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Performance Assessment of Hearing Protection and Communication Enhancement Devices: Peltor Comtac III and IV

Hilary L. Gallagher
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson AFB, OH

Melissa A. Theis
Oak Ridge Institute for Science and Education
Oak Ridge, TN

Billy J. Swayne
Ball Aerospace and Technologies Corp.
Dayton, OH

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Interim Report

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711 HUMAN PERFORMANCE WING
HUMAN EFFECTIVENESS DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
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//signed//
Hilary L. Gallagher
Work Unit Manager
Battlespace Acoustics Branch

//signed//
Robert C. McKinley
Chief, Battlespace Acoustics Branch
Warfighter Interface Division

//signed//
William E. Russell, Chief
Warfighter Interface Division
Human Effectiveness Directorate
711 Human Performance Wing

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6. AUTHOR(S)
Hilary L. Gallagher
Melissa A. Theis *
Billy J. Swayne**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
2610 Seventh St
Bldg 441
WPAFB, OH 45433

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Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson AFB OH 45433

*Oak Ridge Institute for Science and Education
Oak Ridge, TN 37831
**Ball Aerospace and Technologies
Dayton, OH

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14. ABSTRACT
Hearing Protection and communication enhancement devices were designed for those who want to maintain natural hearing while protecting their ears from impulse and continuous noises like gunfire, explosions, vehicles, and machinery. There were potential advantages for this technology in military applications, provided an accurate and complete assessment of the performance was conducted. Peltor Comtac III (modified and standard) and Comtac IV headsets were assessed for: continuous noise attenuation, impulsive peak insertion loss, auditory localization, and speech intelligibility. The Peltor Comtac headsets reduced the noise level in the ear when the user was exposed to continuous and/or impulsive noise. The devices also reduced critical aural cues required to localize sounds essential to maintaining situational awareness. The active headsets may amplify low level sounds, but the localization performance was degraded in comparison to the open ear performance. The results from the speech intelligibility measurements for the Peltor Comtac headsets were acceptable in low to moderate noise environments, however, at 105 dB, the average scores did not meet current military standards.

15. SUBJECT TERMS Active hearing protection, electronic hearing protection, noise attenuation, localization, blast, impulse, speech intelligibility

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EXECUTIVE SUMMARY

Understanding the noise attenuation performance of a hearing protection and communication device has been important in order to protect the user from excessive noise exposure. Active electronic hearing protection devices have been designed to allow for enhanced communication and situational awareness, while at the same time protecting the auditory system from both impulsive and continuous noise. The objective of this study was to assess the Peltor Comtac III (modified and standard) and Peltor Comtac IV headsets for: continuous noise attenuation, impulsive peak insertion loss, auditory localization, and speech intelligibility. The Peltor Comtac headsets reduced the noise level in the ear when the user was exposed to continuous and/or impulsive noise. The devices also reduced critical aural cues required to localize sounds essential to maintaining situational awareness. The active headsets may amplify low level sounds, but the localization performance was degraded in comparison to the open ear performance. The results from the speech intelligibility measurements for the Peltor Comtac headsets were acceptable in low to moderate noise environments, however at 105 dB, the average scores did not meet current military standards. The data collected in this assessment should be used to determine how and when such devices could be integrated successfully into a mission.

1.0 INTRODUCTION

Military personnel have been working in unpredictable noise environments, which require a more flexible type of hearing protection in order to complete a normal duty day without the risk of permanent hearing loss. It was necessary to obtain accurate and complete measures of the total performance capabilities of hearing protection and communication devices and their effect on the user to ensure that military personnel could maintain mission effectiveness while preventing noise induced hearing loss. A multifactorial assessment approach was used to adequately determine if currently available tactical hearing protectors meet the needs of these personnel, including the following measurements: continuous noise attenuation, impulsive peak insertion loss, auditory localization, and speech intelligibility.

Continuous noise attenuation measurements characterized how much protection a hearing protection device (HPD) provided in an environment where the ambient noise levels were fairly stable (for example, riding in a HMMWV or a helicopter, or working in a machine shop). These measurements were conducted in accordance with American National Standards Institute (ANSI) standard S12.6-2008[1] Method A.

Impulsive peak insertion loss measurements demonstrated how much a hearing protection device provided against impulsive noises (for example, gun shots or explosions), and were measured in accordance with ANSI S12.42-2010.[2] Understanding the noise attenuation of a hearing protector (both continuous and impulsive) was important in order to estimate the user's noise dose. Noise dose was calculated using the estimated level of

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noise under the hearing protector (using methods described in ANSI S12.68[3]) and the duration of time spent in that noise environment. Speech intelligibility measurements were conducted in accordance with ANSI S3.2-2009[4] and were critical to understanding the communication performance for users wearing a hearing protection and communication device in multiple noise environments.

It has been found that wearing a hearing protection and communication device can degrade the user's ability to localize low-level sounds, which is essential to situation awareness. Understanding these potential degradations would promote a more informed decision for those in charge of selecting hearing protection for the warfighter. A balance between providing adequate hearing protection for the expected noise environment and maintaining a level of situation awareness appropriate for the mission is necessary. Measurements were made to demonstrate the impact of hearing protection devices on auditory localization and on the amount of time required to locate a visual target that was generating noise.

2.0 BACKGROUND

Military ground operations have been taking place in complex environments which necessitate creating balance between operational effectiveness and personnel safety. The goal of effectively protecting the hearing of personnel has been complicated by the need for warfighters to maintain access to acoustic cues in the ambient environment (Figure 1). Firing even a small number of rounds from a weapon has been known to cause temporary hearing loss, which therefore can produce the undesired result of impairing the ability to monitor the environment. Repeated unprotected exposures to small arms fire may generate these temporary changes and could eventually result in permanent hearing loss. Noise exposures from larger weapons and blasts could instantly cause permanent hearing loss if no protection is worn.

Figure 1. Special Operations Forces using Communication Devices in an Operational Environment

The objective of this study was to evaluate the Peltor Comtac III (modified and standard) and Peltor Comtac IV headsets for: continuous noise attenuation, impulsive peak insertion loss, auditory localization, and speech intelligibility. These devices were

developed to improve situation awareness by providing a hear-thru, or active capability while mitigating hearing loss and tinnitus caused by exposure to loud, steady-state and impulse noise. Active devices should theoretically provide improved performance in the areas of communications and auditory localization versus passive hearing protection devices, while continuing to provide adequate attenuation for continuous and impulsive noise.
The requirements associated with the military's use of tactical hearing protection and communication devices fueled the development of new performance metrics and measurement methods in order to best determine the impact of these devices on the mission[5]. These systems have been actively providing some level of ambient listening capability in an attempt to restore the ability of an operator to localize sounds[6,7]. Several metrics and measurement methods were employed to quantify the effects of these devices on operator performance. The first was a measure of localization error. This metric quantified the amount of errors >45 degrees between the target location and the listener's response. A second metric was the number of front-back reversals of the target location that an individual demonstrated during the task. The third metric was a measure of reaction time, time to find a visual target, when sound was collocated with the visual target. The listener had to use the auditory localization information to locate the target and subsequently identify the target in this task. The reaction time was a salient measure of the quality of the localization cue[8-12].

AFRL conducted a series of measures to describe the performance of hearing protection and communication devices. The measures included passive continuous noise attenuation, impulsive noise insertion loss, input/output gain function, localization error with short duration (250 ms) and long duration (>1 sec) stimuli, reaction time from an aurally guided visual search task with distracters, and speech intelligibility.

3.0 METHODS AND RESULTS

The assessment of the Peltor Comtac III (modified and standard) and IV hearing protection headsets included: continuous noise attenuation, impulsive peak insertion loss, auditory localization, and speech intelligibility. These devices were developed to improve situation awareness by providing a hear-thru, or active capability while mitigating hearing loss and tinnitus caused by exposure to loud, steady-state and impulse noise. The general approach was to use ANSI standard measurement procedures for continuous noise attenuation, impulsive peak insertion loss, and speech intelligibility performance and to use AFRL defined procedures for localization. Performance results of these devices should be used to determine which protectors would be made available to the warfighters and the results may also lead to improved design criteria for the next generation of hearing protection and communication devices.

The overall methods and results are described in the following sections. The first section describes the hearing protectors that were used in the study. The second section describes how the device settings were configured for the evaluation. The subsequent

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sections describe each measurement method including a description of the subjects, the facilities, and the details of the specific measurement methods and results.

3.1 Communication Devices

Three hearing protection and communication enhancement devices were selected for the measurement: a modified Peltor Comtac III (model number 14-0098), a standard Peltor Comtac III (referred to as just Comtac III), and Peltor Comtac IV (Figure 2). The modified Comtac III was a closed circumaural headset with gel ear cushions. The Comtac III was a closed circumaural headset with foam ear cushions. The Comtac IV forgoes the traditional circumaural configuration in favor of a hybrid system that employed an ear plug style earpiece and a gel cushioned U-shaped frame in place of standard ear cups. Skull Screws earplugs by 3M Peltor were selected for the measurements with the Comtac IV. All three headsets were equipped with an ambidextrous noise-canceling boom microphone and had the capability to send and receive external communications via a connecting wire and TP-120 NEXUS plug that enabled the user to connect to a compatible portable radio or intercom system. The modified Comtac III had a cable from each earcup with a NEXUS connector on each lead to enable communications across multiple radios/communication channels. All three headsets also featured a level-dependent stereo, ambient "hear thru" setting that functioned independently of the radio. The headbands of each device were adjustable to accommodate a range of head sizes.

The headsets were designed to be worn alone or in combination with an Advanced Combat Helmet (ACH). The Ops-Core Fast ACH was selected for the measurements. Both Comtac IIIs had the option to mount directly to the helmet's Accessory Rail Connector (ARC) via a mounting mechanism by 3M. This ARC configuration was designed to address the challenges in donning and doffing the helmet in addition to reducing "hot spots" created by the head band rubbing under the helmet. No ARC system was developed for the Comtac IV.

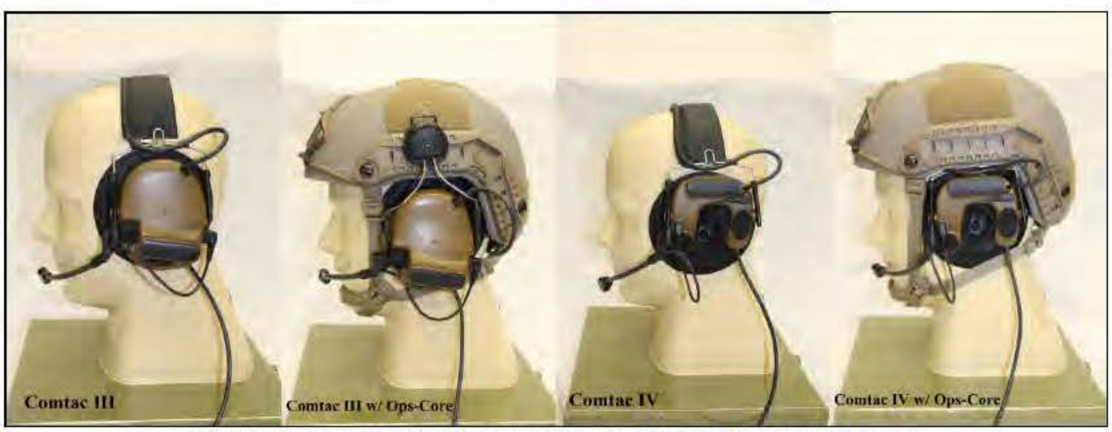

Figure 2. Comtac Headsets with and without Ops-Core Helmet

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3.2 Device Gain Setting

Both Comtac IIIs and the Comtac IV were equipped with a hear-thru setting designed to amplify soft sounds and conversational speech while allowing loud sounds to pass though without amplification. To normalize the hear-thru setting, a unity gain measurement was collected in the Audio Localization Facility (ALF) at Wright Patterson Air Force Base (WPAFB). The unity gain of the device referred to the volume setting at which the input/output gain curve of the device best matched the input/output gain curve of the Knowles Electronic Manikin for Acoustic Research (KEMAR). Matching the gain structure created a baseline volume setting and provided the most accurate comparison of how devices performed in relation to other devices.

KEMAR was equipped with two G.R.A.S Type 26-AC preamps and 40AO prepolarized pressure microphones positioned inside the head with the microphone diaphragms aligned to each ear canal. KEMAR's gain structure was obtained by measuring specific locations of sounds in ALF with the manikin's ears unoccluded. The unity gain for each Peltor Comtac headset was determined by activating the hear-thru setting, equipping KEMAR with the device, and collecting the same series of sounds. Starting from either the maximum or minimum volume, the level of the device was adjusted until the gain structure of the device matched that of KEMAR, Figures 3, 4 and 5. The unity gain for the modified Comtac III was set at one increment below the maximum volume. The unity gain for the Comtac III was set at one increment above minimum volume. The Comtac IV was set at maximum volume.

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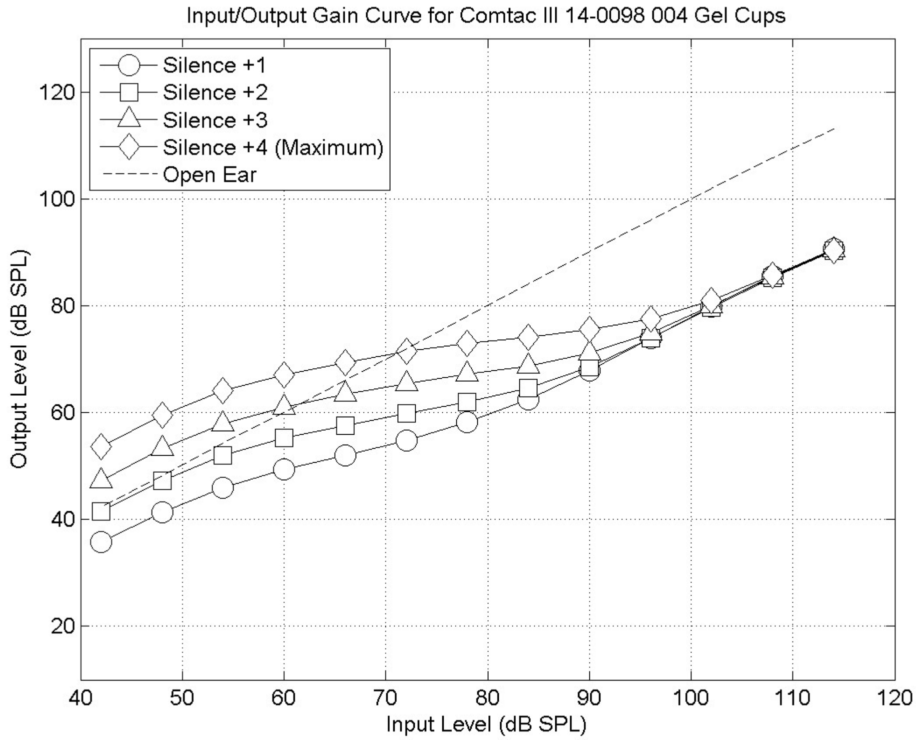

Figure 3. Input /Output gain curves for modified Comtac III in hear-thru mode as measured on a KEMAR Manikin

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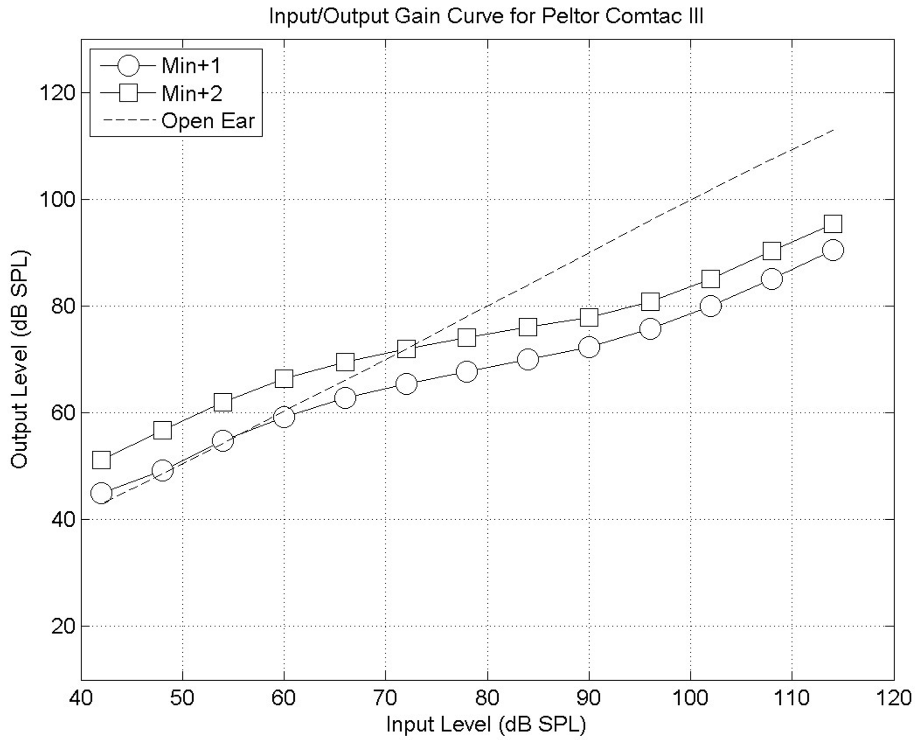

Figure 4. Input /Output gain curves for Comtac III in hear-thru mode as measured on a KEMAR Manikin

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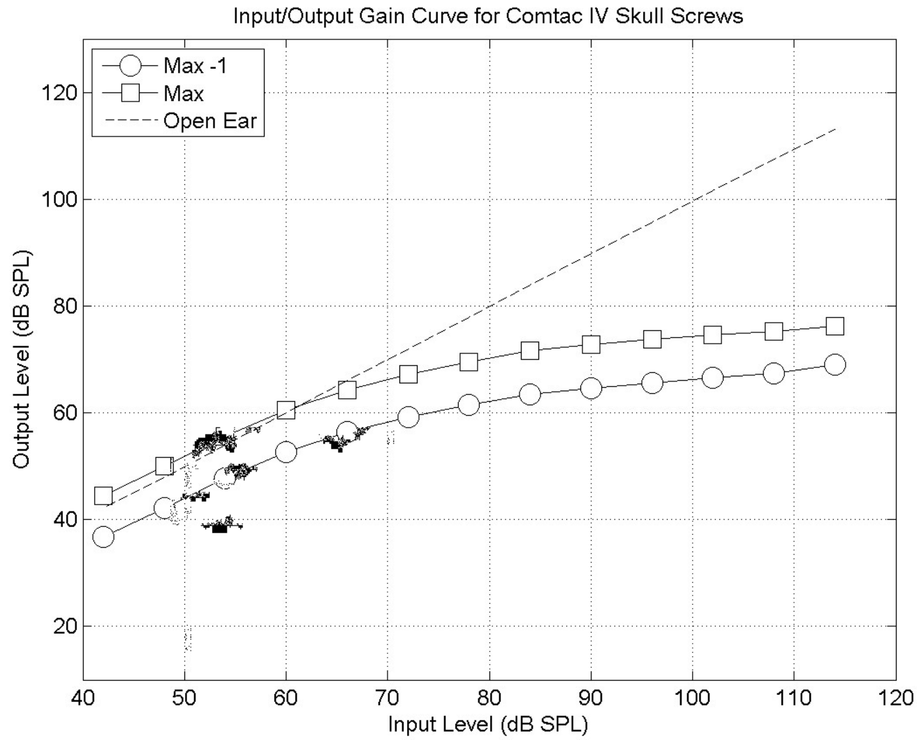

Figure 5. Input /Output gain curves for Comtac IV in hear-thru mode as measured on a KEMAR Manikin

3.3 Continuous Noise Attenuation

Attenuation data was collected for the Comtac III (modified and standard) and IV. Attenuation data was also collected with Oakley® SI Ballistic M Frame spectacles Versions 2.0 and 3.0 and the Oakley® SI Ballistic Goggles worn in combination with the headsets (Figure 6). These additional test configurations were added to assess the impact of wearing vision protection in combination with the hearing protectors.

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a. **b.** **c.**

Figure 6. Oakley eye wear a. Version 2.0 spectacles b. Version 3.0 spectacles c. Ballistic goggles

Continuous noise attenuation performance measurements were collected with the devices in the "passive" (electronics off) condition using human subjects. All human subjects were compensated volunteers. There were ten male and ten female subjects, ranging in age from 18 to 34 years. All subjects were required to have a computer administered screening audiogram via Hughson-Westlake method, with behavioral hearing thresholds inside the normal hearing range;25 dB hearing level (HL) or better from 125 Hz to 8000 Hz.

The facility used for this portion of the study was specifically built for the measurement of the sound attenuation properties of passive hearing protection devices. The chamber (Figure 6), its instrumentation, and measurement procedures were in accordance with the ANSI S12.6-2008[1]. This standard required measuring the occluded and unoccluded hearing threshold of human subjects using a von Békésy tracking procedure. The thresholds were measured two times for the unoccluded ear condition and two times for the occluded ear condition (with device in place). The real-ear attenuation at threshold for each subject was computed at each octave frequency, 125 to 8000 Hz, by averaging the two trials (the difference between unoccluded and occluded ear hearing thresholds).

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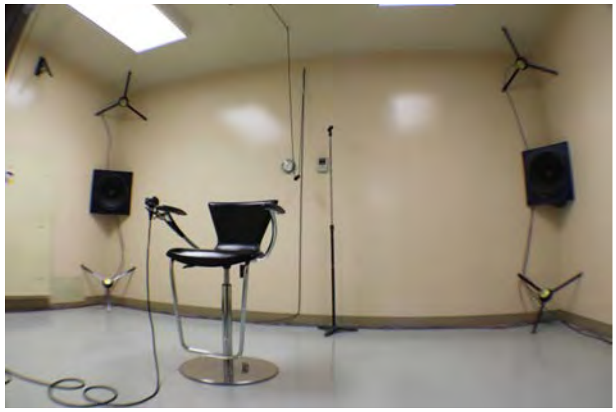

Figure 7. Facility used for measurement of continuous noise attenuation

Passive noise attenuation data were analyzed using the methods described in ANSI S12.68.[2] This ANSI standard detailed the methods for estimating the effective A-weighted SPL when hearing protectors were worn. The octave band method was the "gold standard" method for estimating a users' noise exposure. This method required both the noise spectra per octave band and the attenuation data per octave band. Mean and standard deviation (SD) noise attenuation data were calculated across subjects at each octave frequency band. A single Noise Reduction Rating (NRR) was also calculated for mean minus 1 and mean minus 2 standard deviations, Table 1. Figure 8 displays a graphical representation of the attenuation results at each measured frequency (mean minus 2 SD).

Table 1. Passive mean and standard deviation noise attenuation for all configurations, electronics off and the calculated NRR (mean minus 1 and 2 standard deviations (SD))

		Frequency (Hz)							NRR	
Device		**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	Mean – 1SD	Mean – 2SD
Comtac III (Modified 14-0098)	Mean	14	18	24	33	31	30	37		
	SD	3	3	3	3	3	3	3	23	20
Comtac III	Mean	13	18	24	28	31	36	38		
	SD	5	4	5	4	4	4	3	21	16
Comtac III with Oakley v2.0	Mean	7	12	19	25	26	32	30		
	SD	4	5	4	4	5	5	8	16	11
Comtac III with Oakley v3.0	Mean	8	15	22	28	27	34	35		
	SD	4	5	5	5	7	4	6	17	12
Comtac III with Oakley Goggles	Mean	5	10	15	25	23	28	33		
	SD	3	4	3	3	5	7	5	14	10
Comtac IV with Skull Screws	Mean	28	28	30	34	32	40	43		
	SD	7	8	9	7	5	6	8	25	17

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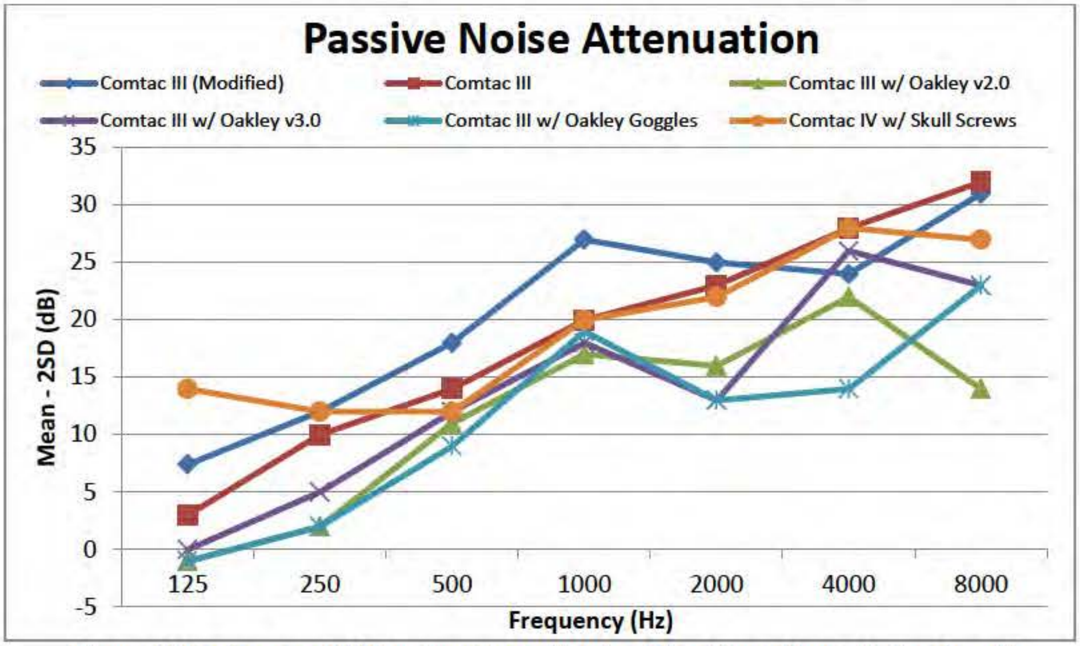

Figure 8. Passive mean-2SD noise attenuation for all configurations, electronics off

It was not always possible to calculate the effective A-weighted level under the hearing protector using the octave band method due to the lack of detailed noise data for all noise environments. Two other methods were described in ANSI S12.68: Noise Level Reduction Statistics, Graphical (NRS_G) and Noise Level Reduction Statistics for use with A-Weighting (NRS_A). NRS_G and NRS_A were calculated for all configurations and displayed in the tables and figures below.

The NRS_G rating required knowledge of both the C- and A-weighted noise levels, and used this additional information about the noise spectrum to more precisely estimate the range of protection provided. For example, if the C-weighted noise was measured at 100 dB and the A-weighted noise was measured at 94 dB then the difference between the two weighting levels would be 6. Therefore, the range of protection provided by the hearing protector could be found in Tables 2-7 and Figures 8-13 where B = 6. NRS_A was appropriate for unpredictable noise environments that may vary widely as was the case with many military operations. However, if one was considering a noise environment that was relatively constant (e.g., dominated by low frequencies such as an aircraft or other vehicles), then NRS_G should have been used to calculate more accurate attenuation performance values.

Table 2. NRS_G results for Comtac III (Modified), electronics off

NRS_G table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	32.4	28.8	24.8	19.5
Performance	x = 80%	28.8	24.8	20.2	14.0

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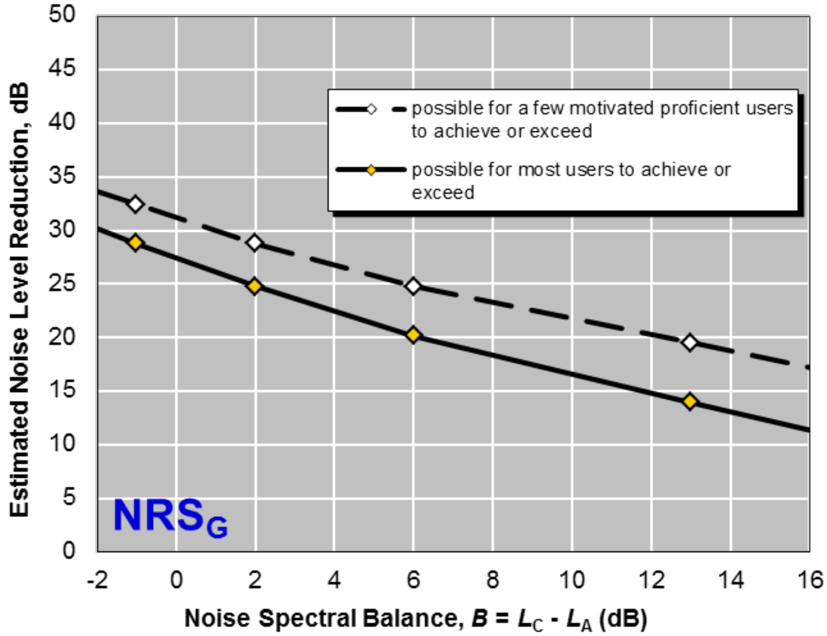

Figure 9. NRS_G results for Comtac III (Modified), electronics off

Table 3. NRS_G results for Comtac III, electronics off

NRS_G table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	34.0	29.0	25.1	19.5
Performance	x = 80%	27.9	22.1	17.5	11.1

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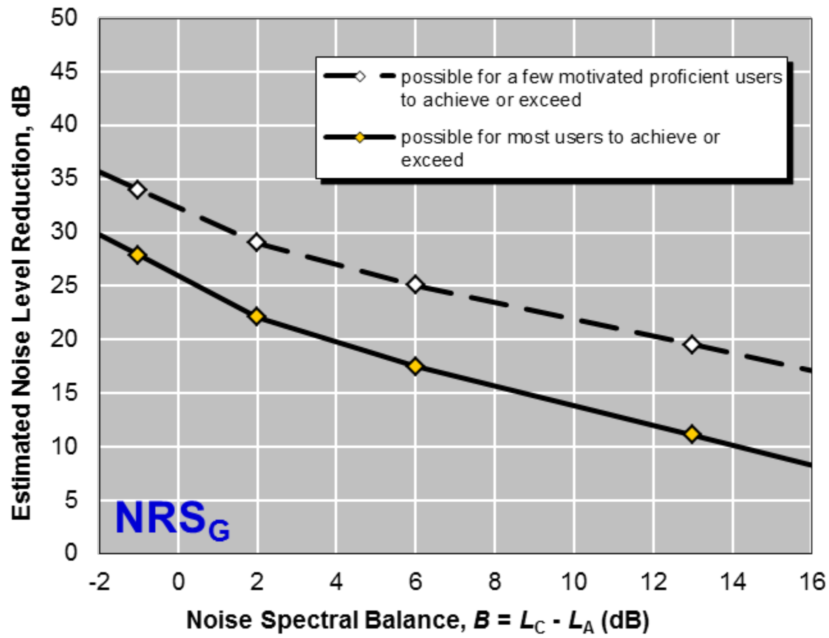

Figure 10. NRS_G results for Comtac III, electronics off

Table 4. NRS_G results for Comtac III with Oakley 2.0, electronics off

NRS_G table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	29.8	23.8	19.3	13.4
Performance	x = 80%	22.1	16.8	11.9	6.1

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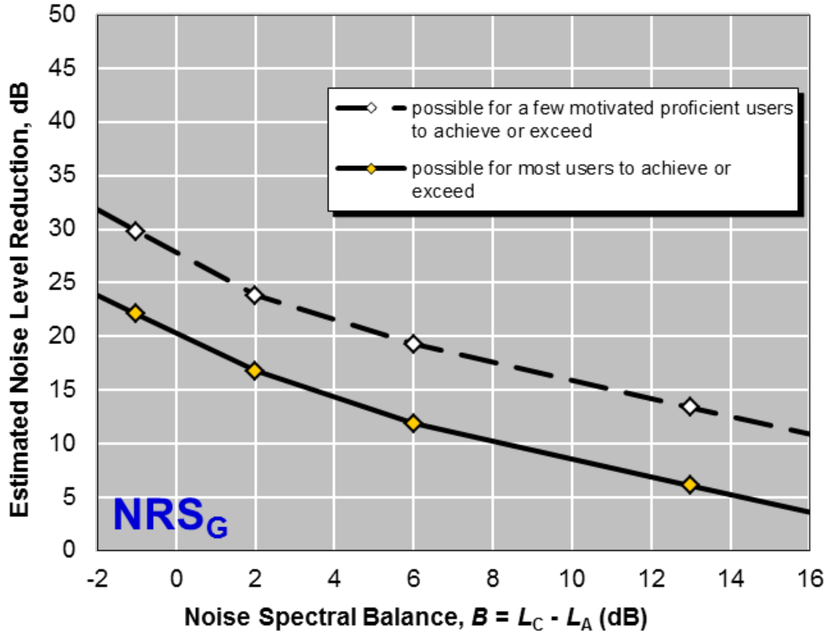

Figure 11. NRS_G results for Comtac III with Oakley 2.0, electronics off

Table 5. NRS_G results for Comtac III with Oakley 3.0, electronics off

NRS_G table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	32.4	26.3	21.5	14.7
Performance	x = 80%	22.9	18.6	14.1	7.4

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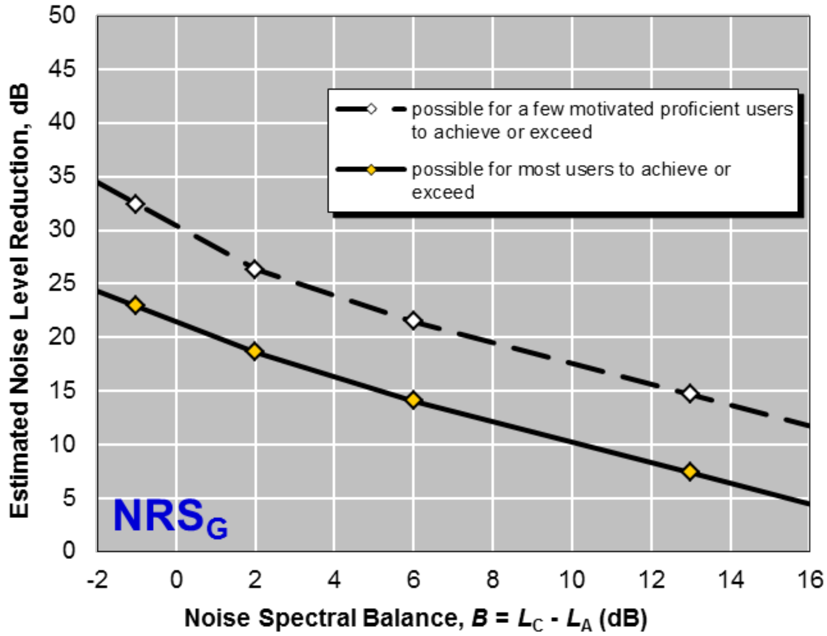

Figure 12. NRS$_G$ results for Comtac III with Oakley 3.0, electronics off

Table 6. NRS$_G$ results for Comtac III with Goggles, electronics off

NRS$_G$ table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	27.3	21.2	16.6	10.6
Performance	x = 80%	20.3	15.6	11.0	5.0

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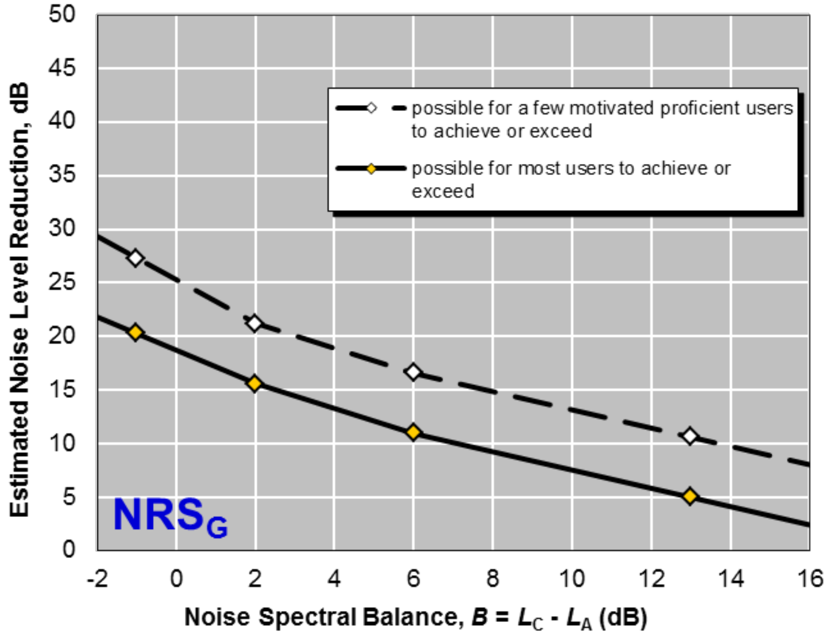

Figure 13. NRS_G results for Comtac III with Goggles, electronics off

Table 7. NRS_G results for Comtac IV with Skull Screws, electronics off

NRS_G table	$B = L_C - L_A$	-1	2	6	13
Protection	x = 20%	39.1	37.2	36.0	34.3
Performance	x = 80%	29.6	26.0	23.9	22.3

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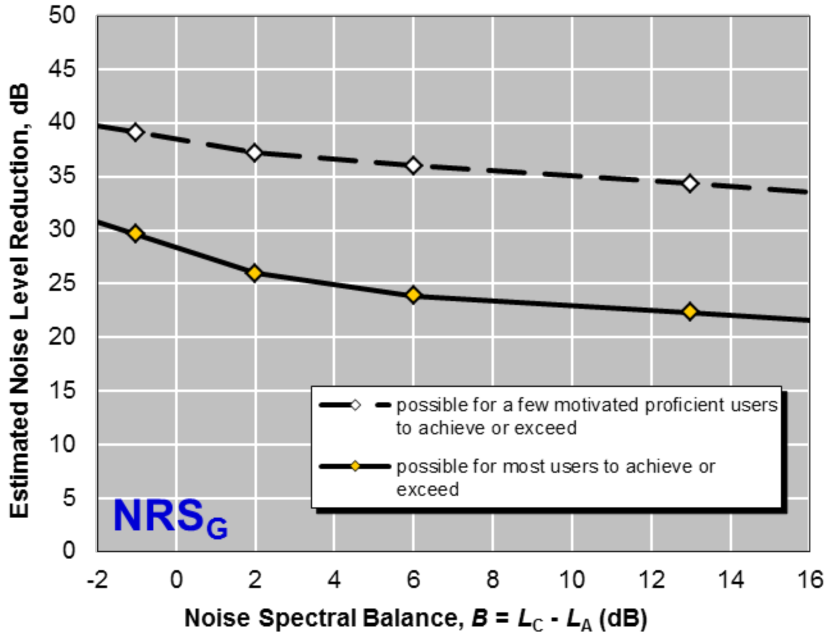

Figure 14. NRS_G results for Comtac IV with Skull Screws, electronics off

NRS_A was the simplest method and could be used by subtracting the value from the measured A−weighted noise level to estimate the level of sound at the ear under the hearing protector. This method offered several advantages over the well-known NRR. The NRR was developed to be subtracted from the C-weighted noise exposure, with a 7-dB adjustment that must be applied prior to subtracting it from A-weighted exposure values. C-weighted exposure values were often not known, and therefore the rating for subtraction from A-weighted exposures with the NRS_A eliminated these problems with the NRR. Another advantage of the NRS_A was that it calculated two levels of protection to indicate the range of performance that was achieved (Figures 14-20); this range reflected both the variation across the subjects in the test panel providing insight into how hard/easy the device may have been to fit, as well as variation in noise level reduction with the noise spectrum in which the device was used.[14] The majority of users (80%) could achieve the performance specified by the lower value in the range, with only the most motivated proficient users (20%) able to achieve the higher value. A narrow range indicated the hearing protection device provided a more stable and predictable level of protection. When the methods described in ANSI S12.68 (octave band method, NRS_A, and NRS_G) cannot be used, the use of the NRR (mean-2SD) was acceptable with the use of appropriate deratings.

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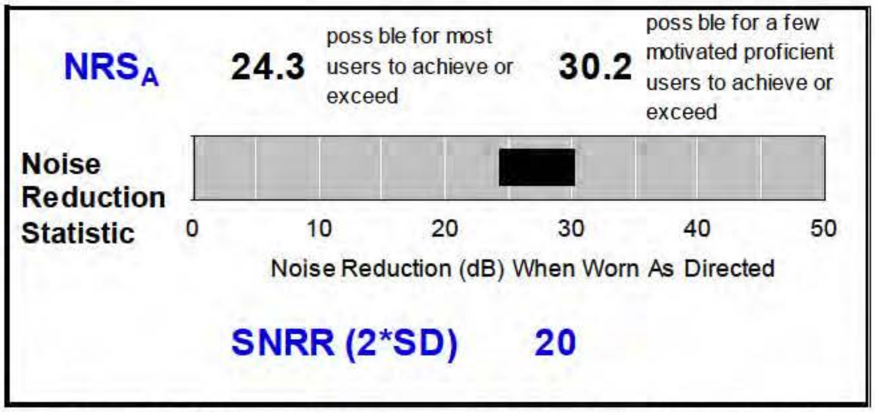

Figure 15. NRS_A results for Comtac III (Modified), electronics off

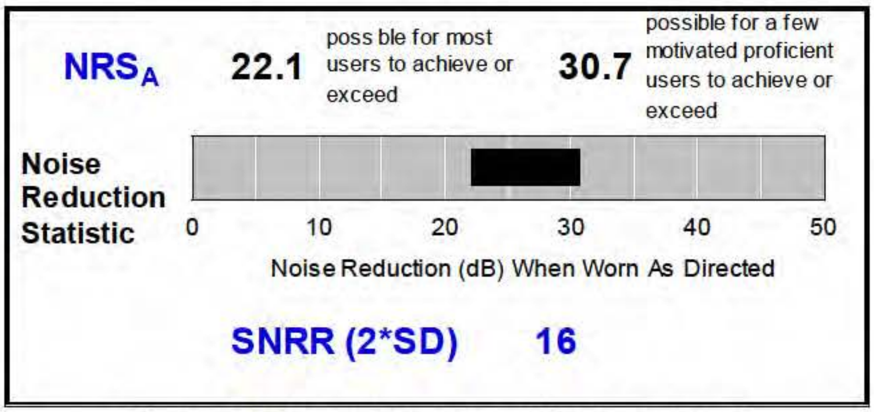

Figure 16. NRS_A results for Comtac III, electronics off

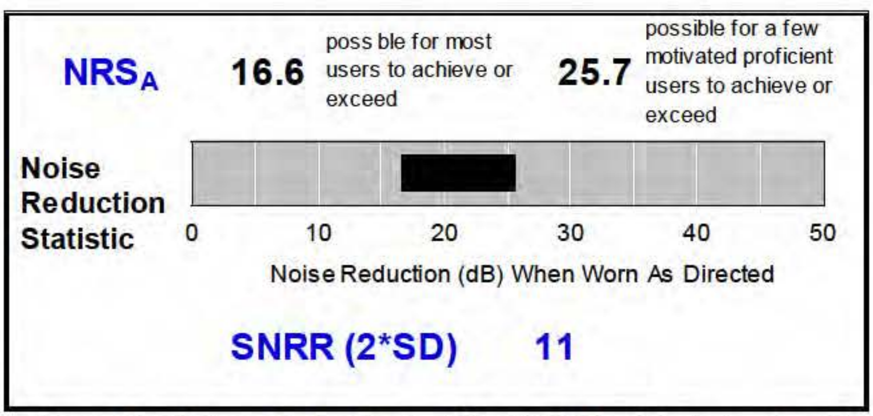

Figure 17. NRS_A results for Comtac III with Oakley 2.0, electronics off

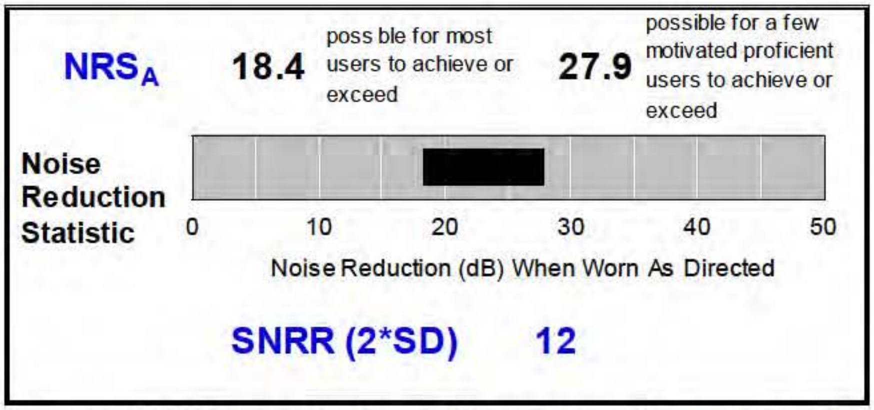

Figure 18. NRS$_A$ results for Comtac III with Oakley 3.0, electronics off

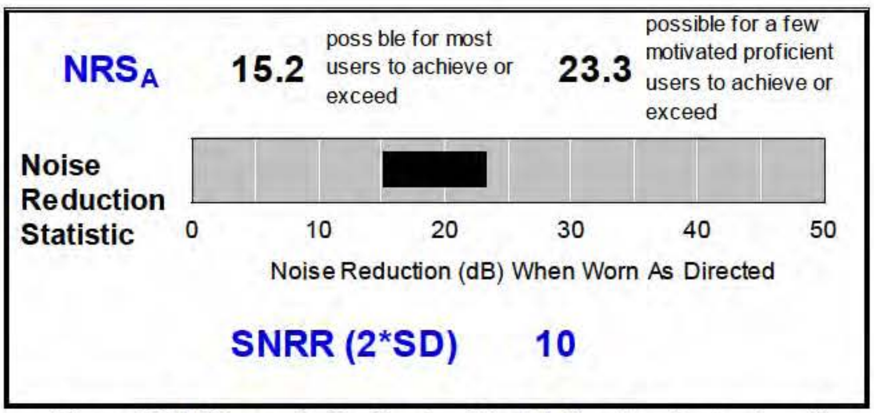

Figure 19. NRS$_A$ results for Comtac III with Goggles, electronics off

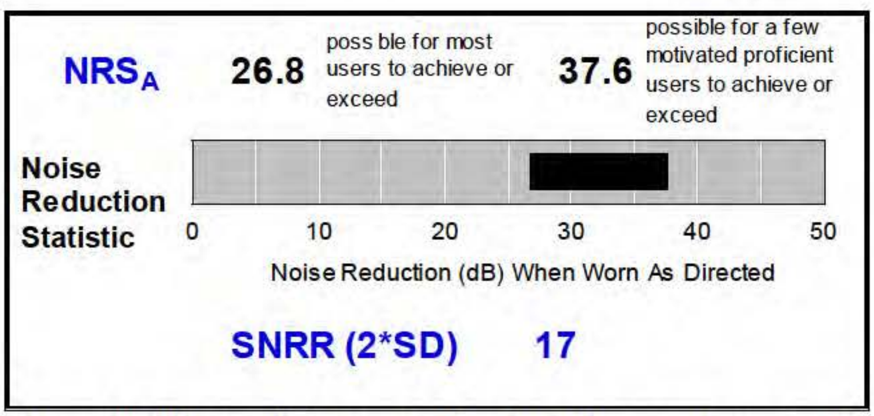

Figure 20. NRS$_A$ results for Comtac IV with Skull Screws, electronics off

3.4 Impulse Noise Attenuation

Impulsive noise attenuation performance measurements of the Comtac III and IV in various configurations when exposed to acoustic blast (impulse noise) with high peak

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pressure levels were conducted. (The modified Comtac III was not included in this measurement.) Impulsive peak insertion loss (IPIL) data was calculated at multiple peak noise levels ranging from 170 dB to 195 dB sound pressure level (SPL). Devices were measured in the passive (electronics off) mode.

IPIL (i.e., reduction in peak pressure of the impulse noise) measurements were conducted to determine the effect an acoustic blast may have on the auditory system of the user. Four acoustic test fixtures (ATFs) were used simultaneously in these measurements to allow for the evaluation of different hearing protectors at one time. The ATFs were ISL-1 type heads equipped with ¼" microphones in the ear canals. Each ATF was fit with a hearing protector and was exposed to acoustic blasts. IPIL data was calculated at 170, 185, and 195 dB SPL peak levels. The measurements were collected in accordance with ANSI S12.42-2010[2] Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise using Microphone-In-Real-Ear or Acoustic Test Fixture Procedures. ANSI S12.42 required a measurement at 130 dB SPL and 150 dB SPL; however, measurements were conducted at 185 and 195 dB SPL, which was more typical of a blast that a user may be exposed to in a military setting.

The measurements were conducted on the test range of the French-German Research Institute of St. Louis (ISL) situated in Baldersheim, France. The test area being used for the measurements was equipped in a way to allow the detonation of an equivalent of 300g of C4™ explosive. Using this mass of explosive it was possible to initiate a shockwave with a peak pressure level of up to 195 dB SPL and an A-duration of about 1.5 ms. An A-duration of an impulse signal was the time interval between impulse onset and the first crossing with the baseline.

A ¼" microphone or slender probe (tapered pencil gauge) was used to measure the free-field pressure wave according to the International Test Operations Procedures (ITOP) 4-2-822, Electronic Measurement of Airblast Overpressure and Impulse Noise.[14] Figure 21 shows the placement of the ATFs during the blast measurements. For each blast, the sound pressure level at 9 transducers was recorded. This included 8 signals from the ATFs, each equipped with two microphones and pre-amplifiers (one for each "ear drum") and 1 signal from the free-field pressure transducer (slender probe). Daily microphone calibrations were completed with a B&K 4226 calibrator at 125 Hz with a level of 114 dB.

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Figure 21. Placement of ATFs and free-field pressure transducer

Pressure measurements were recorded using 16-bit digital recorders at a sampling rate of 100 kHz. In order to visualize the movements of the hearing protectors, high-speed video (minimum speed of 10,000 frames per second) was recorded of the ATFs right ear at 195 dB SPL for each headset configuration.

Initially, an unoccluded ear measurement (no hearing protector) was conducted to calculate the free-field to ear canal transfer function using a 150 dB SPL nominal peak noise level with an A-duration of 2 ms, Figure 22. The Transfer Function of the Open Ear (TFOE) was used to calculate the IPIL for each fit of the hearing protectors.

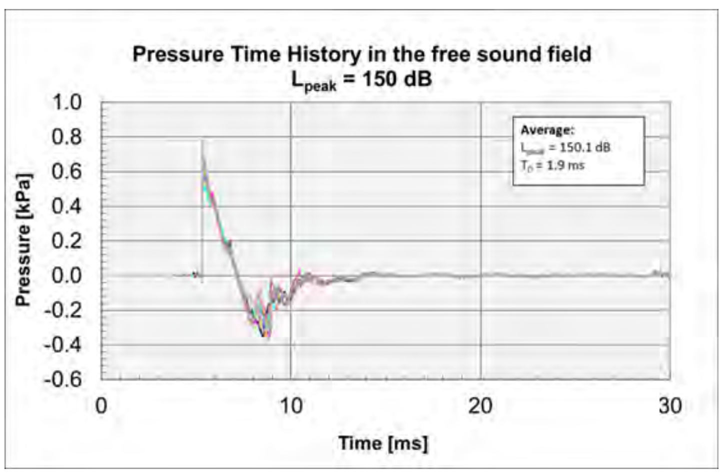

Figure 22. Pressure-time history of the impulses generated for the determination of the TFOE

For the calculation of the Insertion Loss (IL), the TFOE was calculated for all 1/3 octave-bands centered between 25 and 16 kHz. The TFOEs were used to calculate the IPIL; the complex transfer function with a resolution of 6.1 Hz has been calculated. Mean TFOE for left and right ears separately are graphed in Figure 23.

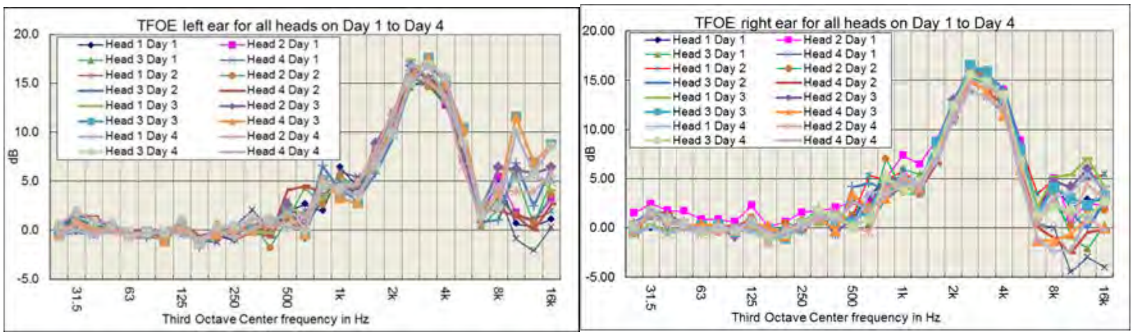

Figure 23. Mean TFOE for each head, each day, left and right ear

After the determination of the TFOE, the measurements were completed with the different hearing protectors in place. Each hearing protector was measured five times at each peak noise level; each time, the hearing protector was removed and refitted or replaced by a hearing protector of the same type.

The impulse (blast) waves were generated by explosives. Figure 24 shows a schematic of the set-up. The type and the mass of explosive as well as the distance between the explosive and the ATF determined the peak noise level and the A-duration of the generated signal, Table 8. Figure 25 shows an example of the pressure time history and sound spectrum for a 170 dB SPL noise level.

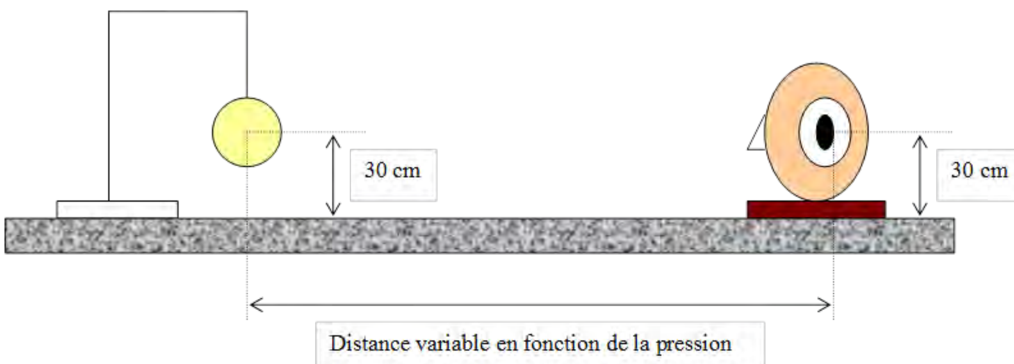

Figure 24. Schematic of the set-up of the explosive charge for the creation of a shock wave

Table 8. Type and mass of explosive and distance between ATF and explosive for different peak pressure levels and A-durations

Peak Noise Level (dB SPL)	Explosive Type	Mass (g)	Distance from ATF (m)	Measured Average A-Duration (ms)	Measured Average Peak Noise Level (dB SPL)
170	Primer (RDX 95/5)	35	6.5	2.3	170.8 (0.991 psi)
185	C4	130	3.4	2.2	184.6 (4.85 psi)
195	C4	300	2.2	1.7	195.9 (17.82 psi)

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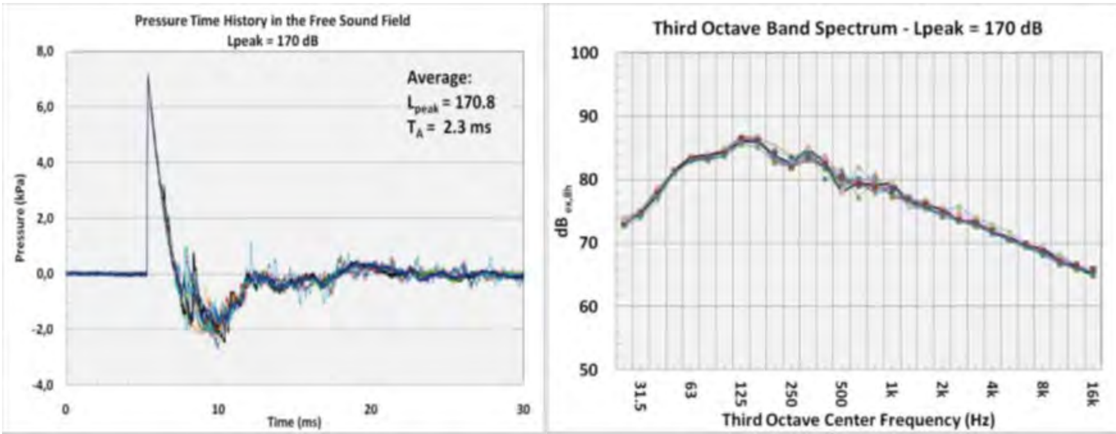

Figure 25. Pressure time history and 1/3 octave band spectrum for the 170 dB SPL noise level

The insertion loss for each ear and each peak pressure level were recorded. No significant differences were recorded when comparing the device powered on and off. Figure 26 displays an example graph of insertion loss for the five individual blast measurements for the Peltor Comtac III. Table 9 lists the average IPIL for each device powered off at 170, 185, and 195 dB. The data is displayed in Figure 27 for all configurations.

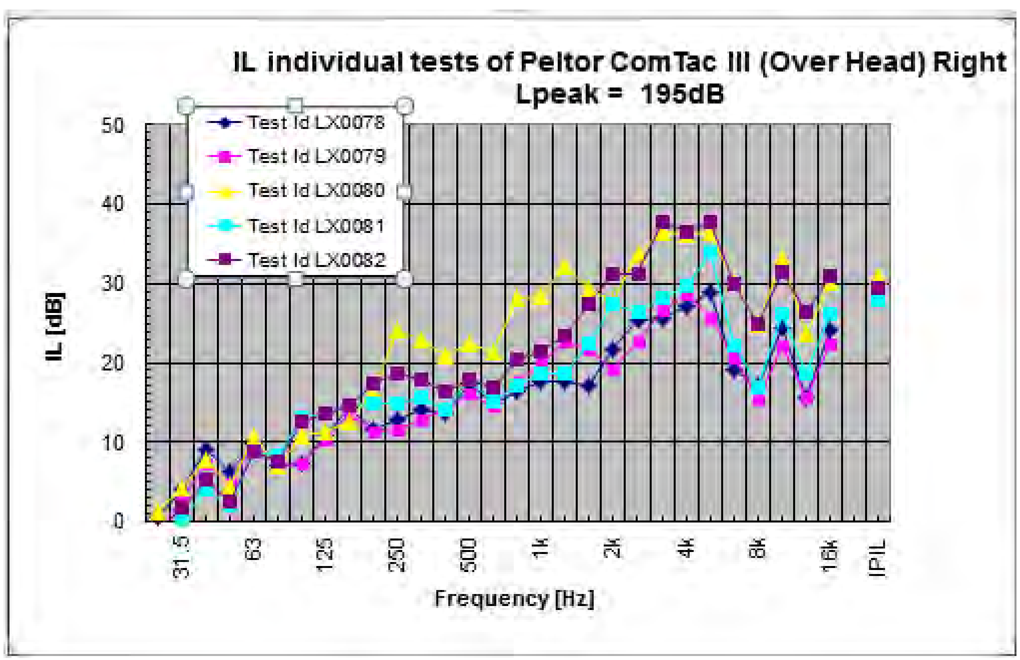

Figure 26. Example insertion loss data from Comtac III device, right ear of ATF

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Table 9. Average Impulse Peak Insertion Loss (IPIL) data from blast measurements

Hearing Protector	170 dB SPL	185 dB SPL	195 dB SPL
Comtac III	24	23.9	29.5
Comtac III with Ops-Core Helmet & ARC System	17.9	20.7	30.6
Comtac III with Oakley 3.0	20.1	22.3	29.2
Comtac IV with Skull Screws	48.1	47.3	52.1
Comtac IV with Skull Screws & Ops-Core	44.4	45.1	44.3

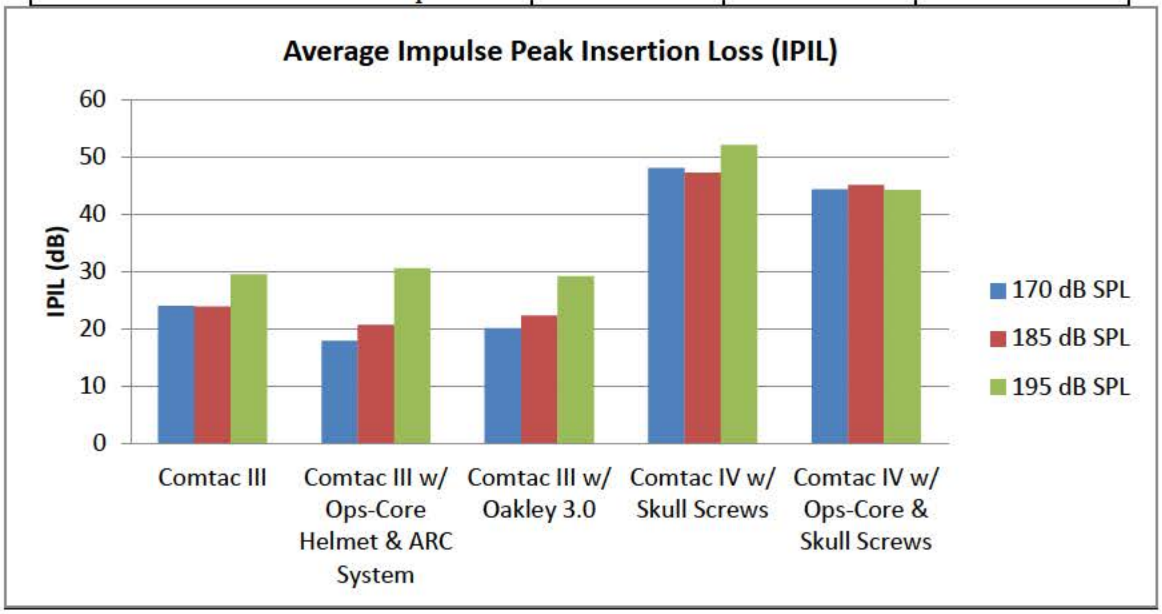

Figure 27. Average Impulse Peak Insertion Loss (IPIL) data from blast measurements

3.5 Auditory Localization

Localization response measurements were collected for 8 paid volunteer subjects; 4 male and 4 female subjects ranging from 18 to 32 years of age. All subjects had bilateral hearing threshold levels less than or equal to 15 dB from 125 to 8000 Hz.

All measurements were collected in ALF (Figure 28) at WPAFB. The aluminum-frame geodesic sphere was 14 feet in diameter with 4.5 inch loudspeakers equipped with four light-emitting diodes (LEDs) located at each of the 277 vertices on its inside surface. The ALF apparatus was housed within an anechoic chamber. The subject stood on a platform in the center of the sphere. The location of the platform had the potential to distort the signals from the speakers located directly below the subject, therefore only 237 loudspeakers, evenly distributed, above -45° elevation, were used in this study. The distance between speakers ranged roughly between 8° and 15°.

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Figure 28. Auditory Localization Facility (ALF) at WPAFB

Subjects registered their responses with an Intersense IS-900 tracking system (Figure 29). The IS-900 used inertial-ultrasonic hybrid tracking technology to provide precise position and orientation information. The tracking system includes a head tracker coupled with a response wand. The head tracker was mounted on the subjects' head to provide tracking data on the X, Y, and Z coordinate location of the head, as well as the yaw, pitch and roll during the duration of each trial. The head tracker also assisted the subject in aligning his/her head to the 0° azimuth, 0° elevation speaker location to begin each trial. The response wand was equipped with a joystick and five buttons which could be programmed for various purposes depending on the task. For this study, the subjects were required to press a single button while pointing the wand at their desired response location.

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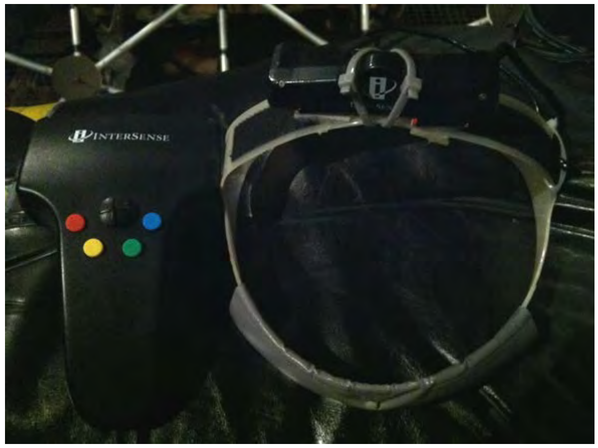

Figure 29. Intersense IS-900 tracking system

The stimuli were presented to the subjects in two different conditions. In one condition, the stimulus was a 250-ms burst of broadband (200 Hz - 16 kHz) pink noise. This duration was chosen in order to reduce the possibility that a subject would initiate a head movement during the stimulus presentation. Such a movement would provide dynamic localization cues, which would result in improved performance. In addition many real world sounds encountered by the user were likely to be short duration (e.g. weapons fire, explosions). In another condition, a broadband (200 Hz - 16 kHz) pink noise was presented continuously until a localization response was made. This allowed subjects to make use of dynamic localization cues and move their heads during stimulus presentation to orient to the sound.

The test configurations were the Ops-Core helmet only, Modified Comtac III, Comtac III, Comtac III with the Ops-Core, Comtac IV, Comtac IV with the Ops-Core, and a control configuration labeled as "Open," meaning the subject would run the task without a device (unoccluded ear). The experiment was coded and executed using the MATLAB programming language by Mathworks™. For each condition the subject fit him/herself with the appropriate device according to the directions provided by the manufacturer. The fit was verified by the experimenter, the hear-thru mode was activated, and the unity gain was set. The experimenter then directed the subject from the control room, where the fitting took place, into ALF. Once inside the sphere, the standing subject was raised or lowered by adjusting the height of the platform to ensure the subject's head was in the center of the sphere.

To start each trial the subject aligned his/her head to a loudspeaker located directly in front of them (0° azimuth, 0° elevation) and pressed a button on the response wand. A stimulus was presented randomly from one of the 237 speakers in the sphere. The stimulus was either a 250 ms burst of pink noise or a presentation of continuous pink noise. The subject would then locate and select the target speaker by pointing at it with the wand and clicking the response button to enter his/her selection. The LEDs on the speakers were tracked to the wand's movement so the subject could verify the location of

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his/her response. After a response was recorded, the LEDs of the target speaker were activated to give the subject feedback on his/her performance.

Each of the eight subjects completed 320 trials in the burst noise condition and 64 trials under the continuous noise condition for each device configuration and one control condition in which no device was worn. The ratio was weighted 5:1 for burst to continuous because the short bursts more accurately represented sounds a user would encounter in a real world environment. Both burst and continuous stimuli could be presented in a single block of trials. All stimuli were presented at 65dB.

Two metrics of particular interest were percentage of angular errors > 45˚, and percentage of front-back reversals. Both of these metrics were obtained from the same data set. Table 10 and Figure 30 show the percentage of mean angular errors that were > 45º with each device configuration for the burst and continuous noise conditions. Angular error was the difference between the actual target location and the subject's response location as measured by the distance between the two points along the surface of the sphere. The rationale behind including this measurement was its operational relevance. In general, we assume that if an operator's attention can be directed to within 45°, he/she would then be able to use other sensory information, especially vision, to acquire the target. Subject data was collected with an "open" ear configuration (unoccluded ear) in order to serve as a reference point for determining how wearing a hearing protection and communication device affects localization. Subjects had errors > 45° 1.4% of the time in the burst noise condition and 0.4% in the continuous noise condition when no device was worn. The data demonstrated that localization performance was degraded when both versions of the Comtac III and the Comtac IV were worn. However, the addition of the Ops-Core helmet had no negative effect on localization performance with or without a headset.

Table 10. Percentage of mean angular errors > 45˚ for burst and continuous noise conditions

Hearing Protector	Burst (%)	Continuous (%)
Open	1.4	0.4
Ops-Core Helmet	1.8	0.8
Comtac III (Modified)	27.6	8.6
Comtac III	39.7	11.8
Comtac III with Ops-Core	34	16.2
Comtac IV	34.4	7.9
Comtac IV with Ops-Core	27.5	7.8

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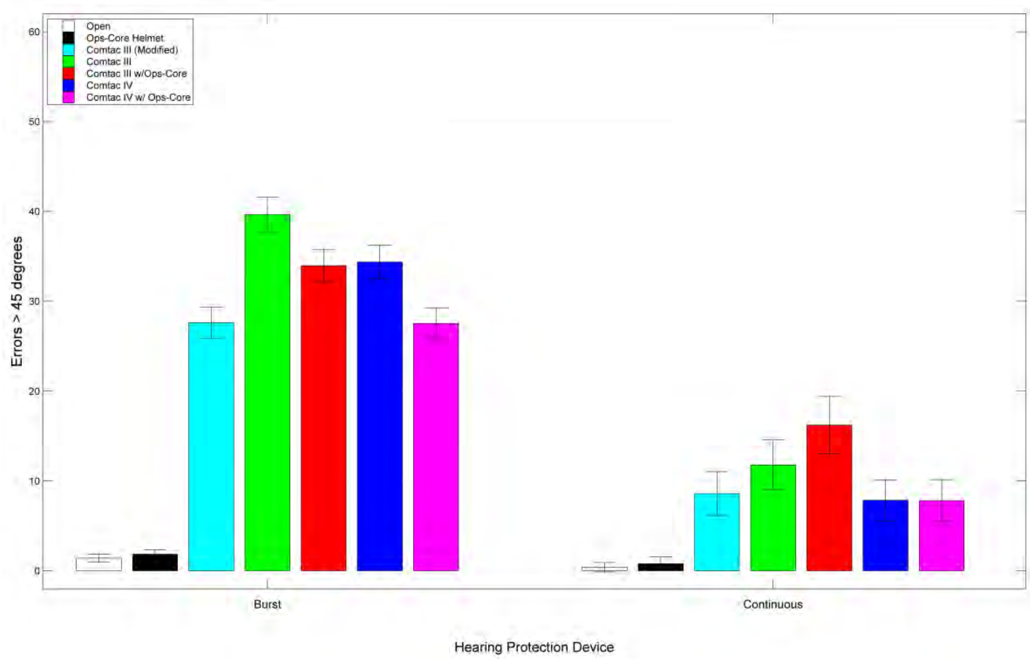

Figure 30. Percentage of mean angular errors > 45° for burst and continuous noise conditions

Front-back reversals occured when a subject was unable to determine whether a sound was in front of them or behind them. The percentage of front-back reversals is displayed in Table 11 and Figure 31. The front-back reversal percentages were compiled from the same measurement as the errors > 45°; these metrics were two different ways to interpret the same data set. In the open (unoccluded) ear configuration the subjects had front-back reversals 3.9% of the time in the burst noise condition and 1.0% in the continuous noise condition. The data demonstrated that localization performance was degraded when both versions of the Comtac III and the Comtac IV were worn. The percentage of front-back reversals for the continuous noise conditions more closely matched the open (unoccluded) ear data with a range of 0.6% to 5.2%.

Table 11. Percentage of front-back reversals for the burst and continuous noise conditions

Hearing Protector	Burst (%)	Continuous (%)
Open	3.9	1
Ops-Core Helmet	5.1	0.6
Comtac III (Modified)	18	2
Comtac III	28.6	1.5
Comtac III with Ops-Core	23	1.6
Comtac IV	30	5.2
Comtac IV with Ops-Core	24.9	1.2

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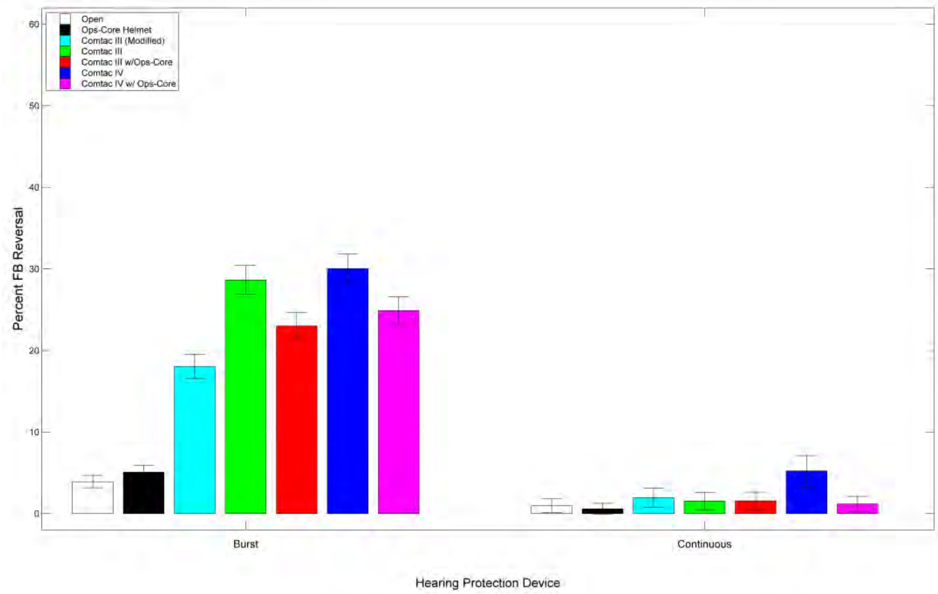

Figure 31. Percentage of front-back reversals for the burst and continuous noise conditions

3.6 Aurally Guided Visual Search

Data were collected in an aurally guided visual search task using the same eight subjects that participated in localization measurements. All measurements were collected in ALF at WPAFB. The facility design and setup, as well as the subject fitting procedure and setup procedure once inside facility, are described in detail in the localization section above.

At the center of each speaker in ALF was a cluster of four LEDs. Subjects were tasked to complete an aurally guided visual search task where they identified a visual target in the presence of 50 visual distracters at randomly selected positions around the sphere. For this task, the target stimulus was a cluster of LEDs in which either two or four LEDs were illuminated. The distracter stimuli were clusters of LEDs with either one or three illuminated LEDs. In addition, a 250 ms burst of broadband (200 Hz - 16 kHz) pink noise was played from the speaker at the target location at a predetermined sound level. The time required for the subject to find and identify the target was measured as a function of the noise-burst SPL with the communication device, with the "Open" configuration (unoccluded ear) as a reference.

To start each trial the subject aligned his/her head with a designated loudspeaker located directly in front of them (defined as 0° azimuth, 0° elevation) and pressed the trigger button on the underside of the response wand. At this point, 50 distracter stimuli were illuminated along with the one target stimulus. The subjects' task was to quickly locate the target stimulus and identify whether two or four LEDs were illuminated at the target location by pressing a response button on the top of the ALF response wand. If two

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LEDs were illuminated on the target speaker the subject would respond by pressing either the red or yellow button. If four LEDs were illuminated on the target speaker the subject would respond by pressing either the blue or green button (Figure 28). After the subject recorded his/her response, he/she would realign to the front speaker to begin the next trial.

The configurations were the modified Comtac III, Comtac III, Comtac IV, and a control condition labeled as "Open," meaning the subject would run the task without a hearing protector (unoccluded ear). Each of the eight subjects completed 180 trials per configuration, with 60 trials at three different sound levels. In addition, each subject completed 60 trails in an unoccluded visual only condition. This condition was added to create a worst case scenario situation where the subject was given no auditory cue and forced to visually search for the target. Levels were selected that spanned a range from quiet to easily audible (not to exceed 85 dB SPL at the eardrum).

Previous results from our lab have shown a large reduction in the time it took to acquire a visual target when a sound that was easily detectable and localizable was played from the target location, relative to a visual search with no aural guide. A reference point for the visual only search was added to Figure 31. The subjects averaged a response time of 12.2 seconds to find the target when no aural guide was provided. The average response times for the modified Comtac III, Comtac III, and Comtac IV are presented in Table 12 and Figure 32. Donning either version of the Comtac III or the Comtac IV resulted in increased search times across all conditions in comparison to the open (unoccluded) ear condition, with the difference in search times between the devices within one second. The subjects took at least at least 5 more seconds to find the target when wearing a device with the 15 dB SPL aural guide and at least 3 seconds more with the 40 and 70 dB SPL aural guide.

Table 12. Average response time (seconds)

	Target Level (dB SPL)		
Hearing Protector	**15**	**40**	**70**
Open	4	1.5	1.5
Comtac III (Modified)	9.7	4.7	4.6
Comtac III	9.4	4.1	4.1
Comtac IV	10.4	5.2	5.1

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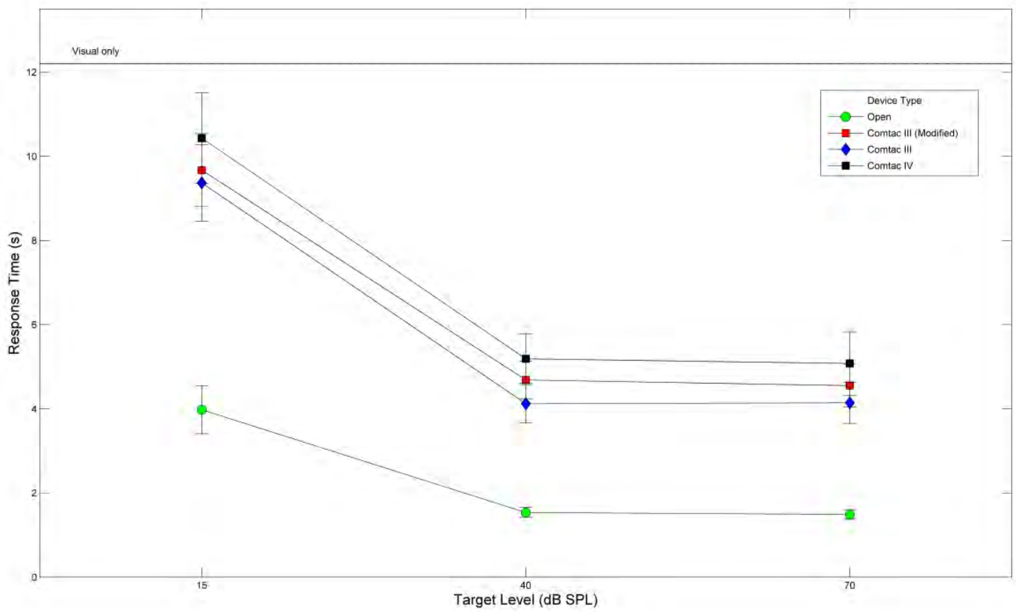

Figure 32. Average response time (seconds)

3.7 Speech Intelligibility

The AFRL VOice Communication Research and Evaluation System (VOCRES) facility was used to measure speech intelligibility performance with both versions of the Peltor Comtac III and Peltor Comtac IV. VOCRES was designed to evaluate voice communication effectiveness in operationally-realistic acoustic environments. The facility consisted of a programmable, high-power sound system housed in a large reverberant chamber, capable of generating high-level (130 dB SPL) noise emulating acoustic environments in operational situations. Ten operator workstations were positioned in the facility (Figure 33), each equipped with a touch-screen display and communication system capable of replicating end-to-end military communication chains (i.e., intercoms, oxygen systems, headsets, microphones, and helmets). In this way, full communication systems, as well as individual system components, could be evaluated under operational conditions to determine the impact these systems might have on speech intelligibility and communication effectiveness.

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Figure 33. AFRL's VOCRES facility used to measure speech intelligibility performance

Participants were monitored by the experimenter using a closed-circuit camera and monitor system. Verbal instructions regarding experimental procedures were provided to participants. Speech stimuli were presented by live talker. Cueing of target words for the talker and recording of listener responses were both accomplished via a custom MatLab 7.0 application. A laptop computer with a graphical user interface (GUI) was utilized for subject responses. The talker and listeners had individual computers at their respective work stations.

Measurements were conducted in accordance with ANSI S3.2[4] with the exception of the number of subjects. A limited number of assets reduced the number of subjects from five talkers and five listeners to four talkers and four listeners. The Modified Rhyme Test (MRT) was selected for the test material. The MRT consisted of 50 six-word lists of rhyming monosyllabic English words. Measurements for the devices were collected in 65, 85, and 105 dB overall sound pressure level (OASPL). The talker and listeners were in the same noise environment. The goal was to quantify the ability of trained listeners to correctly identify target words transmitted by a trained talker using the combination of Multi-Band Intra/Inter Team Radio (MBITR) and the Peltor Comtac Headsets.

For data collection, each presentation of a MRT list consisted of one talker position and three listener positions. The talker position rotated throughout the measurement conditions until a full set of data comprising four talkers and four listeners was collected. Each talker completed three MRT lists in each noise condition. During the experimental task, the talker was presented with the stimulus on the computer screen ("You will mark MRT word, please"). The talker then communicated the phrase to the three listeners via the MBITR radio and headset combination. Listeners selected the word heard by using a pen to click on the correct word from a list of six words on the laptop screen. Responses were recorded and an average score was calculated.

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An example of the MRT format for the talker and listener stations is provided in Figure 34.

Number 1, you will mark **WENT** please.
Number 2, you will mark **HOLD** please.
Number 3, you will mark **PAT** please.
.
.
.

1.

Went	Sent	Bent
Dent	Tent	Rent

2.

Sold	Cold	Told
Fold	Hold	Gold

3.

Pan	Pad	Pat
Path	Pack	Pass

Figure 34. Examples of the talker (left) and listener (right) ensembles

Speech intelligibility results were combined for all subjects per noise levels and device configuration. The subjects' scores were adjusted for guessing as described in ANSI S3.2[4] using the following formula. The speech intelligibility scores for the both Comtac III models and Comtac IV are presented in Table 13 and Figure 35.

$$Score = 2(R - \frac{W}{n-1})$$

Where:

$Score$	=	Percent Correct (Adjusted For Guessing)
R	=	Number Correct
W	=	Number Incorrect
n	=	6 (number of choices available to listener)

Table 13. Speech intelligibility scores

Noise Level (dB)	**SI Score (%)**		
	Comtac III (Modified)	**Comtac III**	**Comtac IV**
65 dB	90.2	87.6	86.3
85dB	87.1	83.8	84.3
105 dB	74.7	73.9	68.1

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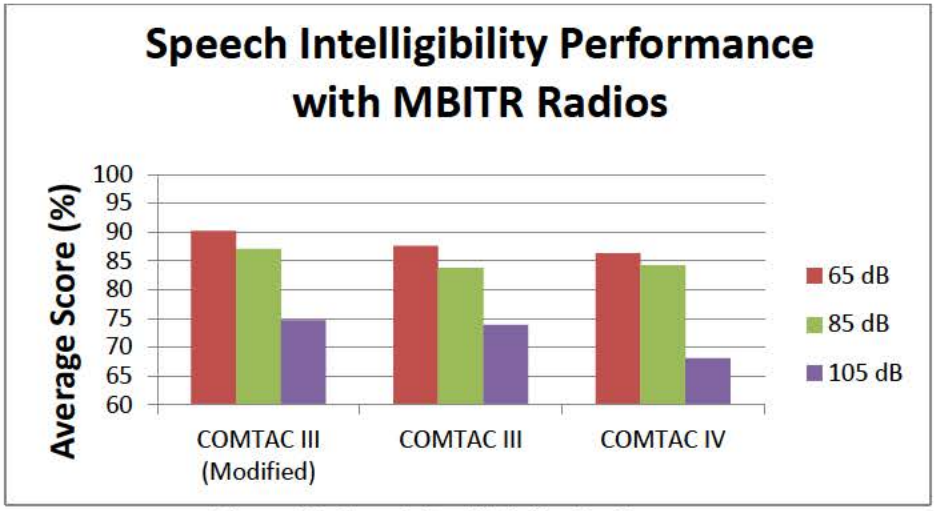

Figure 35. Speech Intelligibility Performance

The speech intelligibility performance of the modified Comtac III, Comtac III, and Comtac IV at the levels of 65 and 85 dB exceeded the 80% score requirement for a communication device to be deemed mission ready[18]. None of the devices met the criteria for "acceptable" in the 105 dB noise environment.

4.0 DISCUSSION

All hearing protection devices should be assessed in multiple ways to describe the performance of the device and the effects on an operator's ability to perform the mission. Subjective and objective measurements could be conducted to characterize a device's noise attenuation performance as well as any negative effect on situational awareness capabilities that may result. Noise attenuation in both continuous and impulse noise environments, auditory localization capabilities, and speech intelligibility were all assessed for the devices in this study.

Selecting an Appropriate Device for the Mission

It is important to consider the environment of the end user, and evaluate the pros and cons in each assessment area independently to come to an informed decision. It is more advisable to pick a top performing device in the area that is most appropriate to the mission and to consider other variables when selecting a device. In general, there will always be a trade-off between attenuation (continuous and impulsive) and localization/detection since these were inversely related metrics. One of the proposed benefits of using active devices was that they may increase the user's situation awareness when compared to passive devices. However, the results of these measurements indicated that active hearing enhancement devices negatively impacted localization and detection abilities when compared to the open (unoccluded) ear. The one major benefit of hearing protection devices like both versions of the Comtac III and the Comtac IV over passive devices was that they allowed the user to communicate directly with other

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users across broadband wireless radio systems, intercom systems, etc. A score of 80% or greater would be considered acceptable for current military standards[15]. All three of the Comtac configurations met the requirement for 65 and 85 dBA noise conditions. However, none of the configurations were able to meet the requirement for the 105 dBA noise environment. This was a limitation of the devices that should be considered when deciding what could be used based on specific requirements of a given mission.

Extra Configurations

The modified Comtac III, Comtac III, and Comtac IV were commonly used in combination with other types of personal protective equipment (PPE). Eye protection was often achieved with the addition of spectacles or goggles to the warfighters' ensemble. The data collected during these measurements suggest that the addition of spectacles or goggles had the potential to negatively affect attenuation in a continuous noise environment. The addition of the Oakley® SI Ballistic M Frame spectacles Versions 2.0 and 3.0 to the Comtac III headset created degradation in attenuation of roughly 5 and 3 dB, respectively. The addition of the goggles resulted in a degradation of almost 7 dB. However, during the high level (185 and 195 dB SPL) impulse noise measurements, the addition of the spectacles showed little, if any difference, when compared to the headset alone. In general, the addition of any material worn between the ear cup and the head has the potential to break the seal around the ear and allow sound to enter, thereby reducing attenuation.

The Comtac III and IV were also measured in combination with the Ops-Core Fast Advanced Combat Helmet (ACH) during the impulse noise and localization portions of the study. The addition of the helmet resulted in a maximum degradation of 6.1 dB during the 170 dB SPL blast for the Comtac III. The maximum degradation for the Comtac IV/ Ops-Core combination was 7.8 dB during the 195 dB SPL blast. Localization measurements were also collected with the Comtac III and IV in combination with the Ops-Core helmet. Based on the data from this portion of the measurement, it was concluded that the addition of the Ops-Core helmet to any configuration had no significant negative effect on localization performance. As a result, device only conditions were measured for the aurally guided visual search portion of the study.

Device Fit and Design

Other considerations beyond these performance areas exist when assessing hearing protectors. Sizing and fit was one such consideration. With circumaural devices like both versions the Comtac III, sizing was typically less of a concern, especially when compared to the incredible variety of ear canal sizes and shapes that earplugs must accommodate. The headband of the Comtac III was fully adjustable to fit many different widths and lengths of heads. It was also designed to be worn in combination with an ACH so it naturally integrated with the helmet currently in use by military ground operations. The Comtac IV shared all of these specifications with the exception of earcup design. The Comtac IV used an open upside down U-shaped earcup design with

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an insert earplug instead of a closed circumaural ear cup. 3M's Skull Screws foam replacement tips were used for this measurement. Although the earplugs came in one size only, the fit didn't appear to be an issue due to the earplugs' tapered design. Typically foam earplugs provide more attenuation than other types of hearing protection. For these measurements, the Comtac IV with Skull Screws provided an additional 2 to 7 dB of attenuation over the modified Comtac III and Comtac III for the continuous attenuation measurements, and an additional 20 dB of attenuation in the impulse noise measurements. The open design of the Comtac IV allows the ears to breathe during extended use; however the closed design of the Comtac IIIs could prevent damage to the outer ear from shrapnel and/or debris during a ballistic explosion or may be more stable on the head.

5.0 CONCLUSIONS

Passive hearing protection devices can potentially provide high levels of attenuation in both continuous and impulsive noise environments. However, due to the level of noise attenuation, communications and situation awareness capabilities could be negatively affected. The Peltor Comtac headsets reduced the noise level in the ear when the user was exposed to continuous and/or impulsive noise. The devices also reduced important aural cues required to localize sounds essential to maintaining situational awareness. The active headsets may amplify low level sounds, but the localization performance was degraded in comparison to the open (unoccluded) ear performance. The results from the speech intelligibility measurements for the Peltor Comtac headsets were acceptable in low to moderate noise environments, however, at 105 dB, the average scores did not meet current military standards.

When considering a hearing protection and communication device, it was necessary to prioritize the needs for the operational environment of the end user and the performance metrics of the device. The results of the hearing protector performance assessments may provide insight into new technologies and/or design criteria for the next generation of hearing protection devices.

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