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Incidence and Risk Factors of Tinnitus in U.S. Navy Submariners

by

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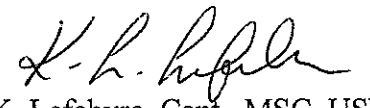

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ABSTRACT

Tinnitus is the most prevalent service-connected disability among Veterans accessing Department of Veterans Affairs (VA) healthcare; however, there have been no studies on the prevalence or incidence of tinnitus in the U.S. Submarine Force. This retrospective cohort study examined tinnitus incidence rates and risk factors in male submariners using Cox proportional hazards regression. From 2004 to 2014, 317 tinnitus medical encounter diagnoses occurred among 19,655 submariners. There were 90,255.82 person-years of risk-time, yielding an incidence rate of 3.5 cases per 1,000 person-years (95% CI 3.1, 3.9). Adjusted hazard ratios indicated being older upon Submarine Force entry or having the most time assigned to submariner duty was associated with highest risk for tinnitus. For officers alone, prior assignment to surface ships was associated with a protective effect. Future hearing conservation efforts should focus on preventive measures including broadening the occupational roles in submarines that require personal protective equipment for hearing loss and tinnitus prevention.

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1.0 INTRODUCTION

In the United States, the prevalence of tinnitus, or "ringing in the ears", is estimated at 1 in 10 adults.[1] Tinnitus is currently the most prevalent service-connected disability among Veterans accessing Department of Veterans Affairs (VA) healthcare. In 2016, 37.0% of the 4.4 million Veterans receiving benefits for service-connected disabilities qualified for compensation for tinnitus in the VA system.[2] This is an increase of 2.2% from the prior year.[3] According to the American Tinnitus Association, the annual aggregate cost of VA disability payments for tinnitus is $1.5 billion, with the estimated costs for health care to treat tinnitus much higher.[4]

Adding to the economic burden, tinnitus can be severely debilitating, impacting cognitive performance,[5] quality of life,[6] and sleep.[7,8] Constant or intermittent tinnitus can distract from work duties and diminish situational awareness. It has also been closely associated with anxiety,[8,9] depression,[8,9] and missed workdays.[8] These compounding factors and comorbidities can severely impact military mission and operational readiness.

Tinnitus can derive from occupational noise exposure, leisure noise, or acoustic trauma.[10] Nearly all military members will be exposed to some occupational noise during their career[11] and are at a high risk for tinnitus due to weapons, artillery, machinery, and engines causing high noise exposures. A recent large-scale study of the U.S. general population found those with a history of regular occupational noise exposure had a 19.2% prevalence of tinnitus compared with 6.8% for those without.[1] Moreover, this study found an increase in the prevalence of tinnitus based on the number of years exposed to noise in the workplace. This latter finding is critical in military settings as warfighters are often required to remain in a noisy environment to complete the mission and are unable to be rotated out as is often an option in civilian settings.[11]

Submariners are especially at risk for increased durations of noise exposures considering they live and work in the same enclosed environment for months at a time.

To date, there have been no studies on the prevalence or incidence of tinnitus in the U.S. Submarine Force. Although a tinnitus diagnosis relies primarily on self-report, its comorbidity with hearing loss (HL), a more objective measure, has been well established.[9,12-14] Often, HL can be used as a proxy in exploring risk factors for tinnitus. It should be noted that tinnitus can occur in individuals with normal hearing thresholds and no HL. In the U.S. Navy, a prevalence study of HL found auxiliary machinery spaces and engine rooms to have the highest noise levels onboard submarines with occupational noise exposures in excess of 85 dBA.[15] Additionally, when evaluating the effectiveness of the Navy's Hearing Conservation Program, medical records from 149 surface ships and five submarines showed 51% of lieutenants had a clinically significant shift in their hearing thresholds, and 47% of submarine sonar technicians had a clinically significant shift.[16] In a separate study which only examined submarine sonar technicians, 5% had hearing loss beyond the Navy's acceptable limits.[17] A cross-sectional Norwegian Navy study that did not differentiate between naval vessels, concluded navigators and engine room personnel had the highest prevalence of HL, and HL was significantly associated with years of working in the Navy and age.[18] U.S. Navy sailors who spent half their 30-year naval career on surface ships were 13% more likely to leave the Navy with a HL than 30-year shore duty sailors.[19]

Individual characteristics have also been associated with increased risk for tinnitus. Older adults tend to have a higher prevalence of tinnitus[1,9,20]; however, a decrease in the incidence of tinnitus was found for those 75 years old and older when compared to groups younger than 75 years of age.[7] Most evidence suggests men tend to have a higher prevalence of tinnitus than women,[1,9,21] but the opposite has also been shown.[22] Whites have been shown to have a higher prevalence of tinnitus than other race/ethnicity groups,[9,21] and higher education levels have been

associated with less risk[21,22] or severity of tinnitus[23]; however, these findings may be influenced by other factors not accounted for in the research.

Given the burden tinnitus represents to the VA healthcare system, and the impact on Veterans and active duty alike, the Institute of Medicine,[24] the Government Accountability Office,[25] and the Department of Defense[26] cited the need for studies that estimate incidence and prevalence of tinnitus. The present study aims to narrow this gap in research by estimating the incidence of tinnitus and identifying characteristics and occupational factors associated with tinnitus in a cohort of U.S. submariners. With no known cure for tinnitus, identifying individuals at risk for tinnitus may help the Department of Defense (DoD) develop targeted interventions aimed at preventing tinnitus in service members in order to reduce their risk, including broadening the occupational roles in submarines that require personal protective equipment for HL and tinnitus prevention. Findings could also identify potential areas for noise reduction engineering controls, and ultimately reduce disability claims resulting from tinnitus.

2.0 METHODS

2.1 Study Design

This was a retrospective cohort study examining tinnitus incidence in male submariners. Submariners in the U.S. Navy were identified from personnel records accessed from Navy Bureau of Personnel (BUPERS) files using unit identification codes (UICs) of Virginia, Los Angeles, Seawolf, and Ohio class submarines. A submariner was included in the study population if his first assignment to a submarine occurred in 2004 to 2014, if he had at least one audiogram within the Defense Occupational and Environmental Health Registry System – Hearing Conservation (DOEHRS – HC) data repository in proximity to joining the Submarine Force (two years prior to first assignment to submarines but no more than 60 days after this first assignment), if he had at least one audiogram after joining submarines but before separating from the Navy, and had a baseline audiogram upon entry into the military.

2.2 Case Definition and Characteristics

The outcome of interest was clinical tinnitus, identified using ICD-9 codes and surveillance definition created by the Armed Forces Health Surveillance Branch (AFHSB) for their surveillance reports (https://health.mil/Military-Health-Topics/Combat-Support/Armed-Forces-Health-Surveillance-Branch/Epidemiology-and-Analysis/Surveillance-Case-Definitions, accessed 29 Sep 19). In this definition, one hospitalization or outpatient medical encounter with any diagnosis of tinnitus (ICD-9 388.30 [tinnitus, unspecified], 388.31 [subjective tinnitus], 388.32 [objective tinnitus]) in any diagnostic position qualifies as a tinnitus case. Person-time (years) was calculated from date of entry into submarine service until either end of study, date of separation from the military, or date of diagnosis of tinnitus, herein collectively referred to as censor date. Baseline tinnitus was defined as meeting the case definition of tinnitus using

medical encounter data prior to the date of entry into submarine service. Submariners with baseline tinnitus were identified and excluded from incidence case analyses.

Demographic and military factors such as age, race, marital status, education, rating, rank, and department were captured at month of entry into submarine service. Cumulative time assigned to submarines and shore duty was calculated from entry into the Navy until censor date; and history of assignment to surface ships was recorded. All analyses were stratified by officer versus enlisted status.

2.3 Statistical Analyses

Frequency distributions of those with and without tinnitus for categorical demographic and military factors (age, race, marital status, education, rank, rating/department, surface ship assignment, and cumulative time assigned to submarines and shore duty) were calculated. Age at entry into submarines and cumulative time assigned to submarines and shore duty were examined as both continuous and categorical variables. Means and standard deviations (SDs) were also calculated for continuous variables and statistically significant differences were determined using the Student's t-test using the Satterthwaithe approximation assuming unequal variance.

Cumulative and stratified incidence rates for tinnitus calculated with 95% confidence intervals (CIs) based on a Poisson distribution were used to assess differences in incidence rates between categorical factors. Statistically significant differences in incidence rates were inferred if the CIs did not overlap. Hazard ratios (HR) and 95% Wald CIs were calculated using Cox proportional hazards regression. Any variable with an unadjusted p-value of $p \leq 0.20$ was initially included in the multivariable model. The final model retained only variables that were statistically significant ($p \leq 0.05$) or that confounded (as measured by a 20% change in the effect

estimate) the relationship between either age or any of the submarine specific variables and tinnitus.

Variables in the adjusted model were tested for violations of the proportional hazards assumption using Martingale residuals. Those in violation were either used as stratification variables (rank, shore duty time) or were modelled as time-varying using a counting process approach (submarine duty time). Additionally, Machinist Mate Auxiliary (AUX) was in violation of the proportional hazards assumption. Time-varying occupational rating was not practical and reporting HRs for other occupational ratings was integral to the objective of this study, so the authors chose not to time-vary or stratify the model on the occupational rating variable. This approach yielded no interpretable HR for the MM (AUX) rating. Finally, as no submariners in the Information Systems Technician (ITS) rating developed tinnitus (n = 26), all submariners of that rating were excluded from the model. Data analyses were conducted using SAS version 9.3 or SPSS version 23.

3.0 RESULTS

A total of 19,683 submariners were included in the initial tinnitus study population. Of these, 28 were found to have tinnitus at the time they joined the submarine service (0.14%). Excluding these baseline cases, 17,211 enlisted submariners and 2,444 officers were followed to identify incident cases of tinnitus after joining the Submarine Force. During the study's time frame, 317 submariners (or 1.6%) received a tinnitus medical encounter diagnosis. In total, there were 90,255.82 person-years of risk-time (mean risk time was 4.6 years), yielding an incidence rate of 3.5 cases per 1,000 person-years (95% CI 3.1, 3.9).

3.1 Enlisted

Among enlisted submariners, there were 268 tinnitus cases, with 77,562.50 person-years of follow-up time and an incidence rate of 3.5 cases per 1,000 person-years (95% CI 3.1, 3.9). Table 1a displays incidence of tinnitus rates by characteristic for enlisted submariners. The mean age at entry into submarine service for enlisted with tinnitus was significantly older ($p < .001$) at 22.9 years (SD 4.0) compared to 21.8 years (SD 2.8) for the enlisted without tinnitus. Sailors who entered submarine service when they were age 30 and older had significantly higher rates of tinnitus than those younger than 30 years of age. Additionally, the incident rate for Sailors married at entry was significantly higher [4.5 cases per 1,000 person-years (95% CI 3.6, 5.5)] than those single at entry [3.1 cases per 1,000 person-years (95% CI 2.6, 3.6)]. Among occupational ratings, the incidence rate for hospital corpsman [12.6 cases per 1,000 person-years (95% CI 3.4, 32.3)] was more than twice the next highest incident rate found for missile technicians [5.0 cases per 1,000 person-years (95% CI 3.0, 8.0)]. However, the confidence intervals around the hospital corpsman estimates were quite wide, and the difference was not significant. With only 26 information systems technicians, none had a diagnosis of tinnitus following entry to submarine service. Overall, no significant differences in incidence rates based on rating were found. For rank, the highest incidence of tinnitus occurred among those who entered submarine service at the E-6 (petty officer first class) or above rank (16.6 cases per 1,000 person-years, 95% CI 7.9, 30.4), which was significantly higher than the incidence rates for those E-4 (petty officer third class) and below (ranging from 2.6 to 3.9 per 1,000 person-years). However, the confidence intervals for those E-6 and above were wide as they represented the smallest proportion of enlisted submariners. Moreover, the difference is likely to be confounded by an age difference. Incidence rates did not significantly differ by race, education, or nuclear training at the time of submarine service entry.

Table 1a: Incidence and characteristics of tinnitus in the enlisted submariner population.

Characteristic	N (%) or Mean (SD) With Tinnitus		Without Tinnitus		Person-years	Tinnitus (Per 1,000 Person-years)	95% Confidence Interval
Overall	268	1.6%	16943	98.4%	77562.50	3.5	(3.1, 3.9)
Age at submarine entry							
Mean (SD)[a]	22.9	4.0	21.8	2.8			
18-20	94	35.1%	7166	42.3%	34870.15	2.7	(2.2, 3.3)
21-23	81	30.2%	6071	35.8%	26941.71	3.0	(2.4, 3.7)
24-26	57	21.3%	2555	15.1%	10749.38	5.3	(4.0, 6.9)
27-29	14	5.2%	790	4.7%	3293.57	4.3	(2.3, 7.1)
30+	22	8.2%	361	2.1%	1707.70	12.9	(8.1, 19.5)
Race							
White	197	73.5%	11972	70.7%	56046.35	3.5	(3.0, 4.0)
Black/African American	13	4.9%	1244	7.3%	5950.12	2.2	(1.2, 3.7)
Multiple races	28	10.4%	1674	9.9%	6115.20	4.6	(3.0, 6.6)
Other/Unknown	30	11.2%	2053	12.1%	9450.83	3.2	(2.1, 4.5)
Marital status							
Single	175	65.3%	12618	74.5%	56906.14	3.1	(2.6, 3.6)
Married	93	34.7%	4325	25.5%	20656.37	4.5	(3.6, 5.5)
Highest education at submarine entry							
Unknown	1	0.4%	71	0.4%	400.76	2.5	(0.1, 13.9)
High school or equivalent	251	93.7%	15783	93.2%	72837.99	3.4	(3.0, 3.9)
Associate's or some college	10	3.7%	592	3.5%	2541.71	3.9	(1.9, 7.2)
Bachelor's degree or more	6	2.2%	497	2.9%	1782.04	3.4	(1.2, 7.3)
Rating at submarine entry							
Information Systems Technician	0	0.00%	26	0.20%	46.79	0	-
Yeoman	2	0.70%	164	1.00%	1002.3	2.0	(0.2, 7.2)
Culinary Specialist	4	1.50%	364	2.10%	1909.5	2.1	(0.6, 5.4)
Fire Control Technician	6	2.20%	573	3.40%	2826.68	2.1	(0.8, 4.6)
Machinist Mate WEP	8	3.00%	877	5.20%	3796.31	2.1	(0.9, 4.2)
Electronics Technician NUC	9	3.40%	1066	6.30%	3901.38	2.3	(1.1, 4.4)
Unrated	25	9.30%	2203	13.00%	10020.35	2.5	(1.6, 3.7)
Sonar Technician	18	6.70%	1344	7.90%	5864.27	3.1	(1.8, 4.9)
Electronics Technician NAV	15	5.60%	834	4.90%	4480.25	3.3	(1.9, 5.5)
Electricians Mate	33	12.30%	2006	11.80%	8887.26	3.7	(2.6, 5.2)
Machinist Mate AUX	54	20.10%	3082	18.20%	14265.7	3.8	(2.8, 4.9)
Electronics Technician COM	26	9.70%	1145	6.80%	6269.94	4.1	(2.7, 6.1)
Logistics Specialist	4	1.50%	176	1.00%	948.01	4.2	(1.1, 10.8)
Machinist Mate NUC	42	15.70%	2393	14.10%	9459.72	4.4	(3.2, 6.0)
Missile Technician	18	6.70%	641	3.80%	3567.14	5.0	(3.0, 8.0)
Hospital Corpsman[c]	4	1.50%	49	0.30%	316.9	12.6	(3.4, 32.3)

Table 1a: Continued.

Characteristic	N (%) or Mean (SD) With Tinnitus		Without Tinnitus		Person-years	Tinnitus (Per 1,000 Person-years)	95% Confidence Interval
Rank at submarine entry							
E-1	24	9.0%	2026	12.0%	9265.49	2.6	(1.7, 3.9)
E-2	43	16.0%	3258	19.2%	15125.14	2.8	(2.1, 3.8)
E-3	62	23.1%	4393	25.9%	20870.10	3.0	(2.3, 3.8)
E-4	111	41.4%	6326	37.3%	28336.16	3.9	(3.2, 4.7)
E-5	18	6.7%	825	4.9%	3361.55	5.4	(3.2, 8.5)
E-6-E-9	10	3.7%	115	0.7%	604.07	16.6	(7.9, 30.4)
Nuclear rating							
Not trained	184	68.7%	11509	67.9%	55421.39	3.3	(2.9, 3.8)
Trained	84	31.3%	5434	32.1%	22141.11	3.8	(3.0, 4.7)
Cumulative time assigned to submarines prior to censoring							
Mean, SD (days)[b]	1214.1	616.7	1276.9	642.1			
< 2 years	67	25.0%	4079	24.1%	7711.74	8.7	(6.7, 11.0)
2 - 3 years	36	13.4%	1972	11.6%	5974.55	6.0	(4.2, 8.3)
3 - 4 years	55	20.5%	3625	21.4%	15620.44	3.5	(2.7, 4.6)
4+ years	110	41.0%	7267	42.9%	48255.76	2.3	(1.9, 2.7)
Cumulative time assigned to shore duty prior to censoring							
Mean, SD (days)[a]	1131.7	885.4	927.0	636.1			
< 1 years	24	9.0%	2568	15.2%	7914.90	3.0	(1.9, 4.5)
1 - 2 years	81	30.2%	5409	31.9%	19088.82	4.2	(3.4, 5.3)
2 - 3 years	55	20.5%	3914	23.1%	14379.00	3.8	(2.9, 5.0)
3+ years	108	40.3%	5052	29.8%	36179.79	3.0	(2.4, 3.6)
History of assignment to surface ships							
No	255	95.1%	16389	96.7%	74509.33	3.4	(3.0, 3.9)
Yes	13	4.9%	554	3.3%	3053.17	4.3	(2.3, 7.3)

Based on t-test, equal variances not assumed: [a]p <.05 and [b]p >.05. [c]Hospital Corpsman was highly correlated with age and rank; 96% were over 26 years old, and 94% were E6-E9.

The average cumulative number of days assigned to submarines was not significantly different (p = .099) between those with tinnitus (mean 1,214.1, SD 616.7) and those without (mean 1,276.9, SD 642.1). However, there was a nonsignificant trend of decreasing tinnitus incidence observed with increasing time assigned to submarines. Those with less than two years of service on submarines had a significantly higher rate of tinnitus (8.7 cases per 1,000 person-years, 95% CI 6.7, 11.0), than those with three to four years (3.5 cases per 1,000 person-years, 95% CI 2.7, 4.6) or four or more years assigned to submarines (2.3 cases per 1,000 person-years,

95% CI 1.9, 2.7). In contrast to no difference between those with tinnitus and without regarding time spent assigned to submarines, tinnitus cases spent 22% more ($p < .001$) time assigned to shore duty (mean 1131.7, SD 885.4) than those without (mean 927.0, SD 636.1) with 40% of cases experiencing three or more years assigned to shore duty. However, no significant differences in incidence rates were found between time assigned to shore duty groups. Additionally, no significant difference in incidence rate was found between those never assigned to a surface ship (3.4 cases per 1,000 person-years, 95% CI 3.0, 3.9) and those with at least one surface ship assignment (4.3 cases per 1,000 person-years, 95% CI 2.3, 7.3).

3.2 Officers

Among officers, there were 49 tinnitus cases, with 12,693.32 person-years of follow-up time, for an incidence rate of 3.9 cases per 1,000 person-years (95% CI 2.9, 5.1). Table 1b displays incidence of tinnitus rates by characteristic for officers. Similar to enlisted submariners, the mean age at entry into submarine service for cases was significantly older ($p = .03$) at 26.6 years (SD 4.5) compared to 25.2 years (SD 2.6) for those without tinnitus. Additionally, Sailors who entered submarine service when they were age 31 and older had significantly higher rates of tinnitus (11.5 cases per 1,000 person-years, 95% CI 5.3, 21.9) than those who joined when they were age 22-24 (3.4 cases per 1,000 person-years, 95% CI 2.2, 5.2). Regarding departments, officers in the engineering department had significantly higher rates of tinnitus (23.9 cases per 1,000 person-years, 95% CI 16.2, 33.9) than executive (0.7 cases per 1,000 years, 95% CI 0.0, 3.7), navigation/operation (0.4 cases per 1,000 years, 95% CI 0.1, 1.1) and weapons department officers (3.7 cases per 1,000 years, 95% CI 1.2, 8.6). Incidence rates were not significantly different by race or marital status, and the proportion of missing data for education was too high (> 40%) to examine the effects of this variable. As was observed with enlisted paygrades, the highest incidence of tinnitus occurred among those who entered submarine service at the highest

paygrades in the cohort, i.e., lieutenant or higher (O3-O5) (21.1 cases per 1,000 person-years, 95% CI 6.8, 49.2), and this was significantly higher than those who entered as chief warrant officers or ensigns (CWO/O1) (3.3 cases per 1,000 person-years, 95% CI 2.3, 4.6).

Table 1b: Incidence and characteristics of tinnitus in the officer submariner population.

Characteristic	N (%) or Mean (SD) With Tinnitus		Without Tinnitus		Person-years	Tinnitus (Per 1,000 Person-years)	95% Confidence Interval
Overall	49	2.0%	2395	98.0%	12693.32	3.9	(2.9, 5.1)
Age at submarine entry							
Mean (SD)[a]	26.6	4.5	25.2	2.6			
22-24	23	46.9%	1329	55.5%	6693.78	3.4	(2.2, 5.2)
25-27	15	30.6%	720	30.1%	3900.97	3.8	(2.2, 6.3)
28-30	2	4.1%	231	9.6%	1318.99	1.5	(0.2, 5.5)
31+	9	18.4%	115	4.8%	779.58	11.5	(5.3, 21.9)
Race							
White	42	85.7%	2086	87.1%	10964.67	3.8	(2.8, 5.2)
Nonwhite	6	12.2%	69	2.9%	1313.25	4.6	(1.7, 9.9)
Unknown	1	2.0%	240	10.0%	415.40	2.4	(0.1, 13.4)
Marital status							
Married	26	53.1%	936	39.1%	5371.42	4.8	(3.2, 7.1)
Single	23	46.9%	1459	60.9%	7321.89	3.1	(2.0, 4.7)
Department at submarine entry							
Engineering	31	63.3%	1433	59.8%	1296.66	23.9	(16.2, 33.9)
Executive	1	2.0%	251	10.5%	1494.73	0.7	(0.0, 3.7)
Navigation/Operation	3	6.1%	295	12.3%	7673.45	0.4	(0.1, 1.1)
Supply	9	18.4%	231	9.6%	876.73	10.3	(4.7, 19.5)
Weapons	5	10.2%	185	7.7%	1351.74	3.7	(1.2, 8.6)
Rank at submarine entry							
CWO/O1	35	71.4%	1914	79.9%	10500.28	3.3	(2.3, 4.6)
O2	9	18.4%	439	18.3%	1955.91	4.6	(2.1, 8.7)
O3+	5	10.2%	42	1.8%	237.13	21.1	(6.8, 49.2)
Cumulative time assigned to submarines prior to censoring							
Mean (SD)[a]	896.9	451.3	1094.3	466.1			
< 2 years	14	28.6%	415	17.3%	817.89	17.1	(9.4, 28.7)
2 - 3 years	24	49.0%	1066	44.5%	5775.08	4.2	(2.7, 6.2)
3+ years	11	22.4%	914	38.2%	6100.35	1.8	(0.9, 3.2)
Cumulative time assigned to shore duty prior to censoring							
Mean (SD)[b]	1798.1	1033.7	1798.9	1112.0			
< 2 years	8	16.3%	459	19.2%	1216.69	6.6	(2.8, 13)
2 - 5 years	22	44.9%	996	41.6%	4521.60	4.9	(3.0, 7.4)
5+ years	19	38.8%	940	39.2%	6955.03	2.7	(1.6, 4.3)
History of assignment to surface ships							
No	47	95.9%	2243	93.7%	11590.52	4.1	(3.0, 5.4)
Yes	2	4.1%	152	6.3%	1102.79	1.8	(0.2, 6.6)

Based on t-test, equal variances not assumed: [a]$p < .05$ and [b]$p > .05$

As was the case with enlisted cases, officer's with tinnitus spent significantly ($p = .007$) fewer days on submarines (mean 896.9, SD 451.2) than officers without tinnitus (mean 1094.3, SD 466.1), showing again a trend of increased tinnitus cases observed for those with decreased time assigned to submarines. Officers with less than two years of service on submarines had a

significantly higher rate of tinnitus (17.1 cases per 1,000 person-years, 95% CI 9.4, 28.7), than those who were assigned to submarines for two to three years (4.2 cases per 1,000 person-years, 95% CI 2.7, 6.2), and more than three years (1.8 cases per 1,000 person-years, 95% CI 0.9, 3.2). Contrary to the enlisted cohort, there was virtually no difference (p = .96) in the days spent assigned to shore duty between the officer tinnitus cases (mean 1798.1, SD 1033.7) and those without (mean 1798.9, SD 1112.0). As was seen with the enlisted cohort, no significant difference in incidence rate was found between those never assigned to a surface ship (4.1 cases per 1,000 person-years, 95% CI 3.0, 5.4) and those with at least one surface ship assignment (1.8 cases per 1,000 person-years, 95% CI 0.2, 6.6).

3.3 Adjusted Hazard Ratios

Using Cox proportional hazards regression to account for time to tinnitus diagnosis, adjusted hazard ratios (HR) and 95% CIs were examined to determine a submariner's risk at any given time point of experiencing tinnitus while adjusting for risk factors included in the model. Factors included in the final enlisted model were age, race, marital status, education, rating, time assigned to submarine, and history of surface ship assignment. The enlisted model was stratified by shore duty and rank, with submarine time modeled as a time-varying covariate.

Among enlisted submariners, those who entered submarine service at ages 24-26 had 1.9 (HR = 1.87, 95% CI 1.31, 2.68) times the risk of tinnitus compared to their youngest (ages 18-20) counterparts (Table 2a). Those who joined the submarine service at age 30 or older were 5.4 times more at risk for tinnitus (HR = 5.37, 95% CI 3.06, 9.43). Compared to respective referent groups, there were no significant differences in risk for race, marital status, education, or rating for enlisted sailors. Contrary to the unadjusted findings, HRs for time assigned to submarines showed enlisted sailors who were assigned to submarines for three to four or four + years of service on submarines had a 1.9 and 3.2 -fold increase in risk of tinnitus (3-4 years: HR = 1.91,

95% CI 1.31, 2.79; 4+ years: HR = 3.16, 95% CI 2.16, 4.61) when compared to sailors with less than two years submarine service. Finally, there was no significant difference in risk of tinnitus between enlisted submariners who spent at least some part of their naval career assigned to surface ships compared to those who never served on a surface ship. While both rank and shore duty time were significantly associated with tinnitus, each variable had multiple levels in violation of the proportional hazards assumption. The models were stratified by these variables, and thus HRs are not available.

Factors included in the final officer model were age, marital status, department, rank, time assigned to submarine, and history of surface ship assignment. The officer model was stratified by shore duty with submarine time modeled as a time-varying covariate. Among officers, those who entered submarine service at ages 31 and older had more than four times the risk of tinnitus (HR = 4.37, 95% CI 1.32, 14.43) compared to those who entered at ages 22-24 (Table 2b). There were no significant differences in risk of tinnitus by marital status, submarine department, or time assigned to submarines. Officers who served on their first submarine as a lieutenant or higher (O3+) had more than five times greater risk of tinnitus (HR = 5.24, 95% CI 1.20, 22.88) than those who served as chief warrant officers or ensigns (CWO/O1). Compared to officers who had never been assigned to a surface ship, those with a history of a surface ship assignment were at a 13% lower risk for tinnitus (HR = 0.13, 95% CI 0.03, 0.66).

Table 2a: Adjusted hazard ratios of characteristics for tinnitus in the enlisted submariner population*

Characteristic		Hazard Ratio	95% Confidence Interval**	p value
Age at submarine entry				
	18-20	Ref		
	21-23	1.04	(0.76, 1.41)	0.811
	24-26	1.87	(1.31, 2.68)	0.001
	27-29	1.74	(0.95, 3.19)	0.073
	30+	5.37	(3.06, 9.43)	0.000
Race				
	White	Ref		
	Black/African American	0.70	(0.40, 1.23)	0.217
	Multiple races	1.19	(0.79, 1.8)	0.407
	Other/Unknown	0.94	(0.64, 1.38)	0.738
Marital status at submarine entry				
	Single	Ref		
	Married	1.11	(0.84, 1.47)	0.455
Highest education attained at submarine entry				
	High school or equivalent	Ref		
	Associate's or some college	0.83	(0.43, 1.59)	0.568
	Bachelor's degree or more	0.41	(0.16, 1.02)	0.056
	Unknown	0.48	(0.06, 3.53)	0.467
Rating at submarine entry				
	Sonar Technician	Ref		
	Yeoman	0.93	(0.20, 4.27)	0.927
	Culinary Specialist	0.87	(0.29, 2.65)	0.810
	Fire Control Technician	0.74	(0.29, 1.86)	0.519
	Machinist Mate WEP	0.72	(0.32, 1.63)	0.431
	Electronics Technician NUC	0.60	(0.24, 1.51)	0.276
	Unrated	0.89	(0.48, 1.63)	0.698
	Electronics Technician NAV***	---	---	
	Electricians Mate	1.10	(0.55, 2.19)	0.783
	Machinist Mate AUX	1.25	(0.69, 2.27)	0.457
	Electronics Technician COM	1.37	(0.73, 2.59)	0.328
	Logistics Specialist	1.73	(0.59, 5.13)	0.319
	Machinist Mate NUC	1.30	(0.67, 2.55)	0.439
	Missile Technician	1.90	(0.94, 3.83)	0.072
	Hospital Corpsman	0.99	(0.29, 3.37)	0.990
Cumulative time assigned to submarines prior to censoring****				
	< 2 years	Ref		
	2 - 3 years	1.18	(0.78, 1.79)	0.434
	3 - 4 years	1.91	(1.31, 2.79)	0.001
	4+ years	3.16	(2.16, 4.61)	0.000
History of assignment to surface ships				
	No	Ref		
	Yes	1.25	(0.69, 2.25)	0.463

*Based on Wald sandwich variance estimates

**Model is stratified by shore duty and rank

***ET(NAV) was in violation of the proportional hazards assumption, no interpretable HR

****Submarine duty time is modeled as a time-varying covariate

Table 2b: Adjusted hazard ratios of characteristics for tinnitus in the officer submariner population*

Characteristic		Hazard Ratio	95% Confidence Interval**	p value
Age at submarine entry				
	22-24	Ref		
	25-27	1.34	(0.70, 2.59)	0.378
	28-30	0.62	(0.14, 2.70)	0.523
	31+	4.37	(1.32, 14.43)	0.016
Marital status				
	Single	Ref		
	Married	1.35	(0.69, 2.67)	0.382
Department at submarine entry				
	Executive	0.30	(0.03, 3.09)	0.313
	Supply	2.85	(0.71, 11.36)	0.138
	Engineering	1.89	(0.57, 6.26)	0.296
	Weapons	1.94	(0.46, 8.25)	0.367
	Navigation and Operations	Ref		
Rank at submarine entry				
	CWO/O1	Ref		
	O2	1.66	(0.79, 3.50)	0.185
	O3+	5.24	(1.20, 22.88)	0.027
Cumulative time assigned to submarines prior to censoring***				
	< 2 years	Ref		
	2 - 3 years	2.11	(0.87, 5.12)	0.098
	3+ years	1.67	(0.60, 4.63)	0.322
History of assignment to surface ships				
	No	Ref		
	Yes	0.13	(0.03, 0.66)	0.014

*Based on Wald sandwich variance estimates
**Model is stratified by shore duty
***Submarine duty time is modelled as a time-varying covariate

4.0 DISCUSSION

Only 0.14% of submariners were known to have tinnitus prior to submariner service entry. Because this clinical diagnosis is based on self-reporting to a physician, the true baseline prevalence may be underreported. Although tinnitus is not a disqualifying medical condition for submarine service, it is possible symptoms were not reported due to fear of disqualification when standards were unknown, or a member aspired to a specialized duty in which tinnitus is disqualifying. Excluding known baseline cases, this study found from 2004 to 2014, 1.6% of

19,655 enlisted submariners and officers, who met our study's criteria, received a tinnitus diagnosis. Our cohort included submariners from 18 to 46 years of age, with 98% aged 30 years old or younger.

With a total of 90,255.82 person-years of risk-time (mean risk-time was 4.6 years), an incidence rate of 3.5 cases per 1,000 person years (95% CI 3.1, 3.9) was found. Although officers were slightly older by about 3.5 years, there was no significant difference detected in the rates for enlisted submariners (3.5 cases per 1,000 person-years, 95% CI 3.1, 3.9) versus officers (3.9 cases per 1,000 person-years, 95% CI 2.9, 5.1).

With a few caveats, our findings can be roughly compared to a recent U.S. tinnitus *prevalence* study that estimated frequent tinnitus of men and women up to 30 years of age at 2.6%.[9] First, our study measured *incidence* during a 10-year submarine service tenure time-frame (mean risk-time was 4.6 years), which would, by definition, be less than prevalence estimates. However, with such a young population we would not expect vast differences between incidence and prevalence. Additionally, the U.S. estimate was derived only from self-reported tinnitus; in contrast, our tinnitus cases were based on self-reports leading to clinical diagnoses. Jointly, we would expect our diagnosis criteria of only new cases (incidence) to yield lower estimates. It should be noted, however, that unlike the general population estimate, we did not include women who tend to have lower rates of tinnitus.[1,9,21] Given these limitations, the findings from both studies are roughly comparable.

Perhaps a better comparison would be two U.K. incidence studies of adults with clinically diagnosed tinnitus.[27,28] As we might expect with a military population versus a general population, our overall submariner incidence rate per 1,000 person years for our mostly under 30 years old population was 3.5, markedly higher than the 0.28 rate[27] and 1.0 rate[28] for the 20-29 year old subgroups of those studies.

Consistent with our incidence rate findings and controlling for other covariates, modelling showed those who entered the Submarine Force at an older age (enlisted submariners, 30+ years; officers, 31+ years) were at an increased risk of a tinnitus diagnosis while a submariner. Enlisted submariners aged 24-26 years at entry were also at an increased risk compared to the youngest group (18-20 years). Interestingly, although those in their late twenties had higher rates than those younger than 24 years of age, this finding was not statistically significant.

For enlisted submariners, no significant associations were found between tinnitus and occupational ratings and nuclear training. However, officers in the engineering department had much higher rates of tinnitus than all but the supply department, but when stratifying by shore duty and accounting for other covariates in the model, no department effect remained. With our relatively young cohort, it was surprising that age, not occupation, was associated with tinnitus, since machinery spaces and engine rooms have the highest noise levels onboard submarines,[15] and sonar technichians,[16] navigators,[18] and engine room[18] personnel have been associated with having hearing loss.

For both enlisted submariners and officers, there was a nonsignificant trend toward increased tinnitus incidence with increased rank. Highest ranking enlisted members (E-6 to E-9) had incidence rates three to six times higher than lower ranking members. Unfortunately, because the enlisted model stratified by rank, we could not determine if this effect remained when controlling for other covariates. For officers, the association of rank and tinnitus remained significant in the proportional hazards model showing a 5.2-fold increase in risk of tinnitus among officers who entered the Submarine Force at the highest ranks (O3+), suggesting a commonality of noise exposure for highest ranking officers that cannot be attributed to age or department.

For enlisted, more time assigned to submarines suggested a protective effect when adjustments for covariates were not made. However, when race and marital status (significant only in unadjusted model) were accounted for, and the adjusted model stratified by rank at entry and shore duty (also significant unadjusted factors), modeling submarine duty time as a time-varying covariate showed more than three years in the Submarine Force was associated with increased risk for tinnitus. For officers, however, no association was found with time assigned to submarines and tinnitus. Because shore duty time violated model assumptions, we were unable to determine its adjusted association with tinnitus. For officers only, a surface ship assignment was associated with a 13% decreased risk for tinnitus. This could be attributed to the types of occupations, such as supply officer, that are transferrable to submarines and are not typically associated with the noisiest shipboard workspaces.

While married enlisted members had a higher crude incidence of tinnitus (no difference was found for officers), adjusting for potential risk factors in the final model showed marital status was not independently associated with increased risk for tinnitus for either group. For enlisted submariners, education was not significantly associated with tinnitus incidence; however, consistent with other studies,[21-23] there was a trend in decreased tinnitus risk with increasing education level. Unfortunately, over 40% of officer records did not have education level, so we could not make this determination for officers.

Contrary to other studies,[9,21] no association was found between tinnitus and race/ethnicity for officers or enlisted submariners. The p-value for unadjusted HR for race/ethnicity for officers, was ≥ 0.20 and was therefore not included in the initial model. This was not surprising, given 87% of the officer cohort was white.

This study did not account for HL prior to or during military service. Future research in this area should account for this important factor given Gubata et al.[29] determined military members waived entry into service with a disqualifying pre-enlistment audiogram had a 10.92

times increased odds of HL disability. Given HL is associated with a higher prevalence of tinnitus,[24] a similar finding with tinnitus may also be true, however waiver information was unavailable for the present study. Another limitation was we did not examine mental health and other health indicators, such as diet, that have been associated with tinnitus.[9,30]

To our knowledge, no other study has examined tinnitus in the U.S. Submarine Force. This large scale study representative of submariners fills the knowledge gap in the association between tinnitus and submarine service and identifies those who may be at the highest risk for tinnitus. A limitation to this study was we were unable to link specific dose (i.e., intensity and duration) of noise exposure to individuals. The difficulty in obtaining this is two-fold. First, we need noise data linked to submarine occupational code, and second we need to know how many hours an individual was onboard working within a specialty. Regarding duration, we were only able to ascertain cumulative days an individual was assigned to a submarine. However, with maintenance time in dry docks and varying boat schedules, actual time underway could vary greatly. Further, our study only identified occupational specialty, or department for officers, assigned upon entry to submarine service, which, although uncommon, may change during a career. Additional information on work location on a submarine attached to the occupational specialty would also contribute to a dose estimate. Fortunately, in its Phase II, the DoD Epidemiologic and Economic Burden of Hearing Loss (DEEBoHL) project aims to link service related noise exposure data to individual members by occupational code.[26] This would provide for a more precise measurement of noise exposures in relation to tinnitus and other noise-induced injuries.

5.0 CONCLUSION

From 2004 to 2014, the incidence rate of a tinnitus clinical diagnosis in the Submarine Force was 3.5 cases per 1,000 person-years. While there are no direct comparison military

incidence studies, lower incidence rates found in similar age groups suggest submariners are at an increased risk of tinnitus when compared to general populations. Similar to age related patterns in other studies, we found enlisted submariners age 30 or older upon entry to the Submarine Force were at the highest risk for tinnitus. When controlling for age in the enlisted population, those with the most time assigned to submariner duty were also at a higher risk. Similarly, higher ranking older officers with the most time assigned to submariner duty were also shown to be at the greatest risk, while prior assignment to surface ships was associated with a protective effect.

Submariners are a unique noise-exposed population because they live and work in industrial environments. With the annual cost of VA disability payments for tinnitus at $1.5 billion, coupled with the debilitating effects of tinnitus, future hearing conservation efforts should focus on preventive measures including broadening the occupational roles in submarines that require personal protective equipment for hearing loss and tinnitus prevention.

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