr off-duty \( \text{L}_{\text{eq}} \), 4 measurements were discarded due to a logged data failure associated with the data management system software, leaving 41 sets of 12-hr on-duty and 12-hr off-duty noise measurements available for further analysis. Supplemental Table 1 presents all 24-hr, 12-hr on-duty, 12-hr off-duty, and peak noise measurements in dBA according to measurement date, SEG, department, and location.

### Descriptive statistics

Table 3 displays descriptive statistic \( \text{L}_{\text{eq}} \) results according to 24-hr, 12-hr on-duty, and 12-hr off-duty for
each SEG. The mean 24-hr $L_{eq}$ across all SEGs was 76.4 dBA. The $L_{eq}$ for 22.2% of personnel exceeded the 24-hr noise exposure limit of 80 dBA. Personnel assigned to SEG 2 (Combat Systems and Operations departments) had the highest mean 24-hr $L_{eq}$ while SEG 3 (Medical and Dental departments) had the lowest mean 24-hr $L_{eq}$. The mean 12-hr on-duty $L_{eq}$ was 78.3 dBA. The $L_{eq}$ for 9.7% of the personnel exceeded the 85 dBA 8-hr OSHA action level/DoD limit, while 17% of the personnel exceeded the 83 dBA 12-hr on-duty limit. Personnel assigned to SEG 2 had the highest mean 12-hr on-duty $L_{eq}$ while SEG 4 (Supply department) had the lowest mean 12-hr on-duty $L_{eq}$. Mean 12-hr off-duty $L_{eq}$ was 74.4 dBA. Personnel assigned to SEG 2 had the highest 12-hr off-duty $L_{eq}$ while personnel assigned to SEG 3 had the lowest 12-hr off-duty $L_{eq}$ with a mean difference of 3.4 dB. The $L_{eq}$ for 95% of the population’s 12-hr off-duty exposure exceeded the 70 dBA ACGIH threshold classified as effective quiet to allow for temporary threshold shift recovery.

Supplemental Table 2 presents descriptive statistic 24-hr, 12-hr on-duty, and 12-hr off-duty $L_{eq}$ results according to predominant department location (03 level, 02 level, 01 level, or 2nd deck). A majority of personnel were predominantly located on the 03 level (location closest to the flight deck). Mean 24-hr, 12-hr on-duty, and 12-hr off-duty $L_{eq}$ results were highest for personnel located on the 02 and 03 levels with mean dBA differences ranging from 0.3 dBA for the 24-hr $L_{eq}$ to 1.6 dBA for the 12-hr off-duty $L_{eq}$. These differences are beyond the 2 dB accuracy of a type 2 noise dosimeter. Mean 24-hr, 12-hr on-duty, and 12-hr off-duty $L_{eq}$ results were lowest for personnel located on the 2nd deck.

### Analysis of variance

Welch Analysis of Variance was used to determine if there were significant differences between the four SEGs because the assumption of homogeneity of variance was not met for the mean 24-hr $L_{eq}$ ($p = 0.017$) and 12-hr on-duty $L_{eq}$ ($p = 0.037$). As displayed in Table 4, there was a statistically significant difference at the $p < .05$ level between the four SEGs for their 24-hr $L_{eq}$ ($p = 0.016$) and for their 12-hr on-duty $L_{eq}$ ($p = 0.028$). The estimated omega squared indicated that between 18.1% and 18.6%, of the total variation in the measured $L_{eq}$ was attributable to the SEGs assigned.

Post hoc comparisons were conducted to determine which SEGs had significantly different 24-hr $L_{eq}$ and 12 on-duty $L_{eq}$. Results for 24-hr $L_{eq}$ indicate personnel in SEG 2 Combat Systems and Operations departments had significantly higher mean 24-hr $L_{eq}$ than SEG 3 Medical and Dental departments ($p = 0.019$) and SEG 4 Supply department ($p = 0.045$) by approximately 5 dBA (Table 5). Only 12-hr on-duty $L_{eq}$ between SEG 2 and SEG 3 were significantly different ($p = 0.030$) with SEG 2 nearly 5 dBA higher than SEG 3 (Table 6).

A one-way between-groups analysis of variance was conducted to explore the impact of SEG membership on 12-hr off-duty $L_{eq}$. As presented in Table 7, there was no statistically significant difference in 12-hr off-duty $L_{eq}$ for the four SEGs ($p = 0.096$).

### Discussion

The current investigation targeted individuals assigned to U.S. Navy Nimitz class aircraft carriers that are normally not included in HCPs due to anticipated low risk noise exposures (<85 dBA OSHA Action Level/ACGIH/DoD OEL) from professional/administrative support duties. Results of this study indicate that mean noise exposures were less than the 85 dBA 8-hr (OEL), however, some noise exposures exceeded noise limits for 24-hr, 12-hr on-duty, and 12-hr off-duty exposure periods. There is limited literature available about noise exposure at sea, during extended work shifts, and for a traditionally low noise risk population. However, a study by Yankaskas and Fast suggest personnel adjacent or below the flight deck on the 03 level during flight operations are potentially exposed to short term hazardous noise up to 100 dBA during flight operations. The current investigation resulted in mean noise measurements of 73–81 dBA at similar locations, but over longer 12-hr on-duty, 12-hr off-duty, and 24-hr periods. The locations measured in the Yankaskas and Fast were in close proximity to occupational work locations and off-duty locations frequented by aircraft support personnel. Mean results from the current study were generally less than the mean results in the Neitzel, Berna, and Seixas study of catcher/processor ships which was likely due inclusion of employees in engine and factory deck hazardous noise areas with mean 12-hr on-duty $L_{eq}$ ranging from 90.2–97.7 dBA.
The results that SEG 2 (Combat Systems/Operations departments) had significantly higher noise exposures than SEG 3 (Medical/Dental departments) and SEG 4 (Supply department) may have been due to the location of SEG 2 relative to flight operations. The flight deck is located immediately above the office spaces of personnel in SEG 2 on the 03 level. Personnel comprising SEG 1 and SEG 4 were similar to the other SEGs in having primarily administrative related duties but specific work space locations varied, ranging from adjacent to a flight deck access hatch on the 03 level to an office space further away from the flight deck on the 02 level. SEG 3 had among the lowest noise exposures between the SEGs which was likely due to being located in work spaces on the 2nd deck which was the furthest way from the flight deck compared to all other SEGs. Significant differences in 24-hr and 12-hr on-duty noise exposures between SEGs, despite similar administrative work tasks, suggests primary location of office/work space and proximity to primary noise source may be a better method of constructing SEGs and determining noise exposure risk in future noise dosimetry measurements than sole reliance on occupational work-tasks accomplished by a SEG.

Off-duty 12-hr noise exposures were not significantly different between SEGs. This may have been due to the fixed number of areas that personnel spend their off-duty time to include sleeping, eating, gym, religious, and library areas. Additionally, because most monitored personnel worked the day shift from 7:00 a.m. – 7:00 p.m. and flight operations ceased most nights by midnight, the noise contribution from flight operations as the primary noise source was expected to be nearly equal for all personnel's 12-hr off-duty period during this study.

The results of the current investigation are generalizable to many other aircraft carriers built to Nimitz class specifications. This class of aircraft carrier are designed similarly to include support for similar types of aircraft, use of similar types of engineering/propulsion equipment, and personnel conducting similar work functions in similar locations. As an example, medical department personnel work on the 2nd deck and at the same relative location to the flight deck and engine room compartments as every other Nimitz class carrier. Additionally, the same noise and vibration design specifications for noise hazardous spaces and non-working spaces are used for each Nimitz class aircraft carrier during ship design and alterations. Because U.S. Navy aircraft carriers are primarily responsible for launching and recovering aircraft, shipboard operations that pose noise exposure opportunities are similar regarding flight operation

| Table 5. Post hoc results for 24-hr $L_{eq}$ noise measurements according to SEG. |
| SEG | SEG | SEG Mean Differences (dBA) | Std. Error | $p$ | Lower Bound | Upper Bound |
|-----|-----|----------------------------|------------|-----|--------------|--------------|
| 1   | 2   | -2.57                      | 2.01       | 0.737 | -8.34        | 3.19         |
| 3   | 2.47 | 0.601                      | 0.778      | 3.19 | -3.03        | 7.35         |
| 4   | 2.16 | 0.71                       | 0.93       | 3.38 | -3.59        | 2.98         |
| 3   | 3    | 5.04                       | 1.44       | 0.019 | 0.71         | 9.37         |
| 4   | 4.73 | 0.045                      | 1.09       | 1.00 | -3.59        | 2.98         |

$p$ values in bold are statistically significant results.

| Table 6. Post-hoc results for 12-hr $L_{eq}$ noise measurements according to SEG. |
| SEG | SEG | SEG Mean Differences (dBA) | Std. Error | $p$ | Lower Bound | Upper Bound |
|-----|-----|----------------------------|------------|-----|--------------|--------------|
| 1   | 2   | -2.49                      | 2.23       | 0.833 | -9.00        | 4.02         |
| 3   | 2.36 | 0.766                      | 0.778      | 3.19 | -3.74        | 8.86         |
| 4   | 2.56 | 0.40                       | 0.35       | 3.30 | -0.10        | 10.21        |
| 3   | 4    | 0.21                       | 1.30       | 1.00 | -3.93        | 4.35         |

$p$ values in bold are statistically significant results.

| Table 7. One-way analysis of variance for 12-hr off-duty $L_{eq}$ noise measurements. |
| Sum of Squares | df | Mean Square | F | $p$ | Eta Squared |
|----------------|----|-------------|---|-----|-------------|
| 12-hr Off-Duty | 83.63 | 3 | 27.894 | 2.275 | 0.096 | 0.155 |
| Between Groups | 453.667 | 37 | 12.261 | | | |
| Total | 537.350 | 40 | | | |

The results that SEG 2 (Combat Systems/Operations departments) had significantly higher noise exposures than SEG 3 (Medical/Dental departments) and SEG 4 (Supply department) may have been due to the location of SEG 2 relative to flight operations. The flight deck is located immediately above the office spaces of personnel in SEG 2 on the 03 level. Personnel comprising SEG 1 and SEG 4 were similar to the other SEGs in having primarily administrative related duties but specific work space locations varied, ranging from adjacent to a flight deck access hatch on the 03 level to an office space further away from the flight deck on the 02 level. SEG 3 had among the lowest noise exposures between the SEGs which was likely due to being located in work spaces on the 2nd deck which was the furthest way from the flight deck compared to all other SEGs. Significant differences in 24-hr and 12-hr on-duty noise exposures between SEGs, despite similar administrative work tasks, suggests primary location of office/work space and proximity to primary noise source may be a better method of constructing SEGs and determining noise exposure risk in future noise dosimetry measurements than sole reliance on occupational work-tasks accomplished by a SEG.

Off-duty 12-hr noise exposures were not significantly different between SEGs. This may have been due to the fixed number of areas that personnel spend their off-duty time to include sleeping, eating, gym, religious, and library areas. Additionally, because most monitored personnel worked the day shift from 7:00 a.m. – 7:00 p.m. and flight operations ceased most nights by midnight, the noise contribution from flight operations as the primary noise source was expected to be nearly equal for all personnel's 12-hr off-duty period during this study.

The results of the current investigation are generalizable to many other aircraft carriers built to Nimitz class specifications. This class of aircraft carrier are designed similarly to include support for similar types of aircraft, use of similar types of engineering/propulsion equipment, and personnel conducting similar work functions in similar locations. As an example, medical department personnel work on the 2nd deck and at the same relative location to the flight deck and engine room compartments as every other Nimitz class carrier. Additionally, the same noise and vibration design specifications for noise hazardous spaces and non-working spaces are used for each Nimitz class aircraft carrier during ship design and alterations. Because U.S. Navy aircraft carriers are primarily responsible for launching and recovering aircraft, shipboard operations that pose noise exposure opportunities are similar regarding flight operation
duration, types of flight training, training and deployment cycles, and work shift duration.

Personnel assigned to aircraft carriers are typically monitored in a DoD HCP when noise exposures reach 85 dBA or greater as an 8-hr TWA. The 8-hr TWA assumes 16 hr of rest will be available for hearing recovery before the next 8-hr shift begins. An operational aircraft carrier is a unique environment where personnel often work shifts >8 hr. Also, spaces designed for off-duty relaxation may be adjacent to hazardous noise areas which minimizes opportunities for auditory recovery. Personnel included in the present study worked 12-hr shifts primarily completing administrative tasks that may have been adjacent to hazardous noise areas such as flight operations or conducting short duration tasks intermittently in hazardous noise areas. Noise exposure characterization in the present study did not consider hearing protection use since personnel’s primary work tasks did not include exposures >85 dBA. However, all aircraft carrier personnel are provided hearing protection and hearing conservation training that includes information on specific general areas that require hearing protection and information about how to read hazardous noise area warning signs. The other 12 hr of each day were typically spent in an off-duty status resting/relaxing in spaces designed for eating, exercising and recreational purposes but in close proximity to hazardous noise environments such as flight operations. Longer duration noise exposure via 12-hr on-duty and 12-hr off-duty shifts is further compounded by both high intensity noise exposure over a longer duration and by the reduced opportunity for auditory recovery that occurs when work shifts are extended beyond 8 hr. 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 to provide respite and auditory recovery. As a result, entry in an HCP based on an 8-hr OEL may not be including all individuals at risk to developing NIHL. Specifically, exposure to elevated noise levels while off-duty (>70 dBA) combined with high levels during on-duty extended work shifts may increase the risk of developing a TTS. Multiple TTSs may then lead to Permanent Threshold Shifts (PTTs) if unresolved over time.

Controlling noise exposures can be achieved by a combination of engineering, administrative, or personal protective equipment controls. Because personal protective equipment is generally considered the least preferred method of controlling worker exposures, engineering controls such as wall and ceiling sound absorption, partitions, and acoustic panels in off-duty spaces such as berthing and leisure areas could allow for reduced noise levels and provide better opportunities for auditory recovery. However, design and use of these controls on an aircraft carrier may be a challenge due to high cost of implementing throughout the ship, space restrictions, and effects on shipboard flammability. Feasibility determinations of engineering control implementation should be further assessed. Administrative controls to include reducing from a 12-hr work shift to 8-hr work shift would allow a simpler method of comparing exposures to OELs and would allow an opportunity to reduce individual noise exposures. However, low/variable aircraft carrier staffing and workload when at-sea makes additional administrative controls difficult to implement.

Limitations/future research

Despite the similarity of the GEORGE WASHINGTON aircraft carrier with other U.S. Navy Nimitz class carriers, there are limitations of the current investigation’s results. The at-sea noise measurements in the current investigation involved FRSCQs and, as a result, noise measurements may differ during at-sea periods with a higher operations tempo such as during deployment or during other types of aircraft carrier training qualifications. Noise levels may also differ for other ship types that support flight operations such as amphibious assault ships. Differences between ship types and ship sizes may be related to ship design, duration of flight operations, and differences in the types of aircraft supported compared to an aircraft carrier.

Another limitation was associated with being unable to control all variables that contributed to noise exposure. The primary noise source affecting personnel was anticipated to be flight operations and machinery on the ship to support flight operations. However, the noise produced from secondary sources such as shipboard engineering and propulsion equipment was not isolated from flight operation associated noise and was not measured to determine unique contribution to 24-hr, 12-hr on-duty, and 12-hr off-duty exposures. Not all berthing spaces, which made up most of the 12-hr off-duty exposure time, were located an equal distance from secondary noise sources such as engineering and propulsion equipment. Proximity variability may have resulted in higher noise measurements during 12-hr off-duty noise exposures for personnel located closest to engineering
spaces compared to personnel in berthing spaces near the flight deck but after flight operations had ceased for the day.

The investigation was limited to a small sample size and to a single Nimitz-class aircraft carrier. The small sample size prevented further analysis according to unique department, shipboard location, or time of day. At-sea duration of this study for the USS GEORGE WASHINGTON was a fixed length and unavailability of other aircraft carriers during the study period precluded additional data collection. Future studies should increase sample size and broaden the number of included departments (specifically departments included in HCPs), additional Nimitz-class aircraft carriers, more people across multiple 24-hr periods to determine day-to-day variability, and evaluate other ship types.

Future noise dosimetry studies should consider grouping low noise exposure risk SEGs according to location of work spaces (by deck) or proximity to the primary noise source instead of by occupational task or departmental assignment. Future studies should focus on TTS and PTS prevalence for populations working extended shifts to determine if personnel, despite exceeding the TLV, are at increased risk of hearing loss. Future study should also investigate if areas designated for auditory rest are providing an effective auditory recovery environment for personnel during their off-duty hours to include quantifying the amount of time each person spends in each auditory location. This could include performing octave band analysis in berthing areas and eating areas to determine the best method of providing sound absorption for noise reduction. Finally, future studies should investigate noise exposures among other aircraft carrier populations such as aviation/flight deck personnel and engineering personnel to reveal additional opportunities for targeted noise control and hearing conservation.

**Conclusions**

Since personnel onboard U.S. Navy Nimitz class aircraft carriers work and live in close proximity, they potentially do not receive adequate auditory rest from occupational and environmental noise exposures. The results of this study indicate that noise exposures may exceed the 80 dBA 24-hr noise limit, 83 dBA 12-hr on-duty noise limit, and the 70 dBA 12-hr off-duty threshold classified as effective quiet to allow for temporary threshold shift recovery promulgated by ACGIH. Results also suggest that some SEGs have higher mean noise exposures than others despite all having primarily professional/administrative work responsibilities.

Considerations for entering personnel in HCP/medical surveillance typically only occurs when personnel are determined to be routinely exposed to noise levels > 85 dBA as a TWA over an 8-hr shift. As a result, occupational and environmental hygienists may be missing a portion of the population at increased risk of hearing loss since personnel may suffer long-term hearing impairment by not be receiving the 14–16 hr of auditory rest needed to recover from TTSs. However, due to the economic cost, TTS and PTS prevalence should also be considered, along with exceedance of extended shift OELs, when selecting personnel to monitor on HCPs.

These results are important for occupational and environmental hygienists since this investigation provides information on an understudied population of personnel working >8 hr work-shifts. Because extended work shifts will continue to be used as a personnel management technique, occupational and environmental hygienists should be sensitive to the potential additional hearing loss risk associated with longer noise exposure durations and shorter recovery periods. Characterizing only on-duty 8-hr exposures may underestimate exposure since exposure durations are typically longer than 8 hr for personnel assigned to an operational aircraft carrier. Noise exposure characterization beyond an 8-hr period could facilitate hearing loss prevention efforts, as well as employee education, resulting in a more effective HCP.

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References

[1] National Institute for Occupational Safety and Health: “Noise and Hearing Loss Prevention.” Available at https://www.cdc.gov/niosh/topics/noise/default.html (accessed July 7, 2018).

[2] Occupational Safety and Health Administration: “Occupational Noise Exposure.” Available at https://www.osha.gov/SLTC/noisehearingconservation (accessed July 7, 2018).

[3] Department of Veteran’s Affairs: Department of Veteran’s Affairs. (2018). Veterans Benefits Administration annual benefits report fiscal year 2017. Available at https://www.benefits.va.gov/REPORTS/ab/docs/FY17-Compensation.pdf (accessed September 29, 2018).

[4] Mills, J.H., R.M. Gilbert, and W.Y. Adkins: Temporary threshold shifts in humans exposed to octave bands of noise for 16 to 24 hours. J. Acoust. Soc. Am. 65(5):1238–1248 (1979).

[5] Basner, M., W. Babisch, A. Davis, et al.: Auditory and non-auditory effects of noise on health. Lancet 383(9925):1325–1332 (2014).

[6] Gan, W.Q., H.W. Davies, M. Koehoorn, and M. Brauer: Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality. Am. J. Epidemiol. 175:898–906 (2012).

[7] Griefahn, B., A. Marks, and S. Robens: Noise emitted from road, rail and air traffic and their effects on sleep. J. Sound Vib. 295(1–2):129–140 (2006).

[8] Berger, E., L. Royster, J. Royster, D. Driscoll, and M. Layne: The Noise Manual (5th Edition). Fairfax, VA: American Industrial Hygiene Association.

[9] American Conference of Governmental Industrial Hygienists: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati OH: ACGIH, 2018. p. 134.

[10] Department of Defense: “DoD Instruction 6055.12 Hearing Conservation Program.” Available at https://www.med.navy.mil/sites/nmcphc/Documents/oem/dodi-6055-12.pdf (accessed July 7, 2018).

[11] Department of the Navy: “OPNAVINST 5100.19E: Navy Safety and Occupational Health (SOH) Program Manual for Forces Afloat.” Available at https://www.med.navy.mil/sites/nepmu2/Documents/industrial_health/5100.19E%20-%20Volume%20I%20Part%20I.pdf (accessed July 7, 2018).

[12] Yankaskas, K., and S. Fast: CVN flight operations: Crossing the aircraft/ship interface. Nav. Eng. J. 111(3):47–57 (1999).

[13] Sunde, E., K. Irgens-Hansen, B.E. Moen, et al.: Noise and exposure of personnel aboard vessels in the Royal Norwegian Navy. Ann. Occup. Hyg. 59(2):182–199 (2014).

[14] Neitzel, R., B.Berna, and N.S. Seixas: Noise exposures aboard catcher/processor fishing vessels. Am. J. Ind. Med. 49(8):624–633 (2006).

[15] Kaerlev, L., A. Jensen, P.S. Nielsen, J. Olsen, H. Hannerez, and F. Tuchsen: Hospital contacts for noise-related hearing loss among Danish seafarers and fishermen: A population-based cohort study. Noise Health. 10(39):41 (2008).

[16] Neitzel, R.L., E.B. Svensson, S.K. Sayler, and J. Ann-Christin: A comparison of occupational and nonoccupational noise exposures in Sweden. Noise Health. 16(72):270 (2014).

[17] Kock, S., T. Andersen, H. Kolstad, B. Kofod-Nielsen, and J. Bonde: Surveillance of noise exposure in the Danish Workplace: A baseline survey. Occup. Environ. Med. 61(10):838–43 (2004).