The Viability of Hearing Protection Device Fit-Testing at Navy and Marine Corps Accession Points

Jeremy Federman1, Christon Duhon2
1 Naval Submarine Medical Research Laboratory, Groton, CT, 2 Naval Hospital Beaufort, BHC, MCRD, Parris Island, SC, United States

Abstract

Introduction: The viability of hearing protection device (HPD) verification (i.e., fit-testing) on a large scale was investigated to address this gap in a military accession environment. Materials and Methods: Personal Attenuation Ratings (PARs) following self-fitted (SELF-Fit) HPDs were acquired from 320 US Marine Corps training recruits (87.5% male, 12.5% female) across four test protocols (1-, 3-, 5-, and 7-frequency). SELF-Fit failures received follow-up to assess potential causes. Follow-up PARs were acquired (Experimenter fit [EXP-Fit], followed by Subject re-fit [SUB Re-Fit]). EXP-Fit was intended to provide a perception (dubbed “ear canal muscle memory”) of what a correctly fitted HPD should feel like. SUB Re-Fit was completed following EXP-Fit to determine whether a training recruit could duplicate EXP-Fit on her/his own without assistance. Results: A one-way analysis of variance (ANOVA) (N=320) showed that SELF-Fit means differed significantly between protocols (P < 0.001). Post-hoc analyses showed that the 1-freq SELF-Fit mean was significantly lower than all other protocols (P < 0.03) by 5.6 dB or more. No difference was found between the multi-frequency protocols. For recruits who were followed up with EXP-Fit (n = 79), across all protocols, a significant (P < 0.001) mean improvement of 25.68 dB (10.99) was found, but PARs did not differ (P = 0.99) between EXP-Fit protocols. For recruits in the 3-freq and 5-freq protocol groups who experienced all three PAR test methods (n = 33), PAR methods differed (P < 0.001) but no method by protocol interaction was found (P = 0.46). Post hoc tests showed that both EXP-Fit and SUB Re-Fit had significantly better attenuation than SELF-Fit (P < 0.001), but no difference was found between EXP-Fit and SUB Re-Fit (P = 0.59). For SELF-Fit, the 1-freq protocol resulted in a 35% pass rate, whereas the 3-, 5-, and 7-freq protocols resulted in >60% pass rates. Results showed that once recruits experienced how HPDs should feel when inserted correctly, they were able to properly replicate the procedure with similar results to the expert fit suggesting “ear canal muscle memory” may be a viable training strategy concomitant with HPD verification. Fit-test duration was also measured to examine the tradeoff between results accuracy and time required to complete each protocol. Discussion: Results from this study showed the critical importance of initial selection and fitting of HPDs followed by verification (i.e., fit-testing) at Navy and Marine Corps accession points. Achieving adequate protection from an HPD is fundamentally dependent on obtaining proper fit of the issued HPD as well as the quality of training recruits receive regarding HPD use.

Keywords: Fit-testing, hearing conservation, hearing protection device (HPD), noise-induced hearing loss (NIHL), personal attenuation rating (PAR)

INTRODUCTION

Noise-induced hearing loss risk

In both military and industry occupational settings, noise hazards are pervasive, and noise-induced hearing loss (NIHL) and tinnitus are common work-related illnesses. NIHL potentially affects as many as 22 million U.S. workers each year.[1] For active-duty service members in the U.S. Armed Forces, the number of medical encounters for NIHL and hearing impairment number in the tens of thousands annually.[2] Wells et al.[3] reported that nearly one-half million U.S. Veterans are service-connected (i.e., receive disability compensation) for hearing loss, that hearing loss leads to higher attrition rates than for those without hearing loss, and that those deployed with combat experience had a 1.6% greater chance of reporting new hearing loss compared to those not deployed. Trost and Shaw[4] analyzed medical hearing test records for nearly 268,000 enlisted Sailors, and found that personnel who had been deployed 2/3rd time to
surface warships had an 18 percentage-point higher chance of leaving active duty with hearing loss compared to those limited to shore duty, and those deployed to sea duty ½ time had a 13 percentage point probability increase. In summary, these results indicate that exposure to loud ongoing and impulse noises in military settings can impact workplace safety and effectiveness, auditory fitness for duty, and risk of NIHL and tinnitus.

The effects of NIHL and tinnitus are well-known. These effects include damage to the structures of the inner ear, auditory threshold shifts, speech understanding difficulty, anxiety and irritability for loud noise, increased heart rate and blood pressure, and general quality of life decrements. [5–9] It is U.S. Department of Defense policy to “Protect all DoD personnel from hearing loss resulting from operational (to include combat) and occupational noise exposure through a continuing, effective, and comprehensive Hearing Conservation Program (HCP) . . . ” and to “reduce operational noise exposure to personnel to facilitate mission readiness, communication, and safety.”[10] Military instructions require that all workers exposed to hazardous noise are enrolled in a HCP.[10,11] As a part of these programs, noise levels are measured and monitored, and engineering and administrative controls are considered. As a last line of defense, personal protective equipment (PPE) is provided when other controls are insufficient. In addition, HCPs provide annual education and training, and regular audiometric monitoring of hearing status for those exposed to hazardous noise.

Despite the existing efforts to mitigate and abate noise as well as to minimize its effects on personnel, there currently exists no coordinated or systematic program to verify that an HPD dispensed to a given individual is fit properly and providing the amount of protection from hazardous noise levels required to prevent hearing loss during basic training.

### Hearing protection device (HPD) fit-testing

Historically, those managing HCPs primarily relied on the Noise Reduction Rating (NRR) values of an HPD that represent laboratory controlled measures of performance for a group of users to estimate the amount of protection that might be achieved by users. That is, the NRR is a value in decibels (dB) that represents the amount of protection the HPD is capable of providing for an average user. However, studies have shown that the amount of protection achieved in the workplace is oftentimes much lower than what is measured in the laboratory.[12–14] As a result, de-rating schemes based on the NRR have been determined and implemented to estimate actual field attenuation values as opposed to laboratory values.[15] Methods that estimate real-world attenuation on individuals are problematic such that all users of a given HPD are predicted to be getting the same amount of reduced protection, when in practice many users may be adequately protected, but these users are not differentiated. In the U.S. Navy, such a de-rating scheme was introduced.[16] Based on the de-rating scheme, the maximum broadband noise level personnel could be exposed to while using double hearing protection would have been limited to 105 dB SPL. This level is frequently exceeded in many military occupational settings, and such a policy would have required a substantial increase in personnel since the alternative to PPE in the short- to mid-term would be administrative control. For the Navy, this alternative would have represented a significant challenge to implement due to the increase in necessary personnel required to fulfill the policy requirements combined with onboard space limitations.

One potential means, by which to have a positive impact on NIHL prevention outcomes, and eliminate the shortcoming of field attenuation estimation using NRR and de-rating schemes, is to objectively verify the performance of HPDs on individual users. One available method for this is to use Field Attenuation Estimation Systems (FAES), more commonly called fit-testing equipment, which measures HPD performance outside tightly controlled laboratory settings. There are a variety of commercial fit-testing systems currently available for this purpose. Namely, there are two general categories of devices. First category of devices comprises Field-Microphone in Real Ear (F-MIRE) systems, which, during presentation of a broadband noise, measure occluded and un-occluded responses at the level of the eardrum. Second are field-based systems fashioned on the gold standard laboratory Real Ear Attenuation at Threshold (REAT) test procedure.[17] The REAT test procedure measures occluded and un-occluded audiometric thresholds for narrowband noises. Both F-MIRE and REAT-based systems output a Personal Attenuation Rating (PAR) that represents the amount of overall attenuation in dB provided by the HPD for an individual. The PAR is calculated from the differences between occluded and un-occluded measurements. A third system type utilizes a loudness-balancing task. Output from this system type, however, has not been as closely correlated with the other two system types and/or the gold standard method.[18] There are pros and cons to each system and system type. Regardless, the intent of all of these systems is to provide an individual assessment of the performance of an HPD on a given user in the field.

Before any improvements to any existing accession point training protocol can be considered or established, current practices for both the training protocol and device option(s) available must be objectively evaluated via fit-testing. The viability of fit-testing on a large scale such as would be required at a military accession point was previously unexplored. This study aimed to investigate the viability of such testing by examining PARs measured during four HPD fit-testing protocols (i.e., 1-, 3-, 5-, and 7-frequencies). In addition, for individuals whose SELF-fit PARs showed inadequate protection from noise hazards experienced during basic training, a potential method to improve outcomes was evaluated. We have named this method “ear canal muscle memory.” The ear canal muscle memory method is not instructional in nature, per se, but simply
the perceptual result for the wearer when an expert correctly fits an HPD. The ear canal muscle memory method is considered successful when the wearer’s ability to replicate the expert’s fit results in a PAR similar to the expert fit PAR. The use of this method was based on the assumption that most recruits who failed to achieve a passing PAR did so because they had inserted the HPD incorrectly or inadequately. The supposition was that training recruits potentially were unaware how the HPD should feel when inserted correctly because the HPD had not previously been inserted correctly. It was hypothesized that once they experienced how their HPDs should feel when inserted correctly (i.e., ear canal muscle memory), proper insertion could be replicated. Differences in PARs were compared between the three fit methods (i.e., SELF-Fit, EXP-Fit, and SUB Re-Fit). PAR pass/fail rates were also compared between methods and protocols.

Since fit-testing an individual’s HPD has costs associated with time and resources (e.g., equipment, personnel, etc.), test duration, expected to be a factor of interest to policy makers, was evaluated. Specifically, to help inform policy-makers’ decisions, we evaluated the tradeoff between improved test accuracy and the amount of time required to complete a test. The use of a greater number of test frequencies is expected to result in improved accuracy when calculating how much protection is provided by an HPD. However, increasing the number of frequencies also increases the amount of time resulting in higher costs to complete a test.

MATERIALS AND METHODS

Overview

On the basis of the increased risks associated with noise hazards experienced in military occupational settings and the availability of test systems to measure in-ear HPD performance outside the laboratory, data were collected during a site visit to USMC MCRD, Parris Island. During the site visit, the viability of fit-testing HPDs on a large scale and the outcomes of test protocols were examined. The current HPD fit-test pass/fail rate of training recruits was measured and a follow-up procedure for those who failed the initial test was completed. Test durations related to the four test protocols were also captured. From these results, an estimation of the quality of the current training and education program was completed.

Research participants

Regarding the viability of HPD fit-testing, 320 training recruits participated in data collection. All participants had their ear canals examined prior to participation. Any participant with excessive earwax was referred for earwax removal prior to testing. Since the majority of recruits have hearing within normal limits upon enlistment, no audiometric testing was completed to confirm this since such testing had recently occurred as part of the intake process to the MCRD. The participant group was 87.5% male and 12.5% female roughly reflecting the current Marine Corps male–female ratio of training recruits.

Procedure(s)

All training recruits received standard HCP HPD-use training two weeks prior to our data collection during which participants completed fit-testing. The metric for fit-testing during this site visit was PAR, which indicates how much protection a specific individual is getting from a specific HPD and is measured using a fit-testing system. PARs were acquired for each training recruit who participated. Four initial (SELF-Fit) test protocols were evaluated (1-, 3-, 5-, and 7-freq) using a test group of 80 participants for each protocol. Participants were randomly assigned to protocols. All recruits tested used the same HPD (Moldex CamoPlug), which is a one-size-fits-all earplug that has an NRR of 33 and was dispensed by the Marine Corps. Un-occluded and occluded conditions were counterbalanced (i.e., ½ were tested un-occluded first, ½ occluded first). The results from the majority of recruits who failed to achieve a passing PAR (i.e., 178 of 320 = 55.6%) were examined to assess potential causes of the failures. Fit-test duration was also measured to examine the tradeoff between results accuracy and time required to complete each protocol. All fit-testing systems were calibrated before testing began and after all testing was completed using a sound level meter and ear simulator (Brueel & Kjaer 2270 and 4153, respectively) calibrated with a piston phone (Brueel & Kjaer [Type 4220]).

Initial fit-testing

Fit-testing is a process by which attenuation of an individual’s chosen or assigned in-ear HPD can be measured. Fit-testing was conducted in this study using a commercially available software-based system called FitCheck Solo manufactured by Kevin Michael & Associates and based on HPD Well-Fit developed by NIOSH personnel. The test system used during data collection and outlined herein utilizes a Method of Limits psychophysical test method. For each test frequency, participants heard a narrow-band noise and, using the scroll wheel of a computer mouse, lowered the output level of the stimulus until it was barely audible. That output level was then recorded by the test system. Each test frequency was presented to a participant starting at an audible level. Subsequent trials (a minimum of two) occurred at a random level above the previous trial’s selected “barely audible” level. Responses had to be within a 10 dB range otherwise additional trials were presented. Thresholds acquired were dependent on the test procedure (see Test time duration and accuracy below). Each of the four test procedures was tested on a different day, on four groups of recruits, and was completed both occluded and un-occluded.

For the initial fit-testing sessions, recruits were instructed on the fit-testing procedure via written instructions. A small percentage of recruits required simple verbal clarifications to the instructions to successfully complete the task. If a training recruit passed the first fit-test (i.e., achieved an amount of hearing protection adequate to attenuate sound to the required military standard safe exposure level), she/he was excused and presumed to be sufficiently trained and
getting adequate protection from the issued HPD for the training evolutions encountered during basic training. If a training recruit failed to pass, a follow-up session was conducted to investigate further the potential causes for failure.

**PAR calculation**

Similar to the method used to calculate a NRR, PARs for this study were calculated using an A-weighted reduction procedure (alternatively named the octave band method or Method 1\(^{[199]}\)). Specifically, the A-weighted octave band attenuation values (i.e., occluded minus un-occluded thresholds) were subtracted from the A-weighted octave bands from an assumed flat noise spectrum of 100 dB SPL. Unlike the A-weighted reduction procedure used to calculate a NRR, no standard deviation information was included in the calculation since the attenuation values were directly acquired via fit-testing and are not estimated from the NRR. In addition, the PAR is an A-weighted numerical value, and not a C-weighted value like the NRR. For PARs calculated using less than the maximum seven test frequencies, the A-weighted reduction procedure used A-weighted noise and attenuation values only from the frequencies tested.

**Follow-up fit-testing**

Most participants who were unable to achieve a minimally acceptable PAR were referred for additional follow-up testing. It was unknown how many training recruits would pass, and because there were four testers completing initial testing and only two experimenters available for follow-up testing, a nominal criterion level of 15 dB was initially used as a referral trigger for the 1-freq testing. For the 7-freq testing, the pass/fail criterion level for referral was increased to 20 dB. **Note:** The overall pass/fail rate observed was based solely on the total number of recruits who achieved a PAR deemed adequate to protect them from hazardous noise encountered during basic training, and is not the same as the referral rate (i.e., the number of recruits who received follow-up testing).

As previously described, all recruits received training on how to use their standard issue HPDs approximately two weeks prior to data collection, and had been to the firing range for one training evolution. A second firing range training evolution was to occur the week following the HPD fitting completed for this study.

The follow-up sessions included a minimum of one follow-up test, but as many as several follow-up tests dependent on the reason(s) for failure to pass (e.g., improper insertion, inappropriate product, etc.). Time constraints during 1-freq and 7-freq protocol sessions only allowed for experimenter fit (EXP-Fit) follow-up testing for most recruits, which was intended to ascertain whether the issued HPD was improperly fit, or if it was simply inappropriate for the individual. For 3-freq and 5-freq protocol sessions, all participants who failed to achieve a passing PAR completed the EXP-Fit follow-up procedure. For most who received follow-up testing for 3-freq and 5-freq protocol sessions, additional follow-up testing included the use of the ear-canal muscle memory method devised by the experimenters. Specifically, the “ear canal muscle memory” is a brief means by which to provide a perception to the user of how a correctly fitted in-ear HPD should “feel” in the ear canal and also to perceive effective ambient sound attenuation. First, the HPD user fits him or herself with an in-ear HPD, and is fit-tested using an in-ear HPD fit-test system. If the user does not pass the fit-test, she/he is correctly re-fitted with the HPD by an expert, and the fit is verified using the fit-test system. If the fit is successful, the HPDs are removed and the user is asked to replicate the expert’s fit, and is subsequently fit-tested again to verify the result (SUB Re-Fit).

**Test time duration and accuracy**

Four initial (SELF-Fit) test protocols were evaluated (1-, 3-, 5-, and 7-freq) using a test group of 80 participants for each procedure. The 1-freq protocol tested at 500 Hz. The 3-freq protocol tested 500, 1000, and 2000 Hz. The 5-freq protocol tested 250, 500, 1000, 2000, and 4000 Hz. The 7-freq protocol tested 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. On the basis of the physics of sound, obstructing objects whether in or out of the ear canal obstruct based on size relation to the wavelength. Therefore, higher frequencies (shorter wavelengths) are likely to be attenuated more than lower frequencies (longer wavelengths) due to the greater proportion of any obstruction to the obstructed wavelength.\(^{[20]}\) The 1-freq procedure (i.e., 500 Hz) was selected due to its quick duration and the conclusion that if low frequency sound is effectively attenuated then it is likely high frequencies are also attenuated. The 3-freq protocol was based on previous testing (NIOSH) that showed good agreement with 7-freq testing. The 5-freq was included as a recommended protocol by the test system manufacturer, and the 7-freq protocol was chosen as representative of a complete and most accurate test available on the system and by which the other procedures could be compared.

**Data analyses**

SELF-Fit PARs were acquired for all subjects (\(N = 320\)). EXP-Fit and SUB Re-Fit PARs were also collected for those who participated in follow-up testing (\(n = 79\) and \(n = 36\), respectively). For all data analyses, a PAR pass/fail criterion level was set at \(\geq 25\) dB (as opposed to the study referral criterion levels of 15 and 20 dB). This level was chosen and deemed reasonable due to (a) the impulse sound level emitted by the M4 and M16 rifles used during basic training (e.g., around 165 dB) in some conditions, and (b) the need to attain sufficient attenuation by the issued HPDs to acceptable exposure levels as outlined in the current Military Standard 1474D, which requires peak impulse levels to be below 140 dB.\(^{[21]}\)
Statistical analyses were conducted using commercially available software (IBM SPSS Statistics, Version 23). Comparisons of PAR pass rate percentages for SELF-Fit, EXP-Fit, and SUB Re-Fit included available data collected during all four test protocols. The strength of associations between SELF-Fit and test duration, as well as among all three PAR methods, were examined using Pearson correlations. Mean SELF-Fit test durations were compared between protocols using one-way analysis of variance (ANOVA), and mean differences in PARs were compared among the various fit methods and protocols applying ANOVA designs. Unless indicated otherwise, when applicable, post hoc analyses were conducted using Bonferroni tests. Test durations (minutes) and PARs (dB) are reported as mean and SD. All significance levels were set at $P < 0.05$.

**RESULTS**

**Personal Attenuation Ratings**

Figure 1 shows the number of recruits included in the data analyses, and the PAR means (SD) for each of the four protocol groups by fit method. Eighty participants were SELF-Fit tested in each protocol group (Total $N = 320$) across four initial-fit testers and two follow-up testers. Each of the four groups experienced a different fit-testing test protocol, which varied by the number of frequencies tested. A one-way ANOVA showed that, when the training recruits fit their own HPDs with no instruction or additional training (i.e., SELF-Fit), their mean PARs differed significantly between protocols ($F_{3,316} = 7.00$, $P < 0.001$, $\eta^2_p = 0.06$). Post-hoc analyses using the Games–Howell test revealed that the 1-freq SELF-Fit mean was significantly lower than the SELF-Fit means of all other protocols ($P < 0.03$), but that the others were not different from one another. The multi-frequency protocols resulted in mean PARs of 5.6 dB or more (and standard deviations at least 3.6 dB smaller). Thus, a single frequency of 500 Hz had both lower attenuation and more varied results compared to the other test protocols, showing more stable pass rates and reduced variability.

Including all recruits ($n = 79$) who had both an initial SELF-Fit and EXP-Fit test, a mixed-design ANOVA with method (SELF-Fit, EXP-Fit) as the within-subjects factor and protocol (1-freq, 3-freq, 5-freq, 7-freq) as the between-subjects factor was done to determine if SELF-Fit and EXP-Fit PARs differed significantly, and if so, if differences were found between all protocols. Results showed a main effect for PAR method, ($F_{1,75} = 418.30$, $P < 0.001$, $\eta^2_p = 0.85$), where the mean recruit improvement from SELF-Fit to EXP-Fit was 25.68 dB (10.99). An interaction effect for method by protocol was also found, ($F_{3,75} = 5.27$, $P = 0.002$, $\eta^2_p = 0.17$). After adjusting for multiple comparisons, there was no difference in mean EXP-Fit PAR between protocols ($P = 0.99$). However, for the SELF-Fit method, the 1-freq protocol had significantly lower PARs than both the 5-freq and 3-freq protocols ($P < 0.001$).

Immediately following the EXP-Fit, most 3-freq and 5-freq follow-up participants were instructed to replicate for a third fit-test the “feel” of the HPDs in the ears as previously fit by the experimenter. SUB Re-Fit represents such results when participants repeated the fit of their own HPDs following experimenter fit. SUB Re-Fit was completed to determine whether a training recruit could duplicate experimenter results on his or her own without assistance of any type.

With the primary interest of determining if a recruit could duplicate EXP-Fit independently (i.e., if there was a difference between the EXP-Fit and the subsequent SUB Re-fit), and also if there was a method by protocol interaction when taking into account all three PAR methods, a mixed ANOVA was completed. Because too few recruits had PARs measured during the SUB Re-Fit method ($n = 33$) in the 1- and 7-freq protocols, this analysis only included the 3-freq and 5-freq protocols. Method (i.e., SELF-Fit, EXP-Fit, SUB Re-Fit) was the within-subjects factor and protocol (3-freq, 5-freq) was the between-subjects factor. Results showed a main effect for method, ($F_{2,62} = 92.01$, $P < 0.001$, $\eta^2_p = 0.75$), but no interaction effect, ($F_{2,62} = 0.79$, $P = 0.46$, $\eta^2_p = 0.03$). Post hoc tests showed EXP-Fit and SUB Re-Fit both had significantly better attenuation than SELF-Fit ($P < 0.001$), but no difference was found between EXP-Fit and SUB Re-Fit ($P = 0.59$), suggesting that once the recruits experienced how HPDs should feel when inserted correctly, they were able to properly replicate the procedure with results similar to the expert fit.
No significant associations were found between any PAR methods, (SELF-Fit vs. EXP-Fit; \( r = 0.10, P = 0.41, n = 79 \)), (SELF-Fit vs. SUB Re-Fit; \( r = -0.09, P = 0.60, n = 36 \)), and (EXP-Fit vs. SUB Re-Fit; \( r = 0.22, P = 0.20, n = 36 \)). This suggests that initial self-fit attenuation ratings were independent of the subsequent attenuation ratings.

When recruits SELF-Fit during the one frequency (500 Hz) protocol, 35% achieved a PAR of 25 dB or better compared to the multi-frequency test protocols which resulted in 63, 65, and 60% pass rates for 3-, 5-, and 7-freq, respectively [Figure 2]. Despite receiving prior training on HPD fit, use, and care, these findings illustrate that 35–40% of training recruits failed to achieve the criterion amount of hearing protection when they initially self-fit their HPDs prior to being fit-tested. This suggests training recruits are at the risk of NIHL during basic training and beyond due to inadequate hearing protection.

Figure 3 shows the SELF-Fit, EXP-Fit, and SUB Re-Fit PARs for the 79 training recruits who received follow-up testing. Although not all training recruits who failed to achieve a PAR of 25 dB completed follow-up testing, the data acquired from those referred for follow-up testing clearly demonstrate that a large number of recruits received a little to no protection. Only one of 79 recruits’ PAR results was poorer after being fitted by an experimenter. Specifically, 36 of the 79 received both follow-up tests (i.e., the EXP-Fit and the SUB Re-Fit). The remaining 43 received only EXP-Fit. The primary causes of getting a failing PAR were due to improper insertion of the HPD in the ear canal and/or being issued an improper sized device. Follow-up results showed that, once the device was inserted correctly, training recruits could replicate the results. Of those followed up, 15% failed due to incorrect HPD size (i.e., 12 recruits = 3.75% of total 320 tested), suggesting it is critical to make a range of HPDs prior to being fit-tested. This suggests training recruits are at the risk of NIHL during basic training and beyond due to inadequate hearing protection.

No significant associations were found between any PAR methods, (SELF-Fit vs. EXP-Fit; \( r = 0.10, P = 0.41, n = 79 \)), (SELF-Fit vs. SUB Re-Fit; \( r = -0.09, P = 0.60, n = 36 \)), and (EXP-Fit vs. SUB Re-Fit; \( r = 0.22, P = 0.20, n = 36 \)). This suggests that initial self-fit attenuation ratings were independent of the subsequent attenuation ratings.

The time measured was representative of total test time and not just the amount of time to acquire the PAR. That is, duration was measured from the moment the recruit entered the sound booth and sat down to the moment she/he got up to leave. Not limiting the measured time to only the fit-test provided a result more representative of what might be expected in real-world conditions. A one-way ANOVA on SELF-Fit duration times (minutes) showed mean test durations differed between protocols \((F_{3,316} = 93.50, P < 0.001, \eta^2_p = 0.47)\). Post-hoc analysis showed the mean test duration of each protocol differed from all other protocols \((P < 0.01)\) and test duration increased steadily with number of test frequencies [Figure 4]. However, as previously discussed, increasing to more than three test frequencies did not yield significant improvements in PARs. Therefore, there seems to be little evidence to support spending additional time testing additional frequencies. Additionally, there was no significant association between time and SELF-Fit par \((r = 0.08, P = 0.15)\), indicating those who took longer to take the test did not perform better.
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DISCUSSION
Assessing viability of in-the-field fit-testing and HPD training effectiveness

Fit-testing was used in this study as a process by which to objectively measure an individual’s chosen or assigned HPD attenuation. Prior to the completion of this study, direct knowledge about the number of training recruits who were protected from hazardous noise encountered during basic training evolutions was unavailable. Without such knowledge, there was no means by which to make decisions about which training recruits needed follow-up instruction or a change in HPD unless or until a clinically relevant change in hearing status occurred, which would not likely occur until as long as a year following basic training. Results from this study showed the critical importance of initial selection and fitting of HPDs followed by verification (i.e., fit-testing) at Navy and Marine Corps accession points if the inadequacies of current practices are to be positively impacted. Achieving adequate protection from an HPD is fundamentally dependent on obtaining proper fit of the issued HPD as well as the quality of training recruits receive regarding HPD use. Failure to achieve adequate protection from issued HPDs was found to be due to improper insertion of the HPD in the ear canal, being issued an improper sized device, or both.

Training effectiveness

HPD training provided to USMC training recruits was assessed by fit-testing each participant’s individual standard-issue HPDs. Fit-testing occurred two weeks after HPD-use training. It was expected that, if the HPD-use training evolution was effective, the fit-testing failure rate would be low. Conversely, if the training was ineffective, the failure rate would be high. As described above, 320 recruits participated in the study and were given a pass/fail rating based on a passing PAR of 25dB. The passing PAR was determined by measuring the sound level of an M4/M16 rifle firing in a free-field encountered during basic training (∼165 dBP), and calculating how much noise reduction was needed to comply with Occupational Safety and Health Administration (OSHA) standards and DoD instructions.

Results showed that roughly 35% of all recruits who received current hearing conservation and HPD-use training failed to achieve adequate protection from noise hazards encountered during basic training. This outcome can be mitigated with fit-testing. Fit-testing results during follow-up procedures used in this study also revealed that, when training recruits who initially failed to get required results had their HPDs fit by the experimenter, they were able to replicate the fit and get satisfactory protection from their HPDs. This finding strongly suggests that fit-testing is a viable means by which to mitigate the current pass-fail rate, and be used as part of a training regimen for those who are found to be inadequately trained using current methods. The addition of fit-testing may potentially lead to long-term reductions in incidence and severity of NIHL in active duty personnel, future retired veterans, and civilian workers who are exposed to hazardous noise. However, it is currently unknown whether the approach taken for this study has a lasting impact on HPD fit and use. This work is applicable to all branches of the military. In addition, the work is relevant to civilian industries with personnel at risk for occupational NIHL. Fit-testing will be clinically viable enterprise-wide particularly if the current technology can be either integrated with existing multi-person testing audiometric equipment, or through design of a new multi-person fit-testing system.

HPD availability and fit

All recruits tested used the same HPD (Moldex CamoPlug) in a universal-fit size, which has an NRR of 33 dB. Despite known variability in ear canal size and morphology across individuals and across the lifespan, the Marine Corps MCRD currently dispenses one make, model, universal-sized earplug. Results from the current study revealed that ~4% of the participants were unable to properly fit the dispensed HPD. For those with small or large ear canals, the dispensed earplug simply would not fit properly and thus failed to provide adequate protection. Anecdotal reports from these participants revealed that they had experienced signs and symptoms of temporary threshold shifts following the first firing range evolution the week before data were collected (e.g., “my ears were screaming at me by the end of the week,” “my hearing seems muffled after the firing range evolution,” etc.). For all those who completed follow-up testing, and for whom the issued HPD was appropriate, virtually all were able to get the required amount of protection when fit by the experimenter. For those who needed a different product or size because the issued HPD was not appropriate, 100% were able to achieve the necessary amount of protection once provided an alternative HPD. It should be noted that the fit of the dispensed earplug might have adversely affected additional personnel in that the attenuation achieved and/or
the comfort experienced while using the dispensed HPD may have been compromised due to incorrect sizing, but not to the point of resulting in a failed fit-test. One solution to this challenge is for (a) recruit training commands to have a variety of HPD sizes available in proper proportions, and (b) verification of fit and function to be completed via fit-testing.

**Development of a fit-testing protocol**

Four different protocols were included in this study (i.e., 1-, 3-, 5-, and 7-freq protocols) to assess the relationship between test time duration and reliability of results. That is, although test accuracy is thought to improve as number of frequencies tested increases, test time also increases. However, greater than three frequencies resulted in longer test times without significantly improving test accuracy. As such, results suggest that fit-testing using a 3-freq protocol of 500, 1000, and 2000 Hz is sufficient for accurately estimating PAR. Limiting to three test frequencies significantly reduces test time without compromising results. In addition, the 3-freq test protocol has been shown to be in agreement with the gold standard REAT method. On the basis of the current results, there is little rationale to support additional test frequencies beyond the three including in the 3-freq protocol used for this study.

The challenges associated with follow-up for those who failed to get adequate protection from their HPDs were also partially addressed by this study. Specifically, in planning for the possible future implementation of an HPD fit-testing program enterprise-wide, consideration was given to what a future follow-up protocol might be for individuals who fail a fit-test. At this time, however, a comparison to current training practices with the alternative ear canal muscle memory utilized in this study has not yet been completed. Specifically, it is unknown whether the effects observed during this study are lasting and to what degree. Another consideration is test equipment configuration. The current study utilized a commercially available system that requires on-on-one interaction with each subject. The optimal test system configuration for large-scale fit-testing would be a multi-person fit-testing system integrated with currently deployed multi-person audiometric testing equipment.

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**Administrative information**

This work was conducted under Work Unit #F1016 entitled, “Regional Hearing Conservation Program.” The views expressed in this report are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the United States Government. This work was prepared by employees of the U.S. Government as part of their official duties. Title 17 U.S.C. §105 provides that ‘Copyright protection under this title is not available for any work of the United States Government.’ This research has been conducted in compliance with all applicable Federal Regulations governing the Protection of Human Subjects in Research Institutional Review Board Protocol and was determined not to be human subject research.

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**Conflicts of interest**

Dr. Jeremy Federman is a military service member (or employee of the U.S. Government). This work was prepared as part of Dr. Jeremy Federman official duties. Title 17 U.S.C. §105 provides that ‘Copyright protection under this title is not available for any work of the United States Government.’ Title 17 U.S.C. §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person’s official duties.

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