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Degradation of Auditory Localization Performance Due to Helmet Ear Coverage: The Effects of Normal Acoustic Reverberation

by Angelique A. Scharine

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14. ABSTRACT
Previous research has shown that listeners wearing the Personnel Armor System for Ground Troops (PASGT) helmet performed worse than those wearing the Advanced Combat Helmet on sound localization tasks. The PASGT has greater coverage over the ears. However, these helmets also differ in their suspension systems and profiles. Three versions of a single helmet design, differing only in the ear coverage, were compared in this study. As ear coverage increased, localization performance decreased. Most of the change was due to increases in large errors (>25°). In addition, these effects were tested in both "ideal" laboratory acoustics and in a moderately reverberant environment. Moderate reverberation intensified the effects of ear coverage—improving localization performance without a helmet and impairing it the most in the greatest ear coverage condition.

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1. Introduction

The shape and construction of a ballistic helmet changes the sound signal reaching the Soldier's ear. Although the ability to detect sounds remains unchanged, Soldiers used to report removing their Personnel Armor System for Ground Troops (PASGT) helmet when it was necessary to determine sound source direction. More recently, the Advanced Combat Helmet (ACH) has been shown to allow for better localization (Scharine, 2005; Scharine et al., 2007). Hypothesized reasons for this improvement include the reduction in ear coverage, the change in profile and the type of suspension system used to mount the helmet on the Soldier's head, but the existing data did not allow us to conclusively argue for one feature or the other. Therefore, in order to isolate the effects of ear coverage on localization, three versions of the same helmet design, differing only in ear coverage (0%, 50%, 100%), were compared in this study.

Traditionally, localization experiments are conducted in anechoic or semi-anechoic laboratory conditions so as to minimize the factors that could affect localization performance. However, Soldiers hear sounds in various environments, inside rooms, near buildings, and in fields where sound reverberation from nearby objects is present. It is unknown whether this added reverberation would change the relationship between ear coverage and sound localization ability. It seemed quite possible that differences in localization ability previously observed would become insignificant due to reduced localization ability under the more reverberative acoustic conditions typical of normal listening (Giguere and Abel, 1993; Hartmann, 1983; Shinn-Cunningham et al., 2005). Therefore, localization data were collected in two different acoustic conditions, one representing the minimal reverberation present in a laboratory, and one representing moderate reverberation that one might find in an average room. The moderately reverberant condition was achieved by placing two rows of opposing "walls" in the test facility. This resulted in increased reverberation; however, the amount of reverberation in the moderate condition was still relatively low and similar to what would be found in a carpeted office with acoustically absorbent ceiling tiles. That is to say that the reverberation would not be noticeable as it would be in a bathroom or a gymnasium.

2. Method

Twelve listeners were asked to point to the perceived location of sounds using a rotating chair equipped with a laser pointing device. A digital compass recorded the listener's horizontal angular position when responding. Figure 1 shows the test apparatus, with black acoustically

Figure 1. Test apparatus consisting of a suspended loudspeaker array, a rotating chair, and a digital pointing device. The curtains were used to hide the loudspeakers and the walls were used to create additional reverberation.

transparent cloth hung to hide the location of the loudspeakers. During testing, the lights were kept low in an effort to reduce visual information. Also shown in figure 1 are the walls used to create the higher reverberation condition.

Each of the listeners did the localization task while in each of the helmet conditions and in each of the reverberation conditions. Figure 2 shows the helmets used in this experiment. The four helmet conditions were: (1) No-Helmet, (2) 0% ear coverage (H0), (3) 50% ear coverage (H50), and (4) 100% ear coverage (H100). The red oval shows the approximate location of the ear and the yellow dot shows the location of the ear canal. The helmet shells were produced by Shawn Walsh of the U.S. Army Research Laboratory's Weapons and Materials Directorate. They were made of Kevlar fabric and were formed to match the Future Force Warrior* (FFW) FYO7 prototype helmet design. The helmets were covered with camouflage covers and outfitted with FFW FY07 prototype suspension systems provided by David Krasnecky of the Natick Soldier Research, Development, and Engineering Center.

*The main point of the study was to test the effects of ear coverage, while holding other variables such as shape and suspension system constant. So, it was not really important for our purposes to use a particular shell design. However, localization performance with the FFW helmet shell has been shown to be similar to that of the ACH in our laboratory.

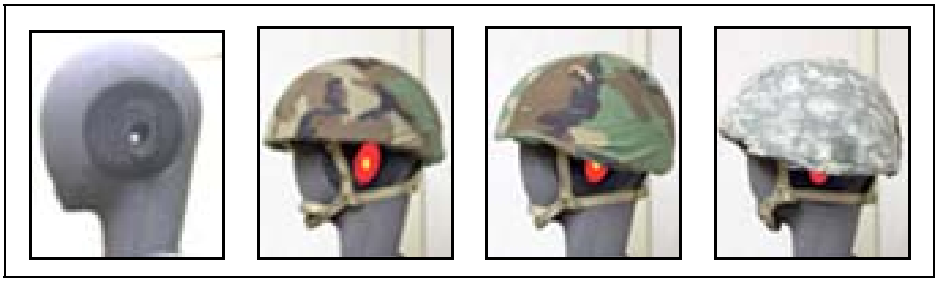

Figure 2. Four helmet conditions tested in this study (a) No-Helmet, (b) H0 = 0% ear coverage, (c) H50 = 50% ear coverage, and (d) H100 = 100% ear coverage.

The target sound used was a 250-ms white noise with 5-ms onset/offset ramps presented at 70-dB Sound Pressure Level (SPL). It was presented from each of 12 target loudspeakers eight times. The circular array of 12 target loudspeakers was suspended from the ceiling and was adjusted for each listener so that it was on the same horizontal level as his or her ears. The loudspeakers surrounded the listener and were separated equally by 30° in the horizontal azimuth. Background noise, in the form of a continuous pink noise signal played at 70-dB SPL, was played from five loudspeakers separated by 72° in the horizontal azimuth and placed outside the circular array of target loudspeakers. The intensity levels of the target and background loudspeakers were calibrated by placing a microphone at the listener position and adjusting the amplifiers until the intensity reached the desired level.

Two different acoustic environments were created by increasing the reverberation present. This was achieved by placing two rows of panels formed by mounting 4 × 8 panels of 1/4-in plywood vertically on 2 × 4 frames. Two rows of four panels were placed opposing each other and just outside the boundary of the loudspeaker array. Testing was done with and without the panels present. Without the panels present, the average reverberation time (RT_{60})* for frequencies above 250 Hz was 0.24 s. With them in place, the RT_{60} increased to 0.34 s.

3. Results

See figure 3a for absolute localization error as a function of helmet condition. Increasing ear coverage significantly increases localization error. There was no statistically significant difference between the No-Helmet and the H0 conditions. Partial (H50) or complete (H100) ear coverage significantly increased errors compared with the No-Helmet and H0 conditions. Figure 3b shows that this effect was stronger in what could be considered normal acoustic

*Reverberation time or RT_{60} is the time required for a sound to decay by 60 dB once the source of sound has stopped.

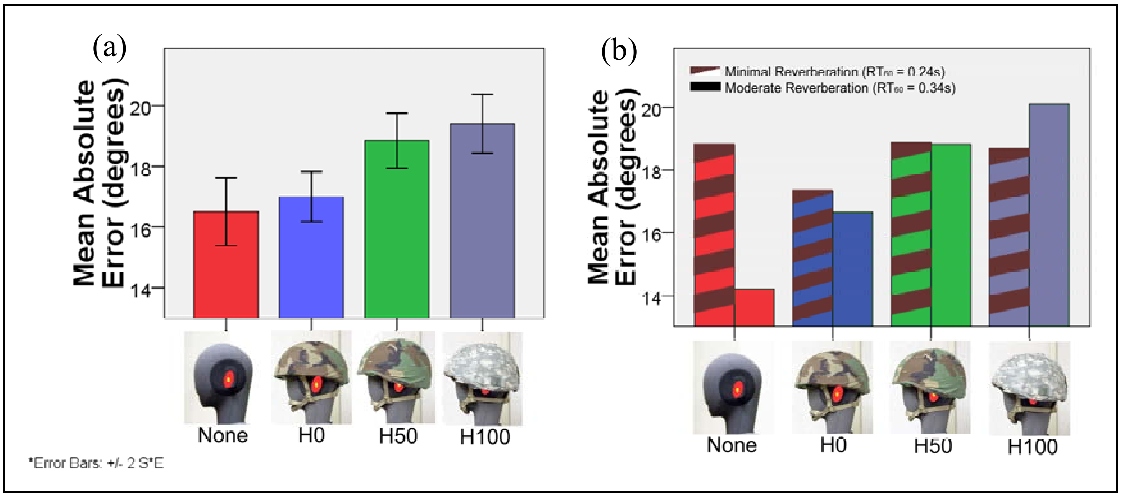

Figure 3. Absolute localization error as a function of helmet condition. (a) Error shown collapsed across acoustic environments. (b) Error shown broken down by acoustic condition. Note, in figure 3b, that for moderate reverberation (solid bars) in the No-Helmet condition, localization performance is better than in the minimally reverberant condition; but when a helmet is worn and as ear coverage increases, localization performance becomes worse in moderate reverberation.

conditions, that is, with moderate reverberation (RT_{60} = 0.34 s). It is interesting that in the No-Helmet condition, the average localization error in the moderately reverberant condition is even smaller than in the minimally reverberant condition. One cause of large localization errors is front-back confusions. In the higher reverberation condition, these errors are probably reduced for someone not wearing a helmet because the reverberation provides the listener with more information to distinguish front from back (front-back confusions will be discussed more in a subsequent paragraph). Once the ears are covered, reverberation increases the number of large errors. Therefore, the detrimental effect of ear coverage is greatest in normal reverberant conditions.

Perhaps more important, operationally, than the total number of errors, is how many of these errors are large (greater than 25°) across the differing ear coverage conditions. A small error in the auditory localization of a visible target is easily corrected because the target is within one's field of view. If we assume that any erroneous localization that is within 25° of the target is sufficient to bring the eyes to the position where the target falls within their field of view, then only errors that are larger than 25° should be important.

Figure 4a shows the percentage of large errors as a function of helmet condition. Note that a larger percentage of errors made with the ears completely covered are large errors. Once again, this effect is exacerbated for normal acoustic conditions (figure 4b). Therefore, under normal acoustic conditions, the percentage of large errors when no helmet was worn is about 11%. This percentage increases to 19% when a helmet (with no ear coverage) is worn, a 77% increase.

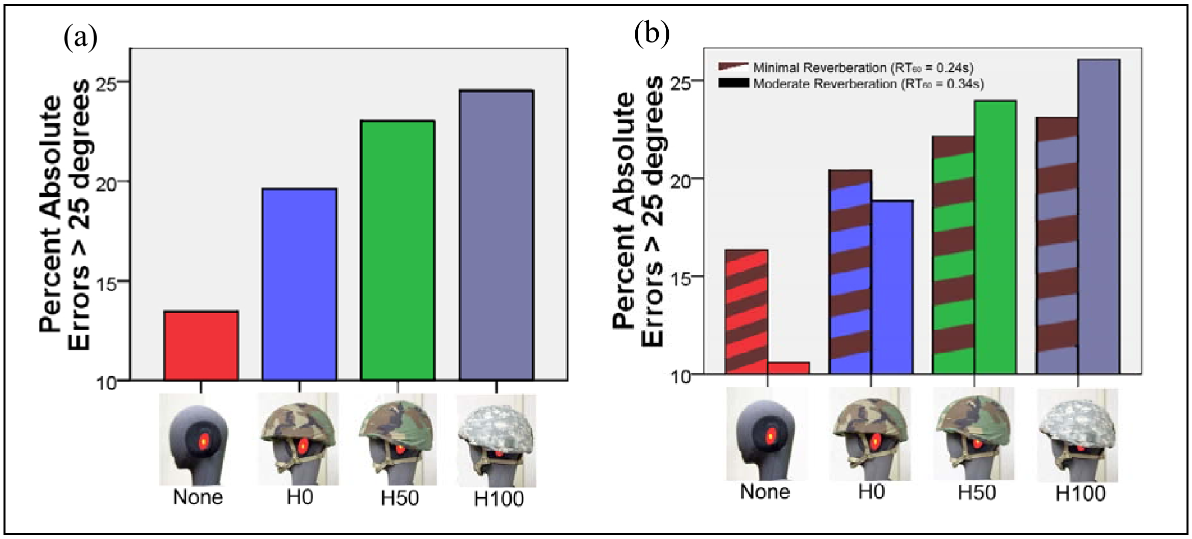

Figure 4. Percent of total errors that were large errors: (a) shown collapsed across acoustic conditions and (b) broken down by condition. Again, note that the impact of ear coverage is larger for the normal reverberative condition than for the minimized reverberative condition.

Partial ear coverage (H50) increases large errors by 27% with respect to a helmet with no ear coverage (H0); complete ear coverage (H100) increases large errors by 38% with respect to a helmet with no ear coverage (H0). These data suggest that caution should be exercised when increasing coverage around the ear area, as it can cause significant decreases in auditory situational awareness.

Table 1 provides this same information for a range of error sizes. The ranges were chosen to reflect the possible operational effect of such an error. When the distance from the estimate to the sound source is less than 10° in many cases, vision will allow one to detect the target and react. The greatest percentages of correct estimates are found for the No-Helmet and H0 conditions; performance decreases as ear coverage increases (row 1, table 1).

If an error is less than 25° it still is within one's field of view, and, if visible, it is likely to be detected quickly. The number of sound localization errors in the range of 10°–25° doesn't differ much between the helmet conditions (row 2, table 1).

The number of large and very large errors, however, (defined as errors greater than 25°) increases significantly with ear coverage (rows 3 and 4, table 1). Thus, the increase in average error for the helmet conditions with greater ear coverage is not due to an increase in small/medium errors, but rather to an increase in large errors. From an operational perspective, large errors in sound localization are likely to require greater movement to correct and may increase the response time needed to react appropriately, decreasing confidence, and increasing other mission errors.

Table 1. Percentage of responses that were: correct, small errors, large errors and very large errors, shown as a function of headgear for each of the acoustic conditions (minimal reverberation/moderate reverberation).

Accuracy of Estimate	 None	 H0	 H50	 H100
Correct (<10°)	51.4/54.8	46.4/46.0	42.4/45.4	44.9/42.7
Small/medium errors (10°–25°)	32.2/34.6	33.2/35.2	35.4/30.6	32.0/31.3
Large errors (25°–90°)	12.1/8.9	18.6/17.7	20.1/22.6	21.0/23.7
Very large errors (>90°)	4.2/1.6	1.7/1.1	2.0/1.4	2.1/2.3

Errors can be due to imprecision or front-back confusions. Errors of precision tend to be small, 3°–5°. Front-back confusions can be either small or large, depending on the location of the sound source. If the sound is near the front (0°) or the back (180°), a front-back confusion will result in a large error. Therefore, it's safe to assume that most large errors are due to front-back confusions. Front-back confusions occur in part because the binaural (two ear) cues that dominate sound localization do not distinguish the front and rear hemispheres. The two binaural cues relied on are interaural time/phase differences and interaural level differences. If one's head were a perfect sphere, these cues would be ambiguous, providing left/right, but not front back information. Fortunately, one's head is not perfectly spherical and monaural (single- ear) cues do provide information to disambiguate front from back sound sources; but these are less robust and human localization error patterns are consistent with this fact.

The observant reader might note that the No-Helmet condition had a larger average error size in the minimally reverberation condition (figure 1b). This may have been an artifact of the research facility used; however, it can also be explained by the nature of front-back confusions. When no reverberation is present, a helmet can decrease front-back errors because of the shadowing effect of the helmet that makes sounds coming from the rear quieter. However, ear coverage from a helmet reduces the monaural cues that also provide information about which hemisphere, front or back, contains the sound source. Moderate reverberation provides a small amount of information about the environment that the listeners evidently were able to use to distinguish between the front and the rear hemisphere when they weren't wearing a helmet; however, as the monaural cues were disrupted by ear coverage in the H50 and H100 conditions, reverberation became a detriment to localization performance.

4. Discussion and Conclusions

Obviously, during mission operations, the correction of a localization error varies with the initial position of the listener relative to the perceived location of the target, the initial position of the listener relative to the actual location of the target, and the visibility of the target. At times, despite a large auditory localization error, the target may fall within the field of view before the perceiver has completely rotated to the position where it was localized based on audition. At other times, despite correct auditory localization, the target may not be visible despite being within 25° of the auditory localization percept. Depending on the importance of target detection and simultaneous tasks being performed, the listener may persist in attempting to find the source of the sound or fail to attend to it entirely. The consequences of a "miss" may be minor or severe. In general however, it is likely that large localization errors lead to mission errors, slower reaction times and reduced confidence.

This study shows, clearly, the relationship between spatial auditory situational awareness and ear coverage by Soldier helmets; increased ear coverage leads to decreased auditory localization capability and greater size and number of errors, especially those exceeding 25°. Although the amount of reverberation in the moderately reverberant condition was in no way extreme, the effects on performance were notable. Therefore, the ideal condition for localization performance in environments with normal amounts of reverberation is a bare head. Since Soldiers often *must* wear a helmet, the preferred helmet for localization performance is one that leaves the ears uncovered.

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