ARMY RESEARCH LABORATORY

Evaluation of Variants of 3M Peltor ComTAC Tactical Communication and Protection System (TCAPS) Headsets: Measures of Hearing Protection and Auditory Performance

by Angelique A. Scharine and Rachel A. Weatherless

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14. ABSTRACT

The auditory effects of the 3M Peltor ComTAC III Accessory Rail Connector (ARC) and the 3M Peltor ComTAC IV Hybrid headsets were compared to the 3M Peltor ComTAC III. Passive and active attenuation were measured in two steady-state noise levels (85 and 105 dB A) and three microphone settings (off, low, and high). When the noise level was 85 dB A, and the microphones were set to high, the systems provided approximately 20 dB of amplification. However, at 105 dB A, and the microphones off, attenuation was equivalent to that of passive attenuation. The devices provided attenuation of impulsive noise (154 dB peak) exceeding 25 dB for all measured settings. Of the three types of eartips available for the ComTAC IV, the "skull screw" style eartips provided the most impulsive noise attenuation. Auditory localization performance was measured for 12 listeners while wearing the ComTAC systems in combination with two Ops-Core FAST helmets (ballistic and lightweight carbon). There were fewer front-to-back localization errors when wearing the lightweight carbon helmet than when wearing the ballistic helmet but there was no significant difference between the ComTAC systems in their effect on localization performance.

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auditory localization, hearing protection, TCAPS

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1. Introduction

This effort was funded by Special Operations Forces Survival, Support & Equipment Systems (SOF-SSES) to measure the attenuation performance characteristics of three variants of the 3M ComTAC tactical and communications protective system (TCAPS) devices in impulsive and steady-state noise environments. Auditory localization performance was also measured to document any effects of the TCAPS or helmets on situational awareness (SA). Three TCAPS devices were evaluated: the 3M Peltor ComTAC III Accessory Rail Connector (ARC) headset (ComTAC III ARC), the 3M Peltor ComTAC IV Hybrid Communication headset (ComTAC IV), and the standard (baseline) 3M Peltor ComTAC III headset (ComTAC III) (figure 1). The ComTAC III ARC headset attaches to the accessory rail of a helmet, and the Ops-Core Future Assault Shell Technology (FAST)[*] helmet was used for all tests using the ComTAC III ARC headset. The ComTAC IV device consists of earmuffs shaped like an inverted "U" that clamp around the ear, but leaves the ear uncovered. It delivers communications through attached eartips available in three types (E·A·R Classic foam, UltraFIT triple flange, and Skull Screws)[†] (see figure 2). The Ops-Core FAST helmet comes in several forms; the standard ballistic style and the lightweight carbon style were used in the study (see figure 3). During auditory localization testing, the participants wore the Ops-Core FAST ballistic style helmet in combination with all three of the TCAPS devices. Both the ballistic and the lightweight carbon helmets were worn in combination with the ComTAC III ARC headset to measure the difference in their effect on auditory localization ability.

Figure 1. TCAPS devices tested: (a) 3M Peltor ComTAC IV, (b) 3M Peltor ComTAC III ARC (shown with Ops-Core FAST helmet), and (c) 3M Peltor ComTAC.

[*]The FAST helmet is a trademark of Ops-Core, owned by Gentex (maker of the Advance Combat Helmet) and is specifically designed to allow the attachment of a number of components.

[†] The E·A·R Classic foam, UltraFIT, and Skull Screws are all trademarks of 3M.

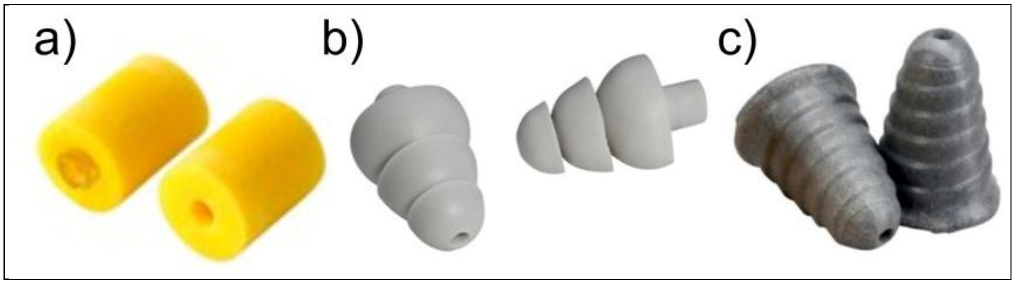

Figure 2. Earplug types used when measuring the impulsive noise attenuation provided by the ComTAC IV TCAPS headset. (a) 3M E·A·R Classic foam, (b) 3M UltraFIT triple flange, and (c) 3M Skull Screws.

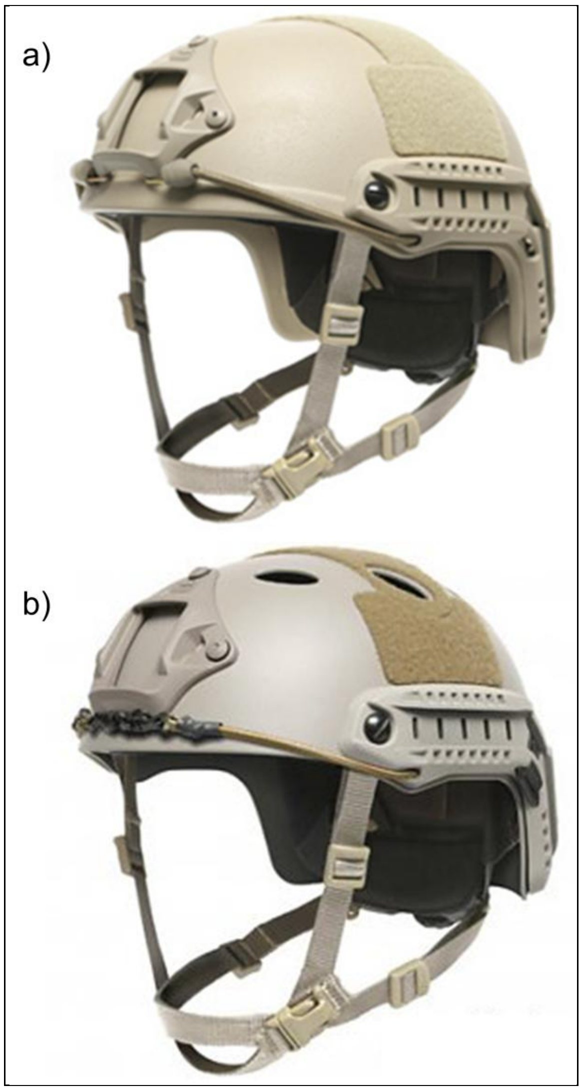

Figure 3. The two Ops-Core FAST helmets (a) ballistic and (b) lightweight carbon used during the auditory localization measures.

2. Steady-State Noise Attenuation

These TCAPS systems are designed with SA microphones located on the earmuffs that transmit ambient sounds to the earphones in the device. When the ambient noise levels are below dangerous levels, OSHA (1981) requires hearing protection if the 8 h average sound pressure levels exceed 85 dB A; these systems allow the user to hear ambient communication and environmental sounds as if the ears were unoccluded. When ambient noise levels exceed approximately 85 dB A, the system limits or compresses the transmitted level, thus protecting the user.

The actual level under the hearing protection device depends, however, on the amount of noise that is not passively attenuated by the hearing protection device, as well as the level of amplification selected by the user. Therefore, we measured the attenuation of the headsets as a function of SA microphone setting and steady-state noise level. From these data, we can determine whether the protective function of the TCAPs are functioning as intended and determine how the SA microphone setting affects the level under the headset.

2.1 Facilities and Instrumentation

2.1.1 Loudspeaker Array and Test Signal

The U.S. Army Research Laboratory's (ARL's) Environment for Auditory Research (EAR) Listening Laboratory (Henry et al., 2009) (figure 4) was used for measurements of steady-state noise. To make the environment more diffuse, two sound-absorbing panels were removed from the center of each wall revealing the plywood surface. A white noise test signal was presented from four JBL PRX512M loudspeakers placed in the corners of the Listening Laboratory about 1 m from the Auditory Test Fixture (ATF) position. The noise was presented at two noise levels, 85 dB A and 105 dB A, as measured with a Brüel and Kjær Sound Level Meter Type 2226 held at the location of the ATF (figure 5). These levels were chosen because the safety features of the SA system should not be activated at 85 dB A, but should be in effect at 105 dB A. Further, both levels fall within the range for which the microphones (inside the ears) of the ATF are designed and are high enough to remain in that range when the earplugs were in place.

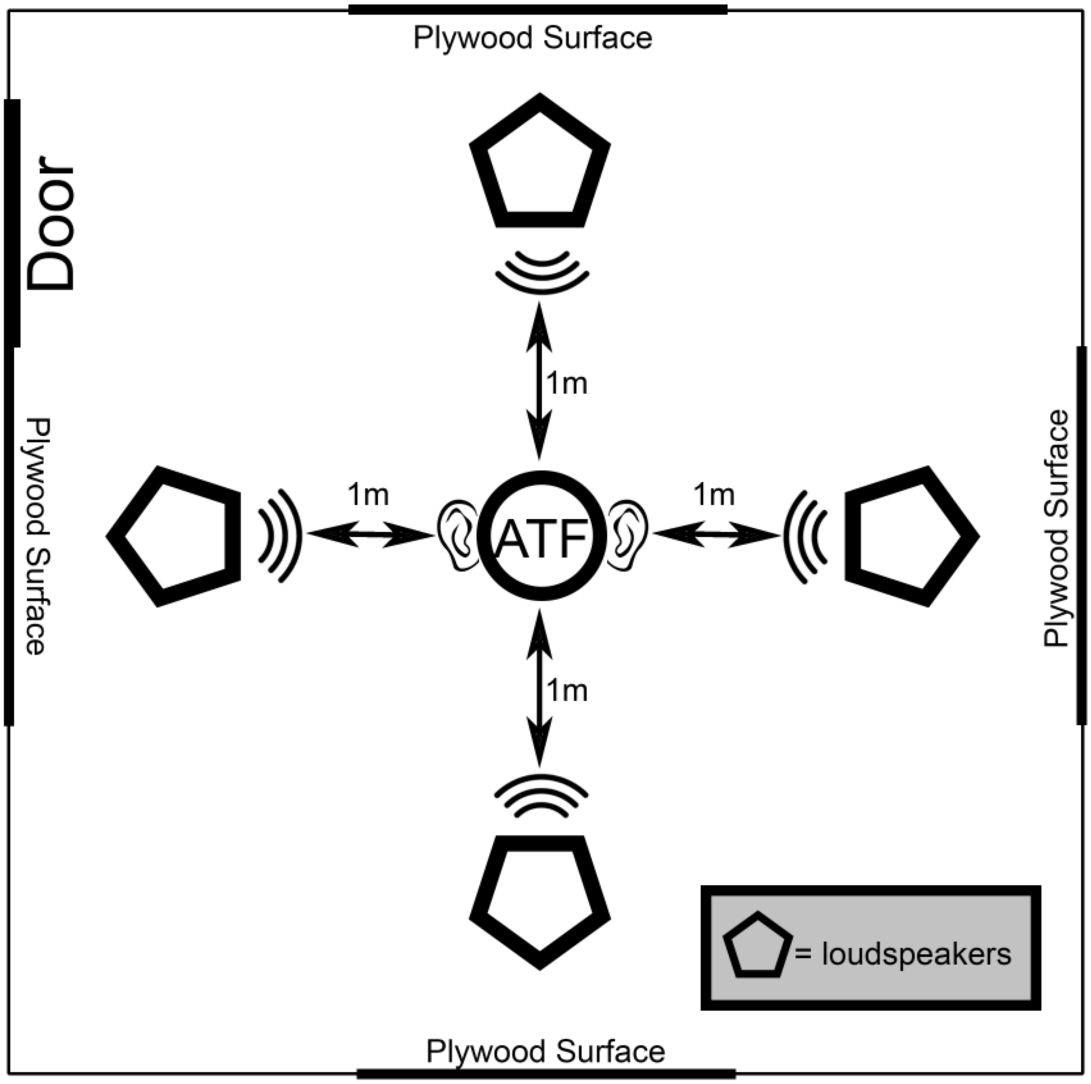

Figure 4. Schematic depicting the Listening Laboratory and the configuration of the loudspeakers and the ATF during the measurement of steady-state noise attenuation.

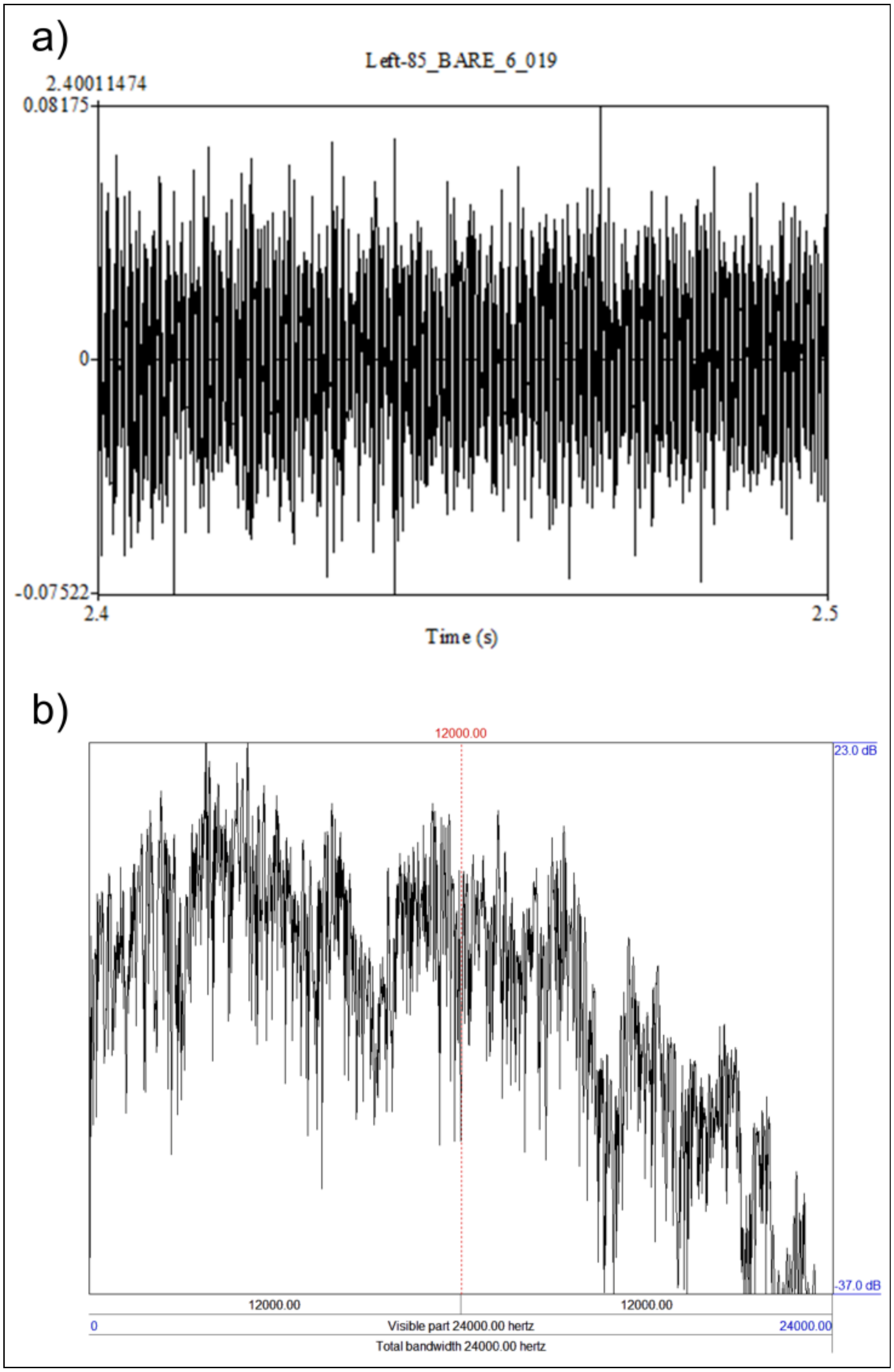

Figure 5. (a) Waveform and (b) spectrogram of the noise recorded through the left ear of the ATF when the white noise was presented at 85 dB A.

2.1.2 Auditory Test Fixture

A G.R.A.S.* Hearing-Protector ATF Type 45CA (figure 6), fitted with IEC 60711 ear simulators and molded pinnae, was positioned in the center of the loudspeaker array and used to record the test signals. An Echo AudioFire 12 recording interface set at a sampling rate of 192 kHz was used to convert the analog signal to a digital format and transmit it to a laptop computer where it was recorded using Adobe Audition 3.0.

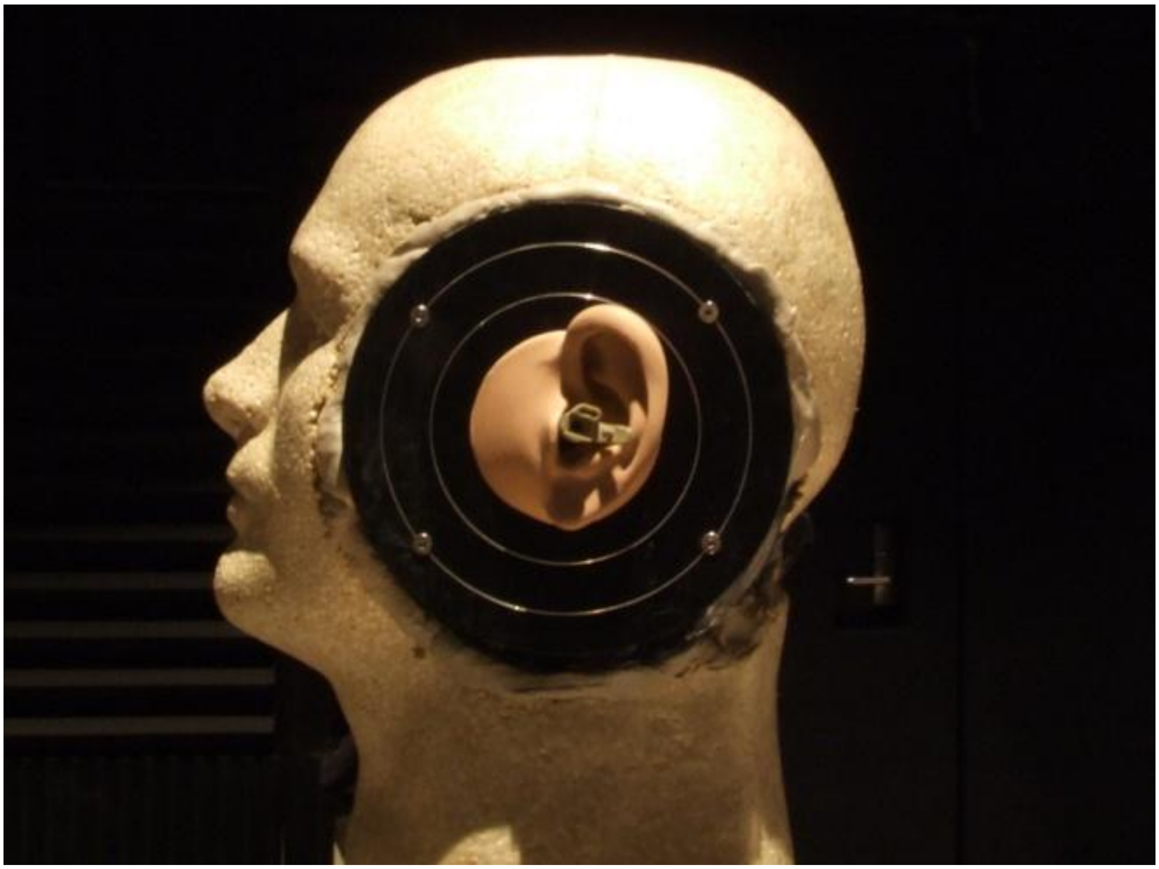

Figure 6. G.R.A.S. Acoustic Test Fixture Type 45CA (shown here with Moldex BattlePlugs inserted).

2.2 Independent Variables

The TCAPS, noise levels, and SA microphone settings were the independent variables investigated in the study. Three TCAPS were evaluated: the ComTAC III ARC, the ComTAC IV, and the ComTAC III. Each system was tested for three SA microphone settings (off, low, and high) and for two steady-state noise levels (85 and 105 dB A). Each SA microphone setting/steady-state noise level combination was measured twice with the system removed from the ATF and refit between measurements.

* G.R.A.S. Sound and Vibration is a Danish company that manufactures high-quality microphones.

2.3 Dependent Variable

The dependent variable of interest was attenuation, defined as the difference between the signals with and without the TCAPS, as measured by the ATF.

2.4 Procedures

A G.R.A.S. 42AA sound calibrator with an adapter that allows it to be coupled to the ATF was used to generate a signal of 250 Hz at 114 dB. The signal was recorded through each channel (left/right ear) of the testing system for reference. The white noise test signal was then played continuously from the loudspeakers at one of the two noise levels. A reference measurement was made by recording the test signal with no TCAPS in place. The TCAPS device under test was fitted to the ATF and a 5 s recording was made from both ATF ears (left−right channels) simultaneously. The TCAPS device was then removed and reinstalled and the recording process repeated. This procedure was repeated for each of the devices under test for each of the noise levels (85 and 105 dB A). It should be noted that in order to ensure that the ComTAC IV 3M E·A·R Classic foam earplugs (FP) were inserted correctly, the molded pinnae were removed from the ATF, the earplugs were inserted, and then the pinnae were replaced. Similarly, to ensure a proper seal of the ComTAC III and ComTAC III ARC earmuffs, the pinnae were removed[*] during testing. These procedures were used for both the steady-state and impulsive noise testing.

2.5 Data Analysis, Results, and Discussion

Each recording was processed using a custom MATLAB® algorithm to compute the levels for each component octave and one-third octave band. A-weighting was then applied and the A-weighted one-third octave, octave, and overall levels were obtained. A-weighted values were used for all analyses reported here. For each TCAPS, overall attenuation was calculated by computing the difference in the overall A-weighted signal level when the device was in place compared to the level in the bare fixture. Attenuation, as a function of one-third octave and octave band frequency was then calculated in the same manner (figures 7 and 8).

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[*]The GRAS 45CA is advertised as a test fixture for measuring hearing protection devices and is sold with optional “molded pinnae” for the testing of ear plugs.

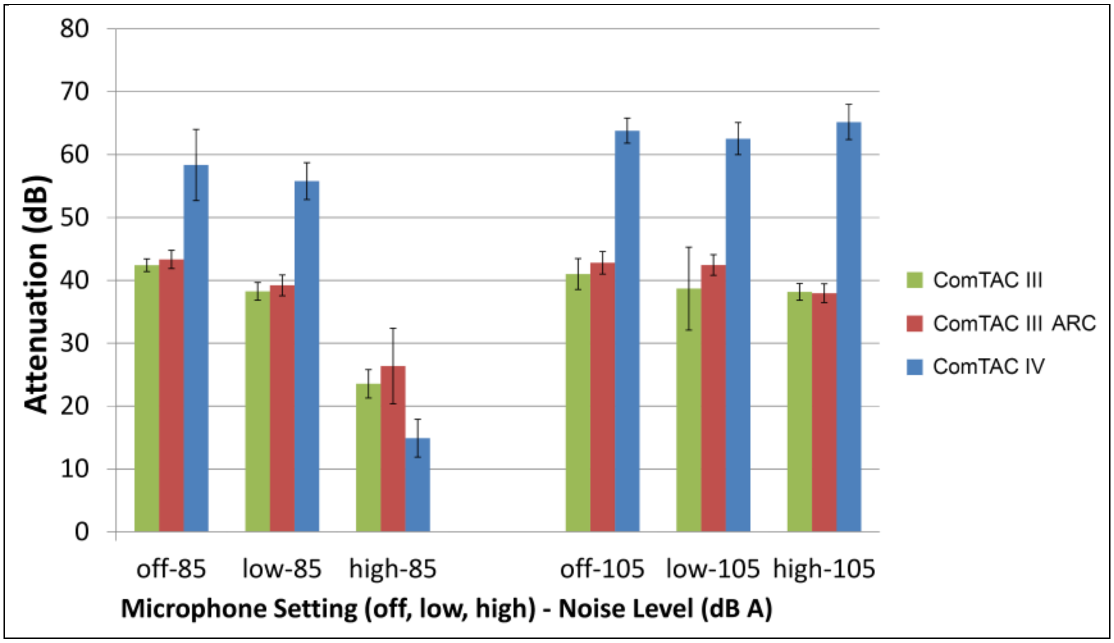

Figure 7. Average overall continuous noise attenuation values for each TCAPS, grouped by SA microphone setting and noise level. Error bars represent ±1 standard deviation.

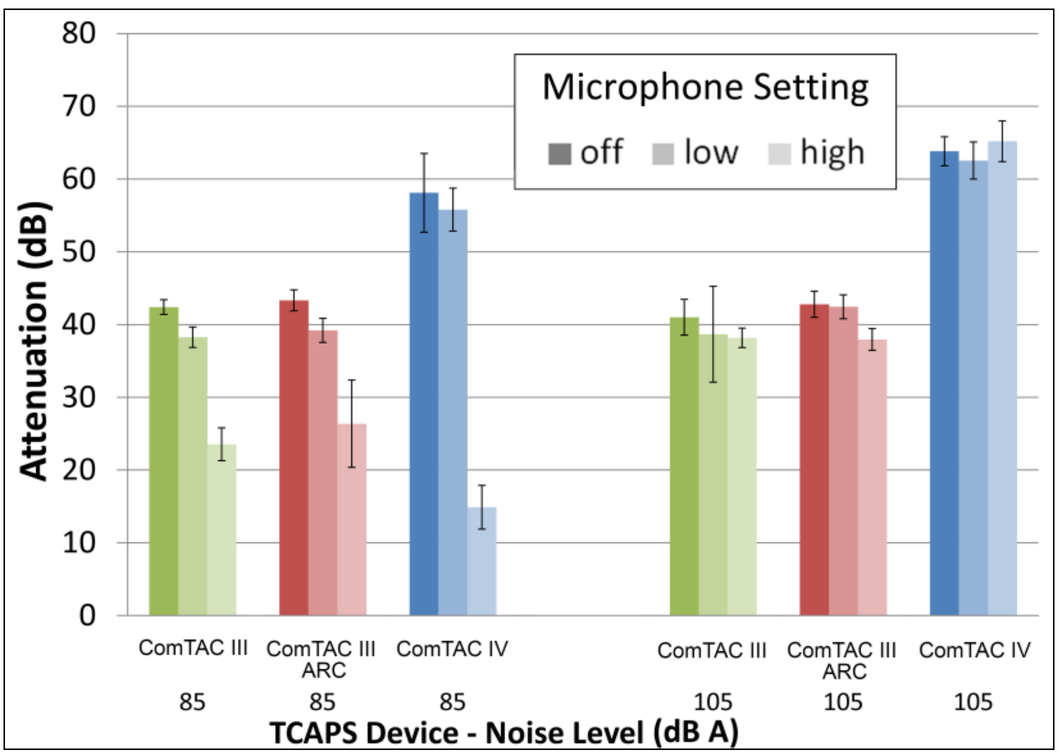

Figure 8. Average overall continuous noise attenuation values for each TCAPS as a function of microphone setting. Error bars represent ±1 standard deviation.

A three factor analysis of variance (ANOVA) was conducted on the overall attenuation values with the independent variables being TCAPS, SA microphone setting, and presentation level (table 1). There is a significant main effect of TCAPS, $F(2,152) = 64.7$, $p < 0.01$. The ComTAC III and the ComTAC III ARC provided significantly less attenuation than the ComTAC IV. $d_{ComTAC\ IV - ComTAC\ III} = 11.0$dB and $d_{ComTAC\ IV - ComTAC\ III\ ARC} = 9.0$ dB, $p < 0.01$.

Table 1. Significant ANOVA results for steady-state noise attenuation (α < 0.05).

Source of Variance	**df**	**F**	**ρ**
TCAPS	2	64.7	0.000
SA mic setting	2	181.5	0.000
Presentation Level	1	72.4	0.000
TCAPS × SA mic setting	4	41.1	0.000
TCAPS × Presentation Level	2	29.3	0.000
SA mic setting × Presentation Level	2	12.6	0.000
Error	152	30.3	—

The ComTAC IV system, used with the 3M E•A•R Classic tips advertises a higher noise reduction rating ([NRR]=30) than the ComTAC III system (NRR=21), and this difference is typical of the difference between the attenuation provided by earplugs and earmuffs. Although well-fit foam earplugs typically attenuate more than earmuffs, it is significantly more difficult to achieve proper insertion of ear plugs, meaning that the average user may not achieve levels as high as that of the earmuffs. There is also a significant main effect of SA microphone setting, $F(2,152) = 181.5$, $p < 0.01$, presentation level, $F(1,152) = 72.4$, $p < 0.01$, and an interaction of SA microphone setting and presentation level, $F(2, 152) = 12.5$, $p < 0.01$. The interaction of SA microphone setting and presentation level appears to be driven by the difference in attenuation when the noise level is 85 dB A, and the SA microphones are on high as compared to when the SA microphones are off or on low, $d_{off\text{ - }on\text{-}high} = 18.1$ dB and $d_{on\text{-}low\text{ - }high} = 15.9$ dB, $p < 0.01$.

When the SA microphones are on but the amplification is set to the lowest setting, the attenuation is not significantly different from passive attenuation for any of the systems and at any presentation level. However, if the SA microphones are set to their highest amplification setting, there is less attenuation for 85 dB A than for 105 dB A. At 85 dB A, the system is not yet attenuating sounds. It appears that when the SA microphones are set on the highest amplification setting, this amplification is not curtailed at 85 dB A, making the actual level under the earmuff exceed 85 dB A. Although the level exceeds 85 dB A, it should be noted that in quiet conditions, amplification can allow a hearing-impaired listener to better hear speech than when unamplified. In noisy conditions, amplification will not aid speech recognition for a normal-hearing user, and will make it worse for a hearing-impaired user, because both the speech and the noise will be amplified (Moore, 2012). Therefore, the standard procedure for SA microphone use should be that they should be turned off when in noisy environments when steady-state noise (such as vehicle or generator noise) exceeding 85 dB A is present as the SA microphones will cease to aid communication.

The one-third octave attenuation levels achieved for each of the SA microphone settings are shown for noise presented at 85 dB A (figure 9) and 105 dB A (figure 10). These data are included for descriptive purposes only with no statistical analyses are reported. They are of interest because the monaural cues used for auditory localization are in the frequency range above 4000 Hz. Understanding the changes to spectral information that occur as a result of passive attenuation and, additionally, the spectral profile of the sound transmitted by the SA microphones, can provide potential causes of changes to the user's ability to localize sounds. In the bottom panel of figure 9, where the SA microphones are on and the amplification is set to the highest setting, there is little attenuation below 4000 Hz, suggesting that the headsets are amplifying frequencies below 4000 Hz, but not those above it. The attenuation above 4000 Hz is similar to that of the passive measurements (with microphones off). This may affect auditory spatial orientation because of the loss of spectral information above 4000 Hz.

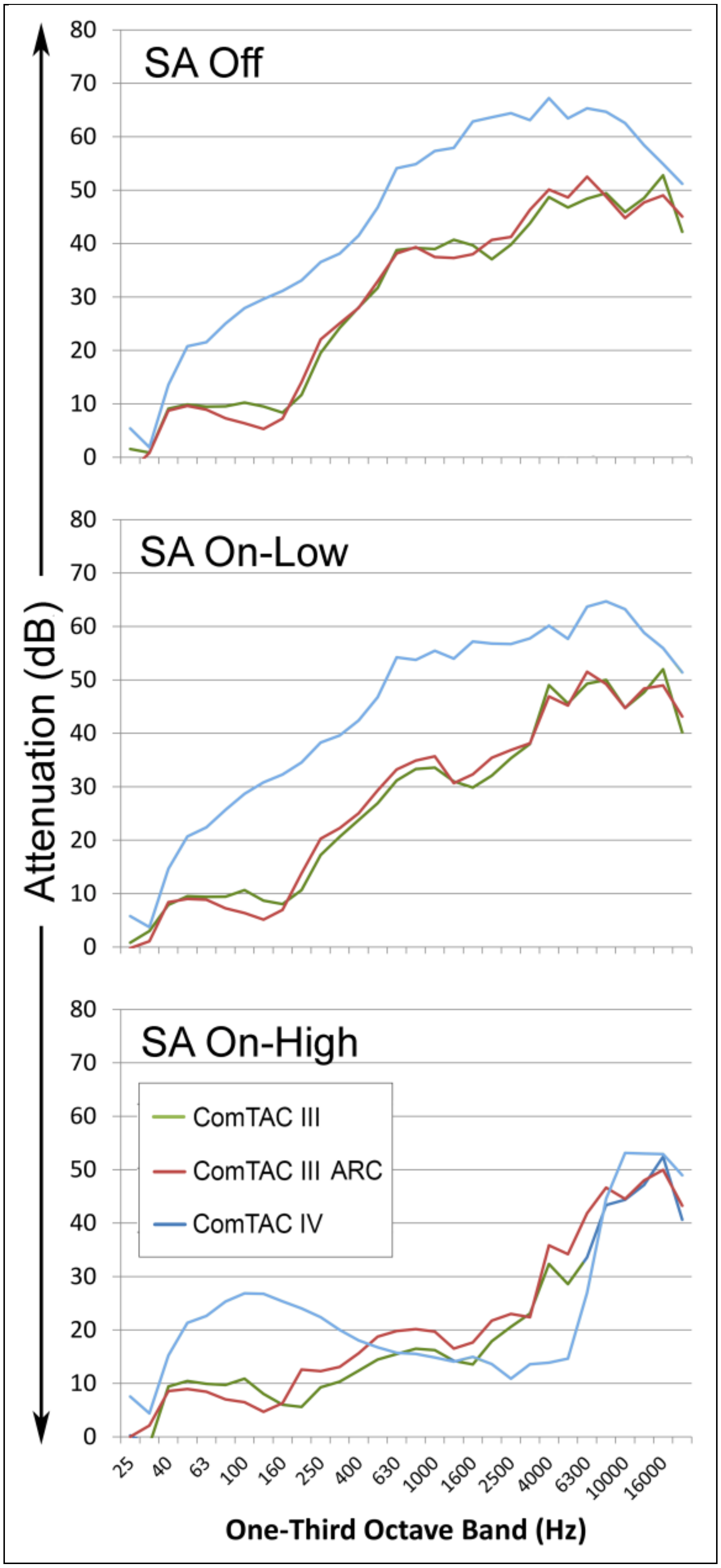

Figure 9. One-third octave attenuation measured for the TCAPS devices as a function of SA microphone settings when presented noise at 85 dB A.

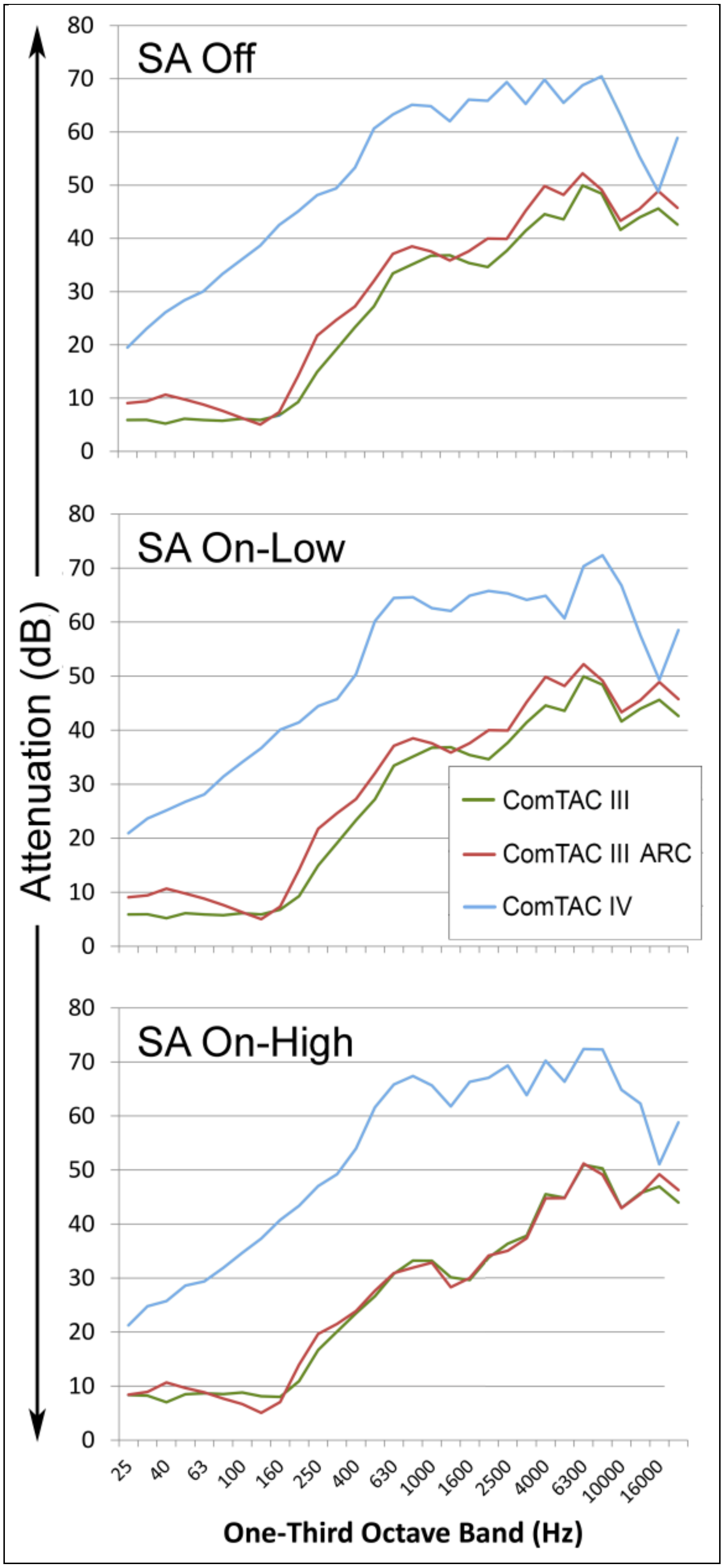

Figure 10. One-third octave attenuation measured for the TCAPS devices as a function of SA microphone settings when presented noise at 105 dB A.

3. Impulsive Noise Attenuation Testing

We tested all three TCAPS (ComTAC III, ComTAC III ARC, and ComTAC IV) for their attenuation of impulsive noise with the SA microphones on low and off. It was assumed, because both levels were above the 140 dB peak, that the shutoff function would perform similarly, regardless of the SA microphone amplification setting. Because the ComTAC IV can be used with three types of earplugs (figure 2), impulsive noise attenuation was also measured for each of the earplug types.

3.1 Facilities and Instrumentation

Recordings were made using the same ATF, and Echo AudioFire system described in section 2.1.2. In addition, a G.R.A.S. 40 BH reference microphone (powered by a G.R.A.S. Power Module Type 12AK) was used to estimate the transfer function of the ATF and to record the signal level of each trial. A pneumatic impulse noise source (PINS) was used to present impulsive noises for measurement (figure 11). The average impulsive noise level presented from the PINS as measured with the reference microphone was a 154 dB peak and the standard deviation of impulsive noises was 0.7 dB. Both the ATF and the reference microphone were placed at 1 m from the PINS and 1 m from each other.

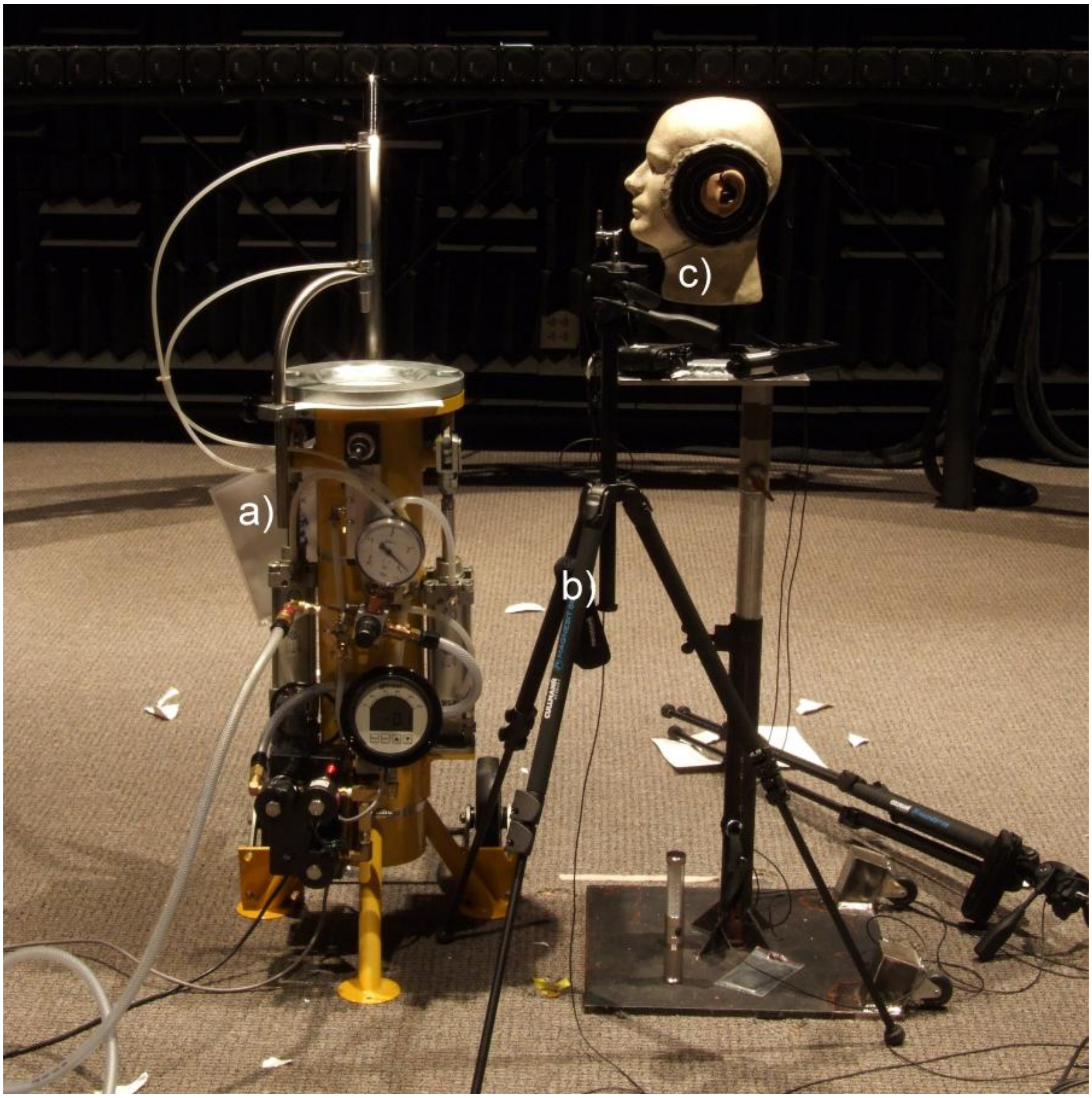

Figure 11. The measurement set up for impulse noise measurement: (a) PINS shock tube used to generate impulsive noises, (b) G.R.A.S. 40BH reference microphone, and (c) G.R.A.S. 45CA auditory test fixture used to record noise levels.

3.2 Calibration

A 114 dB, 250 Hz calibration signal was recorded with each microphone as the reference signal level. Simultaneous recordings were made of two instances of impulsive noise using the microphones of the ATF (unoccluded ears), and the reference microphone. These recordings were used to estimate the transfer function of the ear canal. From these recordings, it was determined that the left and right ears of the ATF contribute amplifications of 9.65 and 7.77 dB, respectively, due to resonance in the ear canal (Shaw, 1974). Attenuation was computed as the difference between the peak level measured by the ATF (the left and right ear each contributed separate data points) and the peak level measured by the reference microphone, minus the transfer function for that ear.

3.3 Testing Procedure

Each TCAPS was positioned on the ATF and three recordings of a PINS-generated impulsive noise were obtained from the microphones of the ATF and the reference microphone. The TCAPS device was then removed and replaced on the ATF and this process was repeated for each of three samples of the ComTAC III ARC and ComTAC IV headsets with the 3M E·A·R Classic foam earplugs. Two samples* were used for the ComTAC III headsets and the remaining two ComTAC IV earplug types (3M UltraFIT triple flange and 3M Skull Screws).

3.4 Data Analysis, Results, and Discussion

Three impulsive noise signals were presented for each hearing protection device, resulting in six attenuation values for each TCAPS device and SA microphone setting. Averages and standard deviations were determined (figure 12a) along with the average attenuation values measured for the different earplug types (figure 12b). The dotted line in figure 12 represents the expected cap on actual protection due to the attenuation limits on bone conducted sound transmission.

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*All of the earplugs styles should all have been tested an equal number of times; however, the alternative styles were added in during the testing process. We made two measurements simply to show that they provided similar attenuation. In retrospect, they did not.

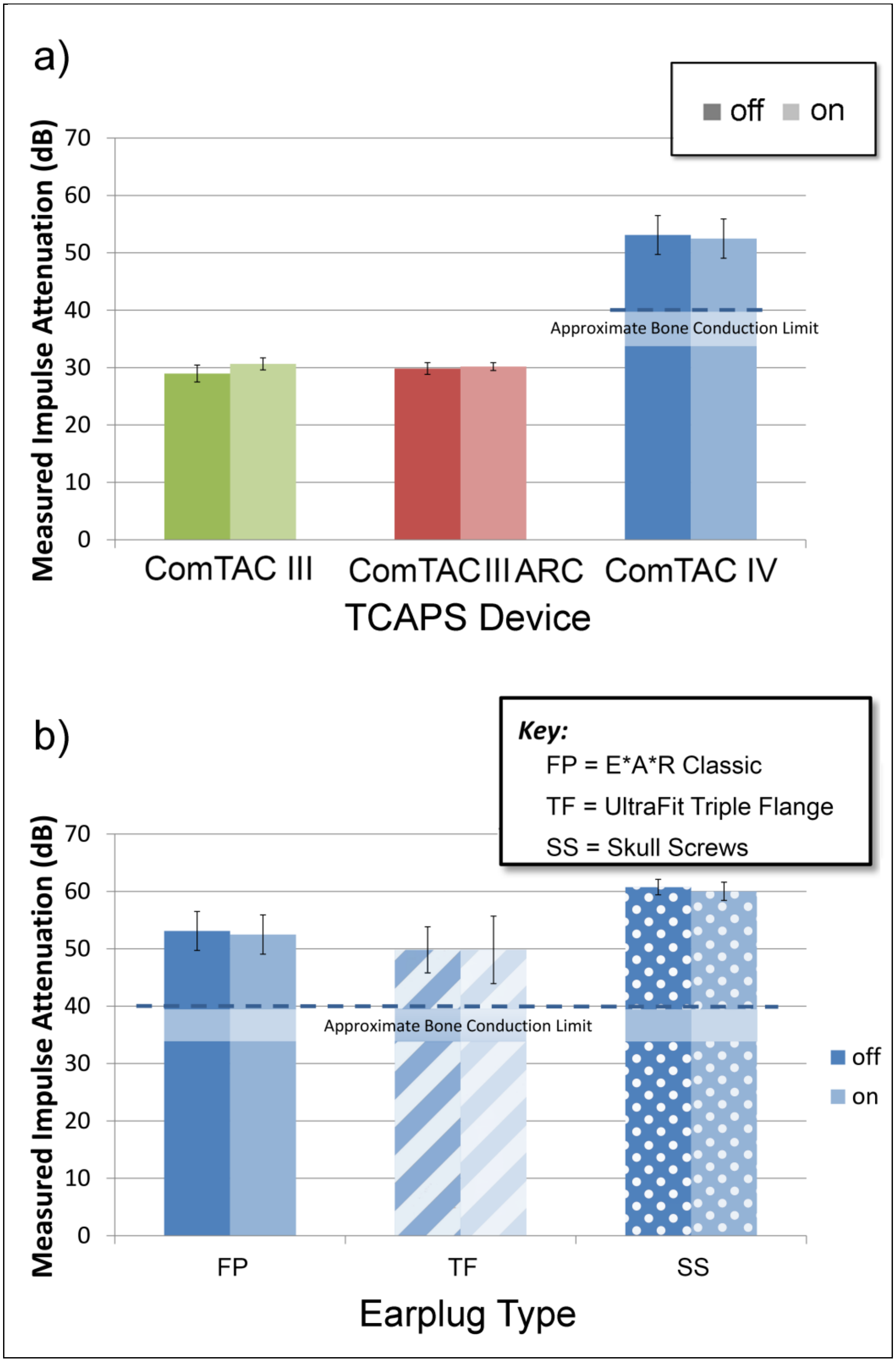

Figure 12. (a) Average impulsive noise attenuation measured for each TCAPS device as a function of SA microphone setting and (b) average impulsive noise attenuation measured for the ComTAC IV TCAPS device as a function of SA microphone setting and earplug type. Error bars represent ±1 standard deviation.

All TCAPS devices provided at least 25 dB of attenuation for impulsive noise. An independent sample t-test confirmed that the difference between the amount of attenuation achieved for the ComTAC III and ComTAC III ARC (earmuff style) as compared to the ComTAC IV (earplug style) was significant, $t(101) = -29.0$, $p < 0.01$. ANOVA was used to evaluate the significance of the observed differences in attenuation measured for the different ComTAC IV earplug types (table 1). There was a main effect of earplug type, $F(2, 52) = 40.0$, $p < 0.01$. A Scheffé post hoc test shows that the main effect of earplug type is due to the significantly greater attenuation of the Skull Screw style earplugs ($d_{SS\text{-}TF}$=7.6 dB and $d_{SS\text{-}FP}$ = 10.3 dB, $p < 0.01$) as compared to the other two earplug types. The experimenters also noted that it seemed to be the easiest of the earplug types to insert into the test fixture correctly.

4. Localization Testing

The ability to localize sounds was evaluated for the ComTAC III, ComTAC III ARC, and the ComTAC IV TCAPS and compared to the bare head. Because the ComTAC III ARC TCAPS is designed to mount on the Ops-Core FAST helmet accessory rail connector system, all TCAPS were evaluated in combination with a helmet. To evaluate the differences in auditory spatial perception resulting from use of the ballistic helmet versus the carbon helmet, the ComTAC III ARC TCAPS was also evaluated in combination with the carbon helmet. For labeling purposes, these conditions were labeled ARC-ballistic and ARC-carbon.

4.1 Participants

Twelve listeners participated in this study. Listeners were recruited from the population of volunteers aged 18–40 years. Listeners were screened to ensure normal hearing by an experimenter (and under the guidance of an audiologist). Listeners' ears were inspected using an otoscope to ensure that their ear canals were unobstructed and that there would be no interference with the use of earplugs. Their pure tone thresholds were measured for octave frequencies from 250–8000 Hz using calibrated audiometric equipment in a sound-treated room. All 12 participants had pure tone thresholds no higher than 20 dB hearing level (HL) for all frequencies screened and, thus, met the Army's H1 hearing classification, defined in the Army Hearing Conservation Program (DA PAM 40-501, 1998) as an average threshold level at 500, 1000, and 2000 Hz that does not exceed 25 dB HL and with no individual threshold greater than 30 dB HL, and the threshold at 4000 Hz no greater than 45 dB HL. The investigators adhered to the policies for protection of human subjects as prescribed in AR 70-25 (1990).

4.2 Facilities and Instrumentation

4.2.1 Loudspeaker Array

Target stimuli were presented from a spherical loudspeaker array consisting of 57 Meyer Sound MM-4XP miniature loudspeakers housed in the Sphere Room of the EAR (Henry et al., 2009). Target sounds were presented from the 16 loudspeakers on the horizontal ring at 0° elevation; the loudspeakers are located at equal intervals of 22.5° separation and the radius is approximately 2 m (figure 13).

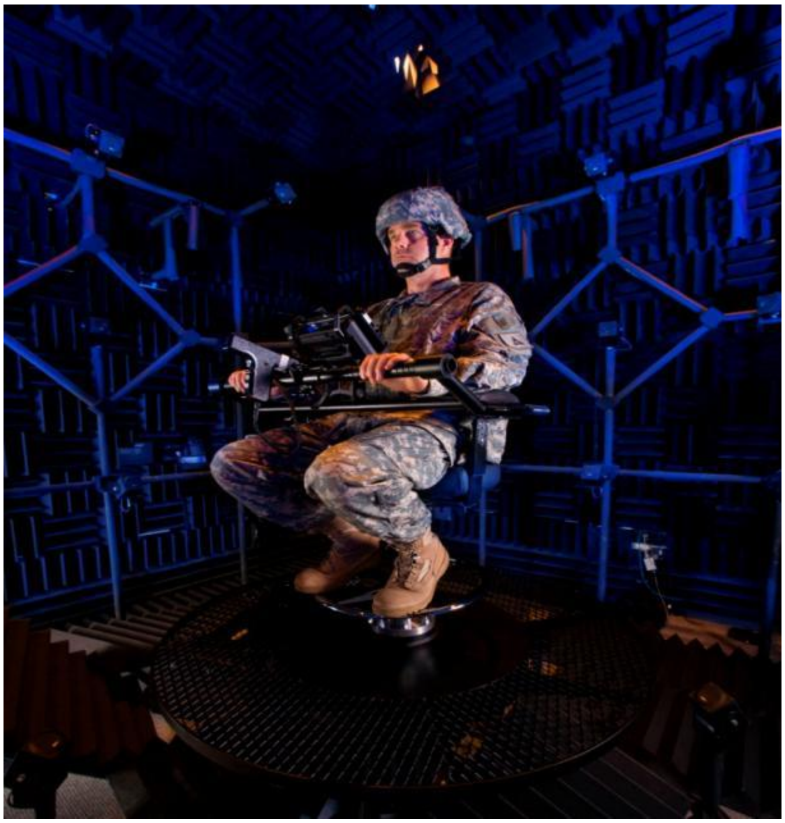

Figure 13. Testing setup used for the localization test (subject shown here is wearing the Advanced Combat Helmet [ACH]).

4.2.2 Rotating Chair

Each participant sat in a rotating chair at the center of the loudspeaker array on a raised platform that placed their ears at the same elevation as the 0° loudspeaker ring. The chair was free to rotate 360° and was equipped with an optical shaft encoder (digital compass), and a laser tracker on the center of a horizontal bar attached to the chair in front of the participant. Although the bar is free to rotate ±90° in pitch, it was fixed in place to allow for responses only from the horizontal plane during this study. Participants began each trial facing 0° azimuth and then responded by rotating the chair to point the laser in the direction from which they believed a stimulus came, pushing a button to register their response. A computer recorded the direction of the response based on the outputs of the laser tracker and the optical shaft encoder, providing redundant positional information. During this study, the optical shaft data was used in the analyses.

4.3 Independent Variables

There were two independent variables investigated in the study: (1) head condition and (2) sound source azimuth. With the exception of the bare head condition, a helmet was always worn, and with the exception of the ComTAC III ARC-carbon condition, that helmet was the Ops-Core FAST-ballistic style helmet. Five head conditions were evaluated: Bare head, ComTAC III, ComTAC III ARC-ballistic, ComTAC III ARC-carbon, and ComTAC IV. During testing, the SA microphones were turned on and set to the lowest amplification setting.

There were 16 azimuth locations (0°, ±22.5°, ±45°, ±67.5°, ±90°, ±112.5°, ±135°, ±157.5°, and 180°). A 250 ms burst (with 5 ms ramps) of white noise at 70 dB A was presented from each of the loudspeakers eight times, for a total of 144 trials per block. The order of presentation location was varied randomly within the block. A single block of trials was presented for each of the head conditions.

4.4 Dependent Variables

The dependent variable of interest was azimuth error, defined, as the difference in degrees between the perceived stimulus source location azimuth (as identified by the listener) and that of the actual stimulus source azimuth.

4.5 Procedures

After the initial audiometric screening, all participants were familiarized with the listening task prior to initiation of their first block. Each participant was then fitted properly with the appropriate TCAPS/Helmet system. Participants listened to blocks of stimuli that consisted of all trials for a particular head condition. Each block lasted approximately 25 min. Participants were given breaks between blocks to reduce the effects of fatigue. Additionally, each trial was initiated by the participant, so additional breaks could be taken if needed.

4.6 Data Analysis, Results, and Discussion

Our objective was to measure the effects of the new helmet/TCAPS on auditory localization ability relative to that with the bare head as a measure of SA. Localization errors made in this study were calculated as both signed (constant) and unsigned azimuth errors. Signed error contains information about both the magnitude and the direction of an error. Average signed error can reveal underlying distortions of the auditory space stemming from the acoustics of the equipment or the test space itself. However, when taken as an average, signed data underestimates overall localization errors, because errors in opposite directions cancel each other out. Thus, the average signed errors do not allow us to evaluate judgment precision (random error), which is reflected by the standard deviation of localization responses (Hartmann, 1983).

Average unsigned error gives a better estimate of the magnitude of error and precision; therefore, both types of error will be discussed.

Two-factor analyses of covariance (ANCOVA) were conducted for the signed (table 2) and unsigned azimuth (table 3) error with the independent variables being head condition and sound source azimuth. Subject ID was included as a covariate in order to account for individual differences. Polar plots of the signed errors as a function of the TCAPS/helmet worn and the sound source azimuth were also calculated (figure 14). In the signed error data, negative errors indicate the subject estimated the sound source estimate was closer to the front (0°), than the actual target location. Positive errors mean that the estimate was farther to the rear than the actual target location. If localization errors are driven by lack of precision, estimates will fall on either side of the target location and on average cancel out. Using average signed data will obscure any real differences in the magnitude of errors occurring for the various helmets. This is not to suggest that all errors are likely to be cancelled out. Differences due to an increase in front-back confusions will result in an increase in positive errors near 0° and an increase in negative errors near 180°. Even with no TCAPS present, it is normal to observe some differences in error as a function of azimuth, due to front-back confusions.

Table 2. Significant ANCOVA results for signed azimuth error ($\alpha < 0.05$).

Source of Variance	**df**	**F**	**ρ**
TCAPS/Helmet Condition	4	65.8	0.000
Azimuth	15	521.1	0.000
TCAPS/Helmet Cond × Azimuth	60	26.4	0.000
Error	8409	1560.1	—

Table 3. Significant ANCOVA results for unsigned azimuth error ($\alpha < 0.05$).

Source of Variance	**df**	**F**	**ρ**
TCAPS/Helmet Condition	4	277.5	0.000
Azimuth	15	197.2	0.000
TCAPS/Helmet Cond × Azimuth	60	12.1	0.000
Error	8409	1522.9	—

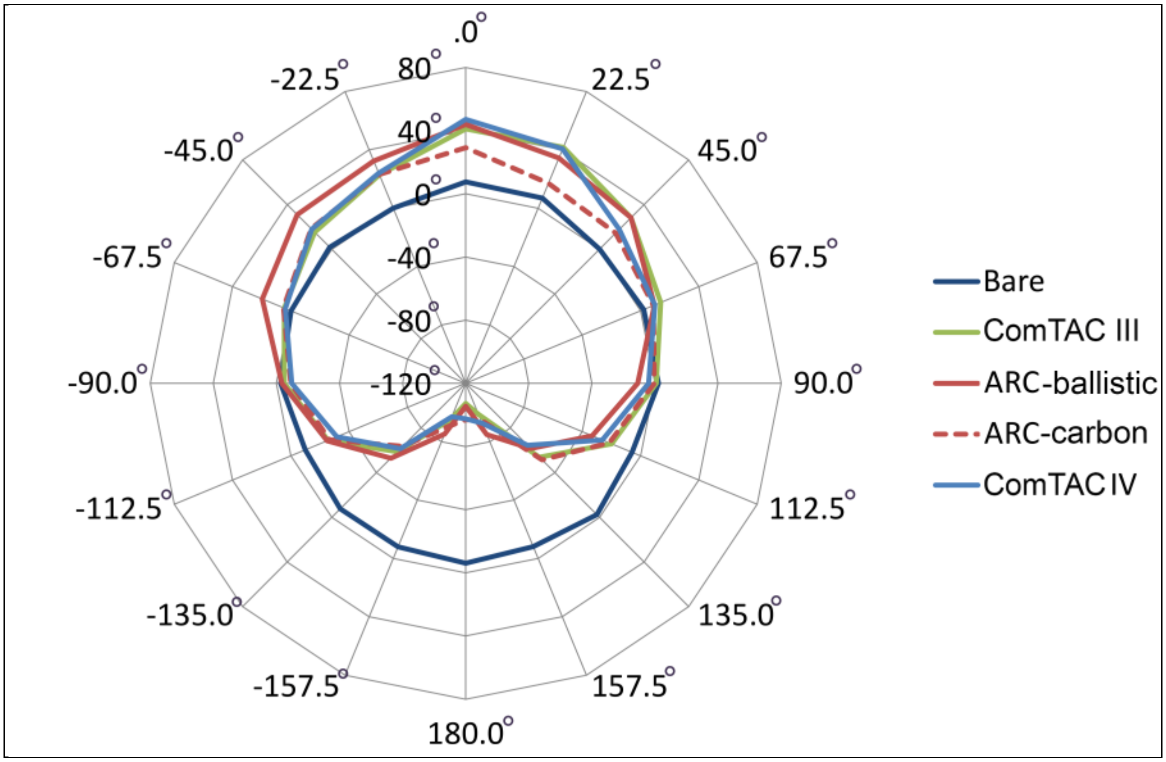

Figure 14. Polar plot showing signed azimuth error as a function of TCAPS/helmet condition and azimuth. Labels indicate degree azimuth. Concentric rings indicate error. Bare indicates the bare head, without any TCAPS.

Wearing the TCAPS and helmet altered one's ability to localize sounds. There was a significant main effect for TCAPS/helmet condition for the signed azimuth error data, $F(4, 8409) = 65.8$, $p < 0.01$. The contrast of localization with a bare head versus any TCAPS/helmet combination was significant, $F(4,8409) = 65.8$, $p < 0.01$. The difference between localization performances with the two helmet types ComTAC III ARC-ballistic and ComTAC III ARC-carbon, was also significant, $F(1, 3420) = 10.0$, $p < 0.01$. As expected, there was a main effect for sound source azimuth, $F(15, 8409) = 521.1$, $p < 0.01$, as well as an interaction between TCAPS/helmet condition and sound source azimuth, $F(60, 8409) = 26.4$, $p < 0.01$. Larger errors were observed when wearing TCAPS/helmet (figure 14); specifically there were increased positive errors in the front near 0°, and increased negative errors in the rear near 180°. The differences between the different TCAPS/helmet conditions were not significant ($p > 0.5$).

The signed error data allows us to detect any biases that would signal problems with the measurement method or acoustics of the facility. The data shown here are symmetric relative to the midline and include some small differences between the left and right hemispheres, suggesting the errors are idiosyncratic and not of practical importance.

There were significant main effects of TCAPS/helmet condition and sound source azimuth [$F(4, 8409) = 277.5$, $p < 0.01$; $F(15, 8409) = 197.2$, $p < 0.01$] (figures 15, 16, and 17). The interaction of TCAPS/helmet condition and azimuth was also significant [$F(60, 8409) = 12.1$, $p < 0.01$]. As before, the differences between the bare head and all of the TCAPS/helmet conditions were significant ($\alpha < 0.05$) and the difference in unsigned localization error for the two helmet types is also significant [$F(4, 8409) = 277.5$, $p < 0.01$]. The pattern of error values, larger near 0° and 180°, is consistent with what would be expected if TCAPS/helmet use were causing front−back confusions. The carbon helmet seems to reduce the average size of errors near 0°, but this difference is small. The practical impact of this difference may not be significant due to the fact that visual feedback may reduce these errors.

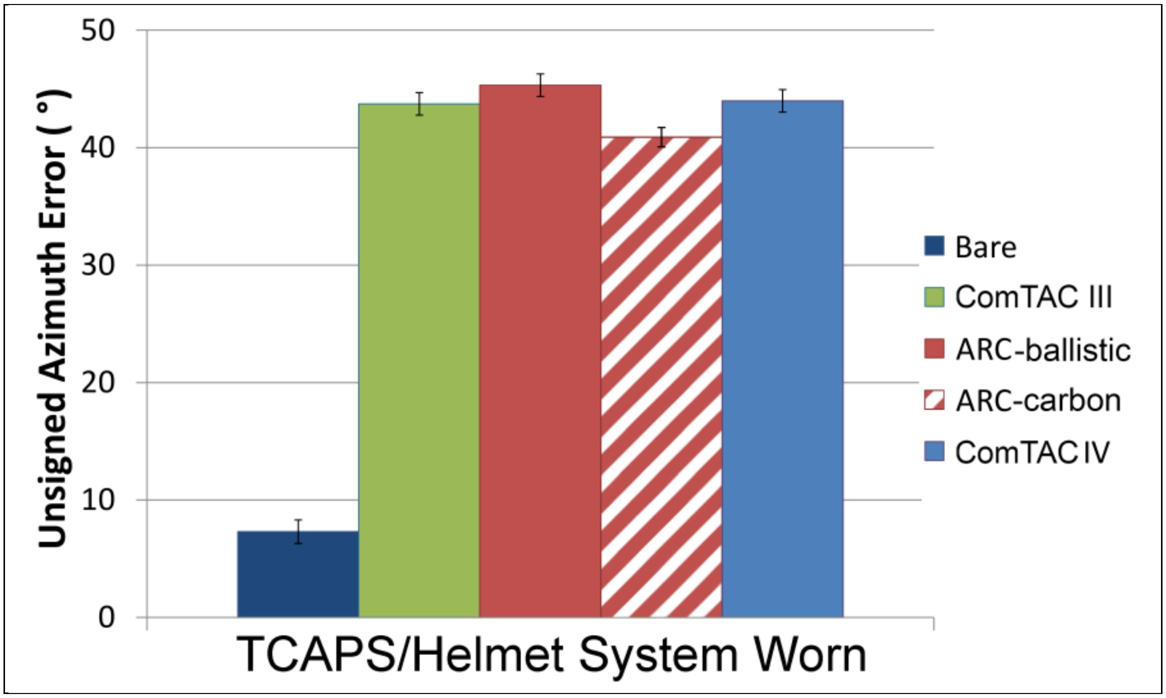

Figure 15. Average unsigned azimuth error as a function of head condition. Error bars represent ±1 standard deviation.

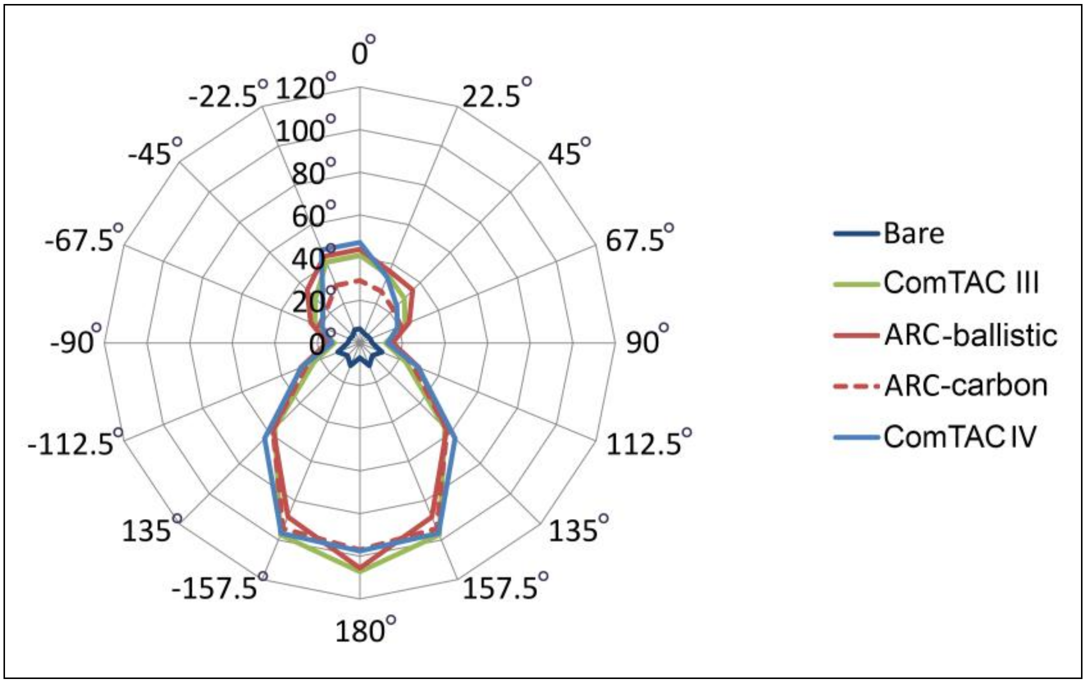

Figure 16. Polar plot showing unsigned azimuth error as a function of TCAPS/helmet condition and azimuth.

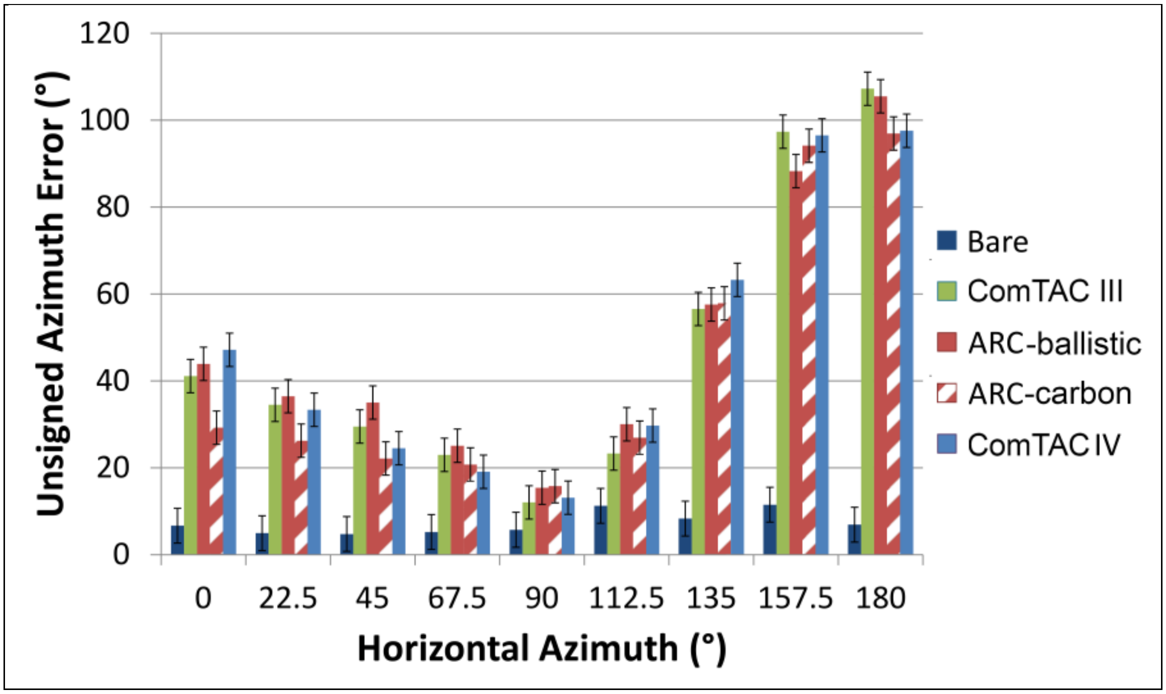

Figure 17. Unsigned azimuth error as a function of TCAPS/helmet condition and lateral azimuth (collapsed across hemispheres). Error bars represent ±1 standard deviation.

5. Summary and Conclusions

Three variants of the 3M Peltor ComTAC TCAPS were evaluated for their attenuation of steady-state and impulse noise and their effect on auditory localization as a measure of SA. Measurements of attenuation of steady-state noise show that when the devices' SA microphones were set at the highest amplification levels, ambient noise presented at 85 dB A was amplified and exceeded the 85 dB A level at the ear. However, when the noise level was 105 dB A, the SA microphones shut off transmission to the ear, regardless of the amplification setting.

Measurements of impulsive noise attenuation show that all the TCAPS provided at least 25 dB of attenuation when impulsive noise of approximately 154 dB peak was recorded with the SA microphones off and at the lowest amplification setting. When the SA microphones were active and in their lowest setting, transmission of impulse noise was not measurable, providing attenuation equivalent to that of passive attenuation. Of the three types of earplug types tested for the ComTAC IV, the Skull Screw style provided the greatest attenuation.

Measures of the effect of TCAPS on auditory localization suggest that there was little difference between the devices effects on localization performance. The devices were worn in combination with two Ops-Core FAST helmets (ballistic and carbon), and of these two, the carbon helmet produced fewer front to back reversals. The lighter weight carbon helmet had ventilation holes in its surface and this may have reduced the disruption of monaural cues as compared to the ballistic helmet.

Overall, performance of the ComTAC III ARC was equivalent to the ComTAC III. The ComTAC IV (earplug style) TCAPS provided greater passive attenuation of noise as compared to the ComTAC III and ComTAC III ARC (earmuff style) TCAPS. This is consistent with the typical laboratory-obtained NRR values advertised for earplug style hearing protection as compared to earmuff style hearing protection (Williams, 2008). However, the ComTAC IV did not have the advantage in terms of auditory localization that has been found for earplugs in previous studies (Scharine, 2005), most likely because the earmuff-like platform was similar to normal earmuffs.

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List of Symbols, Abbreviations, and Acronyms

ACH	Advanced Combat Helmet
ANCOVA	analyses of covariance
ANOVA	analysis of variance
ARC	Accessory Rail Connector
ARL	U.S. Army Research Laboratory
ATF	Auditory Test Fixture
EAR	Environment for Auditory Research
FAST	Future Assault Shell Technology
FP	foam earplugs
HL	hearing level
NRR	noise reduction rating
PINS	pneumatic impulse noise source
SA	situational awareness
TCAPS	Tactical Communication and Protection System

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