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Statistical Analysis of Hearing Loss Among Navy Personnel

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EXECUTIVE SUMMARY

Permanent hearing loss is one of the most common disabilities among sailors. Although noise-induced injury is preventable by limiting exposure, it is generally irreversible once it occurs. In 2004 the Veterans Administration (VA) spent $108 Million dollars in disability payments to 15.8 thousand former Navy personnel for hearing loss. This represents an increase of $65 Million in spending by the VA on Navy hearing disability payments since 1999. The focus of this study is to find out how hearing loss relates to service time spent aboard ships, in order to reduce disabilities and costs.

Over a career in the US Navy, Service Members characteristically are posted to a variety of stations, both afloat and ashore. Many of these posts have high noise levels, such as certain ships; and particular ratings have high exposure, such as jobs near machinery. If assignments of higher risk both in location and tasking can be identified, then focused prevention programs can be implemented, such as closer monitoring of all personnel, preventive measures in key high risk locations and ratings, focused noise control in ship design, and perhaps better rotational schedules. All these preventative methods may reduce damage to the hearing of Navy personnel. This will preserve quality of life for personnel, and save millions of dollars for government.

In order to investigate which duty stations and ratings are at a high risk for hearing loss, this study looked at the Defense Occupational and Environmental Health Readiness System (DOEHRS) medical hearing test records of nearly 251,000 enlisted sailors and officers over the twenty-five year period 1979 to 2004. The study found that enlisted sailors who spend most of a 24 year Navy career assigned to a Naval Surface Warship[1] as opposed to being assigned to ashore duty

1. Surface Warships include Surface Combatants, Carriers and Amphibious ships. They were combined because there was no statistical difference among them.

stations or a Naval Support ship, had a much higher probability of leaving the Service with a reduction in their ability to hear.

Since many individuals lose some hearing as they age, the study controlled for aging along with other factors such as gender and race to properly test if there are differences associated with ship assignments. To accomplish this task, we merged Navy medical records of hearing tests with information on each individual sailor's duty stations.

To give a sense of the magnitude of hearing loss from time spent aboard certain types of ships, we considered a 24-year career. For an enlistee, the probability of a potential hearing loss in a 24-year career if most of that time was spent on a surface warship, is 46 percent. If that same sailor spent the 24-year career ashore, the probability would be 27 percent. This 19-percentage point difference is significant both practically and statistically speaking. This study is the first to identify the magnitude of the problem after controlling for aging and other factors.

The findings of the study are:

- Time spent on surface warships had the largest impact on hearing loss compared to time spent on surface support ships, time spent in some locations on submarines, or time spent ashore.
- Time spent in submarine engine and machine rooms, time spent on surface support ships, and time spent assigned to Air Wings did not have significantly different impacts on hearing loss from time spent at shore stations. Since individuals assigned to Air Wings and submarine engine rooms are issued hearing protection, the study hypothesizes that this is what protected them from damage to their hearing. Use of hearing protection in work areas with only intermittent high noise exposures could reduce total noise exposures and reduce hearing loss.
- Individuals assigned to submarines but not assigned to the engine or machine rooms did suffer hearing loss.
- For enlisted personnel, the predicted probability of have a potential hearing loss in a 24 year career if most of that time was

spent assigned to a Surface warship was 0.46. If that same sailor spent all of the 24-year career at onshore duty stations, the predicted probability would only be 0.27. This 19-percentage point difference is statistically significant, with the t-statistic testing the null hypothesis that the two probabilities are equal being 20.

- Hence, reducing noise levels on Surface warships or enforcing the wearing of hearing protection devices has the potential of reducing the number of sailors that will have a potential hearing loss in their Naval career by 19 percentage points.
- As expected, age has positive effect on hearing loss. Also, individuals categorized as "black" have a protective effect and being male is a risk factor.

While this study made a good start at identifying the sources of hearing loss, much remains to be studied. Among the recommendations for further research are:

1. Look for specific ship effects or at least for specific ship class effects within each Ship Type to identify opportunities for improved ship design. For example, locating sleeping quarters on ships in an insulated low noise area would improve hearing loss recovery and prevent permanent hearing loss and disabilities.
2. Perform longitudinal cohort studies within and across different ship classes suggested by this study. For example, a follow-up study could analyze and perform noise measurements on certain Surface warships, submarines, and Support ships. Then the study could perform a controlled experiment whereby a sample of individuals assigned to “good” ships are compared to a second sample of individuals assigned to “bad” ships to see if there is a significant difference in hearing loss after a deployment between the two samples. In addition, with the newly collected data on noise measurements the study could correlate hearing loss with time assigned to ships in months using a weighted 8 hour average of noise exposure by primary location of job. Since the US Navy is maintaining active audiogram and screening tests on all service members, a study such as this

might be able to provide causal evidence to better inform prevention efforts.

3. Analyze the Marine Corps data and compute the percent STS for active Marines. In addition, find out whether Marines assigned to ships fair worse in terms of hearing loss than their shore counterparts.

4. Look more closely at the data for Air Wings. For example, in the Air Wing data classify jobs using the NEC rather than Rating. Using the NEC to classify jobs will allow the study to distinguish between individuals working on the deck of the carrier versus those working in say the Aircraft Intermediate Maintenance Depot (AIMD).

5. Survey those with and without hearing loss to question for attribution of hearing loss/protection and do a retrospective risk assessment. For example, further investigate the type of ear protection provided, such as ear muff versus ear plug, and how they tend to be used by personnel in each job rating and location, and if this varies by age or experience.

6. Conduct a detailed analysis of hearing conservation programs in job descriptions and ship types, and investigate any cultural issues relating to compliance. For example, a "macho" risk-taking vs. self-protective culture of different work groups, variation of attitude by officers and enlisted, and so forth.

7. Consider getting data from the VA on individuals who are collecting disability payments for hearing loss and see if there is a relationship between the time they spent at various duty stations and their hearing loss.

8. Look more closely at the data on Navy officers.

INTRODUCTION

Permanent hearing loss is one of the most common disabilities among sailors. Although noise-induced injury is preventable by limiting exposure, it is generally irreversible once it occurs. The problem of reduced hearing function in active military personnel has been documented in several studies. For example, using data from 1995 to 1999 Bonhker, Page, et. al. (2002) showed a Significant Threshold Shift[2] (STS) as high 25% in some Navy Personnel Ratings. Wolgemuth and Kopke (2000) performed an unpublished pilot study examining STS/Permanent Threshold Shift (PTS) incidence among crew members of the Navy aircraft carrier USS Constellation after a six month deployment and found that 12% of the crew members tested exhibited STS/PTS. Similar findings of hearing loss among military personnel are discussed in Gwin and Lacroix (1985) for submariners, Wolgemuth, K.S., Lutrell, et. al. (1995) for Navy personnel, Ridgley and Wilkins (1991) for both Army and Navy personnel, and Jan (2000) for Navy enlisted.

In 2004 the Veterans Administration (VA) spent $108 Million dollars in disability payments to 15.8 thousand former Navy personnel for hearing loss. This represents an increase of $65 Million in spending by the VA on Navy hearing disability payments since 1999.

Given the enormity of the increase in spending by the VA on hearing loss disability payments to former Navy personnel, it is important to find the sources of this hearing loss and then investigate ways to reverse this trend. Although there are poorly understood individual susceptibilities to ear injury, and there may be individual predisposing factors such as hypertension, reliable measures for hearing screening on groups has become standard management in occupa-

2. A formal definition of STS will be give in Section II below. In layman's terms, if an individual is found to have an STS, it implies he or she has had a reduction in their ability to hear normally.

tional health and safety. National standards of exposure are established by Occupational Safety and Health Administration (OSHA) of the US Department of Labor at 90 dB for 8 hours a day[3]. The US Navy abides by the standards given in OPNAVINST 5100.19D, "Occupational Safety and Health Program Manual for Forces Afloat," which specifies that the 8-hour time-weighted average (TWA) is 84 dBA. This instruction defines noise hazardous areas as areas where the routine noise is greater than 84 dBA or where peak noise levels are greater than 140 decibels. In these areas, hearing protection or administrative controls are required. This study did not evaluate the degree of compliance with these exposure limits.

The primary focus of this study is to find out if the length of service aboard ships impacts hearing loss. Over a career in the US Navy, Service Members characteristically are posted to a variety of stations, both afloat and ashore. Many of these posts have high noise levels, such as certain ships; and particular ratings have high exposure, such as jobs near machines. If assignments of higher risk both in location and tasking can be identified, then focused prevention programs can be brought to bear, such as closer monitoring of all personnel, preventive measures in key high risk locations and ratings, and perhaps better rotational schedules. All these preventative methods may reduce damage to the hearing of navy personnel. This will preserve quality of life for personnel, and save millions of dollars for government.

In order to undertake this analysis, medical records from the Defense Occupational and Environmental Health Readiness System (DOEHRS) of individual hearing tests given by the Navy since 1979 were merged with information on each individual sailor's duty stations. With this merged data set, Loigt analysis is able to determine the impact of time spent aboard different types of ships versus time at shore duty stations on the probability of a reduction in hearing function.

The remaining parts of this report are divided into the following Sections. In the next Section we describe the data that was used to

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3. See Wallace R.B. (1998), p. 642; or the OSHA website.

perform the analysis. This is followed by a Section that discusses the model and results. The final Section gives the Summary and Conclusions.

DESCRIPTION OF DATA

In this section we describe how the dependent and explanatory variables were defined and determined, and what data sets were used to obtain this information.

We obtain our measure of hearing loss from the Defense Occupational and Environmental Health Readiness System (DOEHRS). Only audiograms corresponding to active duty Navy enlisted and officer personnel were studied. This data set spans the time period from 1979 to 2004.

We obtain our data on time spent at different duty stations from the Navy's Enlisted Master Record (EMR) and Officer Master File (OMF). Information on demographic data such as the age, gender and race also come from the EMR and OMF data set. This data set has information on the careers of all individuals who served in the Navy over the time period 1982 to 2004, with earlier data for many individuals.

Initially it was hoped that we could use noise exposure data from the Navy in order to make an assessment of shipboard and workplace noise and safety practices. We would then use this data to identify which occupations and ships were exposed to the most noise. Because this data was not electronically available and was only for limited number of ships, we were not able to use data on noise exposure to select which ships and occupations were potentially hazardous to hearing. Instead we relied on information found in the literature and obtained from experienced Navy officers and enlisted personnel to make these noise assessments.

The definition of hearing loss and how the ship and occupation classifications were defined are discussed next.

Definition of STS Using the DOEHRS Data Set

The dependent variable of interest in this paper is a measure of hearing loss. To construct this measure the study only utilized annual and termination audiograms taken over the period 1979 to 2004, obtained in accordance with the periodic evaluation required by the hearing conservation program (HCP). They represented audiograms recorded on Department of Defense Form 2216 (DD Form 2216) and are reported and maintained in the Defense Occupational and Environmental Health Readiness System (DOEHRS). Only audiograms corresponding to active duty Navy enlisted and officer[4] personnel were studied.

The study sample is a huge cohort of 250,895 enlisted sailors who have occupational exposure above an 8-hour time-weighted average (TWA) of 84 dBA as well as enlisted sailors who have reached the termination of their service[5]. There are no readily available data to determine what percentage of the exposed Navy population above an 8-hour TWA of 84 dBA is actually tested. The results of this study only apply to the population of enlisted sailors who obtain periodic evaluation as required by the HCP.

The indicator of hearing loss used is this study is whether the person had a significant threshold shift, or STS. The variable STS is an indicator of a change in hearing over time. The DOEHRS data has an indicator for whether someone had an STS based on an earlier baseline test, but the definition of STS for the Navy has changed over the last 25 years. For consistency, we calculate our own STS variable using

4. A preliminary investigation of about 8,000 Navy officers did not yield statistically significant results and the findings of that analysis are not presented in this report. This is an area where further research is needed.

5. We excluded from the analysis obvious data errors such as age outside a reasonable range, when the only hearing test available was the one they took when they joined the Navy, when there was a gap in service, and when there was not at least one hearing test available after 1998, the first year electronic data was collected.

the earliest and latest data on hearing function available for each individual.

Our indicator for STS was based on the change in hearing for three frequencies (2 kHz, 3 kHz, and 4 kHz) between the first and last years of available hearing tests for each individual. When a December test was "followed up" by additional tests in January, we counted the January tests as being in the same year as the December test. If there is only one year of hearing tests for an individual, for that individual we used the STS indicator computed in the original data set. Otherwise, we averaged all the tests in each of the two years and looked at the difference between the average scores in the two years. If the average difference of the three frequencies for either ear was 10 dB or more, we would consider it a significant threshold shift. This is the current definition of STS used by the military[6]. Note that the amount of hearing loss is not quantified in this study, rather it is a "yes or no" determination.

As an example, we will look at someone who joined the Navy in 1986 and was given his or her last hearing test in 2001. He only had one test in each of those two years. Table 1 gives the results of those tests for the relevant frequencies.

Table 1. Determining a STS

	Left Ear			Right Ear		
	2K Hz	3K Hz	4K Hz	2K Hz	3K Hz	4K Hz
1986	10	25	20	5	5	5
2001	25	25	30	25	25	25

Between 1986 and 2001 the left ear changed by 15 dB at 2K Hz, did not change at 3K Hz, and changed by 10 dB at 4K Hz. The average

6. We also tried an alternative definition of STS, whereby if an individual has a 15 dB change in any of the three frequencies, they are also flagged as having a STS even when the average of the three is less than 10dB. In terms of the impact of time spent aboard ships on the probability of hearing loss, this alternative definition gave similar results to the one we used.

of those is (15+0+10)/3 = 8.3 dB. Because this is less than 10 dB, we need to look at the right ear. All three frequencies changed by 20 dB in the right ear, so the average for the right ear is 20 dB. Therefore, this person had a significant threshold shift.

In the following two sections we describe how different ship types and occupations were classified.

Ship Type Classifications

We compute the number of months each individual spent assigned to different types of ships and in different job ratings prior to their last hearing test. We also compute the number of months each of these individuals spent assigned to shore duty stations and to the Air Wing. We will then estimate the impact of these "assignment time" variables with the occurrence of a positive STS. We classify three different ship types: Surface Warships, Submarines, and Support Ships as follows:

Surface Warships

The surface warships included carriers, surface combatants, and amphibious ships. The activity codes to identify surface ships are below. **Amphibious ships:**

0488: LCC , PHIB COMM SHIP

0551: LHD , LNDDKHELCAPABIL

0556: LHA , PHIB ASSAULTSHP

0558: LKA , PHIB CARGO SHIP

0560: LPD , PHIB TRANSPT DK

0565: LPH , PHIB ASSAULTSHP

0575: LSD , DOCK LNKG SHIPS

0595: LST , TANK LNDG SHIPS

Carriers:

0403: CV , A/C CARRIERS

0407: CVN , A/C CARRIER NUC

Surface combatants:

0356: BB , BATTLESHIPS

0381: CG , GUIDED MISL CRU

0382: CGN , GMISL CRU NUC

0441: DD , DESTROYERS

0442: DDG , GMISL DESTROYER

0456: FF , FRIGATES

0457: FFG , GMISL FRIGATES

Submarines

These activity codes were used to identify submarines:

0159: AGSS, AUX & RESCH SUB

0624: NR , RESCH SUBM NUC

0693: SS , SUBMARINES

0695: SSAG, AUX & RESCH SUB

0697: SSN , SUBMARINE NUC

0706: SSBN, FLT BALMISL SUB

Support Ships

These activity codes were used to identify “Support Ships”.

AFS, COMBAT STOR SHP

AGDS, DEEP SUBMSPTSHP

AGS, SURVEYING SHIPS

AH, HOSPITAL SHIPS

AR, REPAIR SHIPS

ARS, SALVAGE SHIPS

AS, SUB TENDERS

ASR, SUBM RESCUE SHP

ATS, SALV&RESCUE SHP

AVT, AUX AIRC TRA SH

MCM, MINECOUNTERMEAS

AD, DESTROYER TEND

AE, AMMUNITION SHIP

AF, STORE SHIP

AGF, MISC COMM SHIPS

AGOS, OCEAN SUPV SHIP

AO, OILER

AOE, COMBAT SUPP SHP

AOR, REPLENISH OILER

ARC, CABLE REPAIRSHP

ARL, LNDG CRFT REPSH

ATF, FLEET OCEAN TUG

AVM, GUIDED MISL SHP

IX, HISTORICAL WSHP

MHC, MINEHUNTCOASTAL

MSO, MINESWEEPER OCN

PHM, PAT COMBAT MISL

YTB, LG HARB TUG SP

Occupational Class Definitions

Based on the published military literature and our discussions with Navy and enlisted personnel, we used three indicators for job conditions: jobs that are near ship engines, jobs that involve heavy machinery such as power tools, and jobs on the flight deck or near aircraft. We based these categories on ratings. About one-third of the enlisted personnel in our sample had jobs that did not fit into any of those categories, such as cryptographers or yeomen. For these ratings, we define an "other" group. Mess management specialists are classified as the machine group.

We selected the individual's rating at the time of their last hearing test. Generally speaking, ratings for individuals remain the same or change very little over their Navy career once they finish basic training and Navy schooling. So the assumption that their basic rating at the time of their last hearing test is the same as it was for their prior Navy career is reasonable.

Engine Work Conditions

Only 4.4 percent of the sample is classified as working near engines. These ratings were used to identify people exposed to noise mostly through ship engines:

BR - Boiler Repairman

BT - Boiler Technician

EN - Engineman

GS - Gas Turbine Systems Technician

GSE - Gas Turbine Systems Technician-Electrical

GSM - Gas Turbine Systems Technician-Mechanical

Machine Work Conditions

Approximately 35.8 percent of the sample of individuals worked near machinery. These ratings were used to identify people exposed to noise mostly through machines such as power tools or construction equipment:

BM - Boatswain’s Mate

BU- Builder

CE - Construction Electrician

CM - Construction Mechanic

CN - Constructionman

CU - Constructionman

DC - Damage Control

EM - Electrician's Mate

EO - Equipment Operator

EQ - Equipmentman

FN - Fireman

GM - Gunner's Mate

GMG - Gunner's Mate-Guns

GMM - Gunner's Mate-Missiles

GMT - Gunner's Mate-Technician

HT - Hull Maintenance Technician

IC - Interior Communications Electrician

ML - Molder

MM - Machinist's Mate

MN - Mineman

MR - Machinery Repairman

MS - Mess Management Specialist

MT - Missile Technician

SN - Seaman

ST - Sonar Technician

STG - Sonar Technician-Surface

STS - Sonar Technician-Submarine

SW - Steelworker

UC - Utilities Constructionman

UT - Utilitiesman

Aircraft Work Conditions

Roughly 28.1% of the sample are classified as working near Aircraft. These ratings were used to identify people exposed to noise mostly from aircraft:

AB - Aviation Boatswain's Mate

ABE - Aviation Boatswain's Mate-Launching and Recovery Equipment

ABF - Aviation Boatswain's Mate-Fuels

ABH - Aviation Boatswain's Mate-Aircraft Handling

AD - Aviation Machinist's Mate

ADJ - Aviation Machinist's Mate

ADR - Aviation Machinist's Mate Reciprocating Engine Mechanic

AE - Aviation Electrician's Mate

AF - Aviation Maintenance Technician

AM - Aviation Structural Mechanic

AME - Aviation Structural Mechanic-Safety Equipment

AMH - Aviation Structural Mechanic-Hydraulics

AMS - Aviation Structural Mechanic-Structures

AN - Airman

AO - Aviation Ordnanceman

AQ - Aviation Fire Control Technician

AS - Aviation Support Equipment Technician

ASE- Aviation Support Equipment Technician - Electrical

ASH - Aviation Support Equipment Technician - Hydraulics and Structures

AT - Aviation Electronics Technician

AW - Aviation Antisubmarine Warfare Operator

AX - Aviation Antisubmarine Warfare Technician

Other Work Conditions

Roughly 31.7% of the sample is classified in the "other" category. These ratings are:

HM - Hospital Corpsman

ET - Electronics Technician

FC - Fire Control Technician

RM - Radioman

SK - Storekeeper

OS - Operations Specialist

YN - Yeoman

DT - Dental Technician

AZ - Aviation Maintenance Administrationman

MA - Master-at-Arms

AC - Air Traffic Controller

PR - Parachute Rigger/Aircrew Survival Equipmentman

PN - Personnelman

SH - Ship's Serviceman

CTR - Crytologic Technician-Collection

QM - Quartermaster

AK - Aviation Storekeeper

IS - Intelligence Specialist

CTI - Cryptologic Technician-Interpreter/Linguist

CTO - Cryptologic Technician-Communications

FT - Fire Control Technician

TM - Torpedoman

DK - Disbursing Clerk

CTT - Cryptologic Technician-Technical

CTM - Cryptologic Technician-Maintenance

SM - Signalman

EW - Electronics Warfare Technician

AG - Aerographer's Mate

PH - Photographer's Mate

MU - Musician

NC - Navy Counselor

PC - Postal Clerk

CTA - Cryptologic Technician-Administration

RP - Religious Program Specialist

EA - Engineering Aid

LN - Legalman

JO - Journalist

LI - Lithographer

DS - Data Systems Technician

AV - Aviation Avionics Technician

DM - Draftsman Illustrator

DP - Data Processing Technician

OTA - Ocean Systems Technician-Analyst

FTG - Fire Control Technician-Gun Fire Control

IM - Instrumentman

OM - Opticalman

FTB - Fire Control Technician-Ballistic Missile

WT - Weapons Technician

TD - Tradevman (Training Devices Man)

PM - Pattern Maker

OTM - Ocean Systems Technician-Maintenance

FTM - Fire Control Technician-Missile Fire Control

OT Ocean Systems Technician

In the following section we give summary descriptive statistics for the sample of observations used in this study.

Summary Statistics of Demographic Data and Length of Time at Various Duty Stations

We obtain our data on time spent at different duty stations from the Navy's Enlisted Master Record (EMR). This data set contains historical data on where individuals spent their careers in the Navy and their job rating. This data contains complete information on individuals over the time period 1982 to 2004, with earlier information for some individuals. We use this data to get the total time individuals had been assigned to various types of ships, assigned to the Air Wing, or assigned to shore duty stations. As noted above, for ships we define three broad categories of ships: surface warships, submarines, and support ships. The EMR data set is also used to assign each individual in to one of four unique job classifications based on their Navy rating. As noted above, these four job classifications were: engines, machines, aircraft, and other.

Our demographic data such as the age, gender and race also come from the EMR data set.

Summary Statistics of Data

Table 2 gives the summary statistics of the 250,895 enlisted sailor that were analyzed in this study. We see that 10.85% of these sailors have a STS between their first and last available hearing test.

The average age of these sailors at the time of their last hearing test is 27.54, with a range in age of 17 to 64 years. The sample was 87.33 percent male and 60.99 percent white race, with 18.61 percent of the sample classified as the black race.The average length of service for the sample at the time of their last hearing test is 80.35 months, with the range from 1 month to 360 months.

The main explanatory variables of interest are the length of time in months each individual was assigned to different classes of ships, the air wing, or to a shore duty stations prior to their last hearing test. Table 2 gives the mean and range of these variables for individuals who spent a least one month at any of the posts. For example, the average amount of time individuals in the sample were assigned to amphibious ships prior to their last hearing test is 33.11 months, with a range of 1 to 173 months. The average amount of time individuals in the sample were assigned to air wings prior to their last hearing test is 53.71 months, with a range of 1 to 288 months. The average time spent assigned to shore duty stations was 40.99 months with a range of 1 to 360 months, and so forth for the length of time individuals in the sample were assignments to carriers, submarines and support ships.

Table 2. Summary Statistics of Data[a]

Variable	Mean	Standard Deviation	Minimum[b]	Maximum[c]
Percent STS	10.85	31.10	0	1
Age	27.54	7.27	17	64
Percent Male	87.33	33.23	0	1
Percent Race White	60.99	48.78	0	1
Percent Race Black	18.61	38.92	0	1
Percent Race Hispanic	10.57	30.74	0	1
Percent Race Asian	6.43	24.52	0	1

Table 2. Summary Statistics of Data[a]

Variable	Mean	Standard Deviation	Minimum[b]	Maximum[c]
Percent Race Other	3.40	18.12	0	1
Air Wing Months	53.71	47.77	1	288
Amphibious Months	33.11	21.26	1	173
Carrier Months	36.10	25.04	1	256
Surface Combatant Months	40.85	29.81	1	206
Submarine Months	57.17	39.81	1	203
Support Ship Months	36.70	24.32	1	229
Shore Months	40.99	48.25	1	360
Length of Service in Months	80.35	74.93	1	360
NOB = 250,895				

a. The mean and standard deviation of ship, submarine, air wing and shore months does not include zero observations.
b. The minimum and maximum values of the percent variables are 0 if the individual does not have the characteristic and 1 if the individual has the characteristic.
c. The minimum and maximum values of the percent variables are 0 if the individual does not have the characteristic and 1 if the individual has the characteristic.

Summary Statistics of Percent STS by Ship Type and Occupation

Although it is tempting to display a Table that gives the percent STS for each of the above ship types and occupation, this could potentially lead to misleading inferences concerning the sources of hearing loss in the Navy. This is because such a Table would not control for other very important determinants of hearing loss such as the length of time of the exposure, and important demographic characteristics. For example, how long an individuals is exposed to noise on a certain class of ship or in a particular job rating is far more important than just being exposed to the noise. Many individuals are assigned to more than one ship and these other ship types can also impact hearing loss. How long has this individual been assigned to shore duty during their navy career is also important. What is this individual's age, gender and race? Has this individual ever been assigned to the Air Wing? In order to control for these factors when drawing inferences about the sources of hearing loss, a statistical regression model is needed.

In the next Section of the paper we discuss how we estimate the probability of having an STS based on the person's job, time spent assigned to different ship types, assigned to the air wing, and at shore duty stations; and controlling for demographic factors which have a known link to hearing loss, such as age, gender, and race.

MODEL AND RESULTS

Model

The probability of a STS is modeled as a logistic[7] function depending on covariates. It has the following mathematical form:

$$P(STS = 1) = \frac{e^{\gamma' Z + \beta' X}}{1 + e^{\gamma' Z + \beta' X}}$$

In the above equation γ and β are vectors of unknown parameters; X is a vector of individual characteristics such as the natural logarithm of age[8], gender, race, and an intercept term; and Z is a vector of variables that define a sailor's career such as length of time spent at various duty station, including time spent on different types of ships and on shore duty. The parameters in γ are the focus of this study. When comparing the magnitudes of the coefficients on specific "time spent" variables in the Z vector, the larger the magnitude of the coefficient, the larger the impact on hearing loss from time spent at this particular duty station.

Results

Table 2 gives the coefficient estimates of the logit model for enlisted sailors. When comparing the coefficients of different length of time

7. This is a standard method for a categorical variable like STS. See Kachigan (1986), p. 355.
8. We used the natural logarithm of age to account for the non-linear impact of age on hearing loss.

variables, a larger positive coefficient means time spent in that particular location (ship, shore station, or Air Wing) has a greater impact on hearing loss than the corresponding smaller positive coefficient[9]. For example, for enlisted personnel the coefficient for time spent in shore duty stations is 0.0037, the coefficient for time spent in the Air Wing and working around aircraft is 0.0031, while the coefficient on time spent on Surface Warships in the “other” category is 0.0066. This means that time spent on surface warships is far more damaging to hearing than time spent on shore or in the Air Wing[10].

There are two ways to look at the importance of coefficient estimates: practical significance and statistical significance. For practical significance we look at the impact of these coefficients on the predicted probability of getting a STS in a Navy career. We test for statistical significance between two coefficient estimates with a log-likelihood ratio

9. Although variables such as age, race, and gender are not the primary focus of this study, the study did control for these effects in the analysis. Like other studies, this study found that hearing loss increases with age, and that males and whites have a higher prevalence of hearing loss than females and blacks. See the National Academy on an Aging Society (1999) analysis of data from the 1994 National Health Interview Survey of Disability, Phase I.

10. A possible explanation for why time spent in the Air Wing is less damaging to hearing than time spent aboard surface warships is because individuals assigned to Air Wings are given hearing protection to wear while on the flight deck, and this hearing protection reduces the impact of the noise inherent in these job.

χ_1^2 (chi-squared) test or by drawing confidence intervals around the predicted probabilities.

Table 3. Logit Model Estimates for Navy Enlisted Significant Threshold Shift (STS) Equation

Variable	Coefficient Estimates	Standard Error of Coefficient Estimates	t-Statistic for Null Hypothesis that Coefficient is Zero
Constant	-5.4549	0.1644	-33.18
Log of Age	0.7954	0.0529	15.04
Male	0.4325	0.0248	17.45
Black	-0.3351	0.0188	-17.80
Hispanic	-0.1193	0.0229	-5.21
Asian	-0.1954	0.0270	-7.24
Other Race	-0.0575	0.0403	-1.42
Machine Air Wing Months	0.0055	0.0018	2.95
Aircraft Air Wing Months	0.0031	0.0002	13.15
Other Air Wing Months	0.0036	0.00048	7.52
Engine Warship Months	0.0043	0.0005	8.57
Machine Warship Months	0.0055	0.0003	18.54
Aircraft Warship Months	0.0045	0.00044	10.31
Other Warship Months	0.0066	0.00032	20.89
Engine Sub Months	0.0073	0.0125	0.59
Machine Sub Months	0.0029	0.00038	7.48
Other Sub Months	0.0051	0.0005	10.30
Engine Supp Months	0.0023	0.0012	1.82
Machine Supp Months	0.0046	0.0005	9.15
Other Supp Months	0.0042	0.00074	5.73
Non-Ship Months	0.0037	0.00019	19.22

Table 3. Logit Model Estimates for Navy Enlisted Significant Threshold Shift (STS) Equation

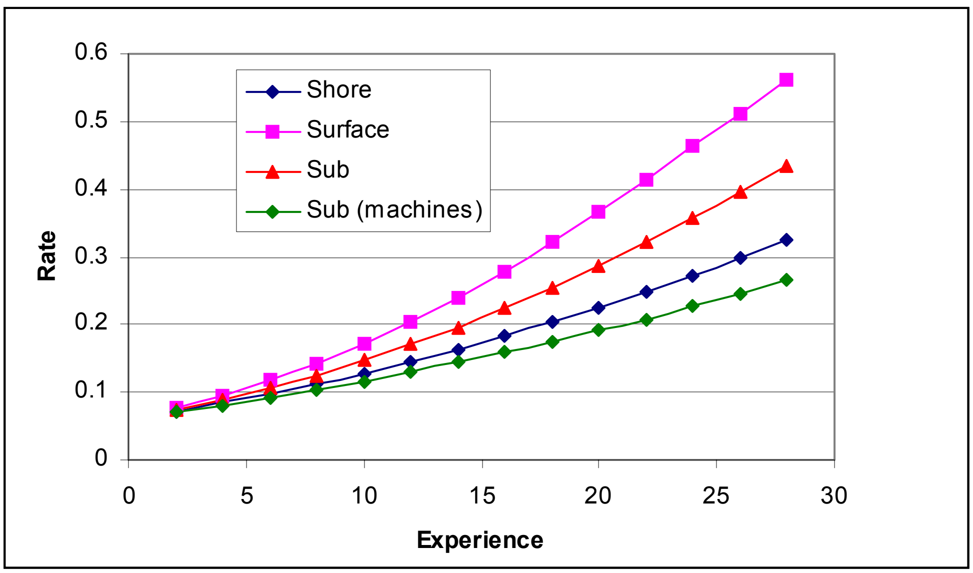
Variable	Coefficient Estimates	Standard Error of Coefficient Estimates	t-Statistic for Null Hypothesis that Coefficient is Zero
NOB = 250,895			
Percent STS= 10.85%			

Practical Significance

Figure 1 below plots the STS probability over time of four white males who enlist at age 18, and spend all their Navy careers in the same activity. For illustrative purposes, Figure 1 gives the probability of an STS for four different career paths: (1)An enlisted white male who spends his entire 28-year Navy career assigned to a submarine working around machines (green colored line), (2) An enlisted white male who spends his entire 28-year Navy career assigned to shore stations other than the Air Wing (blue colored line), (3) An enlisted white male who spends his entire 28-year Navy career assigned to a submarine working in a rating other than machines or engines (red colored line), and (4) an enlisted white male who spends his entire 28-year Navy career assigned to a Surface Warship and working in a rating other than machines, engines or aircraft (rose colored line). Other career paths can be plotted as well.

The four graphs in Figure 1 start at time zero in the Navy, when all four sailors are assumed to have the same baseline hearing. After six years in the Navy the probability of hearing loss increases for all four sailors because of age and work conditions, but it increase the most for the sailor assigned to a surface warship, increasing from 0.07 to 0.14. For the sailor assigned to a shore duty station his entire 6-year Navy career, this probability only increases from 0.07 to 0.11. Although this may seem like a small difference in the increase (0.03), this gap widens considerably over a 28-year navy career. For example, after 24 years in the Navy, the sailor assigned to only shore duty stations has his probability of an STS increase from 0.07 to 0.27, while the sailor assigned to a surface warship for these 24 years has his probability of an STS increase from 0.07 to 0.46. This difference of a 0.19 increase in the probability of an STS has great significance from a practical point of view. It means for every 10,000 enlisted sailors who spend 24 years in the Navy assigned to Surface Warships and working in ratings other than machines, engines or aircraft; nearly 2,000 less of these sailors would suffer an STS if the noise conditions on surface warships in these ratings were lowered to the same noise conditions found at shore duty stations.

Figure 1. Comparison of four different Navy Careers and the impact on STS



Statistical Significance

While practical significance is important in any scientific study, one always has to has the question: What is the likelihood of drawing a sample from the population and observe large practical differences in the probability of an STS for different groups of individual when the actual difference in the entire population between these two groups is zero? To answer this question we need to look at the statistical significance of the results. As noted above, for the Logit model of an STS probability, this can be done with either a log-likelihood ratio χ_1^2 test to test the equality two different coefficient estimates in the Logit model, or with a t-test to test the equality of two predicted probabilities.

For the log-likelihood ratio χ_1^2 test to test the equality of the non-ship time coefficient (estimated as 0.0037) and the other warship time coefficient (estimated as 0.0066), we get 75.0 as the χ_1^2 test statistic. This is statistically significant at greater than the 99.9% level of statistical significance[11]. The meaning of these results is that if time spent assigned to ships was no more damaging to hearing than time spent on shore, it would be virtually impossible to observe the results in our sample that clearly indicate time spent on warships is more damaging to hearing than time spent at shore duty stations.

For the log-likelihood ratio χ_1^2 test to test the equality of the non-ship time coefficient (estimated as 0.0037) and the machine warship time coefficient (estimated as 0.0055), we get 33.0 as the χ_1^2 test statistic. This again is statistically significant at greater than the 99.9% level of statistical significance[12].

Since the predicted probabilities from the Logit model are non-linear functions of estimated parameters, to compute their standard errors and do statistical tests, we need to use a linear approximation. One such approximation is the Delta Method. As discussed in Greene

11. The χ_1^2 log-likelihood ratio test for the equality of two population coefficients is asymptotically equivalent to the standard t-test with infinite degrees of freedom. A χ_1^2 test statistic of 75.0 is equivalent to a t-distribution test statistic of 8.7 and a p-value of less than 0.001, which is statistically significant at most conventional levels of statistical significance.

12. A χ_1^2 test statistic of 33 is asymptotically equivalent to a t-distribution test statistic with infinite degrees of freedom of 5.75 and a p-value of less than 0.001, which is again statistically significant at most conventional levels of statistical significance.

(2003, pp. 674-675), the asymptotic variance of these predicted probabilities $\hat{P}$ is given by:

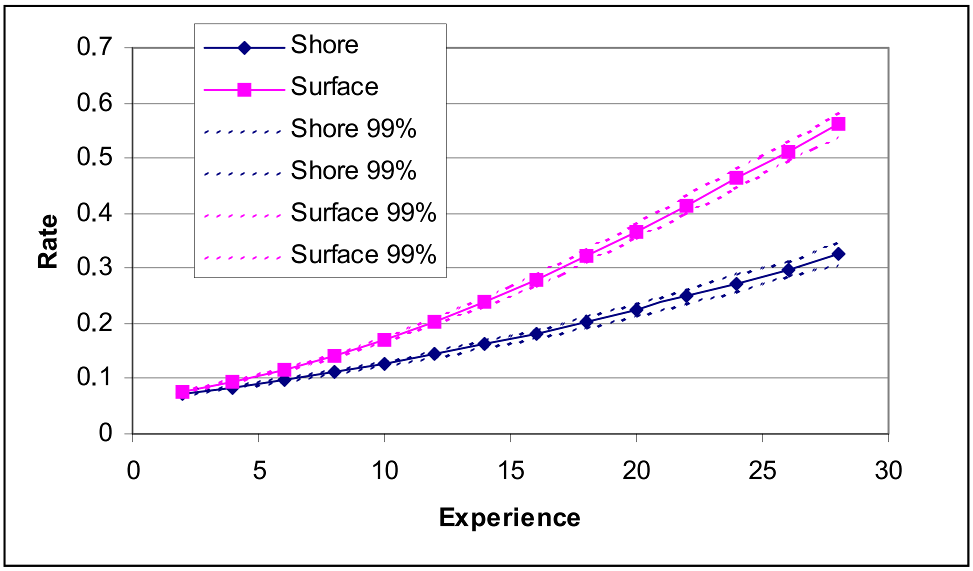
$$Asy.Var(\hat{P}) = \hat{f}W'VW$$

where W is the vector of exogenous variables in Z and X used to predict the probability, V is the variance-covariance matrix of coefficient estimates, and $\hat{f}$ = [P(STS = 1)][1 - P(STS = 1)] evaluated at the estimated coefficients and exogenous variables in W.

Figure 2 gives a 99% statistical confidence interval for an enlisted sailor who spends most of his career on a surface warship and a 99% confidence interval for an identical sailor who spends all of his career on shore duty. Since these two confidence intervals do not overlap, it is clear from a statistical standpoint that the impact of time spent onboard a surface warship is more damaging to hearing function than identical time spent at a shore duty station. The t-statistic testing whether these two probabilities are equal at the end of a 24-year career is 20, which is statistically significant at all conventional levels of statistical significance[13].

13. For officers, the preliminary t-statistic that tests the null hypothesis that the two predicted probabilities are equal for a 24 year career was only 2.2, which is only significant at the 95% level of statistical significance. After these relatively speaking rather weak statistical results, we did not carry out further analysis of the officer data and concentrated our efforts on the sample of enlisted sailors.

Figure 2. 99% Confidence intervals for the Probability of an STS for two different Career paths in the Navy



SUMMARY AND CONCLUSIONS

Permanent hearing loss is one of the most common disabilities among sailors. The primary focus of this study was to find out how service aboard ships impacts hearing loss. In order to undertake this analysis, Defense Occupational and Environmental Health Readiness System (DOEHRS) medical records of individual hearing tests given by the Navy since 1979 were merged with information on each individual sailor's duty stations. With this merged data set, Logit analysis was able to determine that time spent on a certain type of ship has a much higher impact on hearing loss than time spent on shore or in other ship types.

1. A summary of the findings are:
2. Time spent on Surface Warships had the largest impact on potential hearing loss as compared to time spent on Surface Support Ships, time spent in some locations on Submarines, or time spent at shore duty stations.
3. Time spent on Submarine engine and machine rooms and time spent on Surface Support ships did not have significantly different impacts on hearing loss from time spent at shore duty stations.Time spent in the Air Wing was also not significantly different from time spent at shore duty stations. The study hypothesizes this is because individuals assigned to Air Wings are given hearing protection to wear while on the flight deck, and this hearing protection reduces the impact of the noise inherent in their job. Use of hearing protection in work areas with only intermittent high noise exposures could reduce total noise exposures and reduce hearing loss.
4. Individuals assigned to Submarines but not assigned to the engine or machine rooms did suffer hearing loss.
5. For enlisted personnel, the predicted probability of have a potential hearing loss in a 24 year career if most of that time was

spent assigned to a Surface Combatant Ship was 0.46. If that same sailor spent all of the 24-year career at onshore duty stations, the predicted probability would only be 0.27. This 19-percentage point difference is statistically significant, with the t-statistic testing the null hypothesis that the two probabilities are equal being 20.

6. Hence, reducing noise levels on Surface Combatant Ships or enforcing the wearing of hearing protection devices has the potential of reducing the number of sailors that will have a potential hearing loss in their Naval career by 19 percentage points.

7. As expected, age has positive effect on hearing loss. Also, individuals categorized as "black" have a protective effect and being male is a risk factor.

While this study made a good start at identifying the sources of hearing loss, much remains to be studied. Among the recommendations for further research are:

1. Look for specific ship effects or at least for specific ship class effects within each Ship Type to identify opportunities for improved ship design. For example, locating sleeping quarters on ships in an insulated low noise area would improve hearing loss recovery and prevent permanent hearing loss and disabilities.

2. Perform longitudinal cohort studies within and across different ship classes suggested by this study. For example, a follow-up study could analyze and perform noise measurements on certain Surface Warships, Submarines, and Support Ships. Then the study could perform a controlled experiment whereby a sample of individuals assigned to “good” ships are compared to a second sample of individuals assigned to “bad” ships to see if there is a significant difference in hearing loss after a deployment between the two samples. In addition, with the newly collected data on noise measurements the study could correlate hearing loss with time assigned to ships in months using a weighted 8 hour average of noise exposure by primary location of job. Since the US Navy is maintaining active audiogram and

screening tests on all service members, a study such as this might be able to provide causal evidence to better inform prevention efforts.

3. Analyze the Marine Corps data and compute the percent STS is for active Marines. In addition, find out whether Marines assigned to ships fair worse in terms of hearing loss than their shore counterparts.

4. Look more closely at the data for Air Wings. For example, in the Air Wing data classify jobs using the NEC rather than Rating. Using the NEC to classify jobs will allow the study to distinguish between individuals working on the deck of the Carrier versus those working in say the Aircraft Intermediate Maintenance Depot (AIMD).

5. Survey those with and without hearing loss to question for attribution of hearing loss/protection and do a retrospective risk assessment. For example, further investigate the type of ear protection provided, such as ear muff versus ear plug, and how they tend to be used by personnel in each job rating and location, and if this varies by age or experience.

6. Conduct a detailed analysis of hearing conservation programs in job descriptions and ship types, and investigate any cultural issues relating to compliance. For example, a "macho" risk-taking vs. self-protective culture of different work groups, variation of attitude by officers and enlisted, and so forth.

7. Consider getting data from the VA on individuals who are collecting disability payments for hearing loss and see if there is a relationship between the time they spent at various duty stations and their hearing loss.

8. Look more closely at the data on Navy officers.

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