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U.S. Air Force Noise Exposure Demonstration Project

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March 2019

Final Report
for December 2016 to July 2018

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14. ABSTRACT

This technical report summarizes research conducted by the US Air Force School of Aerospace Medicine, Force Health Protection Branch, in support of the Air Force Medical Service Total Exposure Health (TEH) program. Intended to be an initial demonstration of TEH, the primary objective of this study was to develop low-cost sensor technology, in order to capture noise exposure data on a 24-hour basis for study participants. The final product was a Bluetooth Low Energy noise microphone/sensor, connected to a special "app" developed for Apple iOS/Android devices. A total of 19 study participants (12 male, 7 female; 17 enlisted, 2 officer) were consented at Moody AFB, GA. Field data collection over a 7-10 day period yielded 10,607 noise events, defined as being ≥70 dB. The majority (77%) were low noise events (≥70 dB, but < 95 dB). Questionnaire data indicated that noise exposures are due to various occupational, environmental, and lifestyle activities. Results include demonstrating the ability to incorporate low-cost technology to capture data to provide insight into types and extent of noise exposures. Further, this TEH approach to characterizing 24-hour noise exposures helps identify potential interventions ("personalized care") to reduce the risk of hearing loss. Potential interventions include increased training, audiograms, and medical monitoring. Data on preferred types of hearing protection devices, e.g., foam plugs, ear muffs, custom-fitted plugs, were also gathered.

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Total Exposure Health, precision medicine, personalized care, hazardous noise, sensor technology

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This study was supported with Defense Health Program funds through the 711th Human Performance Wing, Wright-Patterson Air Force Base, Ohio, and was approved by the Air Force Research Laboratory Institutional Review Board, Approval #FWR20160134H v2.02 (2018), Wright-Patterson AFB OH.

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1.0 SUMMARY

This technical report summarizes research conducted by the US Air Force School of Aerospace Medicine Force Health Protection Branch (USAFSAM/FHOF), in support of the Air Force Medical Service Total Exposure Health program. Planning for this study occurred from late 2016 through April 2018, in coordination with the Air Force Medical Support Agency, (AFMSA/SG3PB). Data collection occurred during April-May 2018 at Moody AFB, GA. Technology development (i.e., noise microphone/dosimeter, smartphone app, "cloud" platform) was done through a contract with Intel sense Technologies (Fremont, CA).

Intended to be an initial demonstration of Total Exposure Health, the primary objective of this study was to develop low-cost sensor technology to capture noise exposure data on a 24-hour basis for study participants. Results of this study demonstrated the ability to incorporate low-cost technology to capture data around-the-clock, in order to identify potential interventions to reduce the risk of hearing loss.

2.0 BACKGROUND

In recent years, military healthcare has been changing with more emphasis on health risks to warfighters beyond the traditional occupational exposures. The President's 2015 State of the Union Address introduced the initiative called "Precision Medicine," to revolutionize how medical professionals improve health and treat disease. Central to this initiative is that every patient is unique, with individuals having different genetic, environmental, and lifestyle-related exposures.

In response, the Air Force Medical Service has proposed a corresponding initiative called "Total Exposure Health" (TEH). TEH acknowledges that the health of individuals is determined not just by occupational exposures, but also by exposures stemming from the environment they live in and their individual lifestyles. Determining *cumulative* exposures, i.e., beyond the traditional 8-hour workday, is critical in understanding how to tailor medicine to the individual (i.e., "precision medicine"), in order to prevent adverse health outcomes such as permanent hearing loss.

To demonstrate the ability to assess exposures over a 24-hour period for TEH, the then-AF Medical Support Agency's Consultant to the AF Surgeon General for Bioenvironmental Engineering (AFMSA/SG3PB), Colonel Kirk Phillips, proposed *developing*, then *demonstrating*, a protocol for assessing noise exposures to our airmen. This resulted in the study described in this report.

Air Force Bioenvironmental Engineering (BE) personnel, part of the Air Force Medical Service, currently perform health risk assessments for the "workplace" noise exposures, but no protocol exists to capture noise exposure data after duty hours. The primary reason is that exposures occurring during off-duty hours are, generally, not under the purview of the Occupational Safety and Health Administration and maintaining compliance with Occupational Safety and Health Administration regulations is the main focus of BE (i.e., exposures during duty hours). But, hearing loss is a highly compensable injury in USAF, with $1.4B of compensations for major auditory disabilities in 2010, with incidence of tinnitus ("ringing in the ears") and hearing loss increasing 13-18% annually [1]. High noise exposures all contribute to hearing loss, regardless of when during the day they occur, which suggests the potential importance of addressing off-duty exposures.

Currently, only airmen (i.e., active duty military and civil service employees) with workplace exposures at or above 85 dBA are monitored on the AF Hearing Conservation Program (HCP) and thus receive audiograms and other medical monitoring. Unfortunately, this leaves a large portion of the AF workforce not under medical monitoring. However, these "non-HCP" airmen might have high noise exposures after duty hours, such as from listening to portable listening devices/MP3 players and various hobbies (e.g., hunting, motorcycle riding, sports, attending concerts) [2, 3].

In recent years, several studies have looked at the utility of using smartphone apps as low-cost noise meters [4, 5]. Well-designed noise apps, coupled with quality external microphones, can provide performance nearing that of sound level meter and noise dosimeter instruments typically used for occupational health and safety compliance [6]. With commercially available instruments costing hundreds or thousands of dollars each, the prevalence of smartphones may lead to a low-cost solution to conduct noise exposure assessment, especially after duty hours.

In summary, determining those at increased risk for hearing loss can lead to personalized care, including providing training on hearing loss prevention, issuing hearing protection for off-duty use, and providing increased medical monitoring. Addressing "total exposures" in both HCP and non-HCP airmen can help drive down the overwhelming number of compensable claims AF-wide.

3.0 METHODS

3.1 Study Design

Participation in this study required the participant to operate a smartphone and download a special application ("app") onto his or her smartphone to estimate noise exposure levels. Participants wore an external microphone in the collar area for 7-10 days. Participants were also provided free hearing protection devices (i.e., disposable foam earplugs, pre-molded earplugs, ear muffs, and custom-fitted earplugs) for use during the study. Noise event data were automatically sent to a secure cloud server for collection and analysis by the FHOF research team.

Three visits to the base occurred: 1) Visit #1: to enroll and "consent" all study participants, ensure all approval paperwork was complete (i.e., supervisor approvals, off-duty employment forms to accept compensation, and pre-questionnaires), 2) Visit #2: to hand out noise microphones, install the app, provide training, begin data collection, and 3) Visit #3: conclude the data collection, collect all noise microphones, complete post-questionnaires, and receive compensation (gift cards). These visits occurred during April-May 2018.

3.2 Recruitment of Study Participants

AFMSA/SG3PB gained approval from the Moody AFB 23d Wing/CC (host unit) to conduct research at the base. An advertising flyer (Appendix A) was sent to the base for distribution. Personnel at 23 AMDS/SGPB BE helped distribute the flyer by posting in workplaces and emailing it to base organizations. Those with questions regarding the study, or potential interest in enrolling, were instructed to contact USAFSAM/FHOF.

3.3 App Development

Intelesense Technologies, an AFMSA-sponsored vendor/app developer, developed a smartphone noise dosimeter app to meet study requirements. These requirements included, but were not limited to: (a) designing the app to "average" noise levels over a 24-hour period, versus standard 8-hour period, (b) making the app compatible for both iOS and Android operating systems, (c) providing an estimate of noise exposure from music (i.e., ear buds and headphones), (d) allow the user to log information describing any significant noise exposures, (e) alert the user that a noise level greater than or equal to 70 dB was detected, and (f) provide functionality to toggle on/off GPS data.

3.4 Questionnaires

A pop-up screen "event questionnaire" was created as part of the smartphone app to capture information on noise events (exposures) greater than 95 dB. When these "high noise events" occurred, users were asked to enter information on where they were at for the noise event, what the cause was, whether it was a US Air Force workplace, and whether hearing protection was worn (Figure 1). Low noise events, defined as exposures between 70 and 95 dB, did not require event questionnaire data entry, as they occur much more frequently.

Figure 1. Screenshot of Pop-Up Event Questionnaire, from the NEDP App.

In addition to the event questionnaire, subjects were asked to complete pre- and post-study questionnaires (Appendices B & C, respectively) to cover such items as perceived technology issues, adherence to protocols, earphone noise exposure, family history of hearing loss, medication or other known ototoxin exposure, etc. Study participant responses are annotated in Appendices B & C.

3.5 Equipment

Study participants were asked to use their own cell phones for the study, which were coupled with an external, wireless, low-energy Bluetooth microphone (provided by the study) that was designed to be clipped to the collar or shoulder region. A small number of Android smartphones were available for loaning, in the event that an enrolled participant has smartphone problems affecting installation.

3.6 Ear Scanning

A Lantos Technologies/Uvero audiologist traveled to Moody AFB during Visit #1, in order to scan ears of all participants to allow creation of custom-fitted earplugs (Figure 2). The AURA® 3D Ear Scanning System uses a handheld scanner, similar to an otoscope with a video camera in the tip of the probe. Real-time on-screen visuals help maximize comfort during the scan. The tip has proprietary technology to create a detailed 3D topographical map of the ear canal, using 100,000+ data points. Each ear was scanned in about two minutes.
Digital files containing the topographical map data were sent to the Uvero lab to build the earplugs. Earplugs were sent to Moody AFB for distribution during the kickoff of the field study (Visit #2).

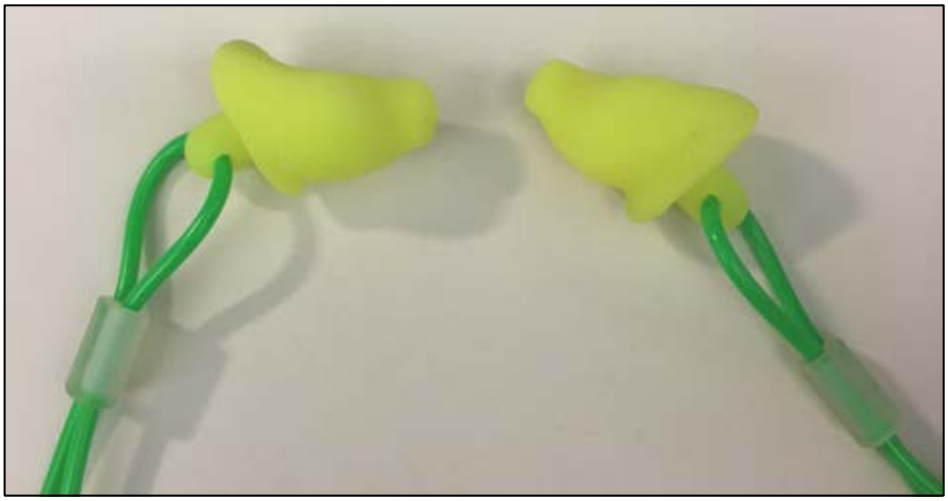

Figure 2. Custom-Fitted Lantos Technologies/Uvero Earplugs (photo courtesy of D. Yamamoto).

3.7 Inclusion Criteria

Subjects who met all of the following criteria were eligible for participation in the study:

- Active duty Air Force, assigned to Moody AFB.
- Own an iOS or Android-based smartphone.
- Willing and able to install a new noise app on their smartphone.
- Willing and able to carry a smartphone and external microphone on and off duty for the entire 7-10-day study

- Acceptable to remove the smartphone and external microphone prior to going into classified areas.
- Had an approved Supervisor authorization form
- Had an approved Off-Duty Employment Form
- Willing to complete a pre-questionnaire, post-questionnaire, and event questionnaire.
- Was available in Spring 2018

3.8 Exclusion Criteria

Subjects who met any of the following criteria were disqualified from participation in the study:

- Not satisfying any of the above mentioned inclusion criteria
- Had safety and/or security limitations that prohibited the wear and use of a smartphone and external microphone for the duration of the entire study.

3.9 Calculations

The app was designed to monitor sound levels, then log any low- and high-noise "events" (>70 dB and >95 dB, respectively). The research team used averaged levels during the duration of these events to calculate an equivalent continuous sound level, $L_{eq,T}$, (Eq. 1) for each 24-hour period:

3.9.1 Equivalent Continuous Sound Level, Leq,T

$$L_{\mathrm{eq,\,T}} = 10\log\left[\frac{1}{T}\sum_{i=1}^{n} t_i \times 10^{\frac{L_{\mathrm{eq}_i}}{10}}\right] \quad (1)$$

Where,

$L_{eq,T}$=equivalent continuous sound level over time period, T
T=time period=24 hours
n=# of noise events for the time period, T
t_i=time duration of each noise event, hrs
L_{eqi}=equivalent continuous sound level for the noise event, dB.

3.9.2 Decibel Averaging. After Leq,24 values were calculated for each day, then these values could be "averaged" over multiple days to provide a single metric to summarize a study participant. Decibel levels (in dB), which are log base-10 transformed sound pressures, are averaged across multiple days using Eq. 2:

$$\mathrm{dB_{avg}} = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{\frac{L_i}{10}}\right] \quad (2)$$

Where,

n=# of dB levels
L_i=dB level.

4.0 RESULTS

The following paragraphs and figures present a summary of the results. The original goal of the study was to have 50 participants.

4.1 Study Summary

- # of study participants successfully enrolled: 19 people (see Figure 3, Study Enrollment Summary)
- 12 male, 7 female
- 17 enlisted, 2 officers
- Age range=19-41 years; average=28.9 years
- Career fields represented by study participants: Aircraft Maintenance, Fleet Management, Military Working Dog Hander, Explosive Ordnance Disposal (EOD), Bioenvironmental Engineering, Weather, Security Forces, Medical Admin, Civil Engineering (CE) Ops/Power Production
- # of days monitored, per participant: range=7-10 days
- Total # of events: 10,607
- Low noise events, $70 \leq L_{eq} < 95$ dB: 8,135
- High noise events, $L_{eq} \geq 95$ dB: 2,472
- Hearing protection: acknowledged to be worn during only 1.4% of high noise events
- 46% of high noise events acknowledged as being at USAF workplaces
- 52% not at USAF workplaces
- 2% undeclared
- Examples of USAF workplace high noise events: talking, door, generator, aircraft, dog kennel, vehicle, door
- Examples of non-USAF workplace high noise events: driving, talking, vehicle, lawn mowing, dogs, tv/music

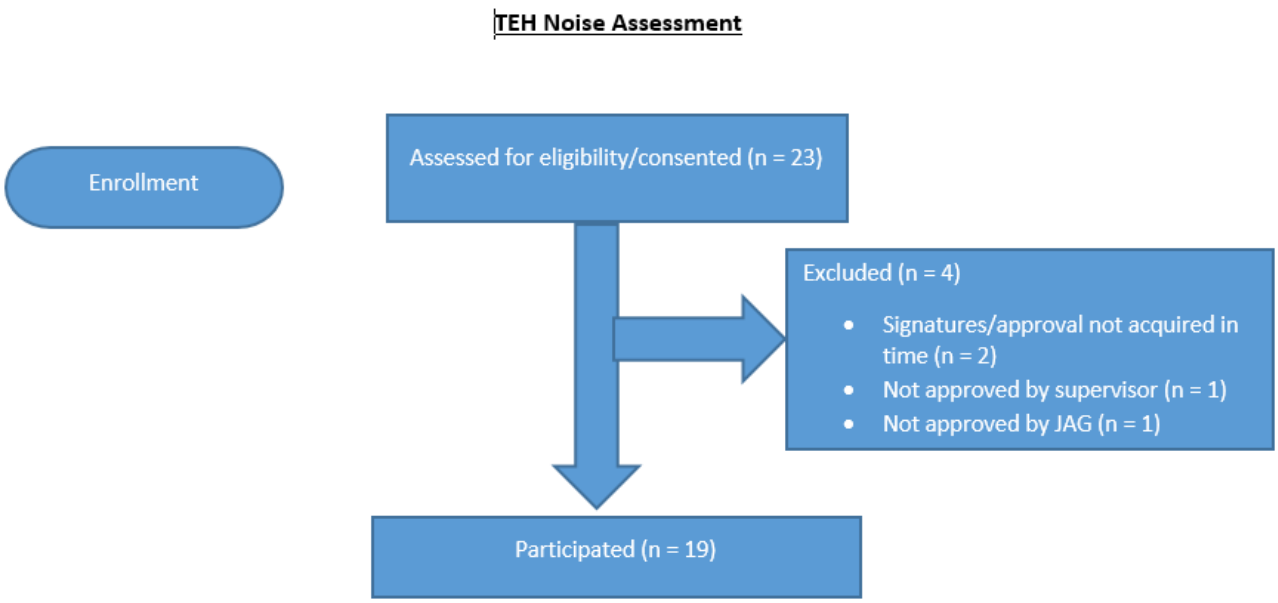

Figure 3. Study Enrollment Summary

4.2 Plots

As mentioned previously, there were 19 consented participants for this study. The following plots display results for those 19 participants. Figure 4 shows the total number of noise events logged during the study. In Figure 5, these noise events are further differentiated as being either "low noise events" (greater than 70 dB, but less than or equal to 95 dB) or "high noise events (> 95 dB). The majority were in the low noise event category.

Labels across the x-axis show the NEDP device number (Bluetooth microphone), ranging from NEDP-50 to NEDP-72. Note that gaps in the sequence exist, as NEDP-59, -61, and -68 had technical issues and were not used for the study.

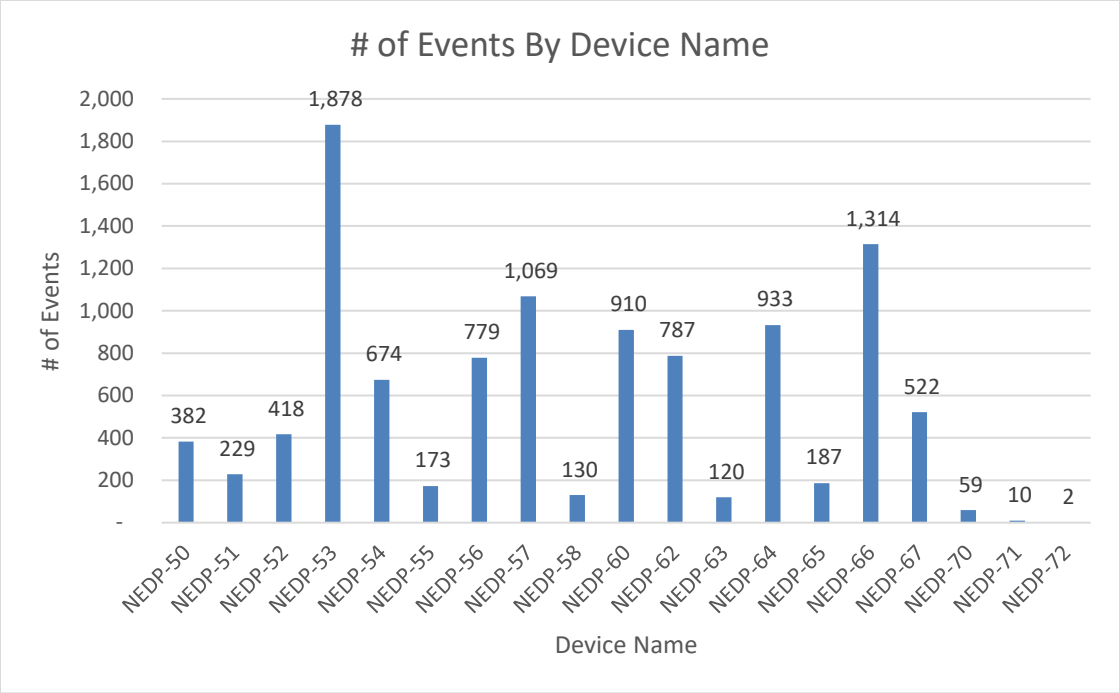

Figure 4. Number of Noise Events, Per Device

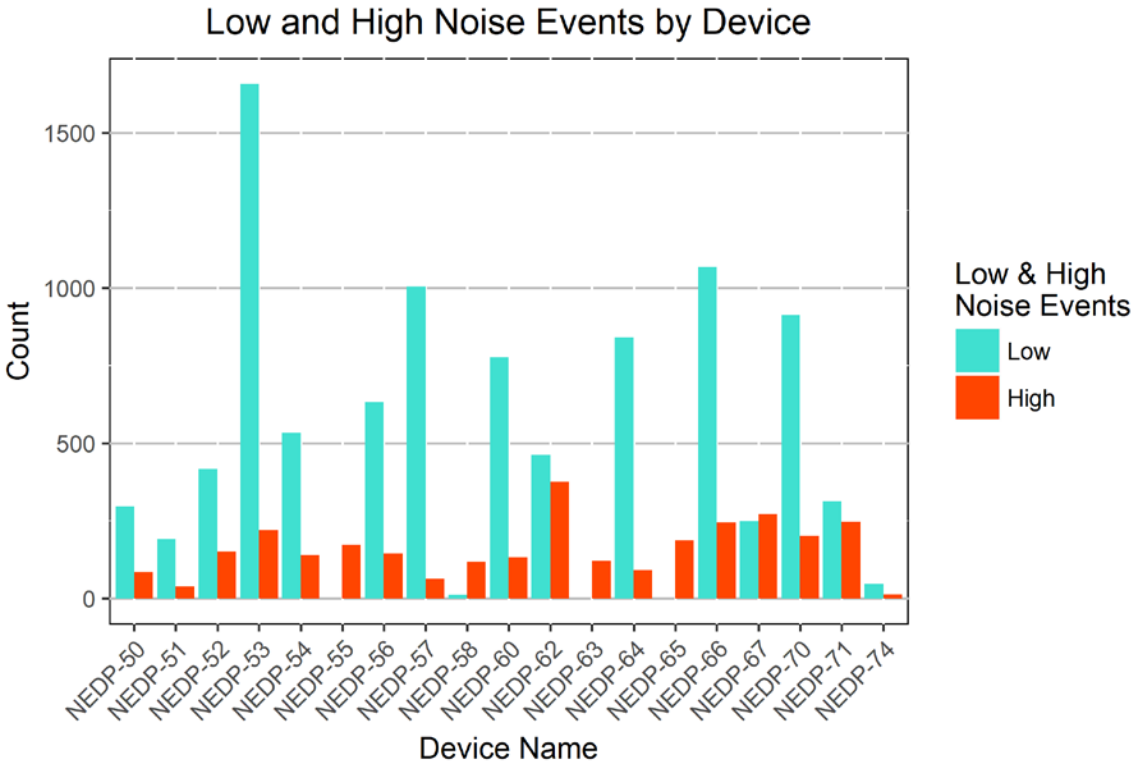

Figure 5. Noise Events, Distributed as "Low" and "High" Noise Events

Box-and-whisker plots (a.k.a., “box plots”) in Figure 6 show a more detailed summary of noise events per device. The lower and upper horizontal lines of each “box” represent the first and third quartiles for noise events for a given device. The middle horizontal line is the second quartile (median). “Whiskers” extend downward/upward to the lowest/highest noise events, respectively. Taller boxes indicate larger variance (“spread”) across noise event values, whereas shorter boxes indicate smaller variance. All participants displayed at least one high noise event above 100 dB during the study. Day-by-day results for each study participant are shown in Appendix D.

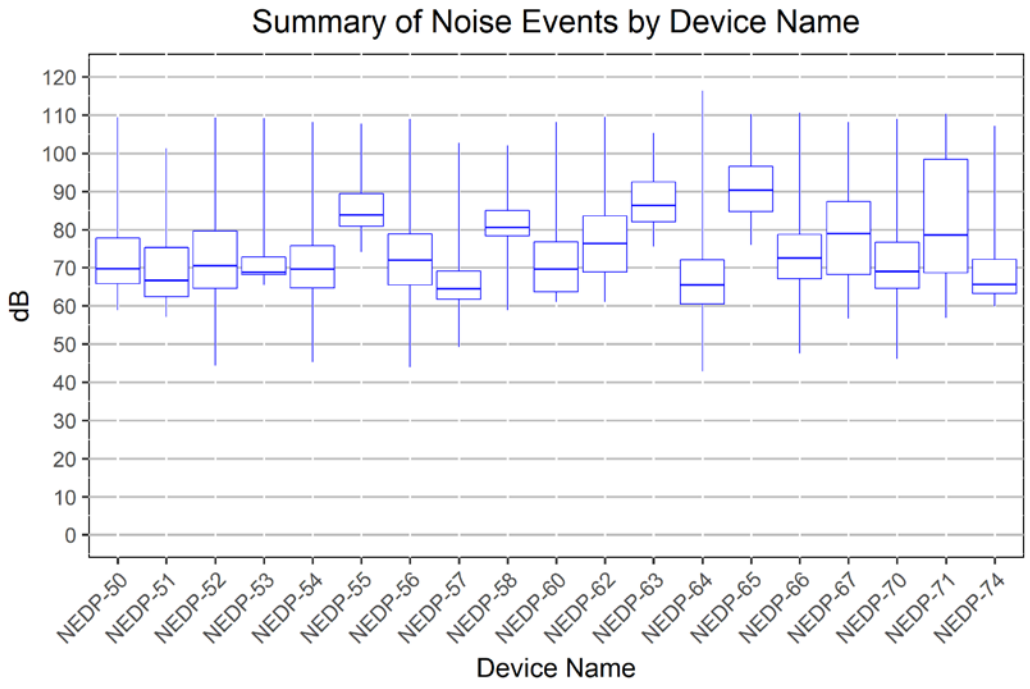

Figure 6. Box Plots of Noise Events, Per Device

In Figure 7, the noise events are categorized by decibel range. Traditional compliance-focused noise monitoring in the US Air Force focuses on those levels at or above 80 dB. Results indicate that the majority of noise events are below 80 dB, which suggests that noise exposures are frequent. Day-by-day results for each study participant are shown in Appendix E.

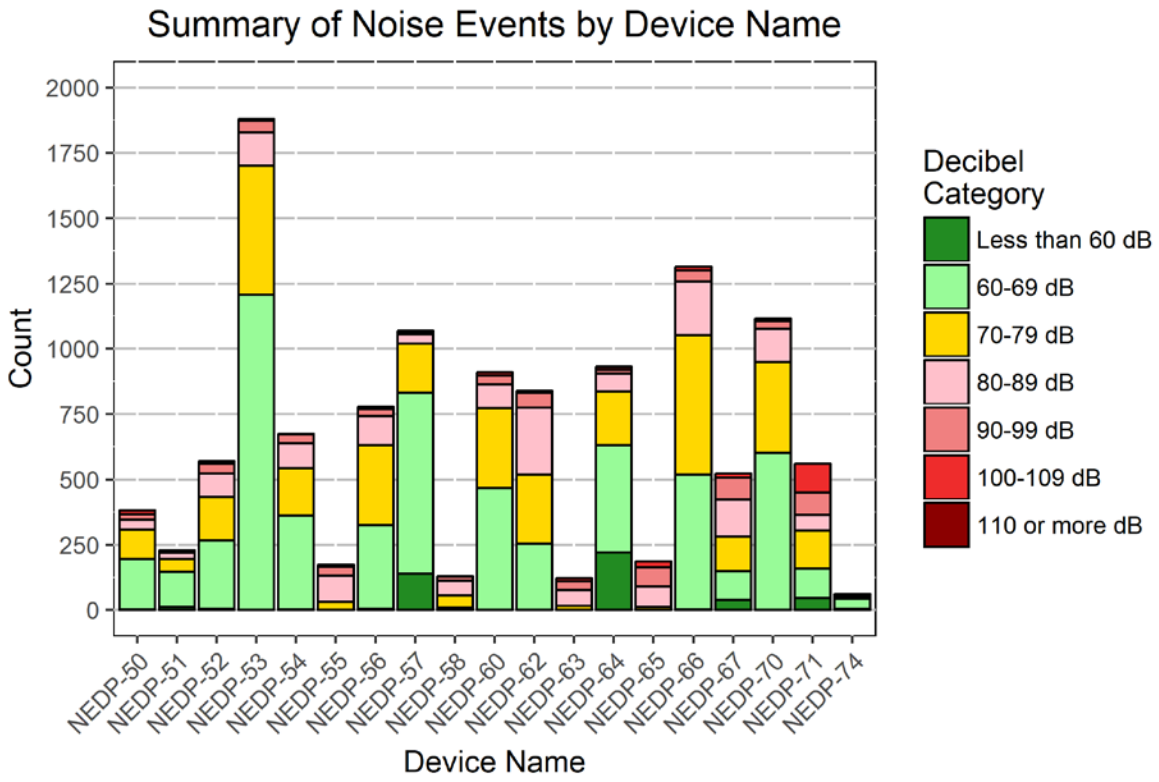

Figure 7. Noise Events, by Decibel Range

In Figure 8, the noise events were categorized by time of day, with the 24-hour day split into four-hour increments. Results indicate that the majority of noise events occurred roughly around the work hours of 8:00 a.m. to 3:59 p.m., with the next most events occurring in the 4:00 p.m. to 7:59 p.m. and 4:00 a.m. to 7:59 a.m. categories. Study participants are believed to have been working day shift only, but exact workplace start/stop times were not recorded. One individual, NEDP-53, not only had a large number of events (1,878, as shown in Figure 4), but had a fair number occur at late/early hours (8:00 p.m. to 11:59 p.m. and midnight to 3:59 a.m.). It is not certain whether any of these were duty-related or were attributable to environmental or lifestyle-related exposures.

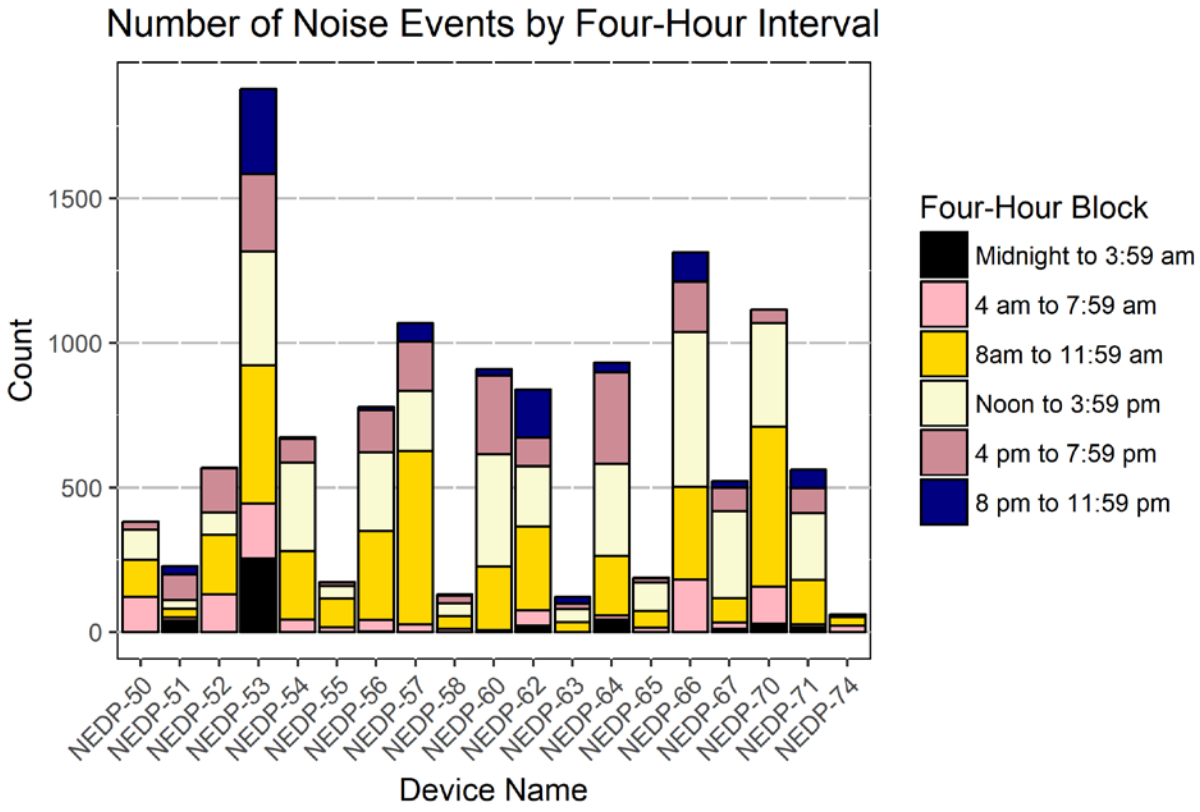

Figure 8. Noise Events, by Time of Day

Figure 9 displays overall results for each device (study participant), using the equation shown in paragraph 3.9.2 for decibel averaging. Although not shown in the figure, there are two noise "thresholds" of interest to compare against: (1) 70 dB, representing the US Environmental Protection Agency (US EPA) noise level (guideline) to "protect public health and welfare with an adequate margin of safety" and (2) 85 dB, representing the noise exposure criterion level used by the US Air Force for workplace health risk assessments [7, 8]. Results show the differences in total noise exposures when monitoring at the individual level. Day-by-day results for each study participant are shown in Appendix F.

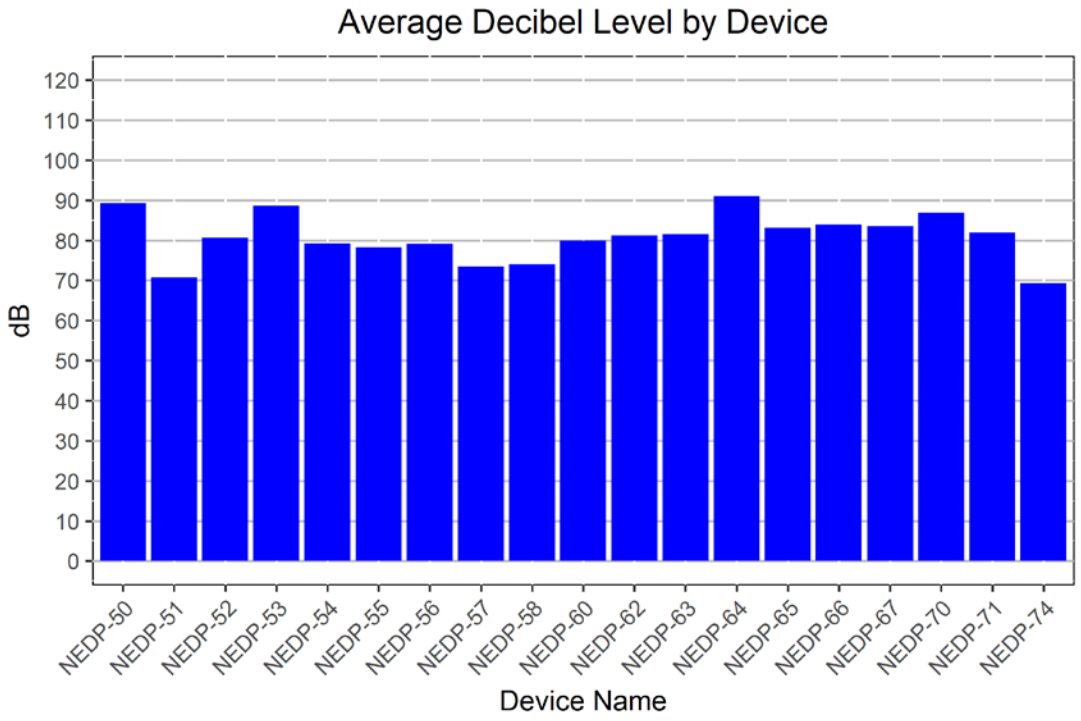

Figure 9. Average Decibel Level, Per Device

Although this study was focused on developing low-cost technology and demonstrating its use to gather noise exposure data on a 24-hour basis ahead of more comprehensive studies, there were two data points of particular interest for the future. As summarized in Figures 10 and 11, the overwhelming majority of study participants acknowledged that the "app" heightened their awareness of exposure to potentially hazardous noise and that they are likely to wear hearing protection more frequently in the future. This suggests that seeing real-time noise levels via the app helped increase self-awareness of exposures to noise. In turn, the use of hearing protection became more important to study participants. Thus, this emphasized the potential importance of changing behaviors, in order to prevent hearing loss.

The "lessons learned" during this study are numerous and are summarized as comments in Appendix G. Many of the comments are regarding the technology and observations regarding study participant behaviors and preferences. These ideas will be useful in planning for future research regarding noise exposures and Total Exposure Health, in general.

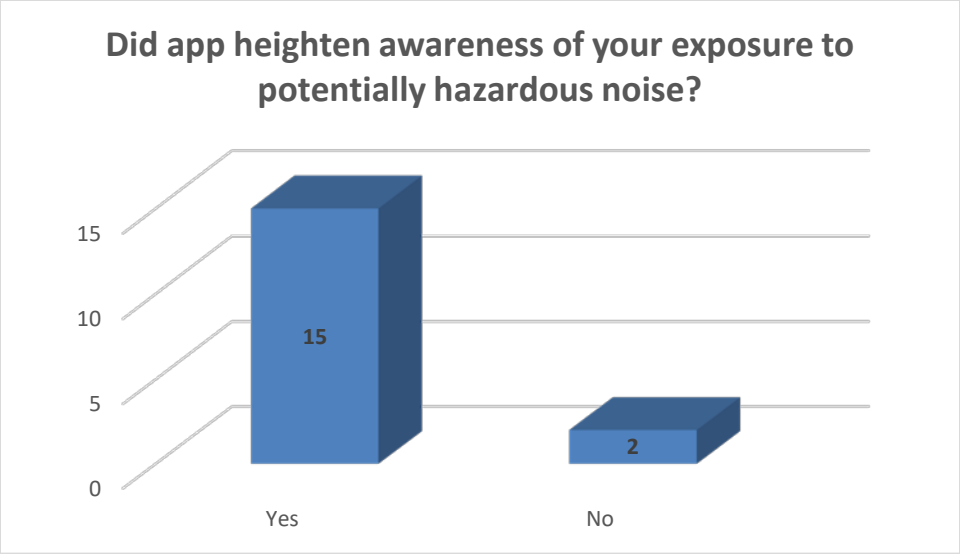

Figure 10. Number of Responses- "Did app heighten awareness?"

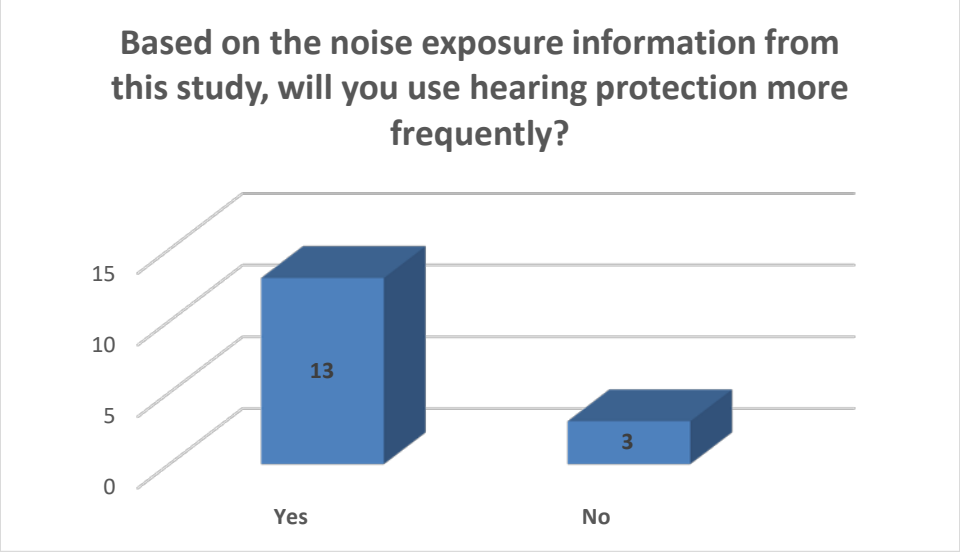

Figure 11. Number of Responses- "Will you use hearing protection more frequently?"

5.0 CONCLUSION

This study was designed to be a demonstration of the TEH concept, which considers the contributions from occupational, environmental, and lifestyle exposures for a host of stressors that an individual might be exposed. For this demonstration, exposures to noise on a 24-hour basis (vs. traditional 8-hour occupational exposure basis) was the focus. Low-cost technology was purposely used as the data collection platform.

Results of the study documented that at least some individuals have appreciable noise exposures outside of the workplace. These exposures include noises attributable to both environmental and lifestyle factors. Department of Defense leaders should consider whether additional interventions, such as increased medical monitoring, increased training on noise hazards and hearing protection devices, and the costs/benefits of providing hearing protection devices for home use, etc., can be used as preventive measures to reduce the risk of noise-induced hearing loss.

Although this research achieved its objective of demonstrating the TEH concept, future research should further develop low-cost solutions to gather noise exposure data, which are validated against gold standard instruments and provide reliable, battery efficient capabilities. Genetic testing to identify proclivity for noise induced hearing loss should also be considered for future inclusion, as people who are predisposed for noise-induced hearing loss are of particular interest.

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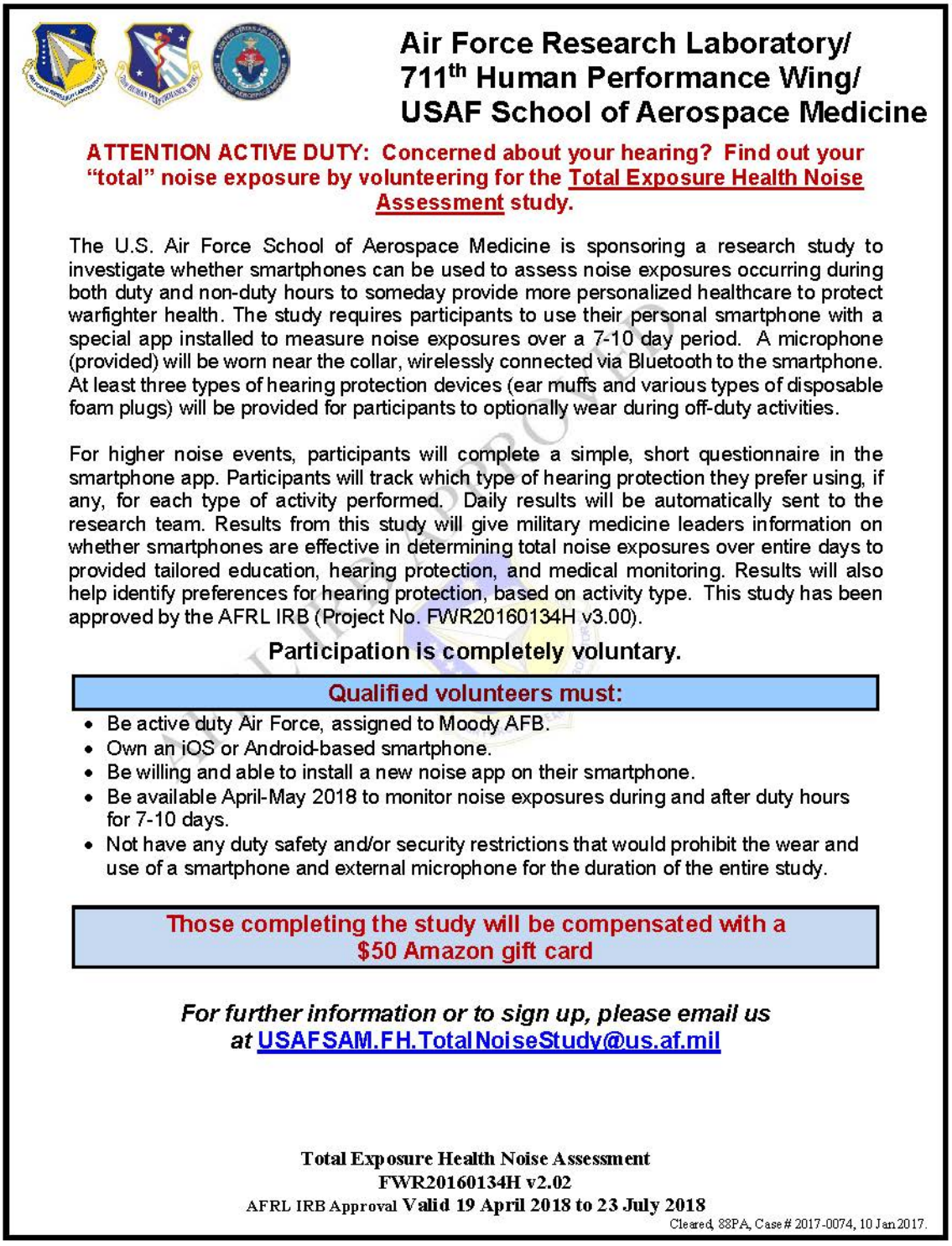
APPENDIX A: AF NEDP Recruitment Flyer



Air Force Research Laboratory/
711th Human Performance Wing/
USAF School of Aerospace Medicine

ATTENTION ACTIVE DUTY: Concerned about your hearing? Find out your "total" noise exposure by volunteering for the Total Exposure Health Noise Assessment study.

The U.S. Air Force School of Aerospace Medicine is sponsoring a research study to investigate whether smartphones can be used to assess noise exposures occurring during both duty and non-duty hours to someday provide more personalized healthcare to protect warfighter health. The study requires participants to use their personal smartphone with a special app installed to measure noise exposures over a 7-10 day period. A microphone (provided) will be worn near the collar, wirelessly connected via Bluetooth to the smartphone. At least three types of hearing protection devices (ear muffs and various types of disposable foam plugs) will be provided for participants to optionally wear during off-duty activities.

For higher noise events, participants will complete a simple, short questionnaire in the smartphone app. Participants will track which type of hearing protection they prefer using, if any, for each type of activity performed. Daily results will be automatically sent to the research team. Results from this study will give military medicine leaders information on whether smartphones are effective in determining total noise exposures over entire days to provided tailored education, hearing protection, and medical monitoring. Results will also help identify preferences for hearing protection, based on activity type. This study has been approved by the AFRL IRB (Project No. FWR20160134H v3.00).

Participation is completely voluntary.

Qualified volunteers must:

- Be active duty Air Force, assigned to Moody AFB.
- Own an iOS or Android-based smartphone.
- Be willing and able to install a new noise app on their smartphone.
- Be available April-May 2018 to monitor noise exposures during and after duty hours for 7-10 days.
- Not have any duty safety and/or security restrictions that would prohibit the wear and use of a smartphone and external microphone for the duration of the entire study.

Those completing the study will be compensated with a $50 Amazon gift card

For further information or to sign up, please email us at USAFSAM.FH.TotalNoiseStudy@us.af.mil

Total Exposure Health Noise Assessment
FWR20160134H v2.02
AFRL IRB Approval Valid 19 April 2018 to 23 July 2018
Cleared, 88PA, Case # 2017-0074, 10 Jan 2017.

APPENDIX B: Pre-Study Questionnaire (w/responses annotated)

Total Exposure Health Noise Assessment Pre Study Questionnaire

Subject ID number_____ Date_____

Demographic Information

1. Rank/Name
2. Duty phone number
3. Work email address
4. Male/Female
5. Age
6. AFSC
7. Shop/office symbol, shop/office name (e.g., 673 MXS/Corrosion Control)
8. Duty type (e.g., maintainer, admin assistant, nurse)

Technology Information

9. Type of phone: iPhone (6s, 7, 8 Plus, X, etc.), Android (LG, Samsung, etc.)
10. What operating system is on your phone, e.g., Android Marshmallow, Lollipop, iOS 11.3, etc.?
11. How much memory does your phone have?
12. How much memory is available?

Audiology Information

13. In the past year have you experienced:
    - Difficulty understanding speech under all circumstances? (Y/N) YES-0; NO-19
        - In background noise? (Y/N) YES-3; NO-16
    - The need to turn up the volume on the radio or TV more than in past years? (Y/N) YES-6; NO-13
    - Bothersome ringing, buzzing, or humming in the ears? (Y/N) YES-4; NO-15
        - Is it constant? (Y/N) NO-5
    - Difficulty keeping your balance? (Y/N) YES-0; NO-19
    - Dizzy spells (i.e., spinning dizziness)? (Y/N) YES-2; NO-17
    - Numbness or painful tingling (i.e., "neuropathy")? (Y/N) YES-16; NO-2
14. During your adult years have you ever had:
    - An ear surgery? (Y/N) YES-0; NO-19
    - Frequent ear infections? (Y/N) YES-0; NO-19
    - A medical provider advising you to receive audiometric monitoring because of medications prescribed to you? (Y/N) YES-0; NO-19
15. Considering only your time on duty in the military:

- Are you currently being monitored with annual audiograms because of workplace noise? (Y/N) YES-5; NO-13
- Were you ever previously assigned to a Hearing Conservation Program? (Y/N) YES-2; NO-17
- Have you ever been told your hearing test showed a significant change from your baseline hearing test? (Y/N) YES-3; NO-16
- Have you noticed you regularly breathe in engine exhaust? (Y/N) YES-3; NO-16
- Have you noticed you regularly breathe in fuel vapors? (Y/N) YES-2; NO-17
- Do you shoot firearms or attend combat arms training at least annually? (Y/N) YES-9; NO-9
- Do you always or almost always use hearing protection for loud noises on duty? (Y/N) YES-12; NO-6
- Are you mandated to listen to earphones or earbuds to perform your duties? (Y/N) YES-1; NO-18

16. Aside from mandatory use of earphones or earbuds at work, consider your personal use of earphones or earbuds for listening to music (e.g., iPod or MP3 player):
    - Have you regularly used earphones or earbuds for >5 years? (Y/N) YES-16; NO-2
    - Do you listen to earphones or earbuds more than 4 hours/week? (Y/N) YES-8; NO-10
    - Do you wear a hat, headband, earmuffs, helmet or use other means to make the earphones or earbuds fit tighter with the ears? (Y/N) YES-3; NO-16
    - Do you often select a volume you consider loud or very loud? (Y/N) YES-5; NO-14
17. Considering only your time off duty over the past year:
    - Have you used a chain saw? (Y/N) YES-7; NO-12
    - Do you use power lawn and garden tools? (Y/N) YES-14; NO-4
    - Have you used other loud power tools? (Y/N) YES-11; NO-7
    - Have you been hunting or target shooting with a firearm? (Y/N) YES-8; NO-10
    - Do you play a musical instrument or are you near people who do? (Y/N) YES-1; NO-18
    - Do you always or almost always use hearing protection for loud noises off duty? (Y/N) YES-10; NO-8
        - If so, what types? e.g., Custom-fitted ear plugs, disposable foam plugs, ear muffs, etc. MUFFS-3; REUSABLE-1; FOAM PLUGS-2
    - Have you noticed you regularly breathe in engine exhaust? (Y/N) YES-2; NO-17
    - Have you noticed you regularly breathe in fuel vapors? (Y/N) YES-1; NO-18
18. Know of any of the following biological relatives that have experienced early hearing loss:
    - Mother at or before age 50? (Y/N) YES-0; NO-19
    - Father at or before age 40? (Y/N) YES-4; NO-15
    - Brother at or before age 40? (Y/N) YES-1; NO-18
    - Sister at or before age 50? (Y/N) YES-0; NO-18

APPENDIX C: Post-Study Questionnaire (w/responses annotated)

Total Exposure Health Noise Exposure Post Study Questionnaire

Subject ID number_____ Date_____

1. Please describe any technical issues you had during the study. For example, battery did not last throughout the day, microphone did not function, etc.
   Battery did not last all day (6); manual sync/reset required (5); connectivity/lost connection often (13); microphone (not specified)(2); microphone too sensitive to voice (1); iPhone ear jack cord (1).
2. Were you able to comply with all requests for a log entry? (Y/N) YES-16; NO-1
3. Please describe any issues/problems you had with the app/usability.

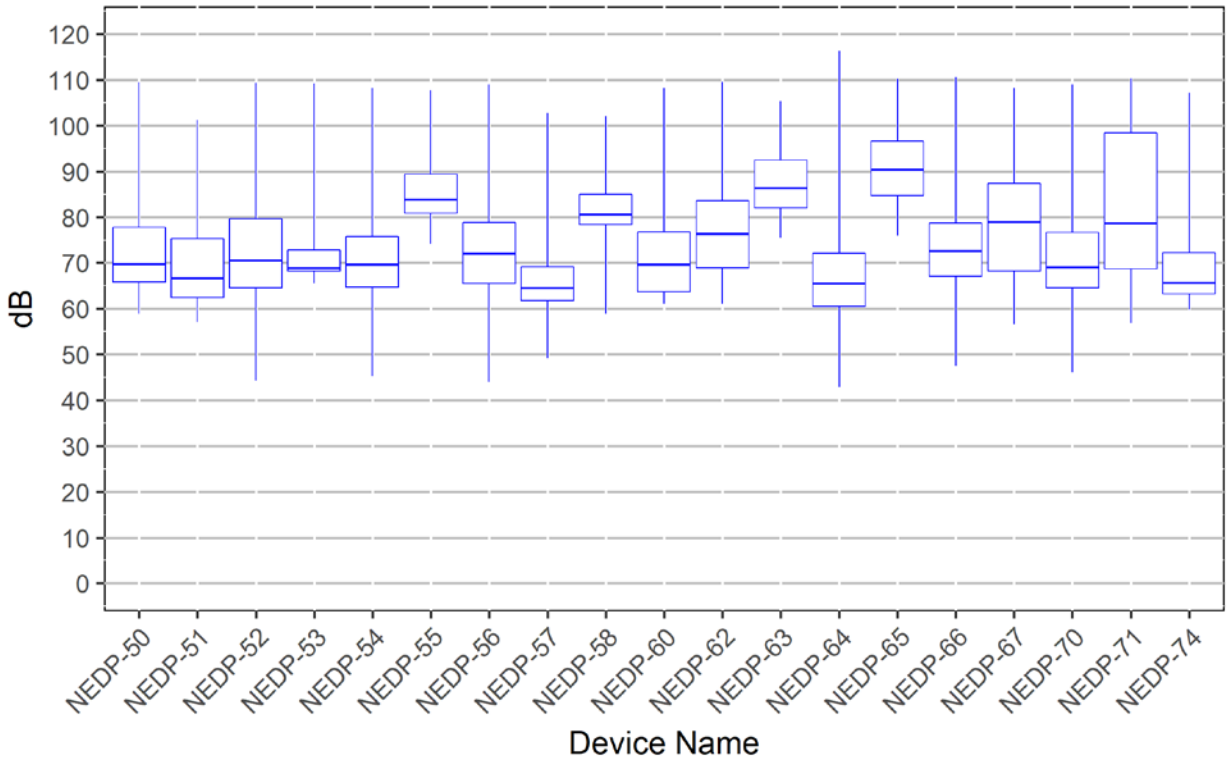
   Various responses, to include: picked up other sensors in the area, app would crash, difficulty syncing, log entry was slow to respond at times, connectivity issues, a lot of surveys to complete.
4. Please describe why you chose to wear foam plugs, earmuffs, or custom-fitted plugs (if provided) for various activities after duty hours.
   [see #5 below]
5. What made you choose one type of protection over another?

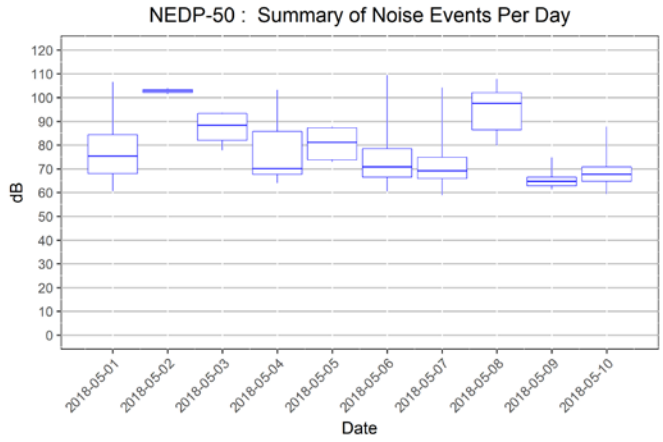
   Various responses, to include: custom-fitted for comfort reasons (4); flanged for better noise reduction rating (NRR) at concert (1); foam—didn't want to ruin custom-fitted plugs (1); ear muffs as they fit over headphones (1); custom-fitted for less isolated feeling (1); ear muffs for mowing (1)
6. For after duty hours, did you ever choose to skip wearing hearing protection altogether? (Y/N) Why? YES-9; NO-6 Not needed (9); activity warranted hearing protection (8)
7. Did this app heighten your awareness of your exposure to potentially hazardous noise? (Y/N) YES-15; NO-2
8. Do you anticipate using personal hearing protection more frequently as a result of the noise exposure information you gained during the study? (Y/N) YES-13; NO-2
9. Would you use this app after the study? (Y/N). Why or why not? YES-11; NO-6

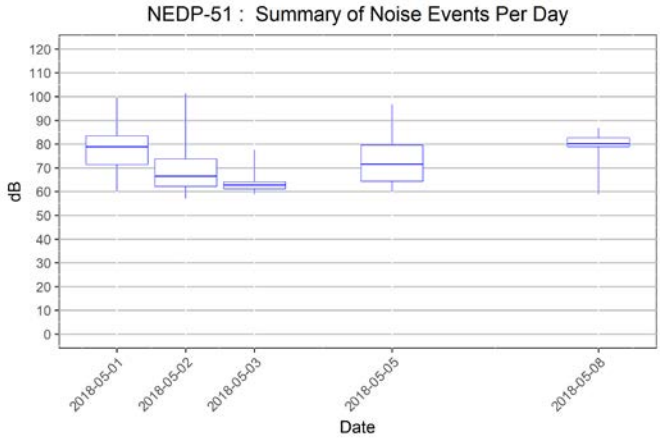
   For "Yes": want hearing to last entire life, good screening tool
   For "No": dosimeter (microphone) is cumbersome, with improvements, too low of a threshold, slugglish app, too many survey pop-ups, have a different app on phone already
10. Please provide suggestions for improvements for future studies.

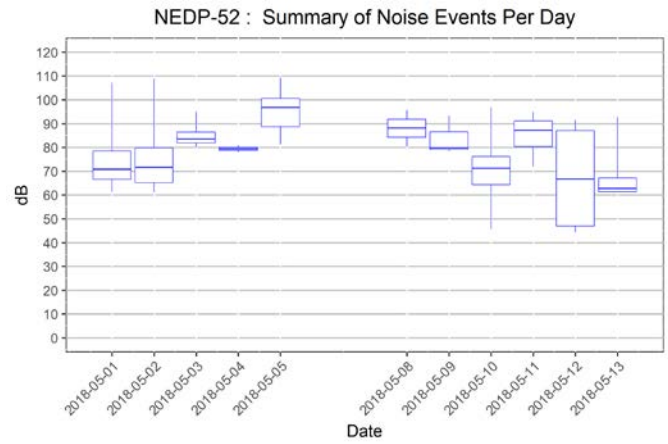
    Memory feature when not connected to app, improved connectivity, add "home" on the app, better battery, improved app speed, wear longer than a week, improvements on how it attaches to clothing, easier access to reset button, easier to see LED indicator when disconnected, place a seconsor in the earplug, raise the baseline for the noise level reported, improved app, less survey pop-ups.

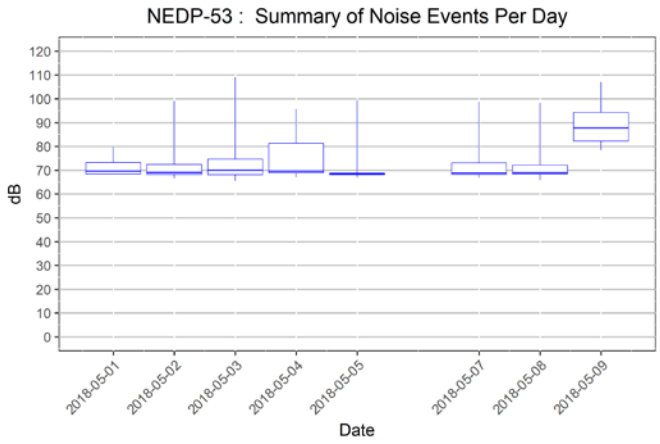
APPENDIX D: Box Plots-Summary of Noise Events by Device Name

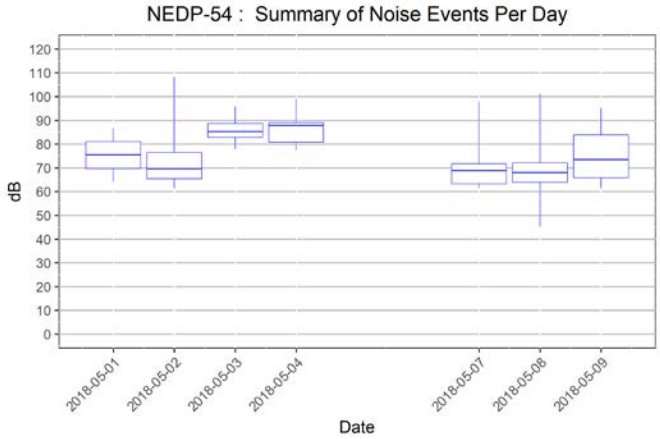


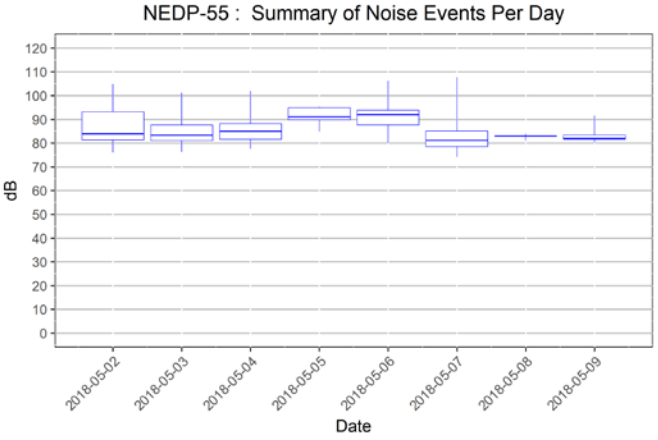


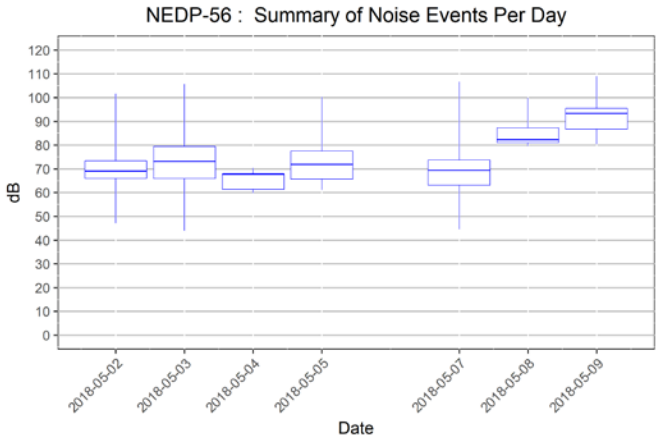


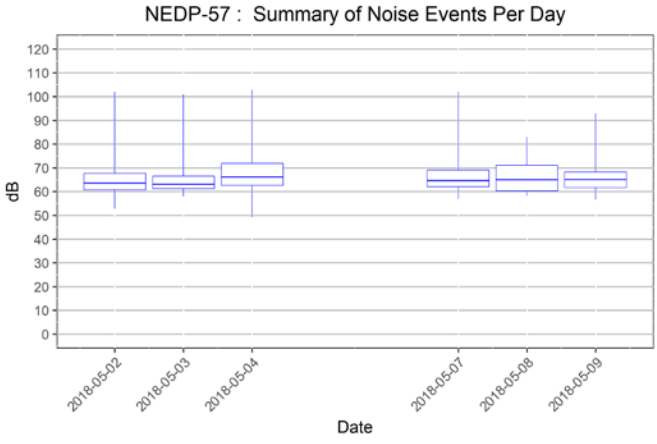


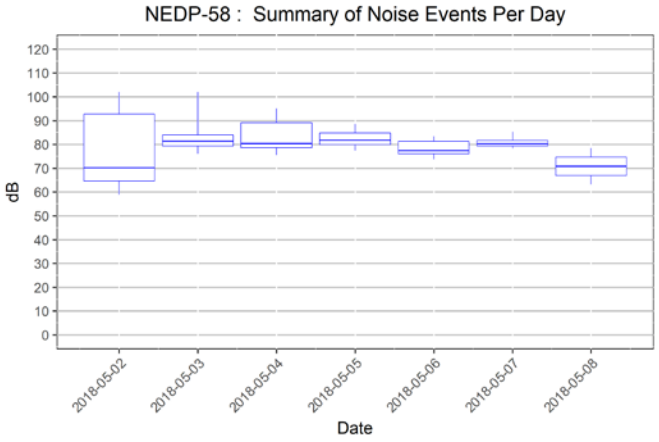


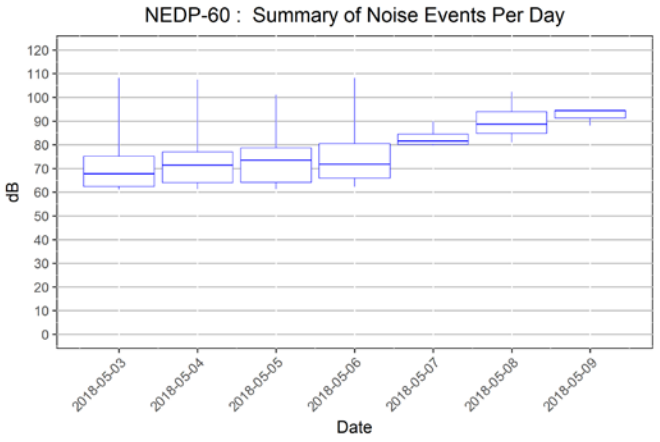


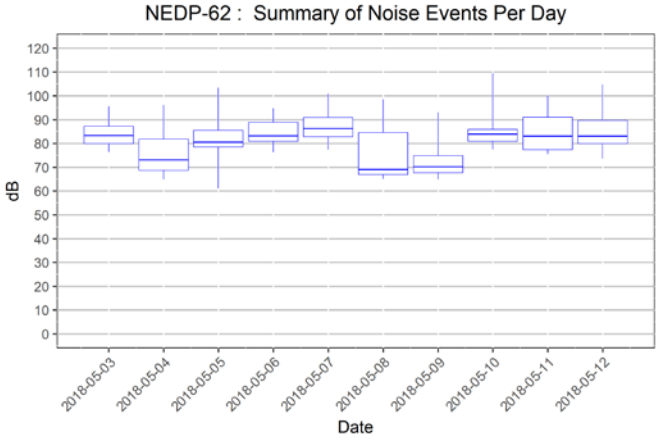


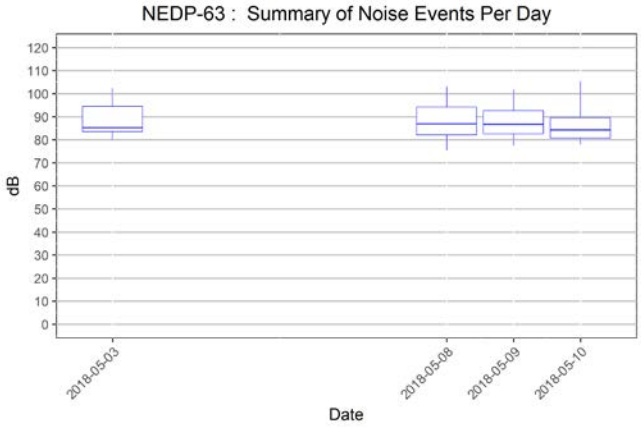


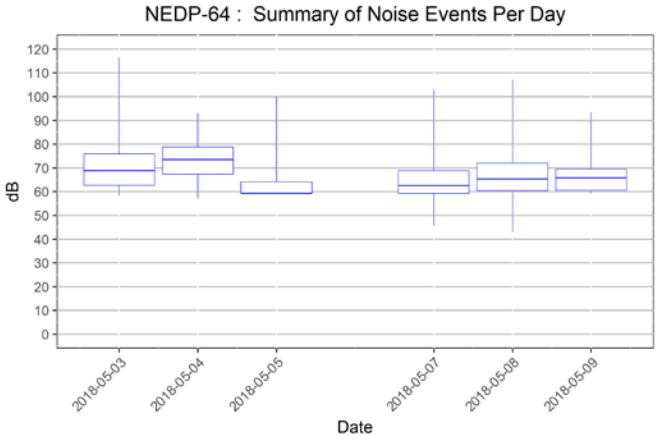


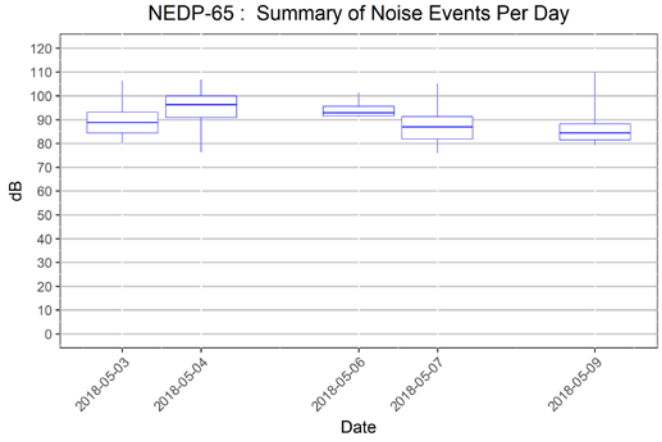


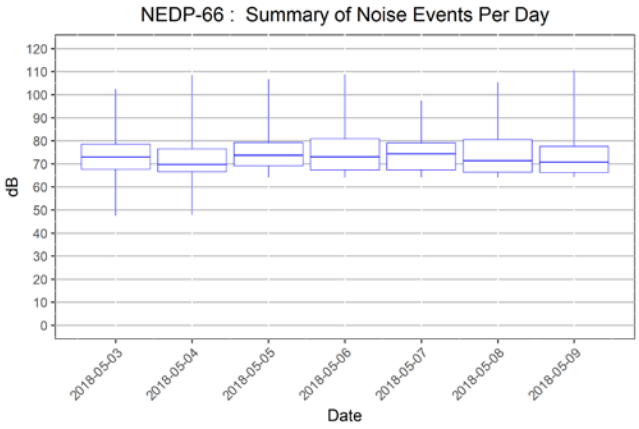


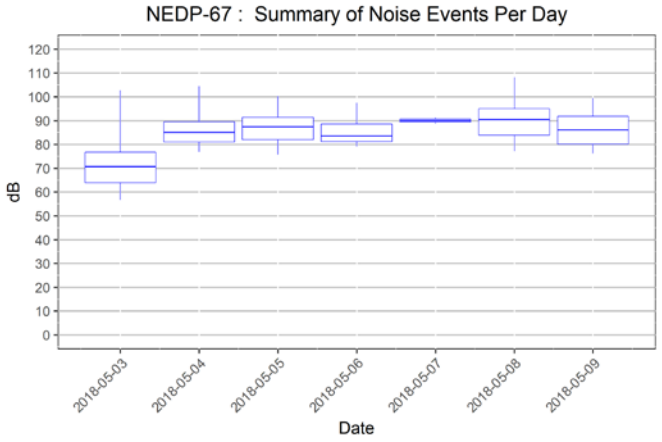


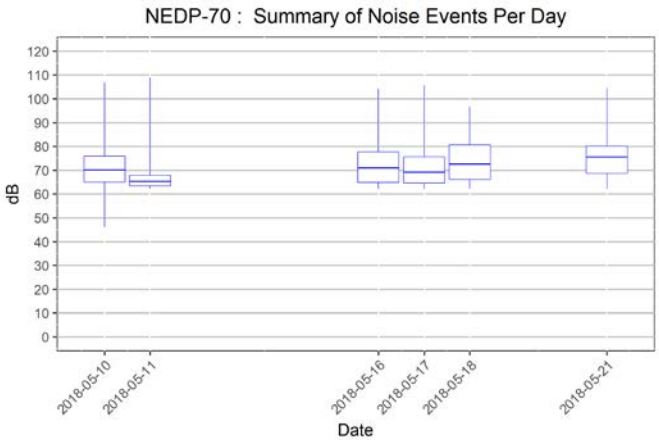


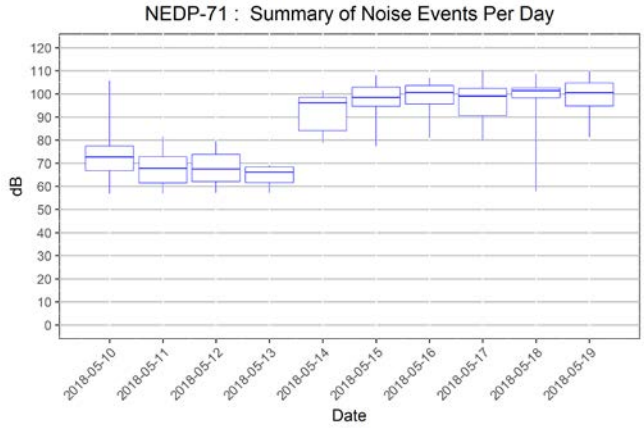


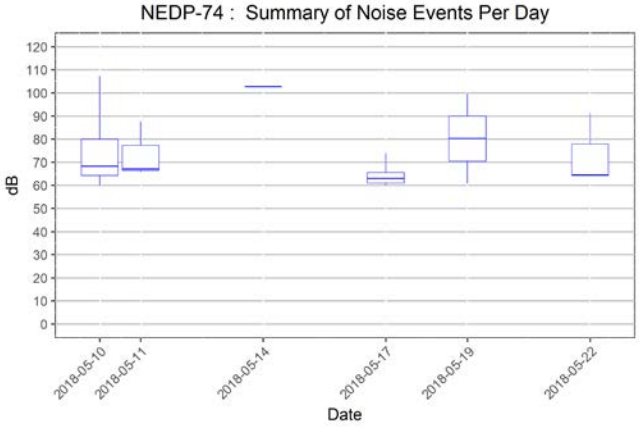




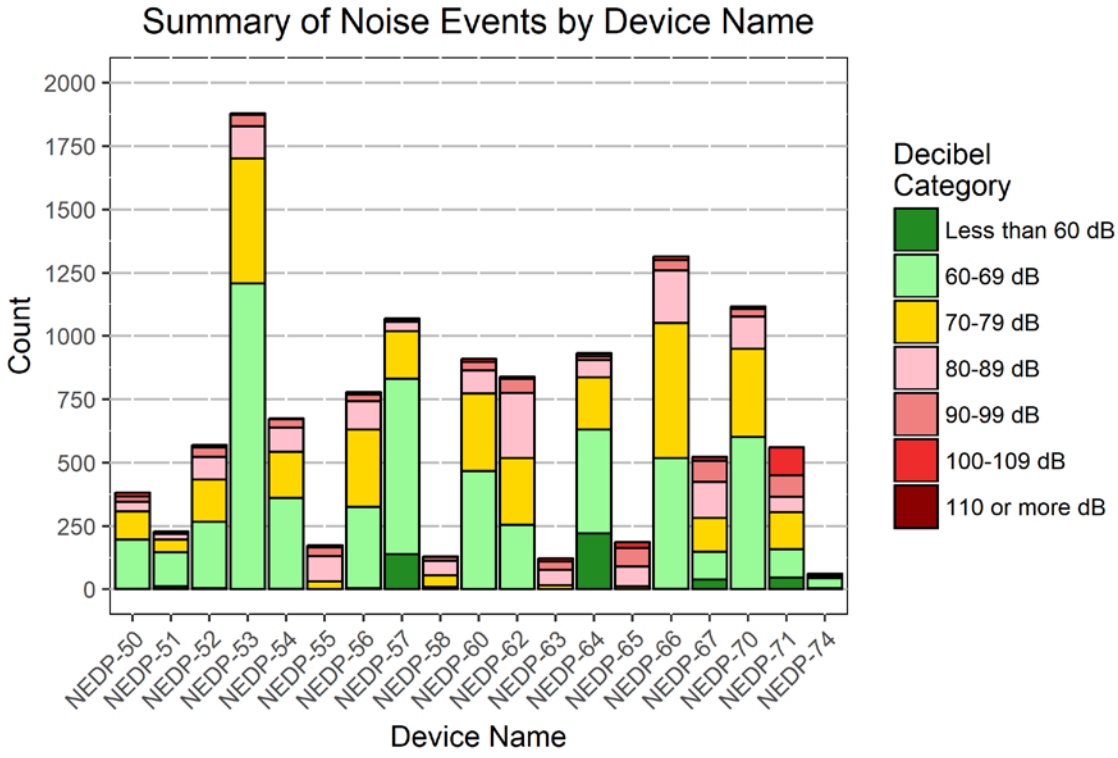


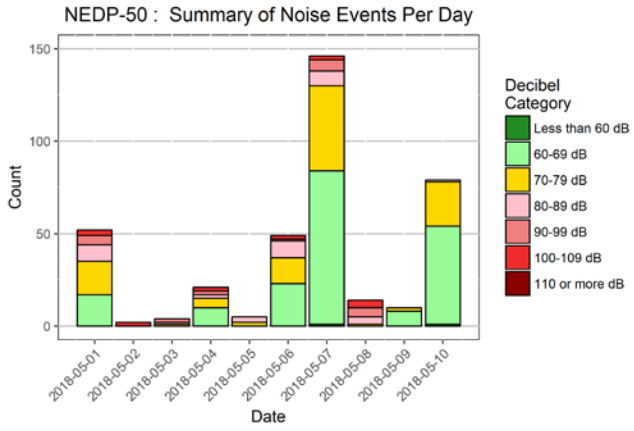


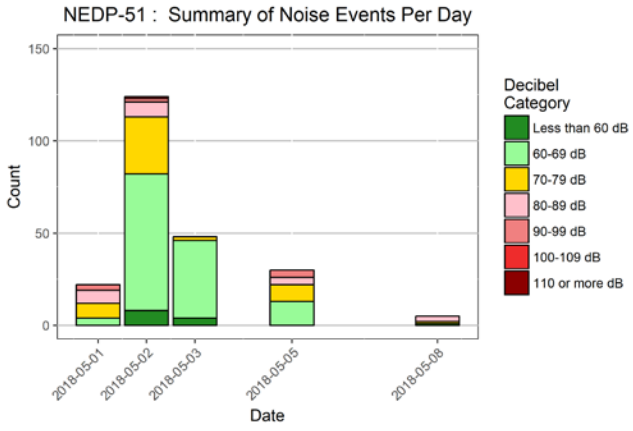


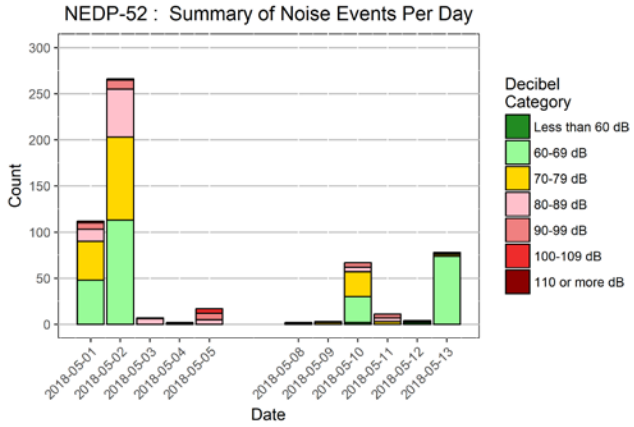


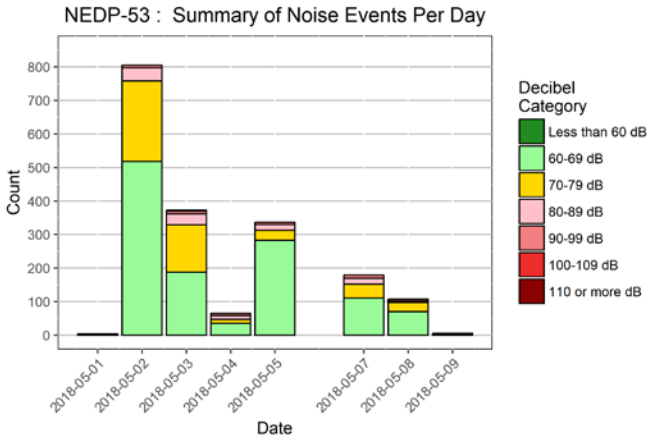
APPENDIX E: Stacked Bar Charts-Summary of Noise Events by Decibel Range

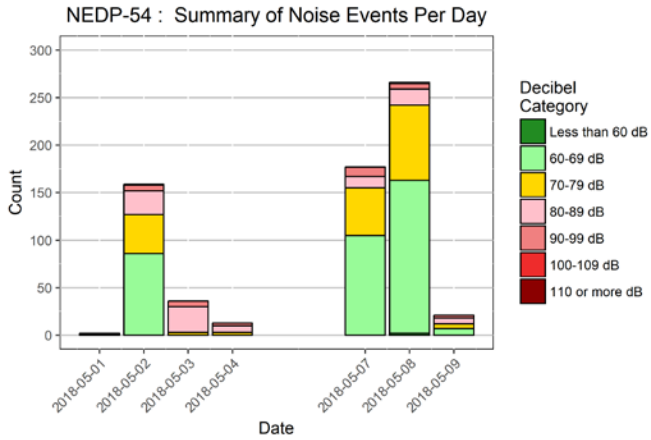


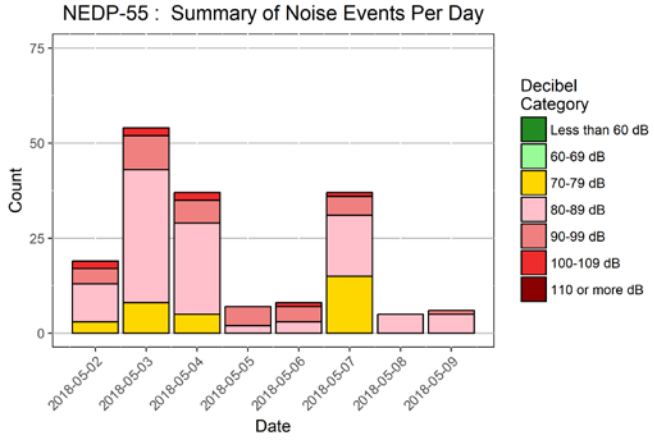


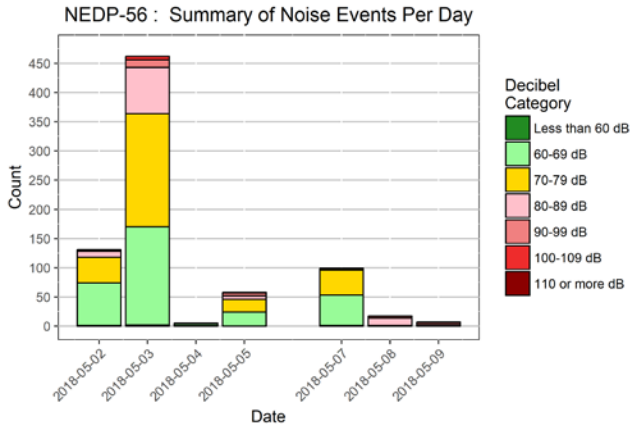


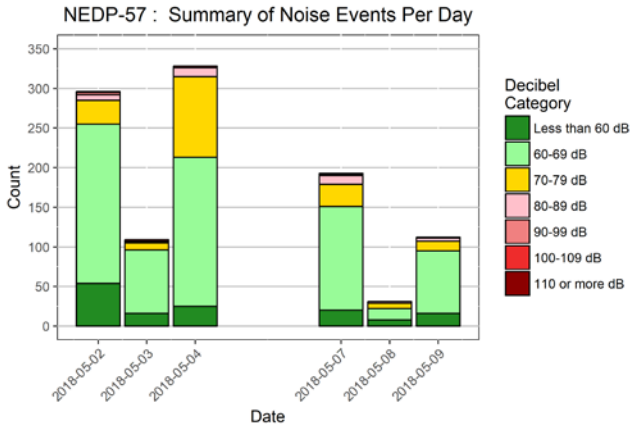


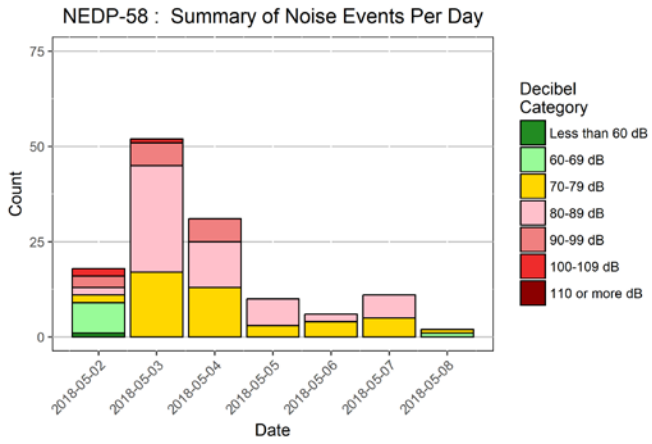


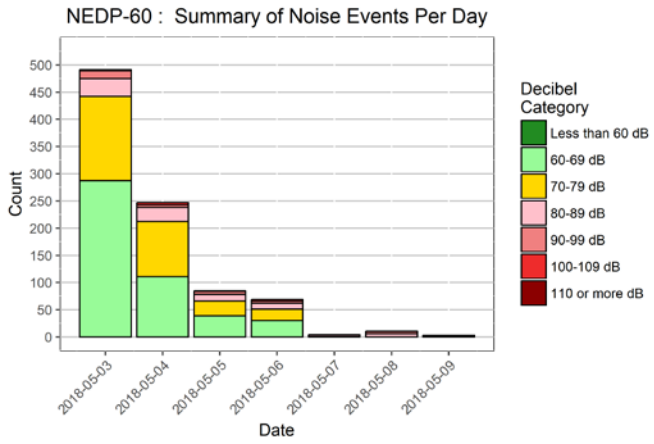


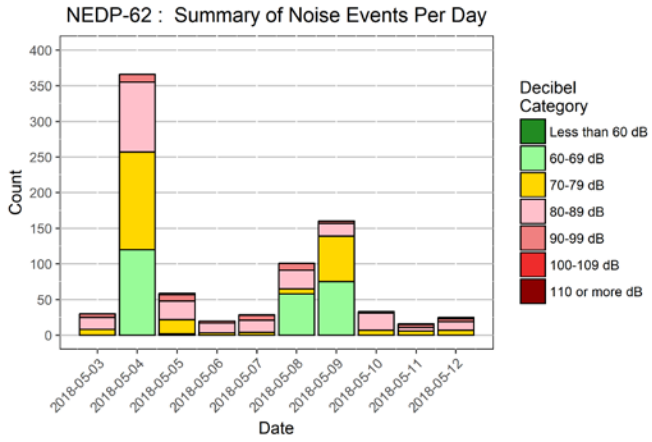


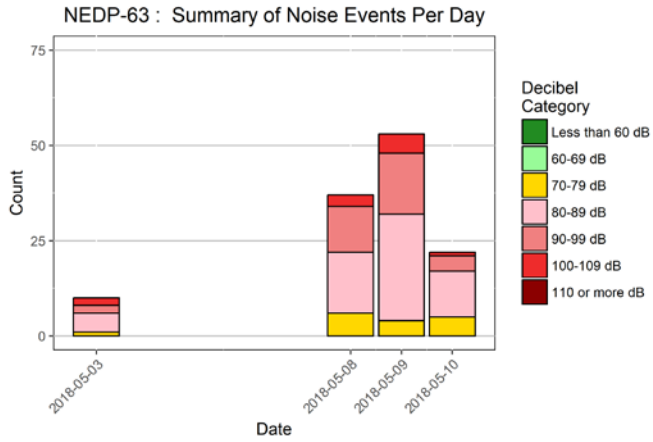


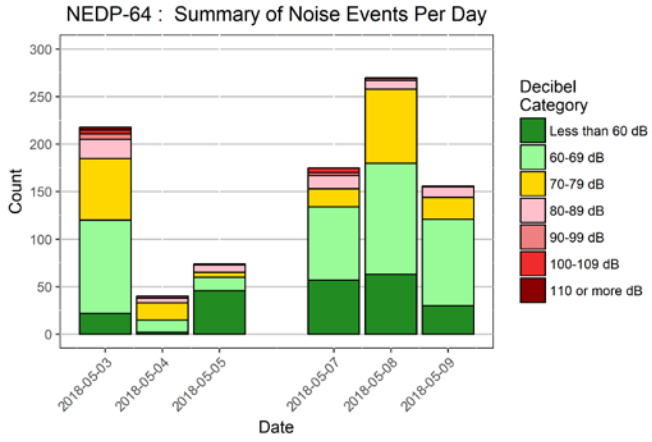


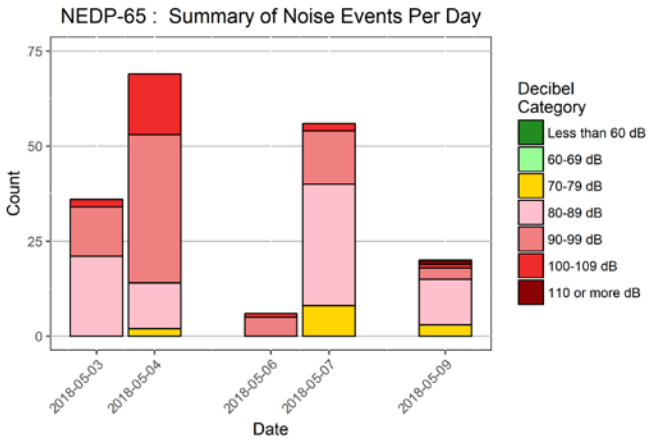


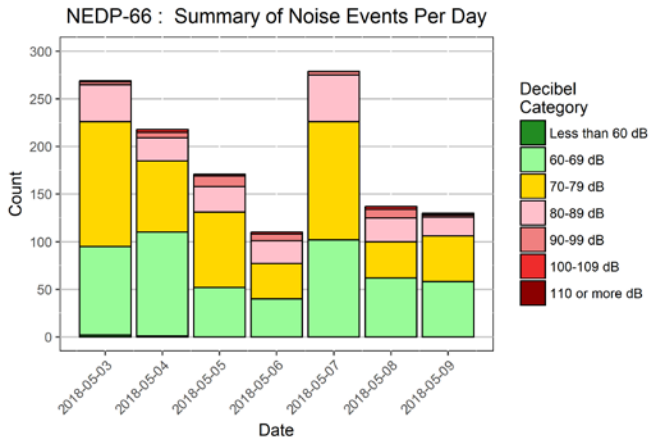


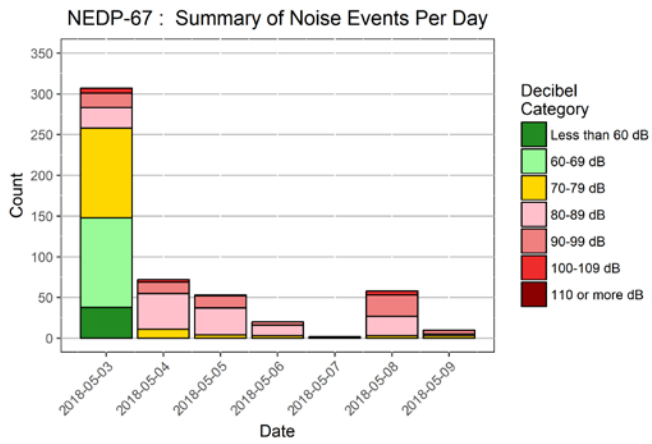


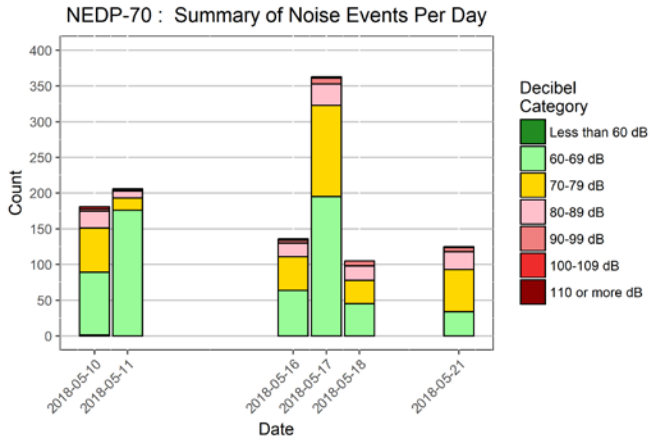


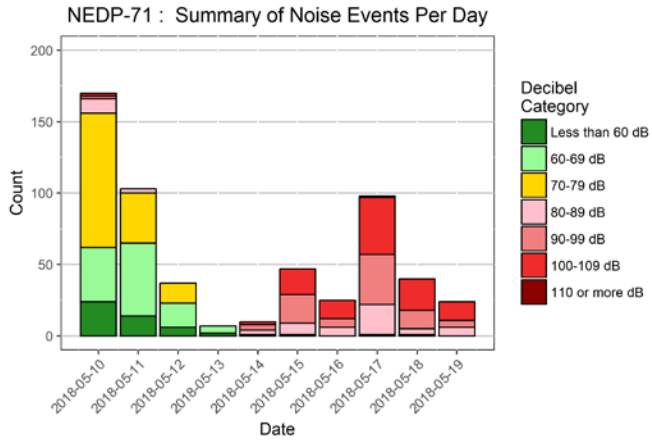


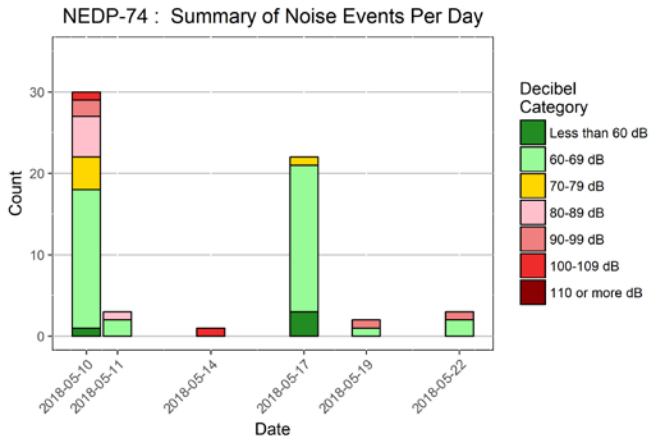




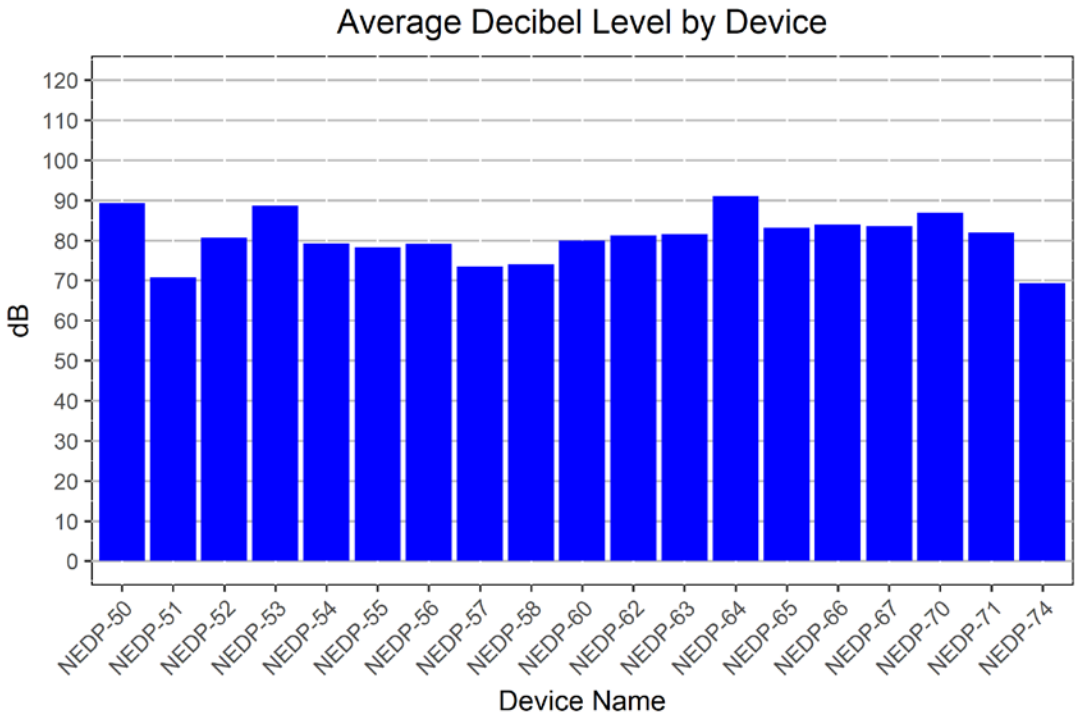


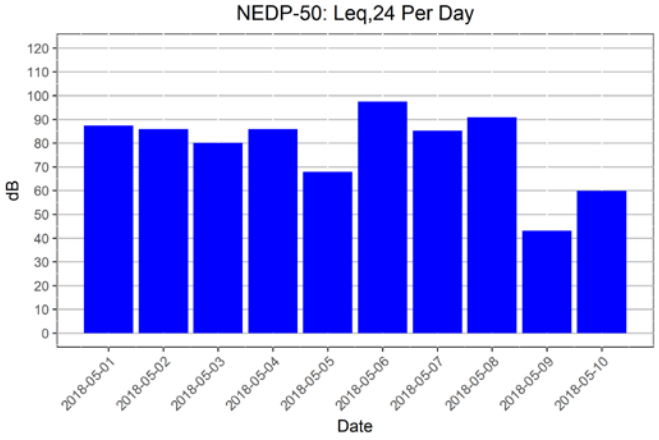


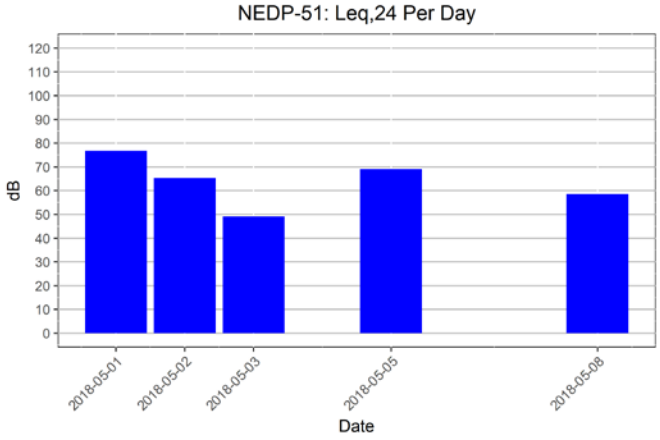


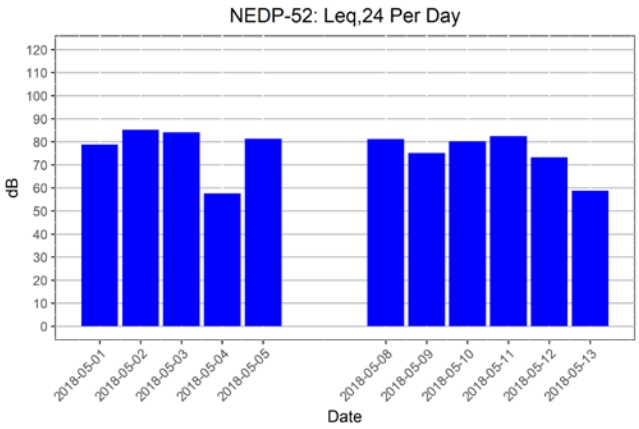


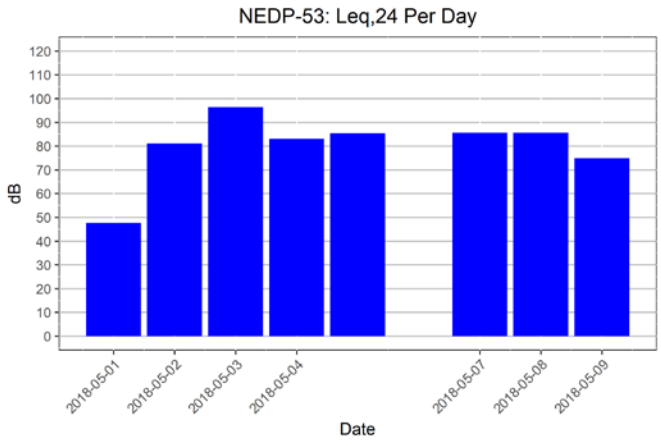
APPENDIX F: Daily Equivalent Noise Levels

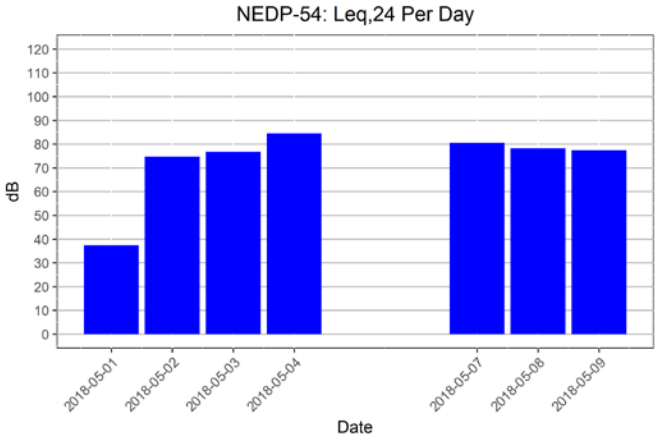


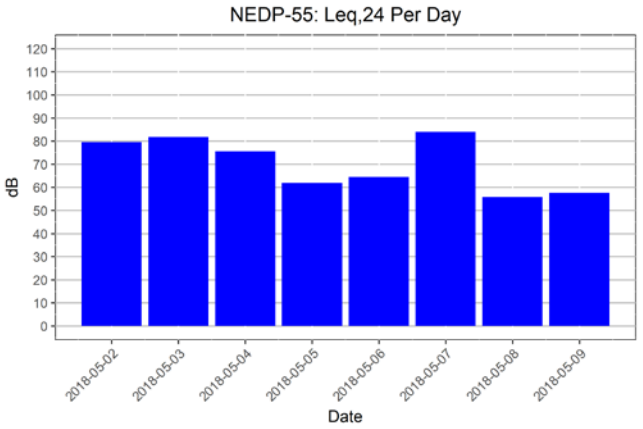


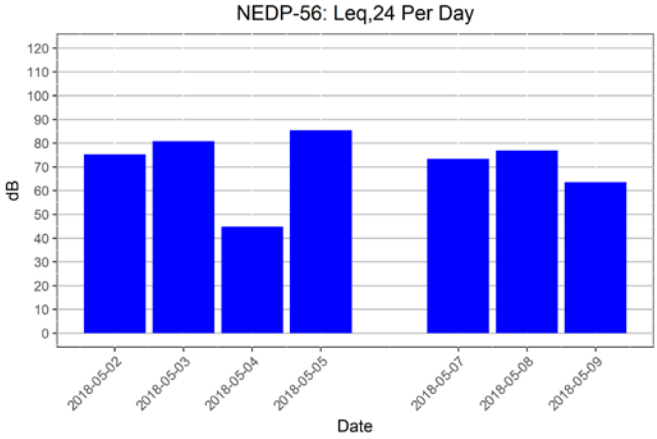


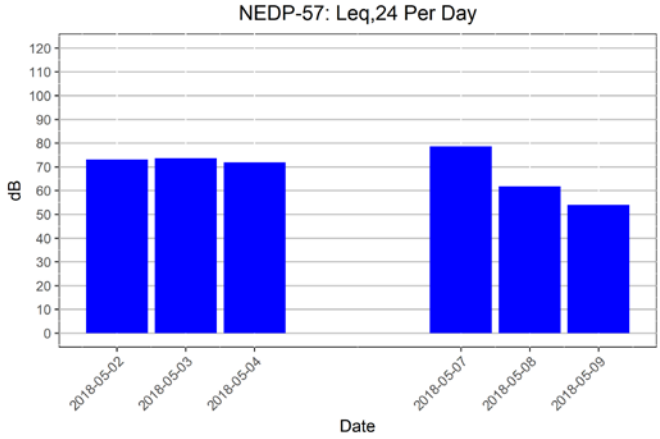


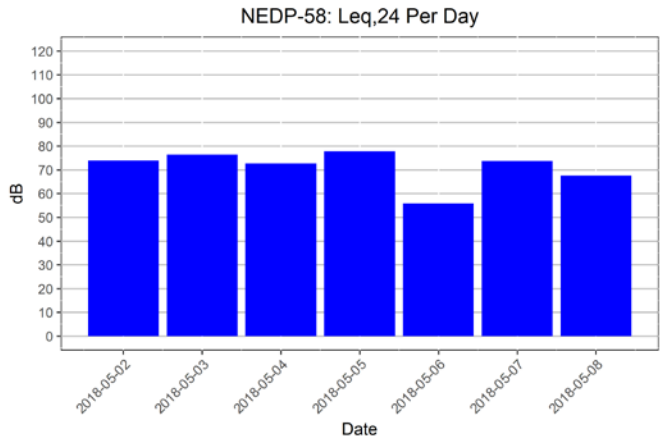


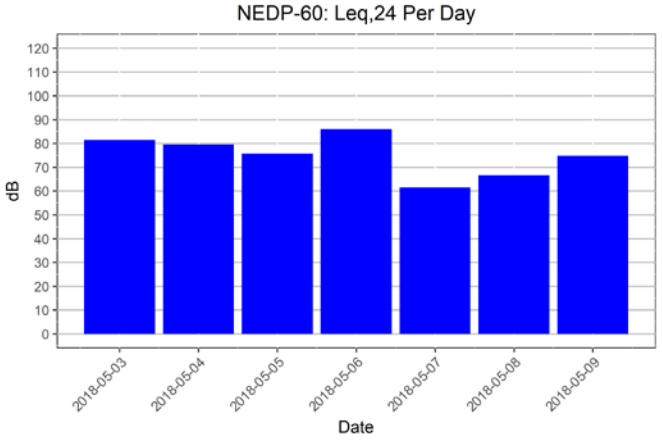


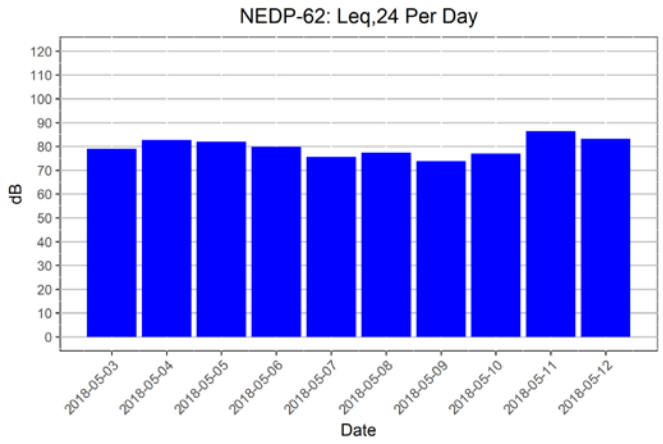


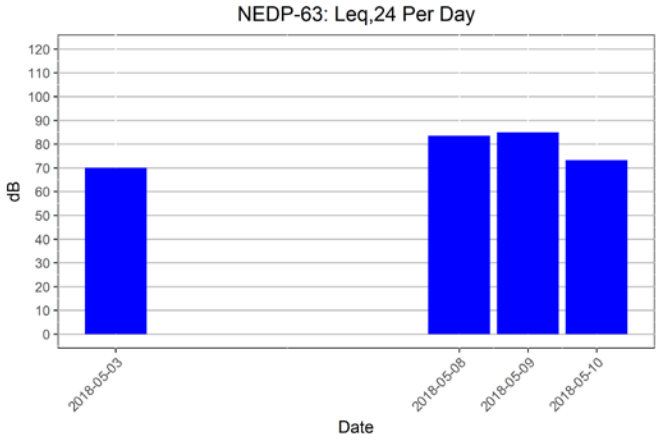


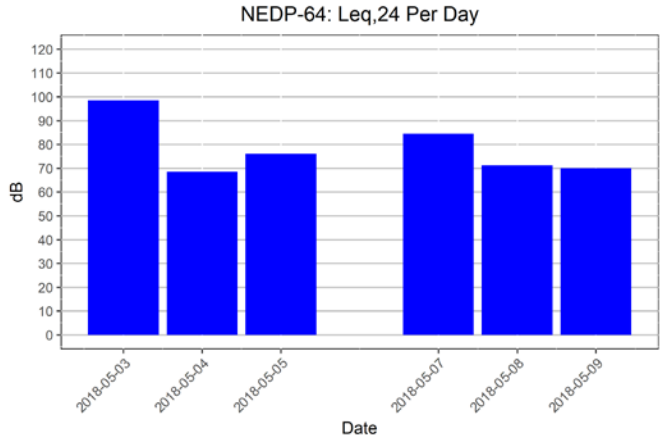


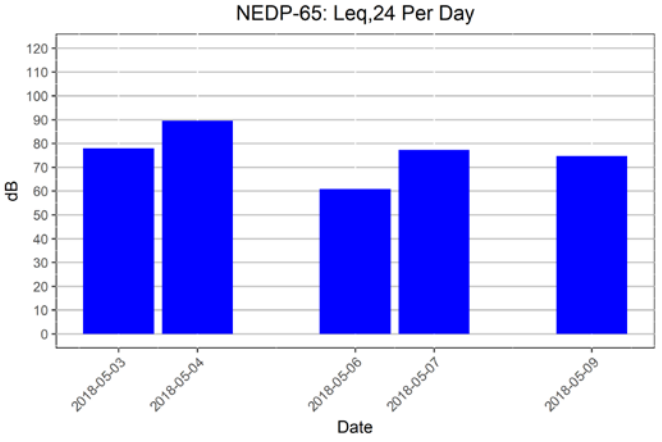


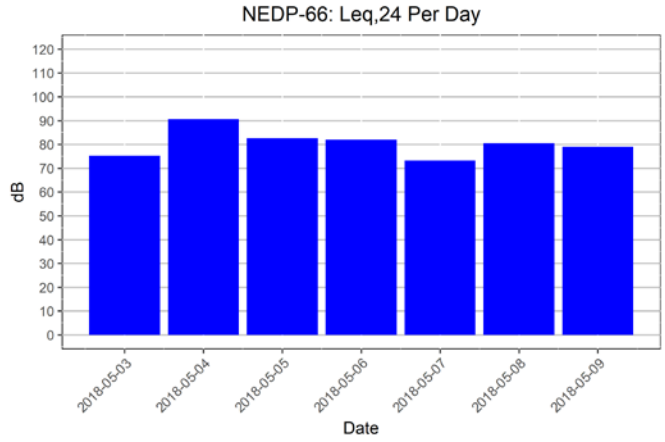


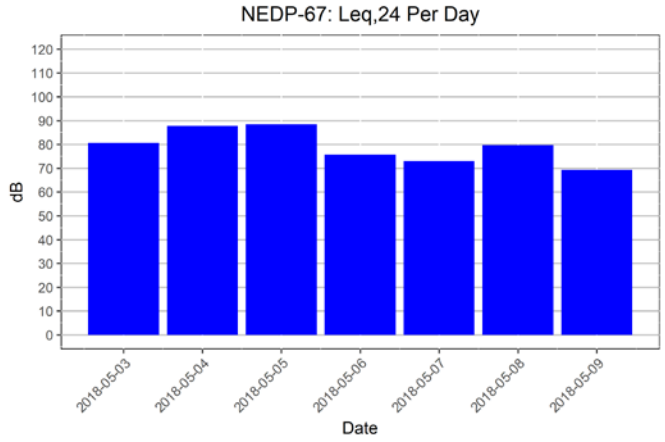


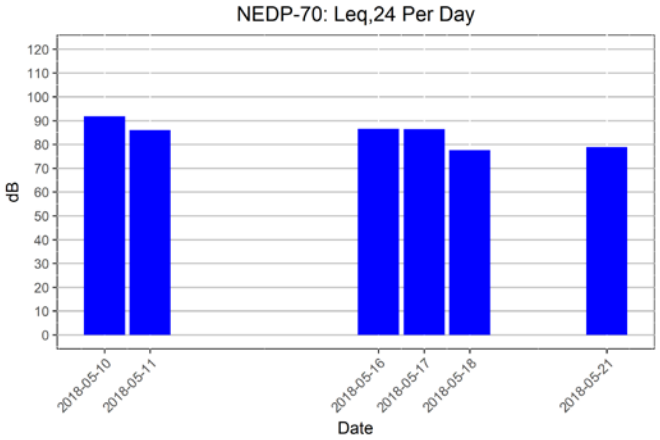


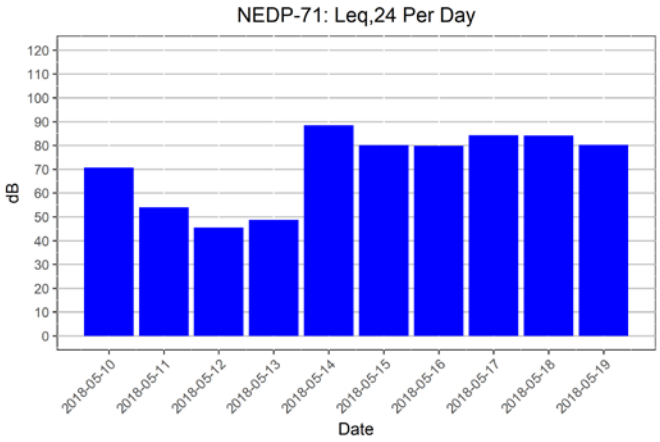


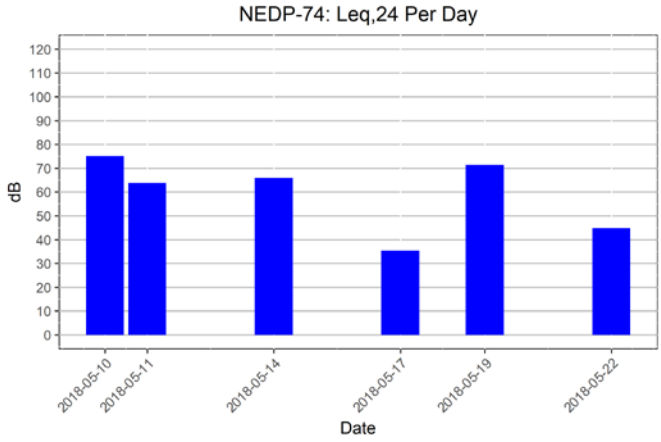












APPENDIX G: Lessons Learned During the NEDP Study

1) Increase advertisement of study to several publications in the base bulletin or base email from PA: Institutional Review Board (IRB) requires that "coercion" (real or perceived) does not occur, which prevents unit commanders, etc., from playing an active role in recruitment.
2) The paperwork requiring signatures was a very big obstacle for volunteers: "Compensation" (i.e., gift cards) triggered the "off-duty employment" approval process for military members (supervisor signature, JA signature, unit/CC signature). Avoid compensation, if possible.
3) Consistent complaints from volunteers on connectivity issues: Any technology used as part of a study needs emphasis on "reliability" and without it, study participants have waning interest in being active participants in the study.
4) Consistent complaints from volunteers on battery issues--not lasting long enough.
5) Fill schedule with volunteers before site visit is planned to ensure maximum participation.
6) More subject contact to include initial appointment set up and then reminder calls and/or emails prior to arriving to confirm appt.
7) Ask volunteers to send flyer to friends to enhance recruitment.
8) Most participants had genuine interest in learning more about their exposures and asked pointed questions to learn more about the study.
9) Free hearing protection seemed to be appreciated: Future TEH studies should consider providing personal protective equipment (PPE) to help participants protect themselves after duty hours.
10) Younger generations have almost exclusively adopted "Bluetooth" technology to listen to music via smartphones. Future TEH studies should consider this, especially if assessing "ear bud" exposures (i.e., listening to music).
11) Noise microphones should undergo more rigorous validation testing against gold standards, in order to give TEH noise-related studies more credibility. Being competitive for being published in higher impact, peer-reviewed literature will likely be dependent on a methodology that uses such rigor.
12) Better training on how to use hearing protection devices: Increased frequency and quality of training, to improve the attenuation provided by foam earplugs and other inserted devices.
13) Include quantitative fit testing of hearing protection: Reinforces the training on how to properly fit, insert, and use hearing protection. Longer term goal should be to demonstrate the utility of fit testing of hearing protection devices across USAF/DOD.

LIST OF ABBREVIATIONS AND ACRONYMS

BE bioenvironmental engineering

HCP hearing conservation program

TEH total exposure health