ARMY RESEARCH LABORATORY

Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPS) Part III – Auditory Localization

by Paula P. Henry

ARL-TR-6560 August 2013

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

ARL-TR-6560 **August 2013**

Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPS) Part III – Auditory Localization

Paula P. Henry
Human Research and Engineering Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
August 2013	Final	July 2010 – March 2013

4. TITLE AND SUBTITLE

Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPS) Part III – Auditory Localization

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Paula P. Henry

5d. PROJECT NUMBER

62716AH70

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: RDRL-HRS-D
Aberdeen Proving Ground, MD 210055425

8. PERFORMING ORGANIZATION REPORT NUMBER

ARL-TR-6560

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Devices that provide hearing protection, situational awareness and radio communications are often referred to as Communications and Hearing Protection Systems (C&HPS). Soldiers use these systems to maintain auditory awareness within their environment, communicate with their team members and protect their hearing. Each of the three features of select C&HPS (hearing protection, speech communication and situational awareness) were independently evaluated by the U.S. Army Research Laboratory (ARL). This report is the third in a series of three and focuses on the auditory localization performance obtained from two commercially available C&HPS: Nacre QuietPro and Silynx QuietOps. These two systems were selected from three C&HPS evaluated for attenuation characteristics in the first report and speech intelligibility in the second report; the third system provided insufficient attenuation to be included. Results of the auditory localization testing indicated that both C&HPS negatively affected auditory localization accuracy performed in background noise, but the observed decrement was not significantly different between the two systems. Evidence from objective measures of the systems such as directivity, calculation of interaural level differences (ILDs), and the measurement of input/output functions indicate that changes in binaural intensity difference cues were the primary factor driving the reduction in performance.

15. SUBJECT TERMS

auditory localization, communications systems

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Paula P. Henry
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*Include area code*)
Unclassified	Unclassified	Unclassified	UU	40	(410) 278-5848

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

Acknowledgments

The author wishes to thank the individuals who voluntarily participated in the study and the three technical reviewers (Frank Morelli, Jeremy Gaston, and Mary Binseel) for providing helpful comments and suggestions for improving this report. The author would also like to thank Timothy Mermagen for creation of the software for data collection and for providing invaluable assistance in obtaining the acoustic measures of the C&HPS. Photographs of the devices used in this study were taken by Ron Carty, U.S. Army Research Laboratory.

1. Introduction

Dismounted Soldiers need to hear what is happening within their immediate surroundings (have situational awareness), communicate with other Soldiers over radios, and be protected from hazardous continuous and impulse noise (hearing protection). These three hearing aspects are essential for dismounted Soldiers and can be seen as conflicting goals for the development of multipurpose communication devices. One of the biggest challenges for developers is maintaining a balance between hearing protection and the need for auditory situational awareness. Hearing protection devices that cover or plug the ears (like earmuffs or earplugs) will provide hearing protection and good radio communication, but they are likely to reduce the situational awareness of the individual Soldier. Leaving the ears open allows for good situational awareness but does not protect against hazardous noise. Providing all three aspects within a single device can be very challenging.

There are several devices available, which are intended to provide hearing protection, yet still allow for adequate situational awareness (talk-through microphones) and radio communications. These devices are often referred to as Communications and Hearing Protection Systems (C&HPS). The Army needs objective information on how these systems function in a militarily relevant environment in order to determine the types of devices that should be provided to Soldiers, as well as to determine appropriate areas for research that can improve the effectiveness of these devices.

In the evaluation of C&HPS, the three auditory aspects that need to be evaluated are attenuation provided for hearing protection, speech intelligibility of radio communications, and auditory localization as a measure of situational awareness through the talk-through microphones. Sound attenuation of these devices can be provided to the user through passive or active means. Passive attenuation is provided by the mere presence of the device in the ear without any processing of the sound. Active attenuation cancels or reduces the background noise by introducing a signal, which is opposite in phase to cancel out the first sound (Kuo and Morgan, 1999; Oppenheim et al., 1994). Active noise processes are referred to as active noise cancellation (ANC) or active noise reduction (ANR). A popular implementation of ANR is in headphones, such as those marketed to frequent fliers for listening to music on airplanes. ANR is much better at reducing low-frequency noise than high-frequency noise.

The goal of the first part (Henry and Weatherless, 2010a) of the three-part study was to measure the passive sound attenuation provided by three in-the-ear C&HPS using Method A (experimenter fit) of the Real-Ear Attenuation at Threshold (REAT) procedure (ANSI, 2002). The values obtained were intended to demonstrate best case scenario attenuation from the products but will provide overestimates of the real-world performance of these devices (Berger, 1986; Franks et al., 2000; Royster et al., 1996).

Three C&HPS were evaluated in that portion of the study: the Nacre QuietPro,* the Silynx QuietOps,† and the Sennheiser SLC-110. The Sennheiser SLC-110 was found to provide very low levels of attenuation and concerns were raised that for at least some participants, the system may not provide adequate hearing protection in the presence of the planned level of background noise of 95 dBA for the third part of the study. Therefore, the Sennheiser SLC-110 was dropped from the present portion of the study.

The goal of the second part (Henry and Weatherless, 2010b) of the three-part study was to measure speech intelligibility across radio communications of the C&HPS (ANSI, 1999). Results of the second part indicated that the Silynx QuietOps provided a significantly higher degree of speech intelligibility than the other two systems, but the difference would probably not affect mission performance (Henry and Weatherless, 2010b). The differences noted in speech intelligibility are likely due to a combination of differences in the frequency responses measured from the earphones of the two systems, differences in the frequency responses of the microphones from the two systems, and small differences in the output intensity of the speech items provided to the listeners.

The goal of the current and final part of this three-part study was to measure auditory localization in the presence of background noise and compare the performance of two C&HPS to a baseline Barehead condition (when not wearing C&HPS).

1.1 Communications and Hearing Protection Systems

Two C&HPS were used for the auditory localization testing: the Nacre QuietPro and the Silynx QuietOps. Descriptions of the two systems follow.

1.1.1 Nacre AS – QuietPro

The Nacre QuietPro system is an in-the-ear digital hearing protector and communications headset designed for use with military tactical radios and intercom systems. A picture of the device is shown in figure 1. Nacre AS, originally based in Norway, is now a subsidiary of Honeywell International Inc. The QuietPro system uses a digital signal processor to facilitate automatic, adaptive digital hearing protection through active noise reduction in addition to its passive attenuation. According to the manufacturer, the QuietPro system helps protect the user's hearing by attenuating ambient noises and canceling excessive acoustic peaks and impulses, resulting from nearby running engines, explosions, and gun shots. Nacre states that by using both passive and active means, the QuietPro system can achieve 34–42 dB of attenuation, but there is no differentiation regarding the attenuation provided to continuous noise levels versus that provided for impulse noise. The talk-through mode of the Nacre QuietPro system has 10 volume control steps. The device was set for the fifth step in the volume selections; when fit to participants, this was deemed to be a typical user setting.

---

* QuietPro is a registered trademark of Honeywell International Inc.

† Silynx QuietOps is a trademark of Silynx Communications, Inc.

The device is fit in the ear with disposable Comply* canal tips that were specifically designed for use with the QuietPro system. The Comply tips are available in three sizes: small, medium, and large. Information about the system can be obtained from <www.honeywellsafety.com/quietpro/>.

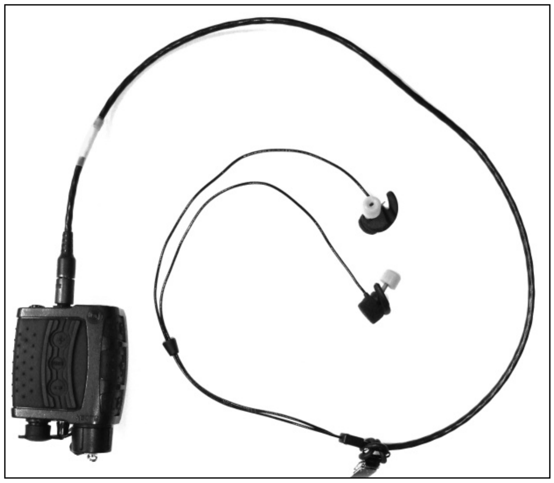

Figure 1. Photo of the Nacre QuietPro system.

1.1.2 Silynx Communications, Inc.–QuietOps

The Silynx QuietOps system is an in-the-ear tactical communications headset designed for use by dismounted Soldiers. A picture of the device is shown in figure 2. Silynx is a Delaware corporation whose principal location is in Rockville, MD. The QuietOps system allows users to monitor one or two communications devices simultaneously—two radios or one radio and an intercom. The device allows the user to determine which communication channel has priority, or the user can program the device to have each communication device go to a different ear. The QuietOps is fit to the listener's ear with a compressible foam plug that mounts onto the end of the device. The foam plugs are disposable and come in three sizes: small, medium, and large. No information is provided from the company regarding attenuation. Information about the system can be obtained from: <http://www.silynxcom.com/>. The talk-through mode of the Silynx QuietOps system has five volume control steps. The device was set for the third step in the volume selections; when fit to participants, this was deemed to be a typical user setting.

* Comply is a trademark of Hearing Components, Inc.

Figure 2. Photo of the Silynx QuietOps system.

1.2 Auditory Localization with Hearing Protection Devices (HPDs)

Auditory localization is the ability to identify a sound source's location in space. Identification of the sound source location is accomplished through a perceptual analysis of the differences in information received by the two ears, termed binaural difference cues (Blauert, 2001). There are two primary types of binaural difference cues: interaural level differences (ILDs) and interaural time differences (ITDs). ILDs refer to the differences in the intensity levels of sounds arriving at the two ears; sounds arriving from one side of the head will be higher in intensity to the ear closest to the sound and lower to the ear farthest from the sound. ILDs are most important in the accurate localization of high-frequency signals. ITDs refer to the differences in time of arrival for sounds traveling to the two ears; sounds will arrive at the closer ear earlier than the farther ear. ITDs are most important for the accurate localization of low-frequency signals.

Studies have suggested that a third cue (spectral) may also assist in auditory localization, although its influence is seen most often in the vertical plane (Gardner and Gardner, 1973; Hofman et al., 1998). Several researchers have hypothesized that spectral information allows listeners to fine-tune the location of a sound source when ILD and ITD information is obscured or inconclusive—as is the case of the cone of confusion when two locations about the interaural axis have the same ILD and ITD information (Jin et al., 2004).

Changes to binaural cues can negatively affect a listener's ability to accurately identify a sound source's location. Binaural and spectral cues can be altered by HPDs in a passive way through covering, plugging, or obscuring the pinnae and outer ears, or in an active way through applying digital signal processing to the signals received by the two ears. The resulting decrements in auditory localization accuracy vary based on the degree to which changes are made. Presumably, greater changes in binaural cues should result in a greater effect on auditory localization accuracy.

Optimal auditory localization precision is estimated to be approximately 2° in the frontal horizontal plane near 0° (directly in front of the listener) with precision decreasing as the sounds are presented toward the sides or rear of the listener to a value of 10^{o} or more (Bronkhorst, 1995; Makous and Middlebrooks, 1990).

Investigators have found that when listeners use active or passive HPDs, in the form of either earplugs or earmuffs, the accuracy of their auditory localization decreases significantly (Abel and Hay, 1996; Atherley and Noble, 1970; Bolia et al., 2001; Carmichel et al., 2007; Noble and Russell, 1972; Vause and Grantham, 1999). In theory, for localization within the horizontal plane, if the amount of attenuation and active signal processing is applied equally to sounds arriving at each ear, then ILDs should be maintained. Similarly, unless there is an active process applied to change the ITDs, those should also be maintained. If ITDs and ILDs are maintained, then the addition of HPDs should have no affect on auditory localization; however, research findings indicate that although equivalent attenuation may be provided, changes to spectral cues contribute to some of the change in auditory localization accuracy. This notion is supported by the evidence that earmuffs have a greater effect on auditory localization than earplugs due to the presumed interruption of spectral cues (Noble and Russell, 1972).

In summary, both passive and active signal processing have the potential to affect binaural cues and decrease auditory localization abilities. In the case of C&HPS, both passive and active processes are present, which can alter a listener's ability to accurately identify the location of a sound.

1.3 Altered Auditory Cues

When alterations are made to the normal binaural and spectral cues provided to a listener, auditory localization accuracy decreases. Research suggests that listeners can adapt to the altered cues that are provided and improve their localization performance over time (Bauer et al., 1966; Butler, 1987; Hofman and Van Opstal, 2003; Hofman et al., 1998; Javer and Schwarz, 1995; Musicant and Butler, 1980; Van Wanrooij and Van Opstal, 2005; Wenzel et al., 1993).

Using altered auditory cues can be challenging to the listener. Bauer et al., (1966) found that putting a passive earplug in someone's ear diminished the participant's localization accuracy. However, allowing them to use the altered binaural cues resulted in improvements in performance over time; further, training sped up the process of learning. Other investigators have demonstrated similar effects with passive earplugs (Bauer et al., 1966; Bolia et al., 2001; Hofman et al., 1998).

In addition to passive alterations, active processes have been used to impose changes to binaural cues. For example, Javer and Schwarz (1995) used hearing aids to introduce a timing delay to sounds arriving at the two ears in listeners with normal hearing. Although the additional time delay caused initial decrements in auditory localization accuracy, these decrements were diminished over the course of hours and days in which listeners were able to adapt to the cues.

It is worth noting that one early study found that no learning took place among their participants, regardless of training provided (Russell, 1977). Russell placed passive earmuffs on listeners and had them identify the location of sounds in the horizontal plane. Even with specific feedback and training, listeners were not able to significantly improve their localization accuracy over time. The failure to find an effect suggests that the binaural changes introduced by the earmuffs were too great for the listeners to adapt.

Much like passive and active hearing protectors, C&HPS can affect auditory localization, and this is especially important for the dismounted Soldier. Dismounted Soldiers are often exposed to noise and impulse sounds. They often have the need to utilize a communications system in addition to hearing protection. The incorporation of active signal processing in addition to the changes in normal binaural cues due to the placement of HPDs in someone's ears can decrease situational awareness by a greater degree than wearing passive HPDs alone. The present study explored auditory localization ability in the horizontal plane for two C&HPS along with objective measures of some of the active signal processing that occurs through these devices.

2. Methods

2.1 Directivity Measures

Directivity measures demonstrate the degree to which the device is more sensitive to sounds arriving from the front or side than from the back or opposite side. Directivity measures were made for the two C&HPS systems on a KEMAR manikin, as well as a Barehead condition. The KEMAR manikin is an acoustic test fixture manufactured by G.R.A.S. All measures were made in the Dome Room of the Environment for Auditory Research (EAR). The KEMAR was placed in the chair located at the center of the room at the same elevation as the average participant. The KEMAR was positioned to face the loudspeaker designated as 0° and a burst of white noise at a level of 75 dBA (as measured by a sound level meter in the center of the room with the KEMAR absent) was output from each of the 90 Meyers Sound loudspeakers located every 4° in the horizontal plane around the room. In the Barehead condition, no C&HPS was placed on the KEMAR. For each of the C&HPS measurements, the C&HPS was fit to both ears of the KEMAR, and the volume control settings were set the same as in the data collection portion of the study.

Recordings of a burst of white noise were made from sounds emitted from each loudspeaker and analyzed in one-third octave bands. Figures 3–5 show the polar plots for bands centered on 2, 4, and 8 kHz. Figure 3 shows the polar plot of the left ear from the bare head of the KEMAR, which served as the baseline for comparison to directivity patterns seen with the C&HPS. The values on the concentric circles in each plot are relative to the value measured at 0^{o} (directly in front of the manikin). Figures 4 and 5 show the polar plots of the left ear as measured through each of the C&HPS devices. The values on the concentric circles are relative to the intensity level measured at 0º. As seen in figures 3–5, the directivity with the C&HPS was much different from that obtained in the Barehead condition.

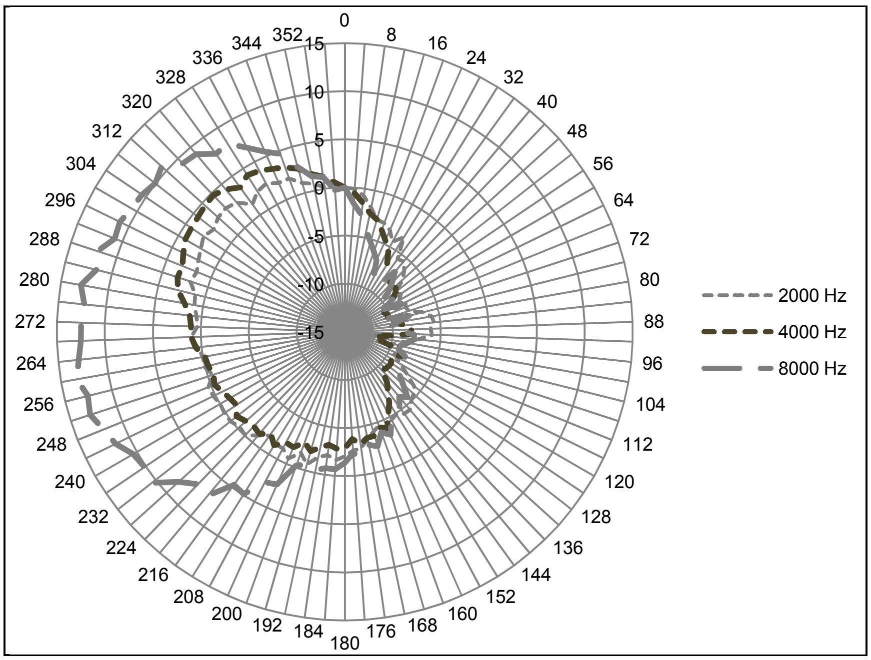

Figure 3. Polar plot of the left ear of the KEMAR in the Barehead condition. Values on the concentric circles are relative to that measured at 0^{o}. Numeric labels indicate every 8^{o} for reading clarity.

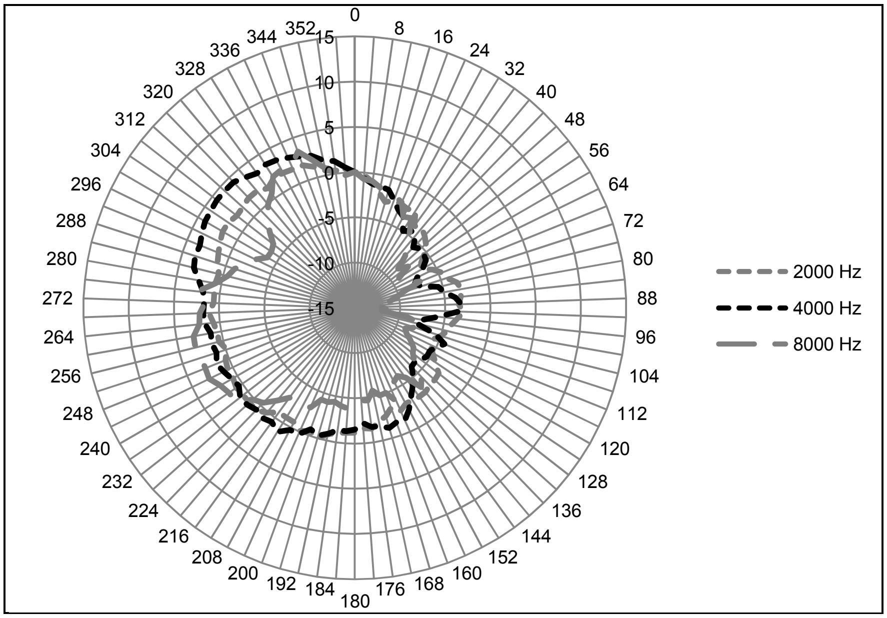

Figure 4. Polar plot of the left ear of the KEMAR through the Silynx QuietOps C&HPS inserted in the manikin. Axes are the same as figure 3.

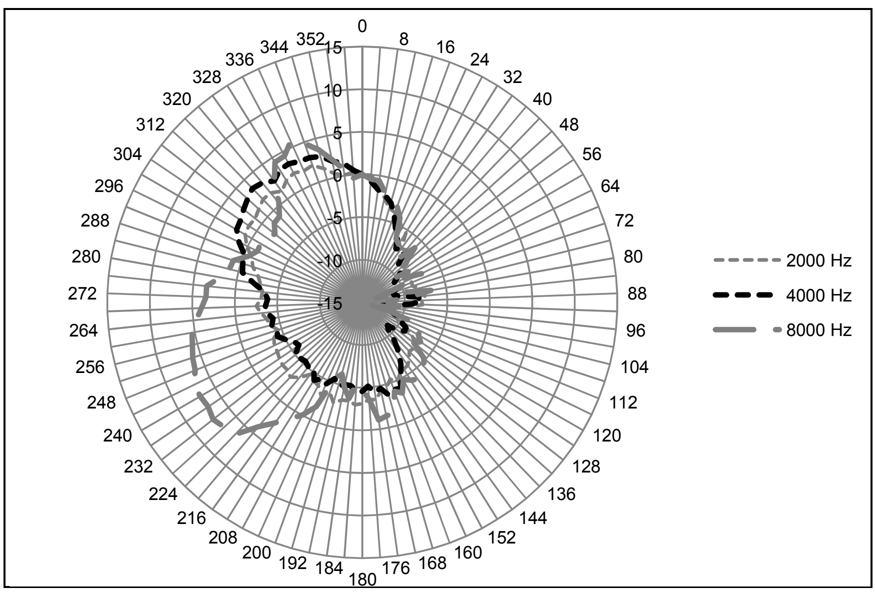

Figure 5. Polar plot of the left ear of the KEMAR through the Nacre QuietPro C&HPS inserted in the manikin. Axes are the same as figure 3.

Auditory localization is accomplished through the internal comparison of interaural level and timing differences. The calculation of ILDs can be accomplished by determining the difference in level at the two ears for each sound source location. The ILD changes systematically as the sound is moved around the manikin.

Figures 6–8 show the ILDs across all measured angles for the three conditions: Barehead, QuietOps, and QuietPro. The angle of the source location is located on the x-axis.

The ILD is located on the y-axis with positive values indicating a higher value in the right ear and negative values indicating a higher value in the left ear. As shown in the figures, the ILDs are largest and, therefore, most salient for the Barehead condition with maximum ILDs occurring across the range of 40–130° for the 8000-Hz band. The magnitude of the ILD is diminished in both C&HPS along with a reduced range of angles where a maximum ILD exists. The decrease in ILD likely contributes to reduced accuracy in localization performance. The ILDs for the QuietOps C&HPS were smaller than the Barehead condition and the QuietPro C&HPS fell between the two.

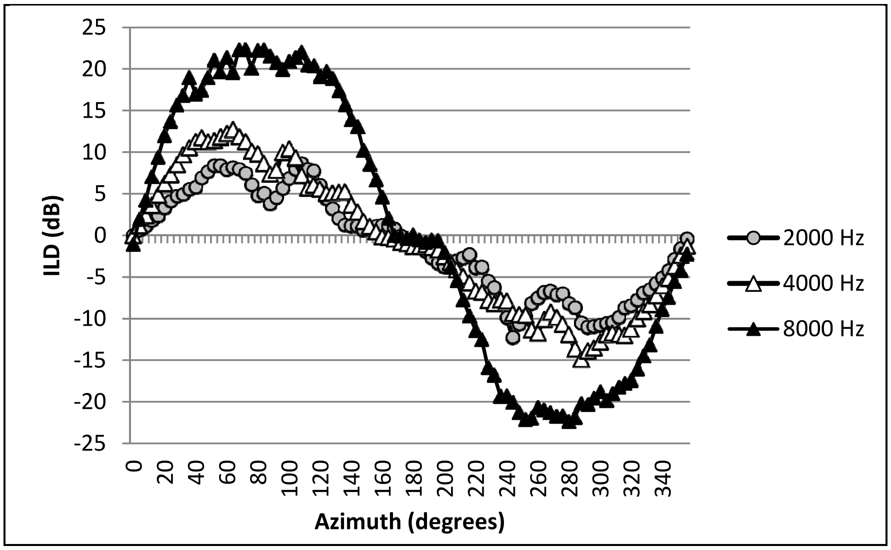

Figure 6. ILDs for the Barehead condition. Azimuth refers to the loudspeaker location beginning at 0° and increasing in a clockwise manner.

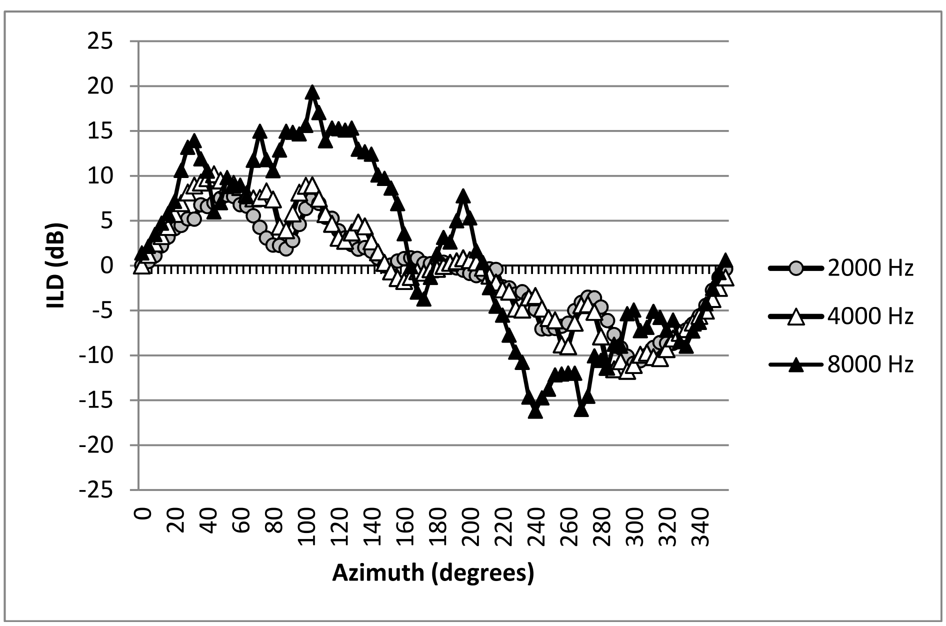

Figure 7. ILDs for the QuietPro C&HPS. Axes are the same as in figure 6.

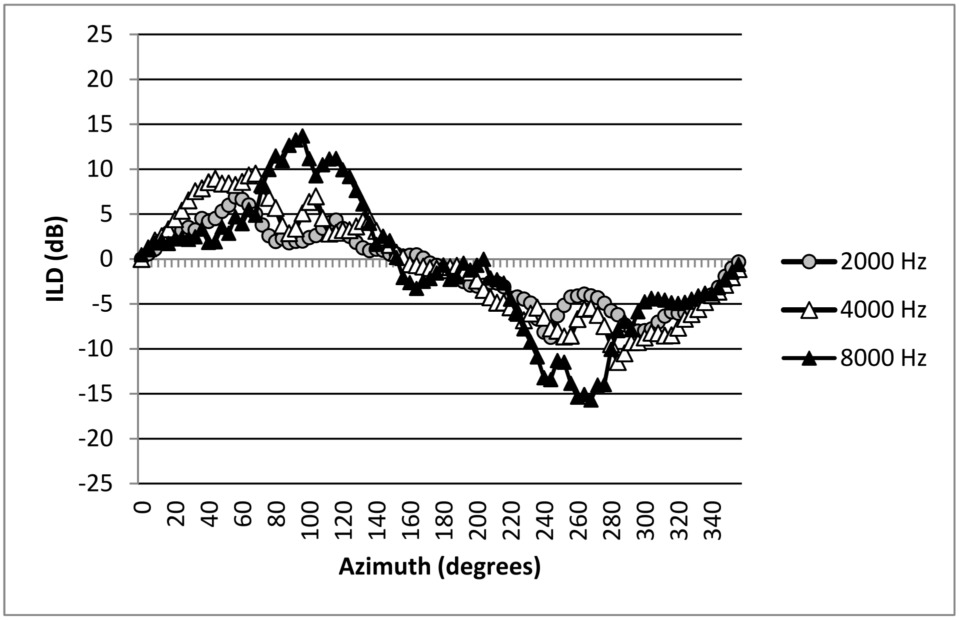

Figure 8. ILDs for the QuietOps C&HPS. Axes are the same as in figure 6.

2.2 Input/Output Measures

Measurements were made on the KEMAR of the output of the C&HPS devices in response to a range of intensity inputs to determine if the talk-through system was providing amplification and whether or not they were incorporating signal processing, such as amplitude compression. The C&HPS devices were placed on the KEMAR, and the volume controls were set at the same levels they were set for the data collection portion (approximately 1/2 volume). Figures 9–11 show the input/output curves for the Barehead condition, as well as each of the C&HPS.

Figures 9–11 show the input/output functions for the three listening conditions for input stimuli that range from 50–100 dBA in 10-dB steps. The input intensity level was measured through a sound level meter placed in the center of the room with the KEMAR absent. Input/output functions were measured for each of three angles: 0, 90, and 270^{o}. The initial input/output function measured at 0^{o} shown in figure 9 serves as a baseline for comparison to figures 10 and 11, which are measured from the sides of the manikin. Output values that fall above the linear reference indicate that the output intensity level of the system as measured in KEMAR is higher than the input signal. Higher output values of 3–6 dB are expected in the Barehead conditions due to the addition of the head-related transfer function and ear canal resonance to the original signal (Shaw, 1974). Output values that exceed 6 dB above the Barehead conditions indicate amplification within the system. Conversely, output values that fall below the reference level indicate a decrease from the input signal or attenuation. The lower output level can occur when the input signal is on the opposite side of the manikin from the ear being measured or when attenuation is provided through the C&HPS.

Assuming that the KEMAR is directly centered in the room and facing the loudspeaker at precisely 0°, the intensity levels arriving to the two ears should be equivalent regardless of intensity level. When differences are noted in the intensity levels between the two ears, they are due either to the position of KEMAR not being in the center of the room, due to KEMAR not directly facing the loudspeaker at 0°, or a result of signal processing taking place in the C&HPS.

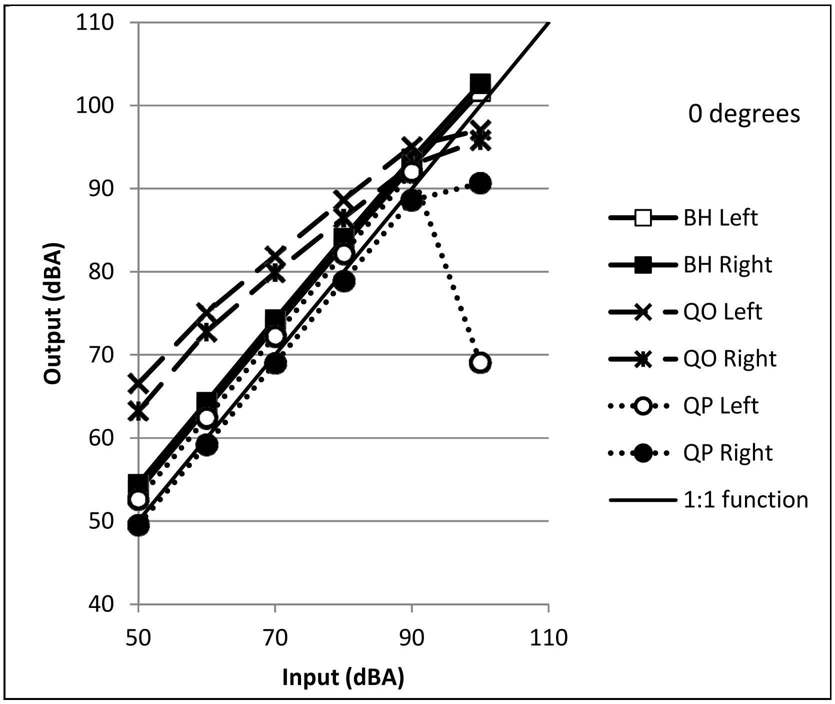

Figure 9. Input/output function for the three listening conditions for the 0° source location; BH = Barehead, QP = QuietPro, QO = QuietOps. The solid line represents linear performance.

Figures 10 and 11 should be mirror images of each other with the right ear favored in figure 10 and the left ear favored in figure 11.

Therefore, the Barehead conditions serve as baselines against which the C&HPS should be compared. In all three figures, the input/output functions for both ears in the Barehead condition follow the linear reference. In figures 10 and 11, the Barehead condition follows the linear reference with higher outputs in the ear closest to the source. Figure 10 shows higher inputs to the right ear when the source is directly facing the right ear at 90°. Figure 11 shows higher inputs to the left ear when the source is directly facing the left ear at 270°.

The results for the C&HPS systems vary substantially from those obtained through the Barehead condition. First, the QuietOps system appears to be providing amplification to signals received to the wearer. This is shown in the consistently higher output levels shown with the dashed lines as compared to the Barehead condition shown with the solid lines. In contrast, the QuietPro system appears to be reducing or attenuating the signal provided to the listener in comparison to what would be received in the Barehead condition.

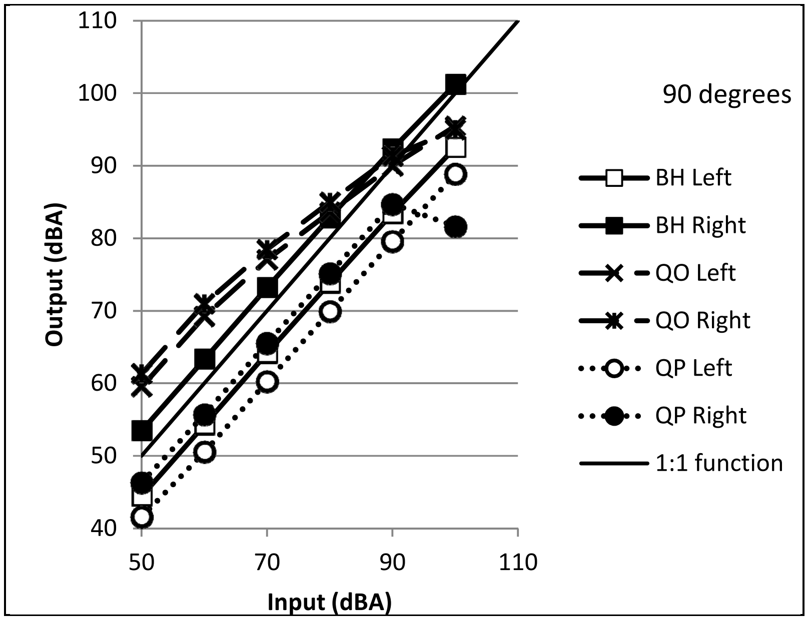

Figure 10. Input/output function for the three listening conditions for the 90° source location (facing the right ear). Symbols are the same as figure 9.

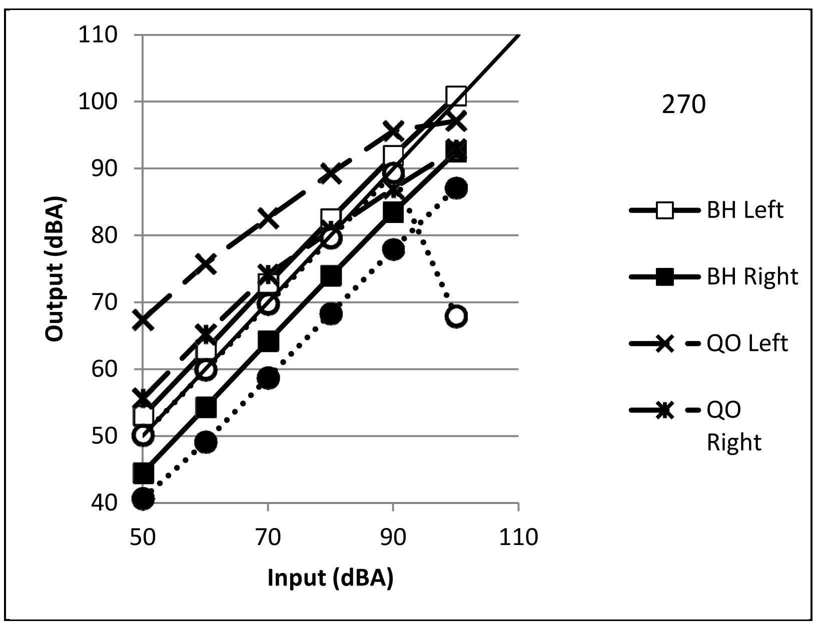

Figure 11. Input/output function for the three listening conditions for the 270° source location (facing the left ear). Symbols are the same as figure 9.

Examination of the higher input levels reveals that the C&HPS appear to incorporate output limiting as compared to what is received in the Barehead condition. The QuietPro appears to have an output limit of approximately 90 dBA, and the QuietOps appears to have an output limit of approximately 95 dBA.

The input/output function for the QuietPro system is essentially linear, but the input/output function for the QuietOps system reflects the application of amplitude compression in its signal processing.

Compression ratios were calculated from the recordings made from directly in front of the manikin to determine the extent of any amplitude compression being incorporated into the C&HPS. The compression ratio was calculated as the change in the input divided by the change in the output for the input range of 60– 90 dB, as this appeared to be the most stable range for calculations (Dillon, 2001). The compression ratio for the Barehead condition was 1:1. For the C&HPS, the compression ratios were 1.02:1 and 1.5:1 for the QuietPro and QuietOps, respectively.

It is worth noting that there is a concern with the measurement made of the QuietPro system. In examining the input/output function, there appears to be a drop in output in one or both ears for an input of 100 dBA. For the two side incidences (90 and 270°) the output level measured in the ear closest to the sound was reduced. In the frontal incidence (0°), the output level in the left ear dropped. Figures 12–20 show the waveforms from the recordings made through each C&HPS.

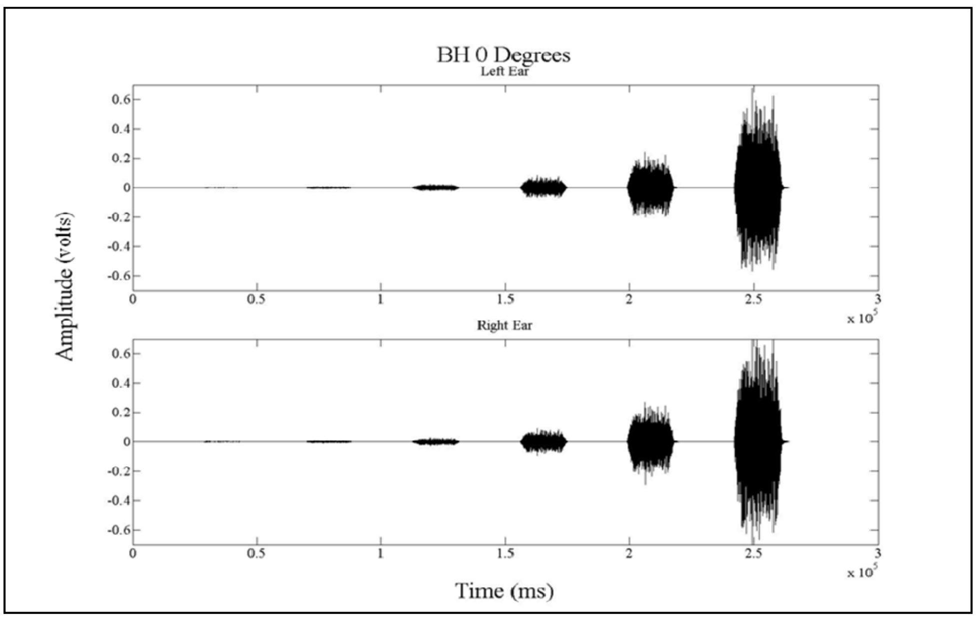

Figure 12. Waveforms of recordings made through the Barehead KEMAR for input intensities 50–100 dBA in 10-dB steps (left to right). The loudspeaker was located at 0^{o} azimuth.

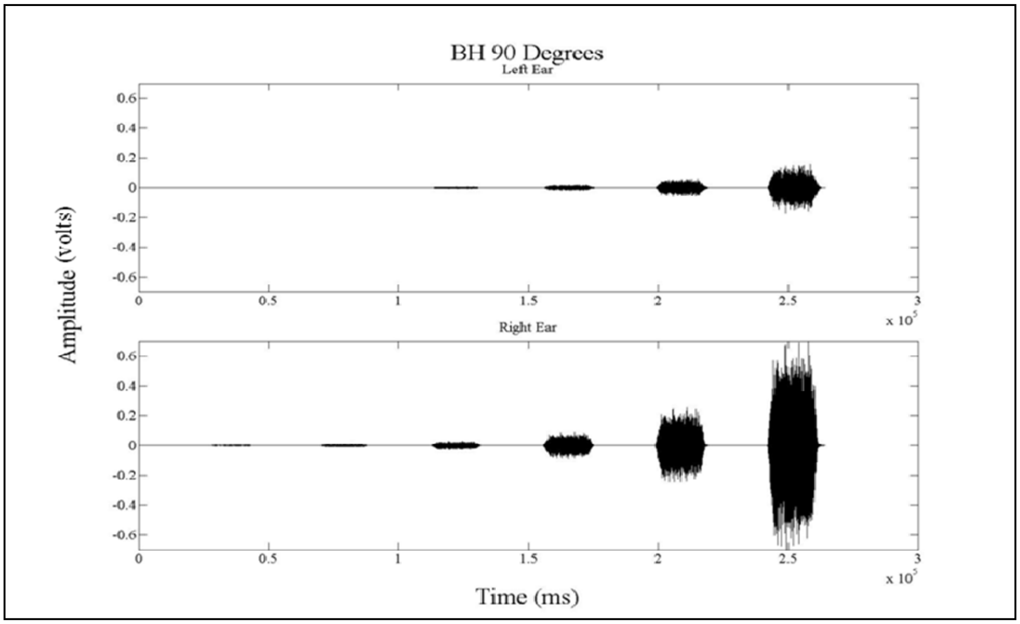

Figure 13. Waveforms of recordings made through the Barehead KEMAR for input intensities 50–100 dBA in 10-dB steps (left to right). The loudspeaker was located at 90^o azimuth, directly to the right of the manikin.

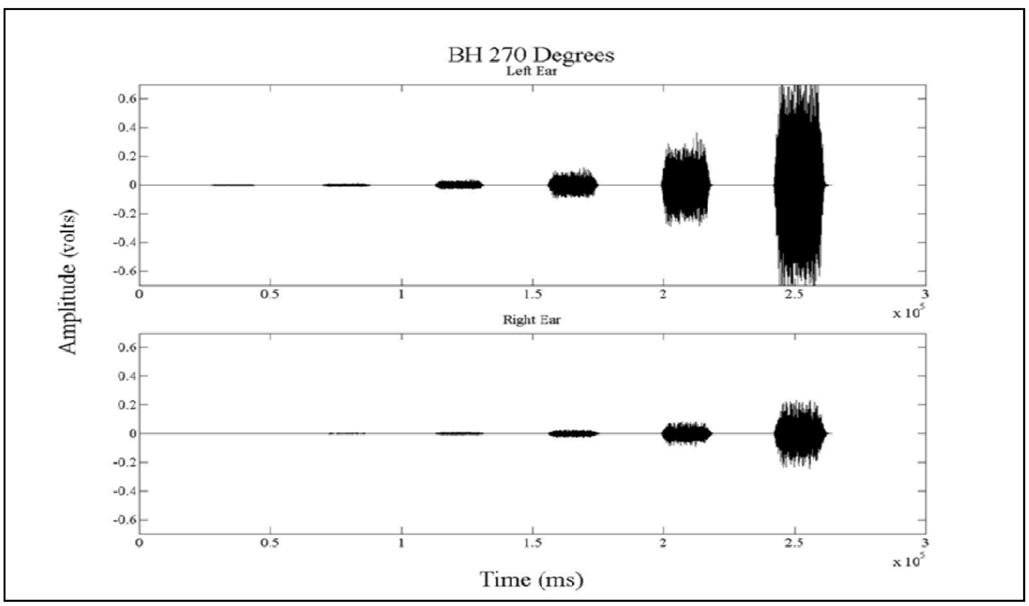

Figure 14. Waveforms of recordings made through the Barehead KEMAR for input intensities 50–100 dBA in 10-dB steps (left to right). The loudspeaker was located at 270° azimuth, directly to the left of the manikin.

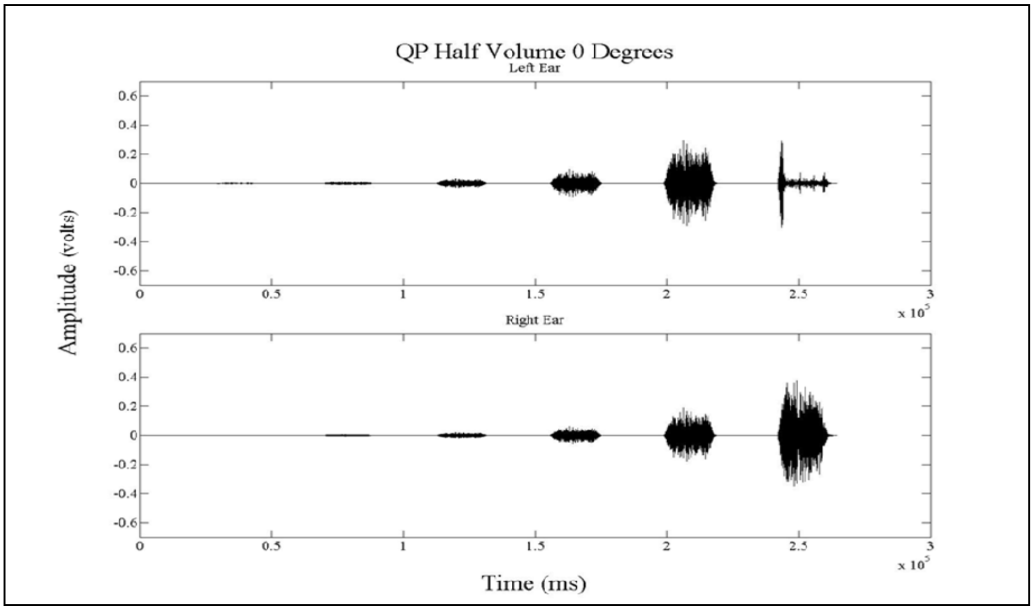

Figure 15. Waveforms of recordings made through the QuietPro C&HPS with the talk-through volume set at approximately 1/2. The loudspeaker was located at 0^o.

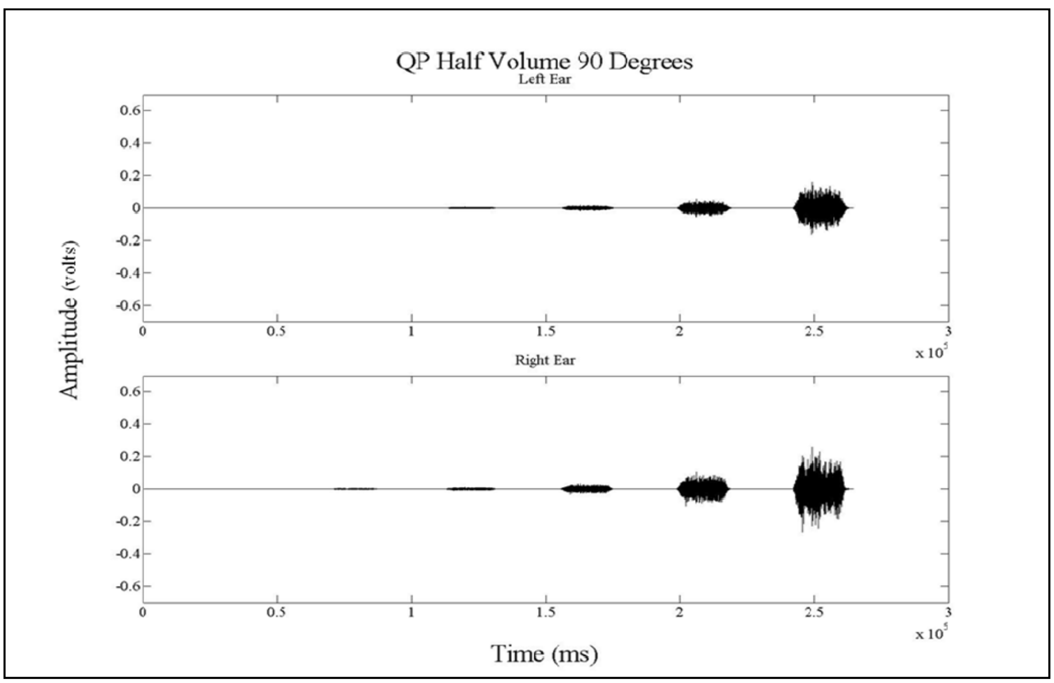

Figure 16. Waveforms of recordings made through the QuietPro C&HPS for the loudspeaker located at 90^o azimuth, directly to the right of the manikin.

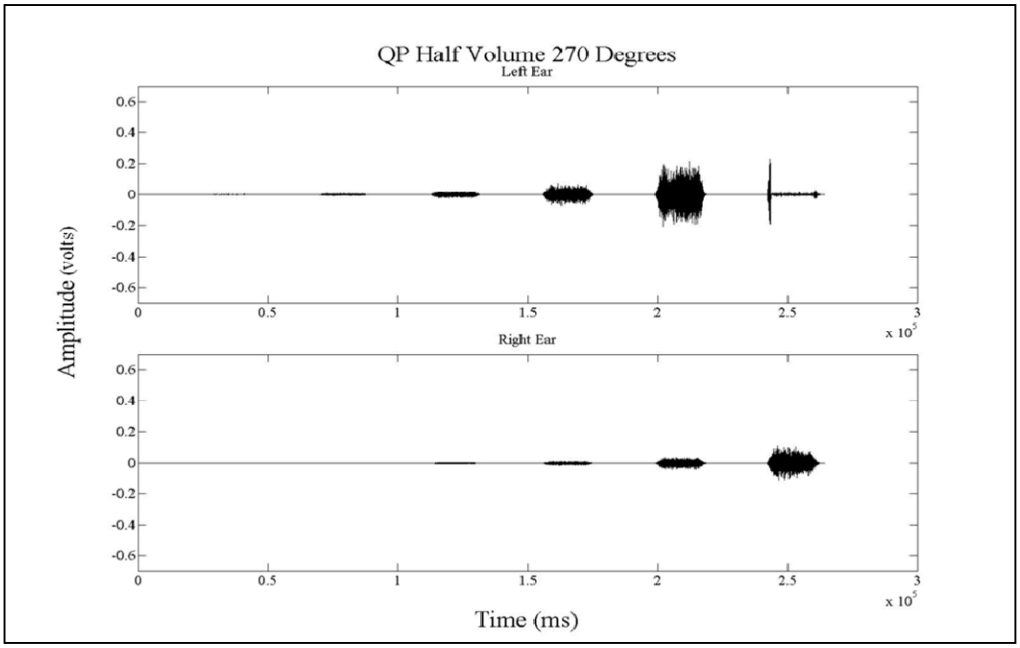

Figure 17. Waveforms of recordings made through the QuietPro C&HPS for the loudspeaker located at 270°, directly to the left of the manikin.

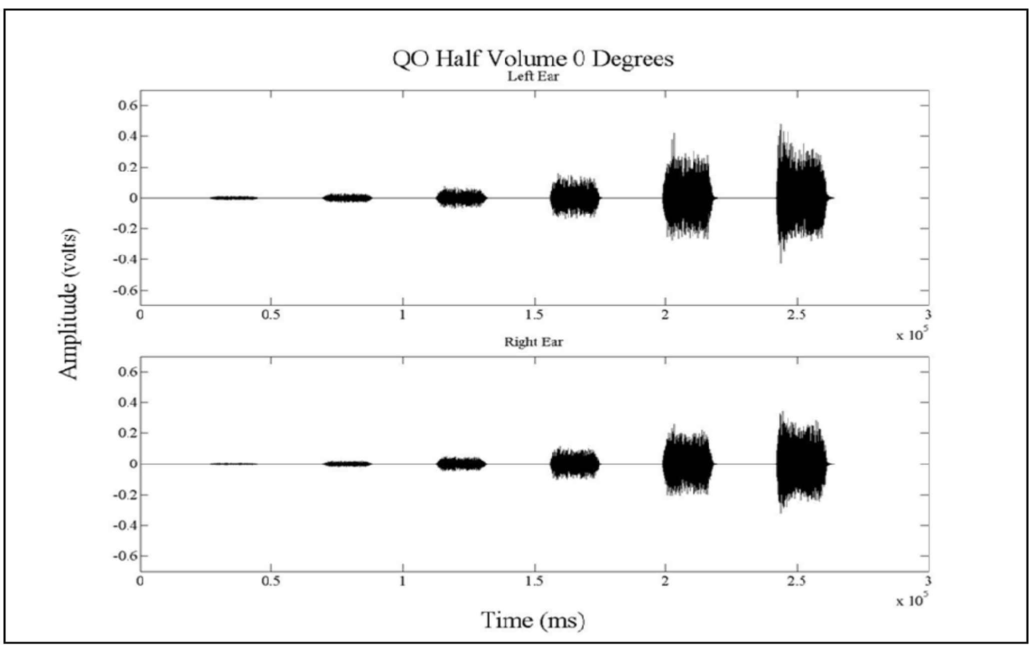

Figure 18. Waveforms of recordings made through the QuietOps C&HPS with the talk-through volume set at approximately1/2 for input intensities 50–100 dBA in 10 dB-steps (left to right). The loudspeaker was located at 0° azimuth.

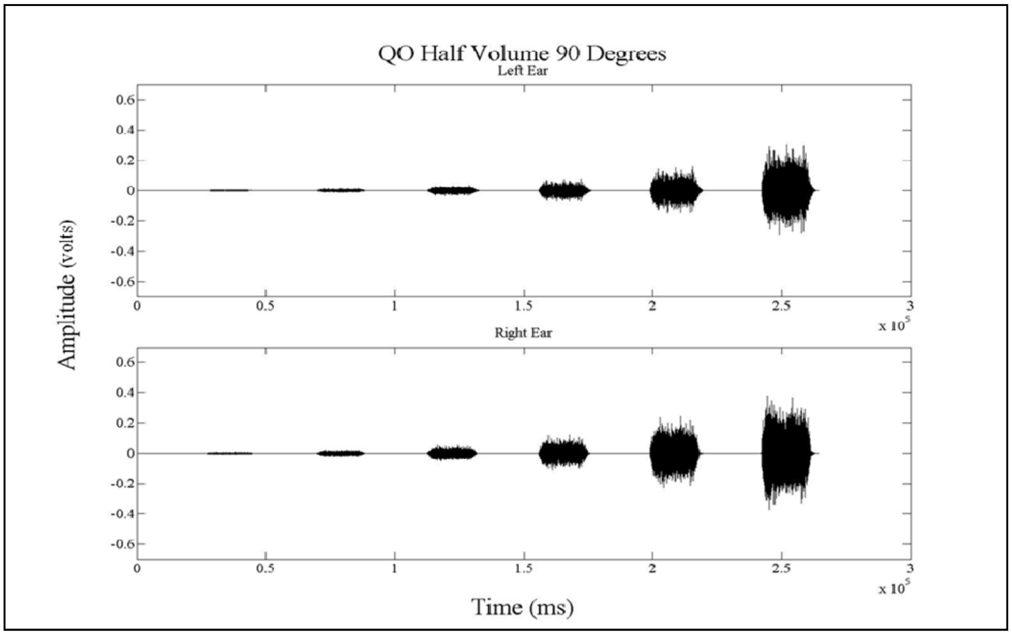

Figure 19. Waveforms of recordings made through the QuietOps C&HPS for the loudspeaker located at 90° azimuth, directly to the right of the manikin.

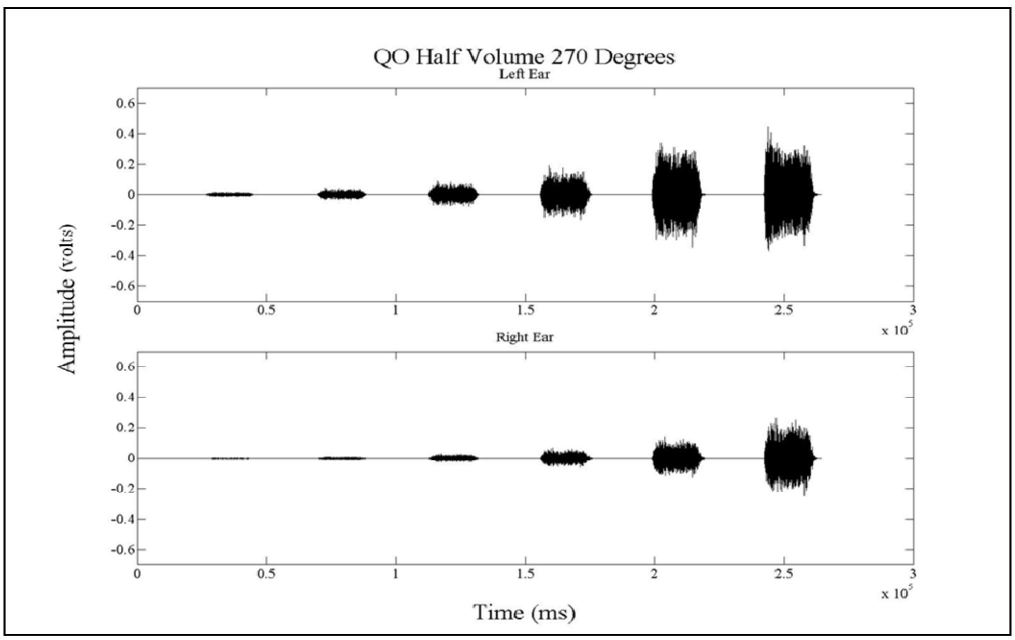

Figure 20. Waveforms of recordings made through the QuietOps C&HPS for the loudspeaker located at 270°, directly to the left of the manikin.

Examination of figures 12–14 shows differences among the recordings made through the KEMAR in the Barehead condition and those made through the C&HPS.

As expected, the waveforms through the Barehead condition show a steady increase in level in both ears as the level of the stimulus is increased from 50 to 100 dBA. For figures 13 and 14, when the stimulus is directly to the sides of the manikin, the ear closer to the stimulus loudspeaker receives a higher level signal as compared to the ear on the opposite side of the KEMAR as shown in the difference in amplitude between the waveforms from the two ears. The waveforms for the QuietPro system (figures 15–17) also show a steady increase in output level as the input level is increased. At the input level of 100 dBA, however, the output waveform shows clear evidence that the system clamps off the output signal provided to the listener. The clamping off of the output signal explains the results shown in input/output figures where there is a drop off in output level for the 100 dBA input through the QuietPro device. The waveforms from the QuietOps device (figures 18–20) also show a clamping down of the output signal with the higher input levels, but the extent of the reduction is much smaller for the QuietOps than the QuietPro.

2.3 Participants

Twelve volunteers (seven male and five female) between the ages of 21 and 45 (M = 29) participated in the study. None of the participants had extensive prior experience with the C&HPS used in the study. All participants had normal hearing sensitivity defined as air conduction pure-tone hearing thresholds of ≤ 25 dB hearing level (HL) at octave audiometric frequencies from 125–8000 Hz (ANSI, 2004). All data were collected in compliance with regulations and approval from the Institutional Review Board at the U.S. Army Research Laboratory. Informed consent was obtained from participants prior to their participation in the research study.

2.4 Stimulus and Apparatus

The study was conducted in the U.S. Army Research Laboratory's EAR utilizing a loudspeaker array comprised of 90 Meyers Sound MM-4XP loudspeakers equally distributed on a horizontal ring. Every third loudspeaker was used to present the stimuli. The stimulus used in the localization task was the sound of a bolt click on an M-16 rifle. The duration of the bolt click was 250 ms. The waveform and spectrum of the stimulus are shown in figure 21. As seen in the frequency spectrum, the bolt click is a broadband stimulus weighted in the high-frequencies.

The intensity level of the bolt click was set to 75 dBA. All testing was conducted in the presence of pink background noise played out of four JBL PRX512M loudspeakers located in the corners of the room. The background noise was set to a level of 80 dBA for a resultant signal-to-noise ratio (SNR) of –5 dB. All noise and stimulus levels were measured at the listener location with the listener not present.

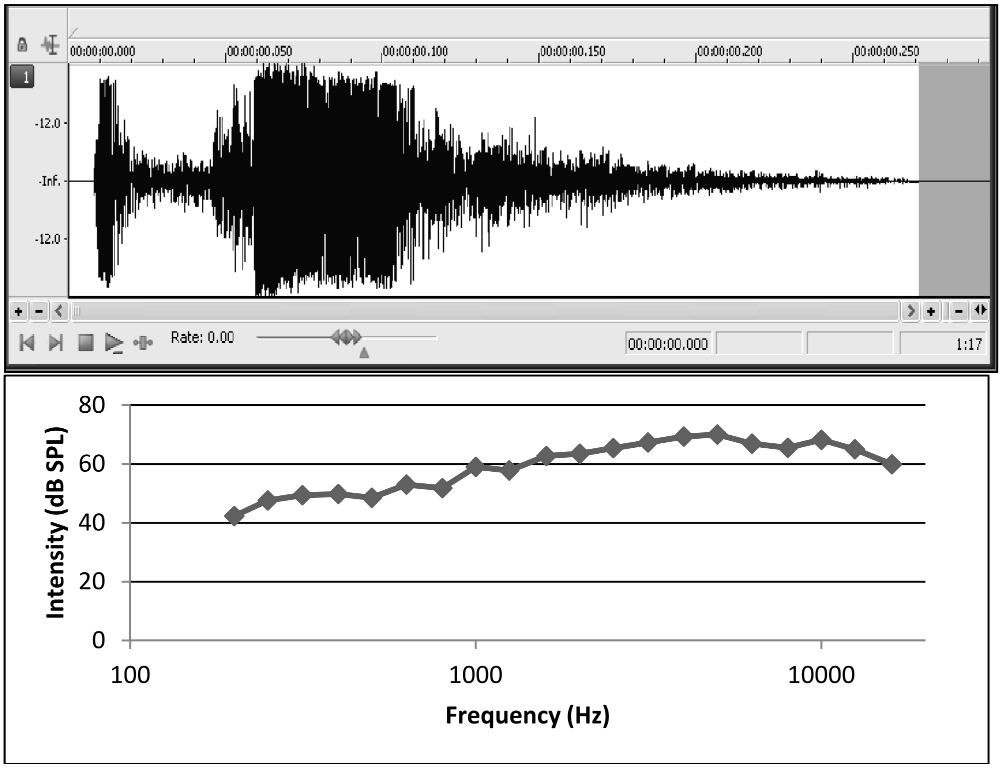

Figure 21. Waveform (upper panel) and frequency spectrum (lower panel) of the bolt click stimulus analyzed in one-third octave bands.

2.5 Task

The listener's task was to identify the location of the bolt click. To accomplish this, the listener was seated in a rotating chair with a laser pointer attached to the chair. The listener used the laser pointer to indicate the perceived direction of the sound source while providing visual feedback on their orientation. An optical shaft encoder mounted to the base of the chair was used to register directional data. At the start of each trial, the listener rotated the chair to face a location established as 0°. Correct alignment of the chair and the participant's head was achieved by having the participant aim the laser pointer and look at a 0° fixed target. Once the chair was properly aligned, the participant pressed a button on the chair to initiate the trial. After the sound was presented, the listener rotated the chair to face the direction of the perceived sound source, thereby directing the laser pointer towards that perceived sound source. The listener then pressed a button on the chair to send the positional data to the computer.

The tests were conducted with each listener wearing no C&HPS (Barehead baseline condition), as well as with each of the two C&HPS for a total of three listening conditions. The insertion of the earplugs for each of the devices was performed by the experimenter. This was done to increase the likelihood of optimal fit, as well as to ensure consistent placement across participants. The ordering of listening conditions (Barehead, QuietOps, and QuietPro) was counterbalanced across participants such that two participants completed the data collection in each of six orderings.

When wearing the C&HPS, the talk-through microphone was engaged to simulate listening in a noisy environment and the volume was set to approximately one-half way on the volume control range. No radio was connected to the headsets.

All participants completed one block of auditory localization trials per listening condition. Each block contained the same stimulus with three trials given for each of the 30 loudspeaker locations for a total of 90 trials per listening condition. A block of trials took approximately 20 min to complete. The entire data collection session lasted just over 1 h.

The measure of interest was localization error reported in terms of the average absolute angular differences in the horizontal plane between the perceived location and the actual location of the sound source. Localization error was computed for each of the estimates of sound source location and each listening condition. Average absolute error is calculated as

$$\overline{D} = \frac{\sum |p - r|}{N}, \tag{1}$$

where p is the actual location of the source, r is the response of the listener, and N is the number of responses. Auditory localization error can be calculated with or without the correction for front-back reversals. A response was considered a reversal if the error calculated with its mirror image was less than the error calculated with the original response. Correcting for reversals by selecting the mirror image source location about the interaural axis reduces the overall error and gives a more favorable view of the error that may be experienced in real-world situations when visual and other information can be used. Data were calculated for both uncorrected and corrected error.

3. Results

Figure 22 shows the average uncorrected and corrected auditory localization error for each of the three listening conditions. As shown in the figure, the Barehead condition resulted in the smallest degree of corrected error (12°), and the two listening conditions with the C&HPS resulted in the largest error (18 and 22° for the QuietPro and QuietOps, respectively). The results follow the same pattern for the two error rates, but the error is much smaller in its corrected form.

A one-factor, repeated-measures analysis of variance (ANOVA) on listening condition with corrected overall error as the dependent variable indicated a significant effect of listening condition, $F(2, 22) = 8.898$, $p<0.01$. Follow-up pair-wise comparisons indicated significantly larger corrected error for each of the C&HPS when compared to the Barehead condition [Barehead vs. QuietOps, $F(1, 11) = 14.859$, $p<0.01$, Barehead vs. QuietPro, $F(1, 11) =$

17.605, $p<0.01$] but there was no significant difference between the auditory localization performance using the two C&HPS devices.

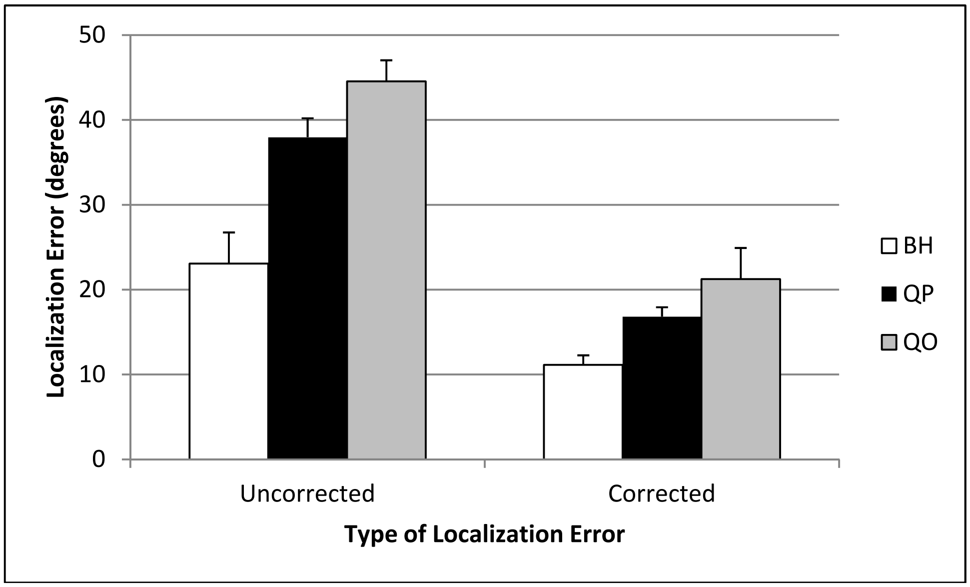

Figure 22. Average overall uncorrected and corrected absolute error for each of the three listening conditions; BH = Barehead, QO = QuietOps, QP = QuietPro. Error bars indicate +1 standard error.

3.1 Reversals

The average rate of reversals for the Barehead condition was 15% with individual participants ranging from 0%–33%. Average rates of reversals for the C&HPS conditions were exceptionally high and nearly double those for the Barehead condition. For the QuietPro and HPS, the rate of reversals averaged 31% with individual participants ranging from 19%–48%. For the QuietOps C&HPS, the rate of reversals averaged 35% with individual participants ranging from 24%–34%.

4. Discussion

The goal of this portion of a three-part series was to evaluate auditory localization ability while using two commercially available C&HPS. The measurement of auditory localization performance allows for some determination of the effect of wearing a C&HPS on immediate situational awareness. Auditory localization performance was measured through the talk-through microphone of the systems to demonstrate how an individual would perform when able to hear their immediate environment.

The present study was conducted in the presence of background noise. The reasons for measuring auditory localization in the presence of background noise were two-fold: to increase the difficulty of the task and to test the noise reduction capability of each C&HPS, if it had one.

Differences in performance between the two C&HPS might not have been observed had they been tested in a quiet environment, and quiet environments are rare in current operations.

The study was conducted using a single occurrence of a short duration stimulus (250 ms). A short duration stimulus was chosen to minimize the benefit that a listener would gain through movement of their head for longer duration sounds or sounds that are repeated over time (Makous and Middlebrooks, 1990). Stimuli that are greater than 500 ms are believed to allow listeners an opportunity to move their head to gain additional samples of the stimulus that they are trying to locate (Makous and Middlebrooks, 1990). The use of a short duration stimulus, in essence, provides a picture of the worst case scenario—the situation in which the listener hears a single occurrence of a short sound that is not repeated. Use of a longer duration sound may reduce the localization error that is documented with this short duration sound and through the use of these devices.

The corrected error for the Barehead condition served as the baseline for error estimates with the C&HPS. The Barehead condition corrected error of approximately 10° corresponds well with bare head error measured in the horizontal plane and reported in previous studies (Bolia et al., 2001; Makous and Middlebrooks, 1990; Vause and Grantham, 1999). Part of the reason for the higher error value obtained in the present study and those of others is due to the greater azimuthal range used in the present study compared to that used by others. Makous and Middlebrooks (1990) examined localization solely in the frontal horizontal plane, whereas we evaluated localization across all 360^{o} within the horizontal plane. Because auditory localization accuracy is poorer for angles to a listener's side, incorporating all angles will yield a larger error than calculations from a reduced range of presentation and response angles in front of the listener.

Auditory localization performance in noise using the present paradigm agrees well with previous studies of this type (Good and Gilkey, 1996). Recall that the signal was presented at 75 dBA and the background noise was presented at a level of 80 dBA. This resulted in an effective SNR of –5 dB. The effects of noise on auditory localization are not expected to be observed until the SNR becomes far more negative (around –10 dB) than what was selected for this study (Good and Gilkey, 1996). The use of noise in the present study was intended to engage the active noise reduction capabilities that may be present in the C&HPS. Had we been interested in the differences in performance with the addition of background noise, a condition in quiet would have been included in the study.

The corrected error rates for the C&HPS conditions were on the order of 15–24°, which is in good agreement with previous studies examining the effects of hearing protection on auditory localization. Bolia et al. (2001) found average error with passive earmuffs or earplugs to be approximately 22–24°. Reversal rates in all three conditions also were within the range reported in previous studies (Bolia et al., 2001; Vause and Grantham, 1999).

The objective measures of directivity and input/output functions allowed for a closer look at the sounds arriving to the listeners' ears through each device. These measures provide evidence to support the reasons behind the performance of the listeners on the auditory localization task.

The directivity measures and subsequent calculations of ILDs demonstrated that the devices do not replicate the directivity of the open ear. The alteration of directivity was not unexpected given that the devices utilize a microphone mounted on an earpiece that sits within the wearer's pinna sometimes extending outward from the side of the head (Shaw, 1974). The result of this microphone placement is a decrease in the binaural intensity cue that is essential in auditory localization. Among the three auditory localization cues (ILDs, ITDs, and spectral cues), intensity cues are the most important for the listener (Blauert, 2001). Robust ILD cues that are available to a listener with a bare head, as demonstrated through the measures made on KEMAR, are reduced and become less useful to the listener when using a C&HPS.

In the present study, the stimulus was a bolt click from an M-16 rifle whose energy is primarily high-frequency, above 1000 Hz. The reduction of the ILD cue and necessity of high-frequency information for accurate localization in the present study precluded the listener from performing well with the C&HPS. Furthermore, the salience of the ILD cue can be rank-ordered as follows: Barehead (best), QuietPro (mid), QuietOps (worst). This same rank ordering is reflected in the auditory localization performance data. Clearly, the alteration of the ILD cues had a significant effect on the auditory localization performance of the wearers as the corrected error nearly doubled between the Barehead condition (12°) and that found with the QuietOps C&HPS (24°).

The input/output functions provide additional data to support the auditory localization performance findings. The two important features of the input/output functions are the maximum output for the devices and the slope of the functions. First, regarding the maximum output, it is important to note the differences for each of the C&HPS devices. In the Barehead condition (no device on the KEMAR), there is a steady increase in output in relation to each successive increase in input level. This follows a linear pattern. At the highest input level of 100 dBA, the stimulus did not saturate the microphones of the KEMAR. The intensity level measured at the KEMAR microphones for the 100 dBA noise stimulus was approximately 106 dBA. The higher level measured at the microphone is due to the enhancement of the acoustic energy through the ear canal resonance (Shaw, 1974). On the other hand, the input/output functions measured on the KEMAR through the C&HPS indicate that both systems are utilizing output limiting. For the same 100 dBA noise stimulus, the C&HPS devices limited the output to the listener's ear to between 90 dBA (QuietPro) and 95 dBA (QuietOps). Presumably, the manufacturers have incorporated amplitude compression in an effort to limit the noise exposure for the listener.

The second important aspect from the input/output functions is the calculation of the compression ratios. The input/output functions demonstrate that the Barehead condition is linear for all inputs and the QuietPro system is essentially linear for inputs up to 90 dBA. In contrast, the QuietOps incorporates amplitude compression in its signal processing that is not present in the Barehead or QuietPro conditions. For a given increase in stimulus level, the QuietOps shows a lesser increase in output. The compression ratio for this device is approximately 1.5:1.

Much like with hearing aids, amplitude compression in this device is most likely utilized in an attempt to put the full dynamic range of sound intensities within a smaller range for the listener—by providing amplification for low-level sounds and attenuation for high-intensity sounds (Dillon, 2001).

Use of amplitude compression can potentially alter binaural differences in intensity and affect the ability to correctly perceive the laterality of a sound (Dillon, 2001). Sounds arriving to the side of a listener are higher in intensity at the near ear and are lower at the far ear. The use of amplitude compression would reduce the intensity of the sound to the near ear, diminishing the ILD between the two ears. In linear systems, input/output functions for stimuli arriving from the sides of the listeners' head are symmetrical. The curves for the two ears have the same slope with the only difference being the reversal of near and far ear. The linearity or non-linearity of the systems can be observed by comparing figures 10 and 11. The fundamental difference between these two figures is the location of the stimulus. In figure 10, the stimulus is to the right of KEMAR and in figure 11, the stimulus is to the left. In comparing figures 10 and 11, the Barehead condition shows the expected linear input/output function with the only difference being which ear has the higher output; the right ear for figure 10 and the left ear for figure 11. This is not the case with the measurements made from the C&HPS.

It is clear in looking at the increase in auditory localization error with the addition of a C&HPS, that the use of the devices negatively affects the user's ability to determine the location of sound sources in their immediate environment. There was no significant difference in listener performance between the two systems; both systems degraded auditory localization to a similar degree. It is important for C&HPS users to know that use of a C&HPS will decrease their ability to locate sound sources; they will need to use vision and their other senses to a higher degree.

5. Conclusions

The bare head auditory localization accuracy, in response to a short duration stimulus, agrees well with previous studies. The decrement in auditory localization with the use of the C&HPS leads to concerns regarding potentially degraded auditory situational awareness for users of these systems. Decrements in auditory situational awareness can lead to a diminished ability to know where sound sources are located within a Soldier's immediate environment. Both C&HPS used in the present study contributed to significant decreases in auditory localization accuracy, indicating diminished auditory situational awareness over what exists with no C&HPS.

Although decrements in auditory localization were measured in initial fitting of the C&HPS to naïve listeners, individuals may grow accustomed to changes in auditory information provided to them over time. Ample evidence suggests that individuals can adjust to changes in binaural cues over time, but the rate at which this change happens and the ability to predict who will adapt and who will not is yet to be defined. In order for a person to adapt to the change in binaural cues, they would most likely need to use the system continuously for a significant period of time.

Clearly, changing ILD cues provided to a listener results in decreased auditory localization ability. Future C&HPS should be engineered to minimize the negative effect on auditory situational awareness in order to maximize Soldier performance in operational environments. The results of this study do not attempt to estimate the degree to which mission performance could be affected by the changes in binaural cues. Criteria defining the minimum auditory localization ability required to perform a given mission task have not yet been defined. Until a better understanding of the localization abilities needed to successfully perform mission tasks, it is difficult to correlate laboratory ability with real-world performance.

6. References

Abel, S.; Hay, V. Sound localization: The Interaction of Aging, Hearing Loss and Hearing Protection. *Scandinavian Audiology Journal* **1996**, *25,* 3–12.

ANSI Method for Measuring the Intelligibility of Speech Over Communication Systems. American National Standard ANSI S3.2-1989, Washington, DC, R1999.

ANSI, Methods for Measuring the Real-Ear Attenuation of Hearing Protectors. American National Standard ANSI S12.6-1997, Washington, DC, R2002.

ANSI, Specifications for Audiometers. American National Standard ANSI S3.6, Washington, DC, 2004.

Atherley, G.; Noble, W. Effect of Ear Defenders (Earmuffs) on the Localization of Sound. *British Journal of Industrial Medicine* **1970**, *27,* 260–265.

Bauer, R.; Matuzsa, J.; Blackmer, R.; Glucksberg, S. Noise Localization after Unilateral Attenuation. *Journal of the Acoustical Society of America* **1966**, *40* (*2*)*,* 441–444.

Berger, E. H. Methods of Measuring the Attenuation of Hearing Protection Devices. *Journal of the Acoustical Society of America* **1986**, *79* (6), 1655–1687.

Blauert, J. *Spatial Hearing: The Psychophysics of Human Sound Localization.* Cambridge, MA: The MIT Press.

Bolia, R.; D'Angelo, W.; Mishler, P.; Morris, L. Effects of Hearing Protectors on Auditory Localization in Azimuth and Elevation. *Human Factors* **2001**, *43,* (*1*)*,* 122–128.

Bronkhorst, A. Localization of Real and Virtual Sound Sources. *Journal of the Acoustical Society of America* **1995**, *98* (*5*), 2542–2553.

Butler, R. An Analysis of the Monaural Displacement of Sound in Space. *Perception and Psychophysics* **1987**, *41* (*1*)*,* 1–7.

Carmichel, E. L.; Harris, F. P.; Story, B. H. Effects of Binaural Electronic Hearing Protectors on Localization and Response Time to Sounds in the Horizontal Plane. *Noise Health* **2007**, *9*, 83–95.

Dillon, H. *Hearing Aids.* New York: Thieme, 2001.

Franks, J.; Murphy, W.; Johnson, J.; Harris, D. Four Earplugs in Search of a Rating System. *Ear and Hearing* **2000**, *21* (3), 218–225.

Gardner, M.; Gardner, R. Problem of Localization in the Median Plane: Effect of Pinnae Cavity Occlusion. *Journal of the Acoustical Society of America* **1973**, *53* (2)*,* 400–408.

Good, M.; Gilkey, R. Sound Localization in Noise: The Effect of Signal-to-Noise Ratio. *Journal of the Acoustical Society of America* **1996**, *99* (2), 1108–1117.

Henry, P.; Weatherless, R. Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPSs) Part I – Sound Attenuation; ARL-TR-5050; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2010a.

Henry, P.; Weatherless, R. *Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPSs) Part II – Speech Intelligibility;* ARL-TR-5075; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2010b.

Hofman, P.; Van Opstal, J. Binaural Weighting of Pinna Cues in Human Sound Localization. *Experimental Brain Research* **2003**, *148 (4),* 458-70.

Hofman, P.; Van Riswick, J. G. A.; Van Opstal, J. Relearning Sound Localization With New Ears. *Nature Neuroscience,* **1998**, *1* (5)*,* 417–421.

Javer, A.; Schwarz, D. Plasticity in Human Directional Hearing. *Journal of Otolaryngology,* **1995**, *24* (2), 111–117.

Jin, G.; Corderoy, A.; Carlile, S.; van Schaik, A. Contrasting Monaural and Interaural Spectral Cues for Human Sound Localization. *Journal of the Acoustical Society of America* **2004**, *115* (6), 3124–3141.

Kuo, S.; Morgan, D. Active Noise Control: A Tutorial Review. *Proceedings of the IEEE* **1999**, *87* (6), 943‑973.

Makous, J.; Middlebrooks, J. Two-Dimensional Sound Localization by Human Listeners. *Journal of the Acoustical Society of America* **1990**, *87* (*5*), 2188–2200.

Musicant, A.; Butler, R. Monaural Localization: an Analysis of Practice Effects. *Perception and Psychophysics* **1980**, *28* (3), 236–240.

Noble, W.; Russell, G. Theoretical and Practical Implications of the Effects of Hearing Protection Devices on Localization Ability. *Acta Otolaryngica* **1972**, *74,* 29–36.

Oppenheim, A.; Weinstein, E.; Zangi, K.; Feder, M.; Gauger, D. Single-Sensor Active Noise Cancellation. *IEEE Transactions on Speech and Audio Processing* **1994**, *2* (2), 285–290

Royster, J.; Berger, E.; Merry, C.; Nixon, C.; Franks, J.; Behar, A.; Casali, J.; Dixon-Ernst, C.; Kieper, R.; Mozo, B.; Ohlin, D.; Royster, L. Development of a New Standard Laboratory Protocol for Estimating the Field Attenuation of Hearing Protection Devices. Part I. Research of Working Group 11, Accredited Standards Committee S12, Noise. *Journal of the Acoustical Society of America* **1996**, *99* (3), 1506–1526.

Russell, G. Limits to Behavioral Compensation for Auditory Localization in Earmuff Listening Conditions. *Journal of the Acoustical Society of America* **1977**, *61* (1), 219–220.

Shaw, E. A. G. Transformation of Sound Pressure Level From the Free Field to the Eardrum in the Horizontal Plane. *Journal of the Acoustical Society of America* **1974**, *56,* 1848–1861.

Van Wanrooij, M.; Van Opstal, A. J. Relearning Sound Localization With a New Ear. *Journal of Neuroscience* **2005**, *25* (*22*), 5413–5424.

Vause, N.; Grantham, D. W. Effects of Earplugs and Protective Headgear on Auditory Localization Ability in the Horizontal Plane. *Human Factors* **1999**, *41* (2)*,* 282–294.

Wenzel, E.; Arruda, M.; Kistler, D.; Wightman, F. Localization Using Nonindividualized Head-Related Transfer Function. *Journal of the Acoustical Society of America* **1993**, *94* (1), 111–123.

List of Symbols, Abbreviations, and Acronyms

ANC	active noise cancellation
ANOVA	analysis of variance
ANR	active noise reduction
ARL	U.S. Army Research Laboratory
C&HPS	Communications and Hearing Protection Systems
EAR	Environment for Auditory Research
HL	Hearing Level
HPD	Hearing Protection Device
ILD	interaural level difference
ITD	interaural time difference
REAT	Real-Ear Attenuation at Threshold
SNR	signal-to-noise ratio

NO. OF COPIES	ORGANIZATION
1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
1 (PDF)	DIRECTOR US ARMY RESEARCH LAB IMAL HRA
1 (PDF)	DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL
1 (PDF)	GOVT PRINTG OFC A MALHOTRA
1 (PDF)	RDRL HRM C A DAVISON 320 MANSCEN LOOP STE 115 FORT LEONARD WOOD MO 65473
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM D T DAVIS BLDG 5400 RM C242 REDSTONE ARSENAL AL 35898-7290
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRS EA DR V J RICE BLDG 4011 RM 217 1750 GREELEY RD FORT SAM HOUSTON TX 78234-5002
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM DG J RUBINSTEIN BLDG 333 PICATINNY ARSENAL NJ 07806-5000
1 (PDF)	ARMY RSCH LABORATORY – HRED ARMC FIELD ELEMENT RDRL HRM CH C BURNS THIRD AVE BLDG 1467B RM 336 FORT KNOX KY 40121
1 (PDF)	ARMY RSCH LABORATORY – HRED AWC FIELD ELEMENT RDRL HRM DJ D DURBIN BLDG 4506 (DCD) RM 107 FORT RUCKER AL 36362-5000
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM CK J REINHART 10125 KINGMAN RD BLDG 317 FORT BELVOIR VA 22060-5828
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM AY M BARNES 2520 HEALY AVE STE 1172 BLDG 51005 FORT HUACHUCA AZ 85613-7069
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM AP D UNGVARSKY POPE HALL BLDG 470 BCBL 806 HARRISON DR FORT LEAVENWORTH KS 66027-2302
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM AT J CHEN 12423 RESEARCH PKWY ORLANDO FL 32826-3276
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM AT C KORTENHAUS 12350 RESEARCH PKWY ORLANDO FL 32826-3276
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM CU B LUTAS-SPENCER 6501 E 11 MILE RD MS 284 BLDG 200A 2ND FL RM 2104 WARREN MI 48397-5000
1 (PDF)	ARMY RSCH LABORATORY – HRED FIRES CTR OF EXCELLENCE FIELD ELEMENT RDRL HRM AF C HERNANDEZ 3040 NW AUSTIN RD RM 221 FORT SILL OK 73503-9043
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM AV W CULBERTSON 91012 STATION AVE FORT HOOD TX 76544-5073
1 (PDF)	ARMY RSCH LABORATORY – HRED HUMAN RSRCH AND ENGRNG DIRCTRT MCOE FIELD ELEMENT RDRL HRM DW C CARSTENS 6450 WAY ST BLDG 2839 RM 310 FORT BENNING GA 31905-5400

NO. OF COPIES	ORGANIZATION
1 (PDF)	ARMY RSCH LABORATORY – HRED RDRL HRM DE A MARES 1733 PLEASONTON RD BOX 3 FORT BLISS TX 79916-6816
8 (PDF)	ARMY RSCH LABORATORY – HRED SIMULATION & TRAINING TECHNOLOGY CENTER RDRL HRT COL M CLARKE RDRL HRT I MARTINEZ RDRL HRT T R SOTTILARE RDRL HRT B N FINKELSTEIN RDRL HRT G A RODRIGUEZ RDRL HRT I J HART RDRL HRT M C METEVIER RDRL HRT S B PETTIT 12423 RESEARCH PARKWAY ORLANDO FL 32826
1 (PDF)	ARMY RSCH LABORATORY – HRED (PDF) HQ USASOC RDRL HRM CN R SPENCER BLDG E2929 DESERT STORM DRIVE FORT BRAGG NC 28310
1 (PDF)	ARMY G1 DAPE MR B KNAPP 300 ARMY PENTAGON RM 2C489 WASHINGTON DC 20310-0300
4 (PDF)	US ARMY NATICK SOLDIER RSRCH & DEV CTR TSPID D LEE A CHISHOLM S GERMAIN J P KRUSZEWSKI
1 (PDF)	RSRCH PSYCHOLOGIST DIR AIRCREW PROTECTION DIV US ARMY AEROMEDICAL RSRCH LAB W A AHROON
1 (PDF)	PROJECT MGR-SOLDIER WARRIOR SFAE SDR SWAR R BUBLITZ
1 (PDF)	AIR FORCE RSRCH LAB LEAD JSF VIBROACOUSTICS AFRL WPAFB US R MCKINLEY
1 (PDF)	STATE COLLEGE PA T LETOWSKI

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND
13 (PDF)	DIR USARL RDRL HR L ALLENDER P FRANASZCZUK C COSENZO RDRL HRM P SAVAGE-KNEPSHIELD RDRL HRM AL C PAULILLO RDRL HRM B C SAMMS RDRL HRM C L GARRETT RDRL HRS J LOCKETT RDRL HRS B M LAFIANDRA RDRL HRS C K MCDOWELL RDRL HRS D B AMREIN P HENRY RDRL HRS E D HEADLEY

INTENTIONALLY LEFT BLANK.