Noise Exposure

The Need for New Measurements on Aircraft Carriers

By Gary A. Morris, Justin Bryant, Kim Kleine and Amanda Dean

For U.S. Navy personnel aboard an aircraft carrier, exposure to noise often does not end with a work shift, which already may exceed 8 hours. Noise hazard environments from shipboard operations may significantly expose personnel beyond 8 hours. Significant noise exposures such as those found aboard an aircraft carrier pose serious health risks beyond the auditory system. For example, according to Stansfeld and Matheson (2003), employees who are regularly exposed to sound levels at or above 85 dBA have higher blood pressure than those who are not. In one study, hypertension was shown to have directly resulted from aircraft noise, a significant noise contributor on aircraft carriers. Although this symptom may be associated with other factors present in high-noise environments, further study should be pursued to gauge the risk noise poses to blood pressure. Noise exposures above 85 dBA also affect the central nervous system (e.g., heightened levels of adrenaline). Stansfeld and Matheson (2003) also report that noise exposure can cause annoyance that can lead to anger, anxiety and more serious psychological problems.

IN BRIEF

- **Noise-induced hearing loss is a serious threat to U.S. Navy personnel and costs the Department of Veterans Affairs hundreds of millions of dollars each year.**
- **New noise exposure data are needed to determine noise exposure across multiple Navy ratings and identify steps toward noise reduction. Past noise level research conducted aboard aircraft carriers is inadequate due to potential electromagnetic interference that may have affected data; the lack of data collection for 24-hour exposure periods; and the lack of task-based noise exposure information.**
- **The authors conducted a study to record noise doses and assess the contribution of each operation aboard the *USS Ronald Reagan*. Exposure groups were created for further study and operations were identified for noise reduction efforts.**

This study aimed to collect new data using the current guidance and requirements specified in the Department of Defense (DOD) Instruction 6055.12, Hearing Conservation Program (HCP). HCPs are designed to prevent noise-induced hearing loss (NIHL). The DOD program is the standard that applies to U.S. Navy operations and, thus, is the relevant standard for the study. The permissible exposure limit (PEL) under this program is 85 dBA, which means an employee should not be exposed to an average sound level above 85 dBA for an 8-hour shift. Therefore, employees should be included in the HCP when their exposure is at or above 85 dBA. They should also be enrolled if impulse, or instantaneous, noise reaches 140 dB. (It should be noted that OSHA's occupational noise exposure standard sets the PEL at 90 dBA, but requires implementation of an HCP at 85 dBA. Since this study involves military operations, the DOD standard is the applicable measure.)

To accomplish this study, the researchers aimed to characterize the entire 24-hour noise exposure for personnel aboard a U.S. Navy aircraft carrier. These exposures are important to understand because NIHL claims are a significant financial burden for the U.S. military and Department of Veterans Affairs. According to a 2006 report, the Veterans Administration (VA) spent $137 million in disability payments to former Navy personnel for hearing loss in FY 2005 (Bowes, Shaw, Trost, et al., 2006). This figure reflected an increase of $94 million in spending by VA on Navy hearing disability payments compared to 1999 figures.

These costs continue to rise and are cause for concern in terms of operational readiness and fiscal detriment. Operationally, NIHL may negatively affect mission readiness and personnel's quality of life. In a study conducted by Center for Naval Analyses, Hattiangadi (2003) reports that satisfaction with shipboard life is more strongly associated with satisfaction with the Navy than any other

Gary A. Morris, Ph.D., CSP, is chair of the Department of Occupational Safety and Health at Murray State University. He holds a B.S. in Occupational Safety and Health Engineering from Murray State University, as well as an M.S. in Environmental Health and a Ph.D. in Health Sciences, both from Old Dominion University. Morris is a professional member of ASSE's Purchase Area Chapter.

Justin Bryant is a senior at Murray State University majoring in Occupational Safety and Health. He is a member of the university's ASSE student section.

Kim Kleine, CSP, CIH, holds a B.S. and an M.S. from Murray State University. She is a member of ASSE's Middle Tennessee Chapter.

Amanda Dean, GSP, holds a B.S. and an M.S. from Murray State University. She is an associate member of ASSE's Gulf Coast Chapter.

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quality of life area. Habitability improvements represent an opportunity to improve shipboard life.

Development of these corrective actions depends on a thorough understanding of the impact of noise on a sailor. Understanding the noise sources that may affect workers has historically been limited to noise dosimetry measurements of operational work shifts. Aboard Navy ships, this process does not capture the true noise dose, as personnel often spend significant additional time beyond a traditional shift in a work location or in a noisy environment.

Occupational noise exposure standards are based on a traditional 8-hour workday with the assumption that the remaining 16 hours of the day are spent in a noise-free environment, which allows for auditory recovery. Historical noise dosimetry monitoring within the Navy has focused on meeting compliance needs with a traditional 8-hour exposure period, with some data collection covering up to 12 hours.

As noted, this may not represent the true noise dose for personnel. The shipboard environment and ongoing evolutions throughout the entire day, whether at sea or in port, provide the potential for a sailor to be exposed to significant noise over a 24-hour period. Therefore, data for 24-hour exposure periods are necessary to more accurately characterize noise exposure to a carrier's personnel. Understanding which activities and locations contribute to noise exposure is also critical. This information will reveal additional opportunities for targeted noise control and hearing conservation efforts. Because exposure duration plays a large role in determining noise dose, previously collected data likely failed to identify all employees who should be part of the HCP according to DOD Instruction 6055.12. These new data can also facilitate more effective worker education efforts within the HCP.

Study Methods

Aboard the *USS Ronald Reagan* (CVN-76), randomly selected individuals across military ratings (including those who work on the flight deck, are members of aviation squadrons and who work in

Table 1

Noise Exposure Data: *USS Ronald Reagan*

Sample	DOSE	L_{AVG}	8-hr TWA
1	9999.00%	113.5	118.4
2	9999.00%	103.5	108.3
3	9999.00%	121.7	126.4
4	9999.00%	102	106.7
5	9999.00%	104.1	108.9
6	9999.00%	102	106.7
7	9999.00%	101.6	106.6
8	9999.00%	151.9	107.3
9	9999.00%	106.6	111.4
10	9999.00%	113.7	118.4
11	9999.00%	111.7	116.7
12	9221.00%	99.9	104.7
13	6669.00%	98.5	103.2
14	4527.00%	96.6	101.5
15	4258.00%	96.4	101.2
16	3470.00%	95.3	100.4
17	2699.00%	94.4	99.3
18	2102.00%	93.4	98.2
19	1610.00%	92.4	97.1
20	1373.00%	91.6	96.4
21	1170.00%	95.9	100.7
22	1144.00%	94.7	100.6
23	1018.00%	90.3	95.1
24	645.30%	93	98.1
25	564.90%	87.7	92.5
26	562.80%	93	97.5
27	485.00%	87.2	91.9
28	474.10%	87	91.8
29	465.10%	87	91.7
30	421.00%	86.5	91.2
31	404.30%	86.3	91.1
32	373.60%	86	90.7
33	371.10%	85.9	90.7
34	317.50%	84.9	90
35	314.00%	84.9	90
36	290.30%	85	89.6
37	247.60%	84.1	88.9
38	235.20%	83.8	88.7
39	232.60%	88.9	93.7
40	219.40%	83.6	88.4
41	193.20%	81.5	89.8
42	171.90%	82.6	87.4
43	165.90%	82.4	87.2
44	161.70%	82.3	87.1
45	160.00%	82.3	87
46	150.30%	82	86.8
47	147.90%	86.9	91.7
48	146.00%	81.9	86.7
49	129.10%	81.3	86.1
50	115.90%	80.9	85.6
51	94.28%	76.6	84.6
52	93.87%	79.9	84.7
53	86.85%	79.4	84.3
54	71.96%	78.8	83.6
55	70.04%	84.3	83.4
56	61.57%	78.1	82.9
57	59.35%	73.4	81.2
58	56.91%	77.8	82.6
59	55.26%	77.7	82.4
60	54.01%	77.3	82.3
61	53.13%	77.5	82.3
62	48.78%	77.2	81.9
63	46.53%	81.7	86.7
64	45.59%	81.8	86.6
65	43.51%	76.6	81.4
66	34.50%	68.7	77.3
67	31.90%	75.1	80
68	31.79%	80.3	85
69	15.67%	72.2	77
70	13.36%	71.4	76.3
71	9.27%	65	72.9
72	7.74%	74.2	78.9
73	4.59%	66.7	71.6

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noise hazardous locations below deck) were fitted with personal noise dosimeters (3M Edge 5). Test subjects wore the devices for a 24-hour period with periodic equipment checks by the research team. During the sampling period, personnel performed their routine duties. Software calculated percent noise dose, time weighted average (TWA) and average sound level of each sample.

The data were used for analysis and development of time-stamped noise profiles and overall noise doses. Primary, secondary and tertiary noise sources were isolated with the use of noise dosimetry surveys completed by observers from a monitoring team. Monitoring events were targeted to coincide with ongoing shipboard operational exercises, including those spanning multiple days, to closely mirror actual operational events. The research teams also conducted monitoring pier-side, with a focus on noise levels during port operations and 24-hour noise doses for duty section personnel. This information was paired with dosimeter data to identify the contribution of each source to a subject's exposure. Noise doses across different groups of workers aboard the carrier were examined, and personnel were placed into similar exposure groups. These exposure groups were identified for further evaluation and targeted interventions to reduce NIHL.

Data were collected aboard the carrier in January 2014. As shown in Table 1, of the 73 Navy personnel fitted with noise dosimeters, 50 were exposed to greater than 100% of the dose allowed under the DOD HCP. Eleven of the samples were so large that the dosimeter clipped the noise dose exposure at 9999%. Including those 11 samples, a total of 23 samples reported a dose of more than 1000%. All of these personnel were severely overexposed and should be in the HCP, leaving only 12 of the 73 participants below the threshold for HCP enrollment.

Discussion

Experiments have shown that when certain dosimeters are exposed to field radio transmissions, they may exaggerate sound-level measurements. For example, in one study, data from noise dosimeters exposed to silent radio transmissions were shown to be affected by as much as 25 dBA (Bohl, 1991). In a separate study, high-frequency electromagnetic fields produced by security systems and cell phones were shown to cause inflated dosimeter readings (Deji, 2006). A third study concluded that instruments that use amplification are more susceptible to radio frequency interference (Cook & Huggins, 1984). These findings cause major concern about the reliability of previously collected noise dosimetry data. Since the world is constantly bombarded by electromagnetic waves and radio frequency interference, every industry is affected by electromagnetic interference (EMI). Its presence in workplaces being monitored by noise dosimeters susceptible to EMI renders previous data questionable.

In addition, some noise dosimeters cannot capture high-end sound measurements. OSHA regulations require dosimeters to be accurate for readings up to 140 dBA. Although OSHA regulations do not permit exposure above 140 dB, in reality, certain tasks, such as gunfire, exceed this limit (Kardous & Willson, 2004). However, since dosimeters can only record frequency to a certain point, they clip the data. Clipping occurs at a point when the device reaches a sound level at which it can no longer accurately measure; the device then begins to report the highest measurement that it can capture. Kardous and Willson (2004) used two separate dosimeters to record the same instances of gunfire ranging from 152 to 163 dB. The dosimeters did not reflect the true sound levels, instead clipping the data at 146 and 150/151 dB, respectively. This limitation affects the accuracy of time-weighted noise levels produced from the data collected by these dosimeters. The integrity of the present study was reinforced by using EMI-resistant dosimeters (3M Edge 5).

The dosimeters can be used for up to 30 hours before recharging is necessary. Since this study aimed to characterize 24-hour noise exposures, this feature is ideal. The ability to capture the entire 24-hour period on one device contributes to data accuracy and eases data analysis. The minimum and maximum thresholds can be easily set at the user's discretion through the software. The dosimeters record values between 70 and 140 dBA, which allows for a maximum range of recorded measurements. Although clipping remains a problem, knowing the range at which the device clips is valuable.

The devices can be easily switched to record according to various standards (e.g., OSHA's PEL, ACGIH threshold limit values). For this study, each dosimeter was set to record measurements according to the DOD HCP. Switching requires only the click of a button, which can be locked to prevent unwanted changes while in use.

Previous noise data are also plagued by a lack of task-based noise exposure levels. This poses a problem when trying to identify inaccuracies in recorded data that result from clipping. Most noise dosimetry studies only calculate the TWA for the entirety of the work shift (Virji, 2009). Whereas these data do not present a full picture of sound exposure, assessing task-based noise exposure makes evident the instances in which dosimeters record inaccurate data. Furthermore, task-based measurements are needed to determine how much each operation contributes to noise exposure.

Understanding how noise exposure is quantified is essential to understanding the data obtained through noise studies. Noise exposure is logarithmic, rather than arithmetic. OSHA utilizes a 5 dB exchange rate for noise; this means an increase in 5 dB is in fact a doubling of the noise dose. For example, an 8-hour TWA of 90 dBA is a noise dose twice as high as an 8-hour TWA of 85 dBA. However, this is not the only exchange rate in use. DOD, for example, uses a 3 dB exchange rate. The significance of this is that an 8-hour TWA of 88 dBA, rather than 90 dBA, is double the dose of an 8-hour TWA of 85 dBA. Although OSHA and DOD differ on the exchange rate, they agree that employees exposed to a TWA of 85 dBA or higher must be placed in an HCP. The key difference is that OSHA allows 8-hour TWAs to reach 90 dBA while DOD restricts TWAs to 85 dBA.

Noise dose is calculated by taking into account the noise level and exposure duration. Therefore, the length of an employee's shift is critical in determining the acceptable level of noise exposure. An employee who works a standard 8-hour shift can be exposed to higher TWAs than an employee who works for a longer period (e.g., 12-hour shift). Similarly, if an employee works fewer than 8 hours, s/he can be exposed to higher TWAs than an employee working an 8-hour shift.

While typical employees work 8-hour shifts and, therefore, have 16 hours away from the noise to which they are exposed at work, Navy personnel aboard nuclear-powered aircraft carriers routinely work shifts longer than 8 hours. Even while off duty, they are subject to near-constant noise due to continuing shipboard operations. Many sleeping quarters are located just under the flight deck. With flight operations regularly occurring around 12 hours a day, personnel in their bunks are being exposed to impact noise at 120 dBA. As a result, shipboard personnel rarely have a rest period from the noise. This creates a problem for using 8-hour exposure limits, as they do not characterize noise exposure. Thus, existing standards may not be sufficient to protect Navy personnel from NIHL.

To obtain the most useful data, noise monitoring must be conducted in a manner that truly reflects an employee's daily exposure. Not only should the employee be subjected to typical noise exposures for usual time periods, s/he must also be monitored for a typical shift length. If an employee works 12-hour shifts, s/he should be monitored for the entirety of that shift. Likewise, shipboard Navy personnel should be monitored for 24-hour exposure periods as they often cannot truly escape noisy operations. Unfortunately, no data available portray these 24-hour exposures. The need for accurate, full-shift noise exposure data is essential as is a comprehensive approach to data collection.

Driscoll (2005) presents three methods for assessing noise exposure over extended work shifts. The first involves converting the measured or projected dose (depending on the length of the shift and sampling period) to an 8-hour TWA. The results are then normalized to 8 hours. This method is convenient for comparing results to applicable exposure limits (e.g., 85 dBA for HCP inclusion),

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because the exposure limits in OSHA and DOD regulations are reported as 8-hour TWAs. However, when reviewing historical data, or comparing current to previous data, one must know how the data were handled. To make direct comparison, one must know methods of data collection, shift time and measured time used in calculation.

The second option Driscoll (2005) outlines involves identifying the regulatory exposure limit to apply based on the work shift length. Noise regulations, such as those from OSHA and MSHA, and the recommended ACGIH TLVs, provide tables that list allowable exposure for specified durations. In addition, the OSHA regulation and AIHA's Noise and Hearing Conservation Manual provide equations for calculating the allowable L_{AVG}, or the average sound level over the sample period, for the extended work shift. The measured L_{AVG} is compared to this extended shift exposure limit. For longer work shifts, a lower exposure limit will be applied. For example, for a 12-hour work shift, the OSHA PEL is 87.1 dBA instead of 90 dBA. As with the first option, this presents challenges when reviewing or comparing historical data without information about how these limits were calculated and the shift lengths used. If multiple limits have been applied within one operation where shift lengths vary, confusion can ensue.

In addition, much confusion can arise from discrepancies between TWA and L_{AVG}. Many incorrectly believe that there are different settings on noise dosimeters for different shift lengths (Banach, 2013). Instead, the difference in monitoring shifts longer or shorter than 8 hours is that the TWA is not the best reflection of actual exposure for these samples. The L_{AVG} is always a true reflection of the average sound level for the measured sample because it averages the sample over the length of measurement. Since TWA averages the sample over 8 hours, this does not truly reflect the average sound level over the sample time. If understanding the true exposure is the goal and shifts are not 8 hours, TWAs make it difficult to interpret and compare data over 24-hour exposure periods. (That said, TWA is the number OSHA uses to determine compliance.)

Driscoll's (2005) third option is to use the dose to assess noise exposure. According to Driscoll, this is the most conducive to understanding extended work-shift data. Although noise is typically discussed in terms of dBA values, by referring to percent dose for shifts longer than 8 hours employees who should be in an HCP or are being overexposed can be more easily identified. If an employee's noise dose is 50% or greater, s/he should be in an HCP. If the measurement is greater than 100%, the employee's exposure exceeds applicable regulation(s). Reporting dose is also the most conducive for comparing samples. By reporting dose, data can be accurately collected and read as long as it is collected according to the applicable standard. This clarity creates more tangible results and leads to a greater understanding of noise exposure levels.

Conclusion

For Navy personnel onboard an aircraft carrier, exposure to noise often may exceed a typical 8-hour shift. Traditional noise monitoring methods, such as conducting personal dosimetry over 8- and 12-hour exposure periods, do not provide a complete assessment of around-the-clock noise exposures. Furthermore, recommended levels of protection based on these results may leave Navy personnel unprotected to noise during periods assumed to be low noise exposure periods. The controls derived from 8- and 12-hour monitoring may not effectively reduce exposures below regulatory limits. When using data collection methods that do not focus on dose, onboard personnel may continue to be overexposed to noise. TWA is the current acceptable method for identifying when employees should be placed in the HCP or are being exposed to excessive noise, yet this measurement system is not conducive to communicating the true magnitude of exposure.

By reporting noise measurements in terms of dose, safety managers can more effectively communicate overexposures. In cases where hearing protection is not sufficient to address the issue, safety personnel can recommend controls to further reduce exposure. Based on this, noise dose percentage is the primary number taken into account in this study as it showed the clearest picture of the data recorded. **PS**

References

Banach, J. (2013). Ask the experts: Noise calculations and shift length. *The Synergist, 24*(3), 32.

Bohl, C.D. (1991). Distortion values caused by radio frequency interference when noise is measured by audio dosimeters. *American Industrial Hygiene Association Journal, 52,* A-156.

Bowes, M.D., Shaw, G.B., Trost, R.P., et al. (2006). Computing the return on noise reduction investments in Navy ships: A life-cycle cost approach. Alexandria, VA: Center for Naval Analyses.

Cook, C.F. & Huggins, P.A. (1984). Effect of radio frequency interference on common industrial hygiene monitoring instruments. *American Industrial Hygiene Association Journal, 45*(11), 740-744.

Deji, S. (2006). Electromagnetic malfunction of semiconductor-type electronic personal dosimeters caused by access control systems for radiation facilities. *Health Physics Journal, 91*(2), 93-100.

Driscoll, D.P. (2005). Noise exposure assessment for extended work shifts: What are the options? *UPDATE, 17*(1), 5-8.

Hattiangadi, A.U. (2003). The third annual Navy workforce research and analysis conference: Supporting military transformation. Alexandria, VA: Center for Naval Analyses.

Kardous, C.A. & Willson, R.D. (2004). Limitations of using dosimeters in impulse noise environments. *Journal of Occupational and Environmental Hygiene, 1*(7), 456-462.

Stansfeld, S.A. & Matheson, M.P. (2003). Noise pollution: Nonauditory effects on health. *British Medical Bulletin, 68*(1), 243-257.

Virji, M.A. (2009). Agreement between task-based estimates of the full-shift noise exposure and the full-shift noise dosimetry. *Annals of Occupational Hygiene, 53*(3), 201-214.