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Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPSs) Part II – Speech Intelligibility

by Paula Henry and Rachel Weatherless

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Evaluation of Auditory Characteristics of Communications and Hearing Protection Systems (C&HPSs) Part II – Speech Intelligibility

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14. ABSTRACT
Devices that provide hearing protection, situational awareness, and radio communications are often referred to as Communications and Hearing Protection Systems (C&HPSs). Soldiers use these systems while deployed to navigate within their environment, communicate with their team members, and protect their hearing. Each of the three features of select C&HPSs (hearing protection, speech communication, and situational awareness) was evaluated by the U.S. Army Research Laboratory in order to obtain data that is independent from that provided by the manufacturer. This report is the second in a series of three and focuses on the speech intelligibility performance obtained from two commercially available C&HPSs: Nacre QuietPro and Silynx QuietOps selected from three C&HPSs evaluated for attenuation characteristics in the first report. Results of the speech intelligibility testing indicated that the Silynx QuietOps provides a significantly higher degree of speech intelligibility, but this difference is probably not significant for field applications. The differences noted in speech intelligibility are likely due to a combination of differences in the frequency responses measured from the two systems and differences in the frequency responses of the microphones from the two systems, along with small differences in the output intensity of the speech items provided to the listeners.

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hearing, communication, C&HPS, situational awareness, speech intelligibility

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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 abilities are essential for dismounted Soldiers and can be seen as conflicting goals for development of such multipurpose communication devices. Balance must be maintained between hearing protection and auditory situational awareness, which is often the biggest challenge for a developer. 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 for the individual Soldier. Leaving the ears open allows for good situational awareness but not protection against hazardous noise. Providing all three aspects within a single device can be very challenging.

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

In the evaluation of C&HPS, the three auditory aspects need to be evaluated: attenuation provided for hearing protection, speech intelligibility of radio communication, and auditory localization as a measure of situational awareness. Sound attenuation can be provided to the user through passive or active means. Passive attenuation is provided by the mere presence of the device without any processing of the sound. Active attenuation cancels or reduces the background noise by introducing a signal which is opposite in phase and time 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 the headphones marketed to frequent fliers for listening to music on airplanes. ANR reduces low frequency noise better than high frequency noise.

The goal of the first part of the three-part study was to measure the passive sound attenuation provided by three in-the-ear C&HPSs 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 be overestimates of real-world performance of these devices (Berger, 1986; Franks et al., 2000; Royster et al., 1996). Three C&HPSs were evaluated in that portion: the Nacre QuietPro,[*] the Silynx QuietOps,[†] and

[*] QuietPro is a registered trademark of Nacre AS, Norway.
[†] QuietOps is a trademark of Silynx Corporation, Rockville, MD.

the Sennheiser SLC-110 (Henry and Weatherless, 2010). 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 dB A. Therefore, the Sennheiser SLC-110 was dropped from this portion of the study. The goal of this second part of the three-part study was to measure the speech intelligibility across radio communications of two select in-the-ear C&HPSs (ANSI, 1999).

Two C&HPSs were used for the speech intelligibility testing: the Nacre QuietPro and the Silynx QuietOps. Descriptions of the two systems follow.

1.1 Nacre AS – QuietPro

The Nacre QuietPro is an in-the-ear digital hearing protector and communication headset designed for use with military tactical radios and intercom systems. A picture of the device is shown in figure 1. Nacre AS is a company based in Norway. The QuietPro system uses a digital signal processor to facilitate automatic, adaptive digital hearing protection through ANR in addition to its passive attenuation. According to the manufacturer, the QuietPro 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. Using both passive and active means, Nacre states that QuietPro can achieve 34–42-dB attenuation, but there is no indication regarding the attenuation provided to low intensity sounds vs. that provided to impulse noise. The device is fit in the ear with disposable Comply* canal tips that are specifically designed for use with the QuietPro system. The Comply tips are available in three sizes: small, medium, and large. Information for the system can be obtained from: http://www.nacre.no.

Figure 1. Photo of the Nacre QuietPro system (downloaded from: armorcorpus.com/products.html, 28 August 2009).

*Comply is a trademark of Hearing Components, Oakdale, MN.

1.2 Silynx Communications, Inc. – QuietOps

The Silynx QuietOps is an in-the-ear tactical communication 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 allows users to monitor one or two communications devices simultaneously—two radios or a radio and an intercom. The device allows the user to determine which communication channel has priority over the other or the user can program the device to have each communication device going to a different ear. The QuietOps is fit to the listener's ear with a compressible foam plug that sits on 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 for the system can be obtained from: http://www.silynxcom.com/.

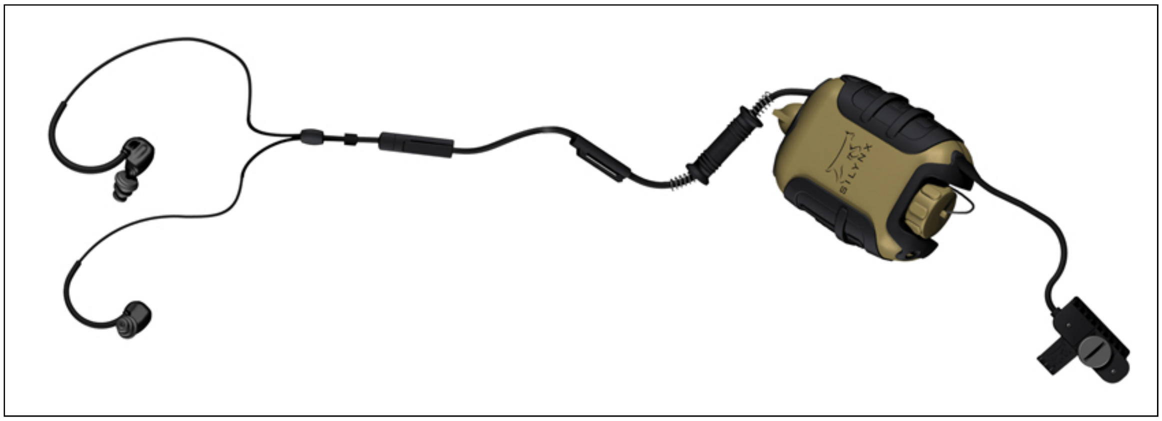

Figure 2. Photo of the Silynx QuietOps system (downloaded from: http://www.janes.com/events/exhibitions/dsei2007/sections/daily/day1/allinone-tactical-headset.shtml, 28 August 2009).

2. Methods

2.1 Participants

Twelve male volunteers between the ages of 19 and 23 (M = 20) participated in the study. None of the participants had extensive prior experience with the C&HPSs used in the study. All participants had normal hearing sensitivity defined as pure-tone hearing thresholds of ≤25-dB hearing level (HL) at audiometric frequencies from 125 through 8000 Hz (ANSI, 2004). All participants had American English as their native language. All data were collected in compliance with regulations 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.

2.2 Procedures

Speech intelligibility was measured as the percentage of words understood in the presence of background noise. Items from the Modified Rhyme Test (MRT) were recorded by a male talker in the presence of background noise through the two C&HPSs simultaneously. These recordings were edited to isolate the individual items. The carrier phrase used for the recordings was "Mark the _______ now" in which the MRT item was inserted into the blank within the phrase. The outputs of the microphones for the C&HPSs were routed through the sound card of a Dell laptop computer. The recordings were then edited using Sound Forge* software and played back to the listeners through the same Dell personal computer routed through a Symetrix† SX204 headphone amplifier to the earphones of the C&HPS headsets. In this way, the C&HPSs were constant components of the test paradigm without the need to have a live talker.

Background noise consisted of a looped 7-min recording of the inside of an M113 traveling on a gravel road at a rate of 10 mph. The intensity level of the background noise was limited to 95 dB A to ensure safe exposure levels based on the attenuation measured made with the C&HPSs in the first part of this series (Henry and Weatherless, 2010). All data collection took place in the acoustically treated areas of Building 520 at Aberdeen Proving Ground, MD. Four Infinity‡ Studio Monitor 150 loudspeakers were positioned in the room to output the background noise during the test trials. The loudspeakers were ~1 m from the position of the listener and were directed toward the listener's chair. The background noise was output to the loudspeakers from a Dell personal computer through a Crown§ D-75 amplifier.

Participants were fitted with each C&HPS according to the manufacturer's guidelines. The intensity level of the systems was equated between the two systems through perceptual comparisons. Participants were not able to adjust the volume.

Test material consisted of the MRT, which consists of 50 six-word groups of monosyllabic English words (House et al., 1965). There are therefore 300 words in the MRT. The words in each group have very similar sounds and they differ by either initial or final phoneme. Almost all the test items are consonant-vowel-consonant words.

Participants listened to all 300 items of the MRT test played through each of the C&HPSs one at a time and selected which word from the given six words was the correct one. Participants interfaced with the computer through a keyboard and/or mouse and a custom written computer software program. Participants completed the procedure with both devices in a single session. The ordering of the devices was counterbalanced across the participants.

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*Sound Forge is a registered trademark of Sony Creative Software, Inc., Madison, WI.

†Symetrix is a trademark of Symetrix, Inc., Mountlake Terrace, WA.

‡Infinity is a trademark of Harman International Industries, Inc., Stamford, CT.

§Crown is a registered trademark of Crown International, a Harman International Company, Stamford, CT.

The individual data points were the listeners' performance on the speech intelligibility task for the transmitted words for each C&HPS. Two transformations were made to the scores prior to data analysis: transformation to rationalized arcsine units (rau) and correction for chance. The transformation to rau was to convert percent correct data into interval data which are appropriate for statistical analysis (Sherbecoe and Studebaker, 2004; Studebaker, 1985). Following conversion to rau, all individual scores were adjusted for the probability of getting a correct response by chance through use of a closed-set task (ANSI, 1999). The conversion to raus and correction for guessing was based on the following formula:

$$T_C = (A * T_U - 100)/(A-1), \tag{1}$$

where T_c is the adjusted score, T_u is the uncorrected score, and A is the number of alternative choices per item (6) (Sherbecoe and Studebaker, 2004).

3. Results

Figure 3 shows the average percent correct scores obtained on the MRT for the two C&HPSs used in the current study. Although analyses were conducted on rau values, results are presented as average percent correct.

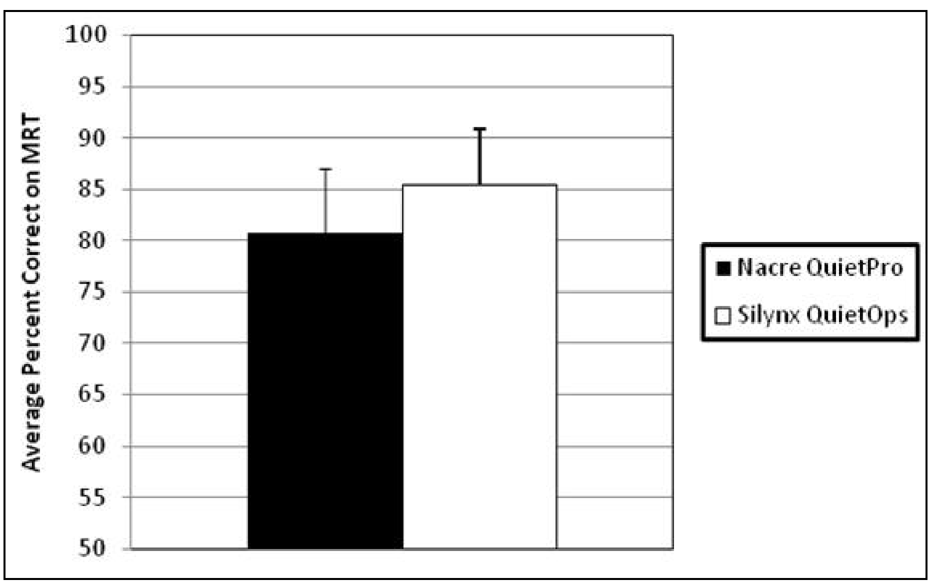

Figure 3. Average MRT scores for the 12 participants for the two communications and hearing protection systems. Error bars indicate +1 standard deviation.

As seen in figure 3, use of the Silynx QuietOps resulted in higher speech intelligibility scores than use of the Nacre QuietPro. The average speech intelligibility scores were 85.46% and 80.79% for the Silynx QuietOps and Nacre QuietPro, respectively. The variability of speech intelligibility across participants was roughly the same between the two devices.

A paired-samples t-test on the transformed and corrected speech intelligibility scores indicated a significant difference between the two systems, $t(11)=3.384$, $p<.01$, with the Silynx QuietOps outperforming the Nacre QuietPro.

4. Discussion

Note that although the statistical analysis revealed a significant difference between the performances with the two C&HPSs, the actual speech intelligibility difference was very small (5%) and is within expected variability of such speech tests. Furthermore, this small difference would not likely be meaningful in a real-world scenario. The testing conducted in this study involved the speech intelligibility of individual words embedded in a carrier phrase. The contextual advantage of phrases and sentences typically allows for higher speech intelligibility than with individual words. Therefore, a 5% difference in intelligibility of individual words is not likely to impact operational performance with connected speech.

There are three possible reasons for the difference in speech intelligibility performance: differences in the presentation signal-to-noise ratio (SNR) due to differences in the frequency responses of the two systems, differences in intensity level of the stimuli provided to the listeners, differences in attenuation between the two systems and differences in microphone characteristics of the two systems.

Differences in SNR are well known to cause differences in speech intelligibility (French and Steinberg, 1947; Hawkins and Stevens, 1950; Plomp, 1978). To investigate differences in the SNR available to the listener, frequency responses of the earphones of each system were measured through a Knowles Electronics Manikin for Acoustic Research (KEMAR). The earpieces of each system were placed into the ears of the KEMAR. A white noise, created through Sound Forge software, was sent out of a laptop computer and through the system in the same way that the speech recordings were provided to the listeners. The outputs from each device were recorded onto a laptop computer through 01dB[*] software. Fast Fourier transform (FFT) analysis was conducted on a 5-s recording of the white noise and analyzed in 1/3 octave bands. Figure 4 shows the responses from the two systems equalized for the value at 1000 Hz.

[*]01dB is a trademark of 01dB-Metravib SA, France.

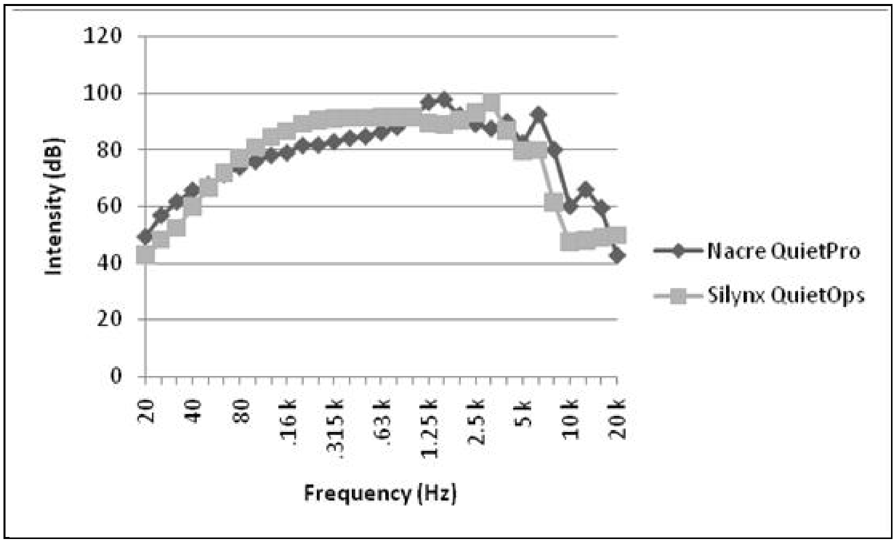

Figure 4. Frequency responses in 1/3 octave bands measured from the earphones of the two systems. The responses are equalized for the value at 1000 Hz. Frequency is shown on the x-axis and intensity is shown on the y-axis.

As shown in figure 4, the Silynx QuietOps system has a flatter response in the low and mid frequencies and a peak around 2500 Hz. The Nacre QuietPro system has a multi-peaked response with peaks at 1300–1600, 4000, and 6300 Hz. It is possible that the differences in the peak energy provided to the listener resulted in the differences in speech intelligibility.

Second, there is a possibility that there were small differences in the intensity level of the stimuli provided to the listeners. Note that the output levels of the two systems were equated for perceptual loudness by the two investigators and that the volume control could not be adjusted by the listener. It is possible that the output of the Silynx QuietOps system was slightly higher than the Nacre QuietPro system leading to a more favorable SNR for the listener when listening through the Silynx QuietOps system. However, given that two listeners agreed on the perceptual loudness of the stimuli, large differences are not anticipated.

It is also possible that the microphones of the two systems differ in their frequency response characteristics that altered the frequency content of the stimuli provided to the listener resulting in additional SNR advantages for the QuietOps.

Lastly, the attenuation provided by the two systems was compared. Data in table 1 were obtained from Henry and Weatherless (2010) which demonstrated that the Nacre QuietPro provided a greater level of attenuation than the Silynx QuietOps. This is the opposite pattern than would be expected if attenuation was a contributing factor to the differences in speech intelligibility seen with the two systems.

Table 1. Average real-ear attenuation at threshold values and standard deviations for the 12 participants for the two communications and hearing-protection systems from Henry and Weatherless (2010).

System	Frequency (Hz) 125	250	500	1000	2000	4000	8000
Silynx QuietOps	17.5 ± 8.6	17.3 ± 8.4	15.4 ± 9	17.1 ± 9.4	23.8 ± 7.6	27.3 ± 9.8	34.1 ± 13
Nacre QuietPro	23.3 ± 8.4	24.6 ± 9.4	25.4 ± 10.7	26.3 ± 8.5	29.2 ± 6.1	31.9 ± 5.2	37.1 ± 6.5

It is worth noting that although only small differences were demonstrated in speech intelligibility for the two devices, all of the participants in the study indicated a strong preference for the sound provided by the Silynx QuietOps system. This preference is most likely due to the improved speech intelligibility provided by this device. This difference in sound quality can be attributed to a combination of differences in frequency responses of the earphones and potentially of the microphones along with possible differences in the output intensity levels provided by the two systems.

5. Conclusions

This is the second in a series of three reports on the evaluation of communication and hearing protection systems. The first study focused on the attenuation provided by each of the systems to low intensity sounds. The present study focused on the speech intelligibility provided by the output of the C&HPSs to the listeners. Across the two systems evaluated, the Silynx QuietOps was shown to result in better speech intelligibility; however, the difference was small and may not be meaningful in field applications. This difference is likely due to a combination of factors including differences in frequency responses of the earphones and microphones along with small differences in the intensity levels of the stimuli provided to the listeners.

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