Noise Exposures Aboard Catcher/Processor Fishing Vessels

Richard L. Neitzel, MS,* Bryan E. Berna, MS, and Noah S. Seixas, PhD

Background Commercial fishing workers have extended work shifts and potential for 24 hr exposures to high noise. However, exposures in this industry have not been adequately characterized.

Methods Noise exposures aboard two catcher/processors (C/P) were assessed using dosimetry, sound-level mapping, and self-reported activities and hearing protection device (HPD) use. These data were combined to estimate work shift, non-work, and 24 hr overall exposure levels using several metrics. The length of time during which HPDs were worn was also used to calculate the effective protection received by crew members.

Results Nearly all workers had work shift and 24 hr noise levels that exceeded the relevant limits. After HPD use was accounted for, half of the 24 hr exposures remained above relevant limits. Non-work-shift noise contributed nothing to 24 hr exposure levels. HPDs reduced the average exposure by about 10 dBA, but not all workers wore them consistently.

Conclusions The primary risk of hearing loss aboard the monitored vessels comes from work shift noise. Smaller vessels or vessels with different layouts may present more risk of hearing damage from non-work periods. Additional efforts are needed to increase use of HPDs or implement noise controls. Am. J. Ind. Med. 49:624–633, 2006.

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KEY WORDS: occupational noise exposure; non-work exposure; L_{eq}(24); L_{eff}(24); commercial fishing; hearing protection; hearing loss; sound pressure levels

INTRODUCTION

Workers aboard commercial fishing vessels are exposed to a wide variety of safety and health risks, and US workers have a full-time equivalent fatality rate of 86.4 per 100,000 workers that is 21 times the overall US rate [BLS, 2004]. Fishing is one of the most dangerous occupations in America [Drudi, 1998] and worldwide [Turner and Petursdottir, 2003]. Since the mid-1970s, large catcher/processor (C/P) vessels, the crews of which may be at somewhat less risk of injury or fatality when compared to smaller (under 24 m) vessels [Wang et al., 2005], have been increasingly used by Western US fisheries [Radtke and Davis, 2000]. C/Ps are vessels with onboard processing facilities capable of catching and converting 75 tons or more of fish into packaged consumable-grade frozen products in 12 hr or less. These vessels have crews of 100 or more workers, the majority of whom function in the processing ("factory") operation. Eight-hour work shifts are uncommon in fishing; most factory workers have shifts of at least 12 hr spent at a single workstation.

Equipment aboard fishing vessels can produce levels of noise high enough to cause permanent noise-induced hearing loss (NIHL) [Ajkashev et al., 1990; Bowes and Corn, 1990; Szczepanski and Weclawik, 1991; Axelson and Clark, 1995]. Exposure to high noise can result in short-term changes in hearing, or temporary threshold shifts (TTS) [NIOSH, 1998], and repeated TTS without recovery is
thought to be associated with permanent NIHL [Berger, 2000]. Full recovery from TTS after high noise can take up to 24 hr, with longer exposure periods requiring longer recovery periods [Melnick, 1977; Nixon et al., 1977]. If commercial fishing workers experience high noise throughout their 24 hr day, rather than high noise during their work shift and low noise during breaks and non-work hours, they may be at higher risk of NIHL than workers who work extended work shifts in noise on land, but who have quiet non-work intervals between shifts. The data available on noise exposures aboard fishing vessels are limited, and the prevalence of hearing loss among commercial fishing workers is unknown. Noise and NIHL are of particular concern among workers employed in hazardous occupations such as fishing, as associations have been shown between work in high noise and increased likelihood of injury [Wilkins and Action, 1982; Melamed et al., 1992] as well as between hearing loss and increased risk of further occupational injury [Moll van Charante and Mulder, 1990; Zwerling et al., 1997].

Noise exposures among US commercial fishing workers are regulated by the United States Coast Guard (USCG) and the US Occupational Safety and Health Administration (OSHA). OSHA jurisdiction of fishing workers extends only 3 miles from shore [Husberg et al., 1998]; at the greater distances where many fishing operations take place, the USCG has jurisdiction. OSHA has established a permissible exposure limit (PEL) for noise [OSHA, 1983b]; however, the USCG has not promulgated an occupational noise regulation, and instead relies on a 1982 Navigation and Vessel Inspection Curricular (NVIC) [US Coast Guard, 1982] which recommends noise limits aboard ships.

Table I shows the allowable exposure levels for various exposure durations and the exchange rate (ER, the change in average exposure level that corresponds to a doubling or halving of allowable exposure time) for the OSHA and USCG limits. The two standards utilize the same ER and allow the same total noise exposure (i.e., the 24 hr equivalent continuous exposure level, \( L_{eq(24)} \), specified by IMO [1982] allows the same total noise exposure as the 8 hr \( L_{eq(8)} \) Recommended Exposure Limit (REL) specified by NIOSH [1998]. The IMO and USCG criteria represent modifications of traditional 8 hr work-shift standards, and reflect the potential for 24 hr exposure to noise in the fishing industry. The OSHA and NIOSH standards require use of hearing protection devices (HPDs) for time-weighted average (TWA) exposures at or above 90 and 85 dBA, respectively, while the USCG and IMO standards require HPDs to be used above 85 dBA, regardless of exposure duration.

This study evaluated noise exposures to US fishing workers through a cross-sectional survey on two C/Ps engaged in fishing operations. Octave band and A-weighted sound pressure levels (SPLs) aboard the vessels were measured and mapped, full-shift dosimetry measurements were made on crew members, and daily activities and hearing protection use were surveyed via questionnaire. These data were combined to produce estimates of 24 hr exposure levels, both unadjusted and adjusted for self-reported use of HPDs. The results were used to assess the need for hearing conservation efforts aboard the vessels.

### MATERIALS AND METHODS

#### Study Overview

Noise exposures aboard two large C/Ps (vessels 1 and 2) operated by the same company were determined through personal dosimetry, noise mapping, and questionnaire responses. The study was conducted after the participating company expressed interest in a survey of noise exposures aboard their vessels. The vessels selected were representative of the company’s fleet, and were chosen based on convenience. Data were collected by a single researcher who remained aboard each vessel for the duration of a single fishing trip. Vessels 1 and 2 were monitored 13 and 18 d, respectively. Vessel personnel assessed included all job roles.

### Table I. Summary of Noise Standards Relating to Commercial Fishing Boats

<table>
<thead>
<tr>
<th>Standard</th>
<th>Exposure limits for various durations (dBA)</th>
<th>Exchange rate (dB)</th>
<th>Use of hearing protection required at or above . . .</th>
<th>Terminology in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Occupational Safety and Health Administration</td>
<td>90*  87  82</td>
<td>5</td>
<td>90 dBATWA</td>
<td>( L_{eq(8)} )</td>
</tr>
<tr>
<td>United States Coast Guard</td>
<td>90  87  82*</td>
<td>5</td>
<td>85 dBA</td>
<td>( L_{eff(24)} )</td>
</tr>
<tr>
<td>US National Institute for Occupational Safety and Health</td>
<td>85  83  80</td>
<td>3</td>
<td>85 dBATWA</td>
<td>( L_{eq(8)} )</td>
</tr>
<tr>
<td>International Maritime Organization</td>
<td>85  83  80*</td>
<td>3</td>
<td>85 dBA</td>
<td>( L_{eq(24)} )</td>
</tr>
</tbody>
</table>

*Criterion level and exposure duration specified in exposure limit; other values for each limit computed using exchange rate.
classifications expected to have potential for high-noise exposures: engine room crew, cargo crew, and factory crew, who operate various types of fish processing machinery. Factory workers comprised over 70% of the crew on the vessels, which totaled 220 workers.

Crew members were invited to attend a short briefing in which the purpose and methods of the study were presented. Interested workers signed a consent form approved by the University of Washington Institutional Review Board. All non-officer crew members on vessel 1 and first shift crew members on vessel 2 were eligible to participate. Vessel officers were excluded, as their job duties primarily occur on the vessel bridge and do not involve regular exposure to noise. No other enrollment exclusion criteria were used in this study.

**Sound Pressure Level Measurements**

Repeated 1/1 octave-band SPL and A-weighted $L_{eq}$ measurements of 10 s duration each were made throughout both vessels using a Type I sound-level meter (SVAN 912AE, Swantek, Warszawa, Poland). The vessels were divided into four interior decks (engine, factory, crew quarters, and miscellaneous locations), and one exterior deck (fishing, which was accessible on vessel 1 only). The layout of the C/Ps, from the bottom of the hull up, consisted of the engine room and storage holds, factory decks, fishing deck, and superstructure. Crew quarters were located in the superstructure above the factory decks and forward of the fishing deck, as was the vessel bridge (which was not monitored in this study). Locations were selected to provide comprehensive coverage of noise sources and locations where noise-exposed workers were regularly positioned. Each location was sampled three times on non-consecutive days under identical conditions, which was possible due to the constant engine noise and the 24 hr operation of all systems of the vessel. The sound-level meter was calibrated prior to each day of sampling.

**Dosimetry Measurements**

Data logging noise dosimeters (Q-300, Quest Technologies, Inc., Oconomowoc, WI, USA) were used to collect full-shift exposure data. Dosimeters were fit and removed by the researcher at subjects’ workstations. Microphones were covered with wind screens and placed on subjects’ right shoulders. Dosimeters were calibrated at the end of each shift. Full-shift levels were measured using slow response and A-weighting, and two channels of data were recorded simultaneously. The first channel was set to the OSHA PEL, and used a 5 dB ER, 80 dBA threshold, and a 90 dBA criterion level. Channel 2 was set to the NIOSH REL, and used a 3 dB ER, 80 dBA threshold, and a 85 dBA criterion level. Full-shift work exposure levels were referred to as OSHA $L_{eq,W}$ and NIOSH $L_{eq,W}$.

**Questionnaires**

At the end of monitored work shifts, workers completed a brief questionnaire which included questions about the worker’s job title, industry work history, type of HPD worn during the measured shift and number of minutes the HPD was not worn, and locations and durations of stay during non-work periods over the previous 24 hr.

**Hearing Protection Adjustment**

All HPD use data were based on self-report, which has been shown to be an accurate measure of HPD use [Lusk et al., 1995]. The effective protection provided by the HPDs was computed using a formula which incorporates both nominal attenuation and time an HPD is worn in high noise [Arezes and Miguel, 2002]. Effective protection values were computed using a nominal attenuation value of 50% of the rated NRR for each type of HPD [OSHA, 1983a], and, in the case of the combination of earplugs and earmuffs, 50% of the higher rated NRR $+5$ dB [Berger, 2000]. The percent of time each worker used HPDs during their shift was calculated and these values were incorporated into Equation 1 below:

$$R_{MBi} = 10\log_{10} \left[ \frac{100}{100 - p(1 - 10^{-A/10})} \right]$$

where $R_{MBi}$ represents the effective attenuation based on a 3 dB ER for individual “i” using a hearing protector with nominal attenuation “A” for “p” percent of the total noise exposure duration in a single work shift. The same equation was used to calculate $R_{MBi}$ values following replacement of the “10” values in the equation with “16.61” to account for a 5 dB ER.

**Non-Work Shift and 24 hr Noise Exposure Estimates**

Non-work-shift $L_{eq}$ and $L_{avg}$ levels were computed for workers based on the results of the sound-level mapping measurements and their questionnaire-reported locations during non-work times. Exposures were computed using Equation 2:

$$L_{eq,NW+i} = 10\log_{10} \left[ \frac{1}{n} \sum_{k=1}^{n} t_{NW} \times 10^{L_{NW+k}/10} \right]$$

where $L_{eq,NW+i}$ is the non-work exposure level for individual i, $t_{NW}$ is the number of hours spent in non-work-shift location k, $L_{NW}$ is the noise level (dBA) measured for non-work-shift location k, and n is the total number of non-work-shift locations visited over the 24 hr period of reporting. The same equation was used to calculate $L_{avg,NW+i}$ following replacement of the “10” values in the equation with “16.61” to account for a 5 dB ER.
Leq(24) and Leff(24) exposure levels were estimated both with and without consideration of HPD use for all workers based on the results of the dosimetry and sound-level measurements and their reported locations during non-work times. The four 24 hr estimates for each subject encompassed that subject’s 12 hr work shift and the remaining non-work time in a single 24 hr period. Subject-specific Leq(24) estimates were made using the HPD-adjusted work-shift exposure levels (i.e., workers’ NIOSH Leq minus their R3dB) and non-work-shift levels (from sound-level mapping) and location durations (from questionnaires) using Equation 3:

\[
Leq(24)i = 10\log_{10} \left( \frac{1}{24} \left( t_w \times 10^{(Leq,w_i - R3dB)/10} \right) + \sum_{k=1}^{n} t_{NW} \times 10^{(LNW_i - R5dB)/10} \right) \]

where Leq(24)i is the IMO 24 hr exposure level for individual i, tW is the number of hours in the monitored work shift, Leq,w is the Leq average noise level (dBA) for the monitored work shift, tNW is the number of hours spent in non-work-shift location k, LNW is the noise level (dBA) measured for non-work-shift location k, and n is the total number of non-work-shift locations visited over the 24 hr period of reporting. The same equation was used to calculate Leff(24)i following replacement of the “10” values in the equation with “16.61” to account for a 5 dB ER, and of R3dB with R5dB. The 24 hr estimates that were not adjusted for HPD use used the same formula, but excluded the R terms. Use of the R-values assumes constant exposure over the monitored period, that is, similar noise levels during periods of HPD use and non-use.

Analysis

Data were analyzed using Intercooled Stata 9.0 (Stata Corp., College Station, TX). Descriptive statistics were computed for 12 hr work shift and non-work-shift periods and 24 hr noise levels, as well as for attenuation R-values, by location and vessel. t-tests were conducted to determine if mean noise levels between certain variables had statistically significant differences. P-values less than 0.05 were considered statistically significant.

RESULTS

Octave-Band SPL Noise Survey

A total of 333 octave-band SPL measurements were made at 106 locations on the two vessels. The A-weighted noise levels recorded during these measurements are described in Table II by vessel deck. The engine deck was associated with the highest mean noise level, followed by the factory deck; the quarters deck was associated with the lowest mean noise level.

An octave-band spectrum for the factory deck is provided in Figure 1. The levels represent the arithmetic average of repeated measurements made at various locations on this deck for both vessels. The majority of the crews spend 12 hr of each day on the factory deck. The spectral profile of the octave bands peaks between 0.5 and 1 kHz. Octave-band spectra for the engine and quarters decks were very similar, though the quarters deck contains much lower total sound energy than the factory or engine decks. t-tests indicated no significant octave-band SPL differences between the two vessels (two-sample t-test, P > 0.05).

Dosimetry Measurements and Non-Work Noise Exposure Estimates

Table III shows the results of the work-shift dosimetry measurements and non-work-shift exposure estimates. Thirty-one subjects (15% of the total crew) were enrolled in the study and wore dosimeters for a single work shift. Three measurements were discarded due to instrument failures, leaving 28 valid work-shift measurements. Two subjects with successful dosimetry measurements did not complete a questionnaire, and non-work-shift exposures

<table>
<thead>
<tr>
<th>Deck</th>
<th>N measurements</th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>333</td>
<td>84.7 (15.0)</td>
<td>46.7</td>
<td>114.4</td>
</tr>
<tr>
<td>Engine</td>
<td>63</td>
<td>102.0 (10.9)</td>
<td>74.5</td>
<td>114.4</td>
</tr>
<tr>
<td>Factory</td>
<td>135</td>
<td>88.6 (7.2)</td>
<td>65.1</td>
<td>99.3</td>
</tr>
<tr>
<td>Fishing (vessel 1 only)</td>
<td>27</td>
<td>83.4 (10.5)</td>
<td>63.1</td>
<td>96.8</td>
</tr>
<tr>
<td>Miscellaneous*</td>
<td>39</td>
<td>76.6 (11.3)</td>
<td>54.8</td>
<td>92.7</td>
</tr>
<tr>
<td>Quarters</td>
<td>69</td>
<td>66.4 (9.0)</td>
<td>46.7</td>
<td>80.6</td>
</tr>
</tbody>
</table>

*Miscellaneous locations were spaces occupied by crew infrequently (e.g., equipment repair areas and storage holds throughout the vessels).
could not be computed for these subjects. All work shifts were scheduled for 12 hr (720 min), and mean measurement duration was 652 ± 58 min. NIOSH $L_{eq,W}$ noise levels were consistently above the OSHA $L_{avg,W}$ for all monitored shifts. The overall mean OSHA $L_{avg,W}$ level was 93.9 dBA, and 26 (93%) of the measured shifts exceeded 87 dBA, the OSHA limit for a 12 hr exposure. The overall mean NIOSH $L_{eq,W}$ level was 95.3 dBA, and 100% of work shifts exceeded the NIOSH limit for a 12 hr exposure (83 dBA). The $L_{eq,W}$ and $L_{avg,W}$ levels were statistically significantly correlated (Spearman coefficient 0.88, $P < 0.001$), and the mean $L_{eq,W}$ and $L_{avg,W}$ values were not statistically significantly different (two-sample paired $t$-test, $P > 0.05$).

The overall non-work average NIOSH $L_{eq,NW}$ for the two vessels ($59.7 \pm 8.8$ dBA) was nearly 35 dBA lower than the $L_{eq,W}$ for the vessels. The difference between mean $L_{eq,W}$ and $L_{eq,NW}$ levels by deck varied from just over 33 dBA for the cargo worker on vessel 2 to nearly 40 dBA for the factory workers on vessel 2. The mean $L_{eq,NW}$ of vessel 1 was significantly higher than the mean of vessel 2 (two-sample $t$-test, $P < 0.001$).

### Hearing Protector Use

Table IV shows use of HPDs aboard the vessels. Workers reported using four different HPD types: one earmuff, two earplugs, and a combination of earplugs and earmuffs. Overall use time was 582 ± 155 min, or about 70 min less than the mean measured shift length. The crews of the two vessels had similar mean usage times, but usage time variability was far greater on vessel 1. Workers who wore earmuffs wore them on average 1 hr more per shift than those who wore earplugs. $R_3dB$ values ranged from 9.3 dB for earmuff users to 17 dB for the worker who wore both earplugs and earmuffs. $R_3dB$ values for vessel 2 were higher than those of vessel 1 due to more workers

<table>
<thead>
<tr>
<th>Table III. Work Shift and Non-Work Average Noise Levels (dBA) on Catcher/Processor Fishing Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Overall</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

* $n$ = 26; non-work exposures could not be estimated for two factory workers from vessel 1 who did not complete questionnaires.
**Non-work period duration 714 ± 19 min on vessel 1, 679 ± 169 min on vessel 2.
***NIOSH $L_{eq,W}$ not significantly different than OSHA $L_{avg,W}$ (paired $t$-test, $P > 0.05$).
with low use time on vessel 1. Overall R3dB and R5dB values were about 11 dB.

No workers reported using HPDs during their non-work hours.

**Twenty-Four Hr Noise Exposures**

Table V shows L_eq(24) values both unadjusted and adjusted for work shift use of HPDs. Two subjects with successful dosimetry measurements did not complete a questionnaire, and 24 hr exposures could not be computed for these subjects. Subjects reported spending most of their non-shift time in two locations: the galley (mean duration about 1.5 hr, mean noise level 72.0 ± 2.6 dBA) and sleeping berths (mean duration about 10.5 hr, 56.0 ± 5.4 dBA). Estimated L_eq(24) and L_eff(24) levels were well correlated (Spearman coefficient 0.88, P < 0.001), and the HPD-adjusted L_eq(24) and L_eff(24) were not statistically significantly different (two-sample paired t-test, P > 0.05). The overall mean unadjusted L_eq(24) was 92.8 ± 5.2 dBA; this dropped to 82.0 ± 7.2 dBA after adjustment for HPD use. The mean unadjusted L_eff(24) was 90.7 ± 4.7 dBA, and the HPD-adjusted mean was 79.8 ± 6.4 dBA. The overall average unadjusted L_eq(24) level was 2.5 dBA lower than the average NIOSH work-shift L_eq,w of 95.6 dBA. One hundred percent of unadjusted L_eq(24) levels exceeded the IMO limit of 80 dBA. Even after adjustment for HPD use, half of the workers still had 24 hr exposure levels above 85 dBA. This observation was also true for the L_eff(24) levels. The greater use of HPDs aboard vessel 2 resulted in less than one-third of HPD-adjusted L_eq(24) and L_eff(24) values exceeding the relevant limits, while aboard vessel 1 greater than three-quarters of HPD-adjusted 24 hr levels still exceeded the relevant standard.

Figure 2 shows a scatterplot of L_eq(24) exposure levels both unadjusted and adjusted for HPD use with a line superimposed indicating perfect agreement. The HPD-adjusted values are about 10 dBA lower than the unadjusted values. Note that worker who did not wear HPDs had no reduction in his 24 hr exposure levels, and lies directly on the perfect agreement line. The three workers who used HPDs for only a small portion of their measured work shifts also had only small reductions in exposure. Conversely, the one worker who wore earplugs and earmuffs during the entire monitored shift had a reduction in L_eq(24) of nearly 20 dBA. Factory workers on vessels 1 and 2 had an average reduction in L_eq(24) of 7.3 ± 4.8 and 12.4 ± 3.9 dBA, respectively, due to hearing protection use.

**DISCUSSION**

The results of this survey indicate that fishing workers working aboard C/P vessels are at risk of NIHL from chronic noise exposure.
exposure to high noise. Comprehensive sound-level maps showed that a substantial portion of the workstations aboard the vessels had noise levels greater than 85 dBA (and therefore warranted use of HPDs). The primary noise sources identified were engine and processing machinery in the engine room and factory decks, respectively. Sound-level spectra from the engine rooms of the vessel showed less low-frequency energy than was initially expected, and other areas of the vessels also had relatively little low-frequency energy. This suggests that structure-borne transmission of low-frequency noise from the engine, a noise exposure pathway which is difficult to control, was not a large issue on these vessels.

Dosimetry measurements indicated that work-shift average exposure levels almost uniformly exceeded the 12 hr exposure limits specified by OSHA and NIOSH, and that work-shift exposures were about 35 dBA higher than non-work exposures, on average. Overall estimated USCG and IMO 24 hr exposure levels unadjusted for use of hearing protection were well in excess of the agencies’ 82 and 80 dBA limits, respectively. Even when use of hearing protection was accounted for, half of workers still exceeded both the IMO and USCG 24 hr limits, and this function was highly dependent on the degree of HPD use, which differed significantly between the two vessels. Data were not available to evaluate the reasons for the differences in HPD use between the two vessels. However, it seems likely that the HPD usage expectations and enforcement policies and practices differed on the vessels.

The results of the study generally agree with the very limited literature available on noise exposure at sea. A study of small fishing vessels identified levels ranging from 56 to 110 dBA, and full-shift $L_{eq,(8)}$ levels that exceeded 90 dBA for some jobs [Martinis, 1977]. Sleeping quarters on small fishing vessels are often located immediately adjacent to or above the engine compartment and can have exposure levels of 85 dBA or more [Axelsson and Clark, 1995]. Maximum noise exposures on large Polish and Russian fishing vessels have been measured at 117 dBA for mechanics and 106 dBA for engineers for a 12 hr work shift [Ajkashev et al., 1990; Szczepanski and Weclawik, 1991], and engine room levels aboard an oceangoing dredge were 100 dBA on average [Bowes and Corn, 1990]. The engine rooms of the vessels monitored in the current study had a mean SPL of 102 dBA—similar to the previous studies—but the engineers monitored here had 12 hr average NIOSH $L_{eq,W}$ levels of 94 dBA. This difference was due to the fact that the engineers in the current study worked in a relatively quiet enclosed control room for a portion of each shift. Workers on the fish processing decks of previously monitored C/Ps had average exposures of up to 97 dBA for up to 16 hr daily [Szczepanski and Weclawik, 1991], levels relatively similar in intensity but longer in duration than those measured here. Living quarters on the vessels were reported to average 58 dBA [Szczepanski and Weclawik, 1991], below the levels measured in the sleeping berths on the current vessels or elsewhere [Martinis, 1977; Bowes and Corn, 1990; Axelsson and Clark, 1995]. The crew of an oceangoing dredge had 8 hr $L_{eq}$ exposure levels that range from 79 to 96 dBA, a range roughly consistent with the work-shift exposures measured on fishing workers in the current study. Engine room workers on the dredge were found to have $L_{eq,(24)}$ levels that exceeded the IMO limit of 80 dBA. None of the previous studies of noise on fishing vessels documented use of HPDs.

The nearly 3 dB difference between the 12 and 24 hr exposure estimates indicates that work-shift noise drives workers’ exposures aboard the vessels. However, the degree to which the noise levels measured in the quarters areas of the monitored vessels are representative of other vessels is not clear. On larger ships, such as those measured here, the
engine and factory floors are located on separate decks from the sleeping quarters of the crew; this physical separation, and the relative lack of structure-borne low-frequency noise transmission, accounts for the low levels in the crew quarters reported here. Smaller vessels, or vessels where quarters and processing areas are co-located, may have much larger contributions of non-work-shift noise to 24 hr exposure levels. On such vessels, workers may not have an opportunity to recover from TTS incurred during their work shift due to the presence of noise at TTS-inducing levels even during their non-work periods. Mills has shown that TTS can develop in the 2–6 kHz frequency range after broadband exposure at just 70 dB [Mills et al., 1981]. Workers on vessels with elevated noise levels in their sleeping quarters, or workers who have work shifts that exceed 12 hr in duration, may have insufficient opportunity for TTS recovery and may therefore have a higher risk of NIHL than would be expected given their work-shift exposures. Over the course of a single fishing season a vessel and its crew can cycle in and out of port up to 18 times, with each cycle lasting approximately 12–15 days. If workers are not given low-noise periods, this work cycle could potentially provide an almost continuous exposure to TTS-inducing levels of noise for upwards of 200 days.

For continuous, steady-state exposure, metrics utilizing 3 dB ERs (e.g., the NIOSH and IMO limits) and 5 dB ERs (e.g., the OSHA and USCIG limits) produce identical measures of exposure. Differences between exposures measured using the two ERs become larger as noise become more variable. The 5 dB ER assumes that exposures are intermittent, and that regular noise-free breaks are interleaved with exposure which provide opportunity for recovery from TTS [NIOSH, 1998]. Factory crew received a single 30 min lunch break in the galley (average $72.0 \pm 2.6$ dBA when occupied) and two 15 min breaks in the vicinity of the changing rooms near the factory floor (average $71.0 \pm 3.8$ dBA), for a total of about 60 min of low noise during a 720 min shift. The presence of several regularly spaced low-noise breaks, combined with the fact that the $L_{eq,W}$ and $L_{avg,W}$ work-shift exposure levels and the $L_{eq(24)}$ and $L_{eff(24)}$ estimates were not statistically different from each other, suggests that 3 or 5 dB ERs make little difference for the monitored workers, where continuous, steady-state noise exposures with regular breaks are typical. However, deck workers, electricians, engineers, and other occupations with more variable exposures may have greater differences in exposure when comparing measurements made using the 3 and 5 dB ERs. These exposures may not meet the assumptions inherent to the 5 dB ER, and, if so, the exposures of these workers should be assessed using a 3 dB ER.

The USCG recommends a hearing conservation program for fishing workers with $L_{eff(24)}$ exposures at or above 77 dBA. The vessels assessed had a hearing conservation program in place, and use of HPDs (as well as other personal protective equipment) was a stipulation of employment on the vessels. Earplugs and earmuffs were available to workers aboard both vessels, and workers receive annual training on the proper use of HPDs. Despite the mandatory HPD use policy, some workers reported partial, and in some cases no, use of HPDs. This indicates that additional focus on implementation of noise controls is warranted to insure that workers are not overexposed to noise.

Application of engineering noise controls to shipboard settings is complicated by space and weight restrictions and flammability, sanitation, and access requirements. Nevertheless, reductions in noise exposure levels may be possible for some work areas through the use of enclosures to isolate specific noise sources, regular maintenance of machinery, use of acoustic barriers (i.e., curtains, partitions, or panels), vibration dampers, and wall and ceiling treatments. Controls such as these can be highly effective at reducing noise levels if they are implemented and maintained properly, and the prevalence and effectiveness of these types of controls aboard fishing vessels deserves further evaluation.

Administrative controls, such as shorter work shifts, restricted work durations in certain areas, or worker rotation may also be utilized to reduce exposure to noise, although production demands and crew size may make these approaches difficult to implement. Given the expense and effort required to implement these controls at sea, the negligible USCG noise-related enforcement activities, and the extremely limited jurisdiction of OSHA, there are few regulatory incentives for vessel operators to take such steps. Furthermore, since offshore fishing workers are not covered through traditional no-fault workers’ compensation but rather through the litigation-based Jones Act [Dobie, 1995] there are almost no data available concerning the incidence or cost of NIHL claims in the US fishing industry. However, NIHL estimates for the Japanese industries of agriculture, forestry, and fishing combined (fishing-only data are not available) suggest that this occupational area has among the highest rates of occupational NIHL [Miyakita and Ueda, 1997], and NIHL claims liability may provide a financial incentive for NIHL prevention efforts.

The combination of operational demands and space and resource constraints aboard fishing vessels mean that increased enforcement of HPD use will probably be the most desirable method for minimizing overexposures to noise for many vessel operators. Fortunately, the results of the current study indicate that HPD use is only needed during work-shift hours aboard the monitored vessels, and that non-work time contributes almost nothing to workers’ exposures over a 24 hr period aboard ship. Dependence on HPDs for reduction in workers’ exposure levels must be accompanied by training on the proper fit and use of HPDs. The findings of the current study should apply to other large C/P vessels; however, smaller fishing vessels or vessels with different
layout may have non-work-shift exposure levels that can contribute substantially to 24 hr exposure levels.

CONCLUSION

Fishing workers aboard C/Ps appear to have substantial overexposures to noise. Even when use of HPDs is taken into account, half of the workers assessed were estimated to have 24 hr exposure levels in excess of the separate limits recommended by the USCG and IMO. Despite the differences in the USCG and IMO exposure metrics, the estimates of worker exposure and risk resulting from the two noise limit recommendations are very similar, suggesting that they are equally protective for workers exposed to continuous, steady-state noise environments on commercial fishing vessels. The dominant source of exposure aboard the vessels assessed was work-shift noise. $L_{eq(24)}$ exposures estimated in the study were almost 3 dB less than the 12 hr average work-shift levels. This difference in exposure is almost exactly equal to the ER used in converting the noise exposure received during 12 hr $L_{eq,W}$ to an equivalent exposure over a 24 hr period, and indicates that noise during the work-shift drives the 24 hr exposure of workers. If non-work noise contributed to the 24 hr exposure level, the difference between the 12 hr $L_{eq,W}$ and $L_{eq(24)}$ would be much less than 3 dBA, and the $L_{eq(24)}$ could even be higher than the 12 hr $L_{eq,W}$. Noise levels during non-work time were 30 dBA or more lower than the highest exposure levels during the 24 hr exposure period; on a logarithmic scale, such exposures make a negligible contribution to the average exposure level. Additional efforts are needed to implement engineering or administrative noise controls or increase the use of hearing protection during work shifts to increase the effective protection achieved by fishing workers and further reduce overexposure situations among this workforce.

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