

Association between veteran status and measures of noise induced hearing loss: A cross-sectional analysis of National Health and Nutrition Examination Survey (NHANES) 2015-2016 data

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A Thesis

Submitted in partial fulfillment of the

requirements for the degree of

Master of Public Health

University of Washington

2020

Committee:

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Program Authorized to Offer Degree:

Environmental and Occupational Health Sciences

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Abstract

A study of veteran Noise Induced Hearing Loss (NIHL)
using National Health and Nutrition Examination Survey (NHANES) 2015-2016 data

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Purpose This study hypothesized differences would exist in NIHL markers among veterans compared to non-veterans.

Methods A data set of 10,000 NHANES records, dating from 2015 to 2016, was obtained from the Department of Health and Human Services website. Records with a complete audiometric exam were examined to exclude subjects with ear disease that would invalidate the audiometric exam. A total of 1,473 records met these criteria. The audiometric notch metric was calculated for each subject's left and right ear using the criteria described by Dobie and Rabinowitz. Notch indexes between negative one (-1) to positive one (+1) were considered normal. Notch indexes below negative one were considered a sign of presbycusis and NIHL was assumed with notch indices greater than positive 1. Univariate statistics were used to examine the sample data. Binaural averages of audiometric scores were also calculated for each subject. Regression analyses were done on the data before and after NHANES weighting codes were applied, using the R 'survey()' package.

Results No statistically significant evidence of increased risk of notch or elevated binaural average was detected among veterans when compared to non-veterans using weighted and unweighted NHANES regressions using the 2015-2016 NHANES data.

Keywords: Noise Induced Hearing Loss, Veterans, non-veterans, Deployer, non-deployer

Introduction

Background and significance

Auditory disabilities are the most prevalent form of Veteran disability (VBA, 2015). Approximately 476,000 hearing aids were issued by the VA through audiology clinics in fiscal year 2009, with associated costs of hearing aids, accessories, assistive devices, and associated clinical services exceeding \$393 million.¹

Ten to eighteen percent of service members tested in military hearing conservation programs experience a threshold shift. This is two to five times higher than what is considered acceptable in civilian industrial hearing conservation programs.²

Noise exposure comes with a broad range of secondary non-auditory sequela that are prevalent in the veteran population, including cognitive impairment, sleep disturbance, and cardiovascular disease.³

In this study we hypothesize that veterans have a history of higher noise exposures than civilian NHANES participants, leading to a greater prevalence of NIHL in that group. We test this hypothesis by comparing a marker of NIHL, the audiometric notch, among a group of veterans and non-veterans. We also will examine the binaural average, a general marker of hearing loss. A previous study has used NHANES data to study the prevalence of tinnitus among veterans.⁴ Literature review reveals that NHANES data has not been used to study the prevalence of noise notches as a marker of NIHL among veterans. Similarly, no studies have been done using NHANES data to compare the prevalence of audiometric notch between veterans and non-veterans.

Various audiometric notch criteria for NIHL have been used in previous research. A key point in notch metrics is to distinguish between the notch patterns seen in NIHL from the more

downsloping audiometric pattern that is associated with presbycusis. NIHL classically begins in the higher frequencies around 4 kHz,⁵ and then extends to nearby frequencies such as 3 kHz and 6 kHz as noise exposure and damage continues.

Older individuals may demonstrate an overlap of both NIHL and presbycusis effects. A study of high frequency loss in young people used a bilateral 10 dB drop in hearing threshold in one frequency as a case definition for NIHL.⁶ Proposed NIHL audiometric notch criteria for medicolegal purposes used a threshold deterioration greater than 10 dB at 3, 4, or 6 kHz when compared to measurements at 1 or 2 kHz and 6 or 8 kHz.⁷ In a subsequent study the notch criteria of Coles was found to be congruent with the pooled judgement of an expert panel of audiogram reviewers.⁸

A study investigating inter-rater variability in audiometric notch recognition used a “V” shaped notch with depth of 15 dB at one audiometric measurement or, alternatively, a “U” shaped notch at more than one audiometric measurement with a notch depth of greater than 20 dB with greater than 10 dB at the high frequency.⁹ A study of noise induced hearing threshold shifts among children examined during NHANES survey from 1988 to 1994 used a different standard for audiometric notch including 3 kHz, 4 kHz, and 6 kHz.¹⁰ Agrawal et al in 2008 used a notch definition of high-frequency hearing loss with a pure-tone mean of 25dB or higher at 3, 4, and 6 kHz.¹¹ Phillips defined the NIHL case definition for the study by the appearance of a notch at 4kHz or 6kHz, with a notch defined as a decrease in hearing sensitivity of at least 15dB, with a recovery of at least 5 dB after the appearance of the notch.¹²

Use of notches identified at 6000 kHz for identifying NIHL can be problematic with certain audiometric equipment. Researchers found that utilizing 6000 kHz in a notch definition can lead to higher false positive rates, therefore causing overestimates of NIHL prevalence due

to variability in readings as high as 5dB when using TDH style headsets, as were used in the 2015-2016 NHANES survey.¹³

A 2006 study of whether objective notch metrics could match the clinical judgements of an expert panel compared the criteria of Coles and Niskar with a simple notch criteria. The simple notch index used by Rabinowitz was used to define cases of noise induced hearing loss. Rabinowitz defined this index as the difference between the pure-tone average of thresholds at 2, 3, and 4 kHz and the average of thresholds at 1 and 8 kHz in the same ear. When the audiogram plotted between 1 to 8 kHz is a straight line the notch index is zero. If thresholds at 2, 3, and 4 kHz are above the line connecting the 1 and 8 kHz thresholds, as seen in presbycusis, the notch index value would be negative. When the thresholds for 2, 3, and 4 kHz are below the line between 1 and 8 kHz the notch index is greater than zero and the pattern can be considered due to NIHL.¹⁴ The frequencies used in Rabinowitz's notch definition were endorsed by the American College of Occupational and Environmental Medicine (ACOEM) in a 2011 position paper on Noise Induced Hearing Loss.¹⁵

The above review of the literature surrounding indicators of NIHL showed that the audiometric notch is an established way of defining this disease phenotype. Recent research, as outlined above, shows high false positive rates can occur when including 6 kHz in the analysis. It is not clear whether this problem was corrected in the TDH-49P headphones used in the 2015-2016 NHANES survey and we chose to use a notch definition that did not include this frequency.

Methods

The sample size for NHANES is 5,000 yearly with participants selected from 15 counties from across the US. The NHANES data posted on their website includes questions regarding military service, noise exposure, pure tone audiometric thresholds, and tinnitus. NHANES participants are selected based on criteria that vary from year-to-year, due to various groups being subjects of study depending on what public health data is sought. We reviewed the audiometry dataset from the 2015-2016 NHANES study and reported the prevalence of audiometric notch among veterans compared to non-veterans, and veterans with deployment exposure compared to veterans with non-deployment exposure, using audiometric notch criteria. Differences among prevalence were noted and then tested, using regressions, to see if differences between veterans and non-veterans, and between veterans with deployment exposure and those veterans without deployment exposure, were statistically significant. Regression analysis was done and a best-fit logistic regression model using the independent variables were developed. A secondary comparison using binaural averages at 2, 3, and 4 kHz was also done with a regression applied with the best-fit model reported.

In this study we used NHANES data from 2015 to 2016, which was downloaded from the CDC website. Audiometric testing is a standardized component of the annual, ongoing, cross-sectional NHANES survey. Testing is performed by technicians at a mobile examination platform belonging to the National Center for Health Statistics. Household interviews and standardized physical examinations are used to collect data. Demographic and audiometric databases from NHANES 2015-2016 survey was downloaded from the NHANES website. ¹⁶

The NHANES Audiometry Procedures Manual provides detailed descriptions of audiometric examination protocol, equipment used, and environmental noise survey administration.¹⁷ We used data from several questions in the NHANES audiometric and demographic questionnaires. These included questions concerning veteran status, deployment history, use of firearms, use of hearing protection while using firearms, and history of exposure to loud noises besides firearms at work. For a list of questions please see Appendix 1.

NHANES utilizes a complex survey design, with oversampling done on groups of demographic interest. Consequently the data is weighted to ensure survey results are reflective of the US population. Only unweighted data is reported in this analysis because more coefficients could be included in an unweighted model using our “R” software package. Regression results for weighted data for presence of a notch index are present in appendix 2.

Inclusion Criteria

Records Available: 10,000
With audiometric data: 4600



Individuals with bilateral normal otoscopic findings (AUXOTSPL=1, AUXROTSP=1) tympanometric compliance value (AUXTCOMR, AUXTCOML) ranges from 0.2 to 1.8 cc and middle ear pressure values (AUXMEPR, AUXMEPL) from -50 to 25 dapa in both ears were considered for further analysis. (n= 2164)



Omit records with "666" or "888" codes (n =1216)



528 males, 688 females

Figure 1. Inclusion criteria.

Analyses

The NHANES 2015-2016 dataset was downloaded from the CDC website and imported into Microsoft Excel 2016 saved as a comma-separated value (CSV) file. A data set of 10,000 NHANES records, dating from 2015 to 2016, was obtained, with 4,600 records containing audiometric data. Data from the audiometric and demographic questionnaires were merged into a sheet along with audiometric data from the Mobile Exam Center (MEC) exam. Data was then

inspected for quality and records with incomplete data were discarded. Duplicate data was also discarded. This yielded 2164 records. Records that had a complete audiometric exam were further examined to exclude subjects with ear disease that would invalidate the audiometric exam. Individuals with bilateral normal otoscopic findings, tympanometric compliance value ranges from 0.2 to 1.8 cc and middle ear pressure values from -50 to 25 dapa in both ears were considered for further analysis. Subjects whose audiometry or survey data suggest hearing loss other than NIHL, such as congenital hearing loss, or profound asymmetric hearing loss, were also excluded. Records with values of “888” or “666”, which signified “unable to obtain” or “not recorded,” were excluded.

Remaining records numbered 1,216. The audiometric notch metric was calculated for each subject’s left and right ear using the criteria described by Dobie and Rabinowitz. Demographic and audiometric data was extracted from the combined database. Notch indexes between negative one (-1) to positive one (+1) were considered normal. Notch indexes below negative one were considered a sign of presbycusis and NIHL was assumed with notch indices greater than positive one. Rates of prevalence were calculated using a continuous notch statistic. Binaural averages for each subject were computed.

High false-positive rates can lead to reduced sensitivity and specificity of analyses examining NIHL factors. In this investigation we used the Rabinowitz notch criteria, which did not include the 6kHz measurement where low values could be due to presbycusis, and reported the presence of an audiometric notch as a continuous variable. For bilateral hearing loss we created a binary (0/1) categorical field and then classified each subject as having left or right ear NIHL using the computed notch index for each ear.

The data was then loaded into the statistical software package R. Descriptive statistics and prevalence rates were calculated. Audiometric data from left and right ears was examined using linear regression with the notch index as the continuous outcome variable. Exposure variables included veteran status, history of deployment, history of non-deployment, non-veteran status, hearing protection use, total number of rounds fired, and exposures to non-firearm noise at work. A potential confounder in this study is age. As individuals grow older, they experience poorer hearing at higher frequencies. To address this potential confounder, we included age as a coefficient in regressions. A potential source of bias is recall bias; individuals may not remember parts of their history accurately or may forget details. Since we are using the NHANES data retrospectively perhaps the only way to control for this is to keep it in mind when interpreting results based off of personal history responses.

We used the recommended NHANES age reporting aggregates to cohort by age for tabular data presentation; 20 to 39, 40 to 59, and 60 and over. In regressions we used age as a continuous variable.

For left and right ear data a multiple linear regression model was constructed, with the dependent variable being the notch index value with values below negative one (-1) being considered due to presbycusis. Using an iterative process, independent variables were discarded or included in the final model to achieve a best fit of the data, with coefficients with p values less than or equal to 0.1 being included. For bilateral hearing loss a logistic regression was used.

Results

N=1216	Summary Data	Non diseased No. (%)	Right ear Notch No. (%)	Left Ear Notch No. (%)	Bilateral Notches No. (%)
Males	528 (43)	12 (39)	169 (60)	201 (52)	119 (67)
20-39	245	6	64	92	43
40-59	207	3	76	80	54
60+	76	3	19	29	22
Females	688 (57)	19 (61)	115 (40)	185 (48)	59 (33)
20-39	314	9	46	72	23
40-59	255	6	50	82	25
60+	119	4	19	31	11
Non-Veterans	1,148 (94)	29 (94)	266 (94)	358 (93)	163 (92)
Veterans	68(6)	2 (6)	18 (6)	28 (7)	15 (8)
Firearms Use					
Yes	461 (38)	11 (35)	109 (38)	149 (39)	75 (43)
No	753 (62)	20 (65)	174 (62)	236 (61)	102 (57)
Don't know	1	0	1	1	1

	Summary Data	Non diseased No. (%)	Right ear Notch No. (%)	Left Ear Notch No. (%)	Bilateral Notch No. (%)
Firearms Hearing Protection n=461					
Always	185(40)	7	27	46	15
Usually	48(10)	1	21	20	15
About Half the time	36 (8)	0	5	14	4
Seldom	45 (10)	1	19	19	12
Never	147 (32)	2	37	50	29
Refused	0	0	0	0	0
Don't know	0	0	0	0	0
Job Noise Exposure					
Yes	366(30)	10 (32)	110 (39)	146 (38)	83(47)
No	837 (69)	21 (68)	172 (60)	236 (61)	94 (53)
Never Worked	12 (1)	0	2(1)	4 (1)	1(1)
Don't know	1	0	0	0	0

Table 1. Summary Demographics and prevalence for included records, n=1216.

In Table 1 above we see several trends in the data regarding prevalence of audiometric notch by sex in the whole sample population. Females (688) out-numbered males (528) subjects. There are more females in the non-diseased category than males by absolute value and percentage (61% females, 39% males). A greater percent of males (60%) were in the right ear

notch category than females (40%). Among left ear notch cases we see about the same prevalence among males (52%) as females (48%). Among bilateral notch cases we see a much greater number of affected males (67%) than females (33%).

Table 1 demonstrates information about prevalence among veterans versus non-veterans. The percentage of non-diseased versus diseased is identical between veteran (94%) and non-veterans (6%) in the summary column, the non-diseased category, and the right ear notch category. Veterans make up a slightly increased percentage of affected individuals in the left ear notch (7%) and bilateral notch (8%) categories.

Comparisons between notch categories for firearms use were also made using questions contained in the audiometry questionnaire. 461 (38%) subjects in our sample indicated firearms use and 753 (62%) indicated no history of firearms use. These percentages remained within $\pm 5\%$ across degrees categories. Data for responses to the question “How often did you use hearing protection when using firearms?” are also reported, along with job non-firearm noise exposure reports.

VETERANS n=68	Summary Data No.(%)	Non diseased No. (%)	Right ear Notch No. (%)	Left Ear Notch No. (%)	Bilateral Notch No. (%)
Males	57 (84)	2 (4)	17 (30)	25 (44)	15 (26)
20-39	20 (35)	0	6	10	5
40-59	27 (47)	1	9	13	8
60+	10 (18)	1	2	2	2

	Summary Data No.(%)	Non diseased No. (%)	Right ear Notch No. (%)	Left Ear Notch No. (%)	Bilateral Notch No. (%)
Females	11 (16)	0	1 (6)	3 (11)	0
20-39	5	0	0	2	0
40-59	3	0	1	1	0
60+	3	0	0	0	0
Deployers	26 (38)	1	11 (61)	11 (39)	9 (60)
Non-deployers	42 (62)	1	7 (39)	17 (61)	6 (40)
Firearms Use					
Yes	63 (93)	2 (3)	18 (26)	28 (41)	15 (22)
No	5 (7)	0		0	0
Don't know	0	0		0	0
Firearms Hearing Protection					
Always	29 (43)	1	5	11	3
Usually	11 (16)		6	6	5
About Half the time	8 (12)		1	4	1
Seldom	8 (12)	1	3	0	3

	Summary Data No.(%)	Non diseased No. (%)	Right ear Notch No. (%)	Left Ear Notch No. (%)	Bilateral Notch No. (%)
Never	7 (10)		3	4	3
Refused	0		0		0
Don't know	0		0		0
Job Noise Exposure					
Yes	38 (56)	1	12 (67)	15 (54)	10 (67)
No	30 (44)	1	6 (33)	13 (46)	5 (33)
Never Worked	0		0	0	
Don't know	0		0	0	

Table 2. Study prevalence results for the veteran population.

Summary data is also reported for veterans in Table 2. We note that there were only 11 female veterans in this study, which made it difficult to compare between female veterans across age groups and exposures. Among male veterans we see that more veterans had left ear notch (44%) than right ear notch (30%). 26% of male veterans had bilateral audiometric notches, compared to only 22% across the entire sample.

A comparison of deployed veterans versus non-deployed veterans is also present in Table 2. Among the 68 veterans in our study 26 (38%) had deployed to an area of armed conflict or a peace-keeping operation and 42 (62%) had not. When comparing deployers to non-deployers across disease categories, before tests of significance, we see some difference in left ear notch, with non-deployers (61%) apparently being more affected than deployers (39%). The bilateral

notch category also shows a possible difference of 20% between deployers (60%) and non-deployers (40%), but this was not significant in regressions. Summary data were reported for veterans for firearms use, firearms hearing protection, and non-firearms job noise exposure.

Fitted Model for Right notch index, including coefficient with greater than 0.10 significance				
Coefficient	Coefficient Value	Standard Error	P value	Confidence Interval
Non-Hispanic white	-2.96	0.72	3.77x10 ⁻⁵ ***	-4.36 to -1.56
Non-Hispanic black	-1.86	0.75	0.013*	-3.33 to -0.40
Other Race	-2.33	0.79	0.0034**	-3.88 to -0.77
Female Gender	-3.38	0.52	1.22x10 ⁻¹⁰ ***	-4.40 to -2.36
Wear hearing protection when shooting?				
Usually	3.85	1.33	0.0037**	1.26 to 6.45
Seldom	4.15	1.37	0.0025**	1.46 to 6.84
Significance levels	“***” < 0.001	“**” < 0.01	“*” < 0.05	

Table 3. Best-fit model for presence of Right ear notch

Cases of left ear, right ear, and bilateral notch, along with non-notch subjects, were considered for linear regression analysis using notch index as the continuous outcome variable. Some of the individuals in these analyses had bilateral notches. Bilateral notch as an outcome was examined through logistic regression after binary recoding of notch index scores to either

“unaffected”=0 or “notch affected” =1. The statistically significant results of these regressions are shown in Tables 3-5. Full regression outputs from the statistical software package ‘R’ are available in Appendix 2.

No significant differences were found between the veteran and non-veteran groups for right ear notch, left ear notch, and bilateral notch. Table 3 above outlines results from the best-fit model predicting presence of right ear audiometric notch. Non-hispanics, “other” race, and females enjoyed protection from having an audiometric notch in the right ear. Answering “usually” or “seldom” to the question “Do you wear hearing protection when shooting?” were risk factors for having a right ear audiometric notch.

Fitted Left Notch Index Model that included Beta Coefficients with significance greater than 0.10				
Coefficient	Coefficient Value	Standard Error	P value	Confidence Interval
Female Gender	-2.63	0.56	2.53x10 ⁻⁶ ***	-3.71 to -1.54
How many total rounds ever fired?				
10k to 50k	4.07	1.70	0.016794*	0.74 to 7.40
How long exposed to very loud noise?				
1 to 2 years	5.42	2.62	0.039*	0.29 to 10.55
10 to 14 years	10.40	2.83	0.00025***	4.85 to 15.96
15 or greater	8.20	2.58	0.0015**	3.15 to 13.25

Past year: worn hearing protection?				
Usually	3.65	1.82	0.045*	0.085to 7.22
About half the time	3.42	1.98	0.085.	-0.46 to 7.30
Significance levels	“****” < 0.001	“***” < 0.01	”**” < 0.05	“.” < 0.10

Table 4. Results of best-fit model with presence of left ear audiometric notch as outcome variable.

Table 4 above shows results from best-fit regression model with left ear audiometric notch as a continuous outcome variable. We see that female gender is again protective. No racial categories were at higher or lower risk for left ear NIHL than others. Several risk factors are suggested, including history of firing between 10,000 to 50,000 rounds, non-firearm exposures to loud noises, and levels of hearing protection in a non-firearm related occupation.

Fitted B/L Notch model, significance >= 0.10				
Coefficient	Coefficient Value	Standard Error	P value	Confidence Interval
Female Gender	-1.13	0.18	9.45x10 ⁻¹⁰ ***	-1.50 to -0.77
How many total rounds ever fired?				
10k to 50k	0.93	0.45	0.038*	0.024 to 1.80
Significance level	“****” < 0.001,	“***” < 0.01	”**” < 0.05	“.” < 0.10

Table 5. Results of best-fit model with presence of bilateral audiometric notch as outcome

Examination of the fitted regression model for presence of bilateral notch as an outcome variable, using a logistical regression with binary comparison, shows again a protective effect for female gender and risk of notch for having fired between 10,000 to 50,000 rounds.

Fitted Binaural Regression, Significance greater than or equal to 0.10				
Coefficient	Coefficient Value	Standard Error	P value	Confidence Interval
Non-Hispanic white	-2.46	0.95	0.0095**	-4.32 to -0.60
Non-Hispanic black	-4.74	1.00	2.20x10 ⁻⁶ ***	-6.70 to -2.79
Other Race	-3.15	1.06	0.0030**	-5.24 to -1.07
Female Gender	-5.60	0.71	6.42x10 ⁻¹⁵ ***	-6.99 to -4.21
Age	0.52	0.023	2x10 ⁻¹⁶ ***	0.47 to 0.56
Ever Use Firearms?				
No	2.96	1.04	0.0047**	0.91 to 5.00
How many total Rounds ever fired?				
10k to 50k	3.83	2.18	0.079.	-0.44 to 8.10

Coefficient	Coefficient Value	Standard Error	P value	Confidence Interval
50k or more	7.36	2.79	0.0081**	1.92 to 12.81
Don't know	12.66	5.06	0.012*	2.75 to 22.57
Wear hearing protection when shooting?				
Seldom	3.12	1.86	0.094.	-0.52 to 6.77
Never	3.88	1.24	0.0018**	1.45 to 6.31
How long exposed to loud noise at work?				
3 to 11 months	-4.52	2.73	0.98.	-9.87 to 0.83
3 to 4 years	-7.42	3.11	0.017*	-5.53 to 4.92
How long exposed to very loud noise?				
3 to 11 months	8.38	3.532	0.018*	1.46 to 15.31
1 to 2 years	6.36	3.59	0.076.	-0.67 to 13.39
3 to 4 years	9.24	3.93	0.019*	1.53 to 16.94
5 to 9 years	7.87	3.64	0.03*	0.74 to 14.99
10 to 14 years	14.99	4.19	0.00036****	6.78 to 23.19
15 or greater	9.97	3.84	0.0096**	2.44 to 17.49

Had off-work exposure to loud noise?				
No	-1.92	0.97	0.048*	-3.82 to -0.02
Significance levels	“***” < 0.001,	“**” < 0.01	“.” < 0.10	”*” < 0.05

Table 6. Results of best-fit binaural model.

The fitted binaural average results above notably do not include veteran status as a risk factor for elevated binaural average. Non-hispanic whites, blacks, and “other” NHANES racial categories appear to enjoy protection against higher binaural average scores. Gender is again protective. Age is a risk factor. Interestingly, those who answered “no” to firearms use were at risk of having a higher binaural average and the confidence interval for this is not unusually large. Those firearms users who had shot greater than 10,000 rounds to greater than 50,000 rounds were at higher risk for higher binaural average. Firearms users who answered “Don’t know” to how many rounds they had fired had the highest risk, but we see the confidence interval is wide. Individuals who had “loud” non-firearm occupational exposures at work lasting 3 to 11 months or 3 to 4 years appeared to have a protection from higher binaural average score. Those with “very loud” exposures appeared to be at higher of elevated binaural average risk across most time frames. Lastly, survey respondents who denied off-work loud noise exposures experienced a protective effect against higher binaural average.

Discussion

This study of veterans in the 2015 to 2016 NHANES survey found no statistically significant

evidence that veterans have higher risk of audiometric notch or elevated binaural average than non-veterans for the left ear, right ear, or bilateral ears. The lack of effect of veteran status on notch index was also present in regressions where the NHANES Mobile Examination Center (MEC) weight was applied, as can be seen in appendix 2. This study also demonstrated, in line with previous studies, that females are less prone to NIHL than males. Non-hispanic whites, blacks, and “other” NHANES race categories appeared to enjoy protective effects against higher binaural averages. Hispanics were not at higher risk of either audiometric notch or elevated binaural average.

A possible explanation for the result that there was no higher risk for veterans compared to non-veterans for presence of audiometric notch and binaural average might be that perhaps NIHL is occurring but that the notch definition is not capturing the hearing loss; no notch or elevated binaural average is visible on an audiogram using our measures. We could hypothesize that military noise exposures might be different from civilian noise exposures, that military noise exposures are different from civilian exposures, such that a different type of audiometric pattern is produced. Prior to running the binaural average regressions we compared the mean binaural average between veterans and non-veterans at 2, 3, and 4 kHz. The mean binaural average for veterans was 17.73 and the mean binaural average for non-veterans was 13.53. Welch’s Two Sample t-test revealed a significant difference between the two groups ($t = -2.0895$, 95% CI -8.20877 to -0.19390, $p\text{-value} = 0.04015$). Using the binaural average mean comparison veterans appeared to have a higher threshold on audiometric testing, suggesting a higher level of hearing loss. However, as seen above when a regression was run with binaural average as an outcome, allowing control for other factors such as race, gender, age, and firearms use, veteran status was not a risk factor for elevated binaural average. The notch index regressions and the binaural average regression were concordant in not showing veteran status as a statistically significant risk factor for each respective outcome variable.

Another concern early in this study was that there might be a disparity between weighted and unweighted results regarding veteran status. Regression analyses for notch indexes were rerun with NHANES weights applied. Results for veteran status were not significant.

It is possible that veterans who were deployed are subject to a “healthy worker” effect. Individuals who join the military may be, on average, healthier than the general US population and this may carry into their hearing health. Indeed, a hearing test is part of military entry exams and applicants with poor hearing may be excluded from service. Another factor is possibly that among the military use of protective controls can be enforced and policed more easily than in the general US population. Every US military service has a hearing conservation program that implements OSHA standards. (IOM, 2006), but not all military members are in hearing conservation programs. Additionally, prior to deployment military personnel must meet fairly stringent pre-deployment criteria, which includes an audiometric standard.

The data on firearms use demonstrated that individuals who had shot between 10,000 to 50,000 rounds were at greater risk of left ear audiometric notch. This would seem to be counter-intuitive because most people shoot with their right hand. One theory to explain the disparity is that when a rifle is shot by a right-handed individual the right ear enjoys more protection from sound due to it being in an acoustic “shadow,” while the left ear is more exposed to the noise of the weapon.¹⁸ Respondents in the deployed category responded “yes,” to the question, “Did you ever serve in a foreign country during a time of armed conflict or on a humanitarian or peace-keeping mission?” It might be that, again, a healthy worker effect is at work. Prior to deployment, military personnel must be cleared to deploy. Military members with hearing loss might not be permitted to deploy. Service members with pre-existing left ear NIHL might not be allowed to deploy. Another issue is that perhaps this question is not a good measure of whether someone was exposed to loud noises, such as gunfire. Many people could answer “yes” to this question and never experience noise from high-impulse weapons fire, that could contribute to NIHL.

An interesting observation regarding the use of hearing protection with firearms was that those who reported imperfect use of hearing protection when using firearms (“usually” or “seldom” wearing hearing protection) had higher risk of right ear audiometric notch but not left ear audiometric notch. This finding supports the acoustic shadow theory of firearms related asymmetrical hearing loss.

Strengths and Limitations

One strength of this study was that it was able to draw on the large set of audiometric data contained in the NHANES exam. This set provided a sample of 4,600 audiometric records with associated general demographic and specific audiology related questions. A significant advantage of this study is that it attempts to obtain a representative example of the US population, making results generalizable to the US population. There was some disadvantage in using NHANES data. NHANES is a complex survey that employs a weighting methodology that had to be navigated. This analysis did use the weighted data for regression with notch index as the outcome variable but only 5 variables at a time could be regressed using the “survey()” package in “R”. Results from the weighted regressions are included in appendix 2.

Another strength of this study was that we used a strict definition of audiological health to ensure included subjects did not suffer from ear pathologies, such as middle ear disease or central nervous system disease affecting hearing, that might influence results. This strength could also be seen as a weakness because it limited the number of subjects we were able to include in the study. This contributed to another weakness of this study; low power. We only had 68 veterans in our final sample. An additional limitation is that by selecting a stricter definition of the audiometric notch we may have excluded possible cases, which may lead to reporting lower prevalence. This study suffered from a representative lack of veterans. The veterans administration estimated in 2018 that 22 million Americans had served in the military. The US population is 328.2 million. The veteran population is then 6.7% of the US population. In our NHANES eligible audiometric samples we find only 4.6% were veterans. Another weakness of this study is that results from the survey questions about noise exposures and firearms use are subject to recall bias. Apart from the question on deployment this study had no

other data to describe the type of exposures veterans had. The results from veterans included in this survey were from a wide sample of veteran ages, with different military experiences.

Results are likely not generalizable to specific veteran cohorts by conflict or age. This study was underpowered with respect to its ability to detect differences among veterans in the deployed versus non-deployed categories, particularly so for female veterans. Finally, another limitation is that we cannot make causal inferences in this study due to NHANES being a cross section study.

Conclusions

In this study we saw evidence that veterans might not have statistically significant increased risk of audiometric notch index, or elevated binaural average at 2, 3, and 4 kHz, compared to non-veterans. This finding may be generalizable to the whole US population. A direction for future research into veteran NIHL outcomes using NHANES data may be to combine the multiyear datasets to achieve greater study power. Morphological comparisons of the notch indexes of veterans and non-veterans might be useful to confirm notch indexes among veterans are the same as non-veterans; it is possible military noise exposures cause a notch pattern that escapes present definitions. Using NHANES data to study hearing loss markers among veterans offers the advantage of the NHANES sampling strategy, which statistically should allow results to be generalizable to the whole US veteran population.

Funding Source

The author, a US Air Force Medical Corps Officer, received no outside funding for this study. The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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