MEASURING THE AUDITORY SITUATION AWARENESS REQUIRED FOR MILITARY OPERATION

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The term “situation awareness” is especially relevant to military personnel; knowledge and comprehension of relevant elements in the current environment are important for prediction of future events. Although the military often uses this term when promoting information technology, the ability of the end user to receive and process information is ultimately dependent on their basic sensory abilities. Those concerned with the hearing of warfighters often struggle with the conflicting need to protect hearing while enabling it. Current efforts include identification of the auditory capabilities required to successfully operate, optimizing application of communications and hearing protection technologies for those operational objectives and the provision of technological aids to overcome auditory challenges. To assess whether such communication aids are successful, it is necessary to demonstrate overall facilitation of operational activities. Standardized measures have been identified to characterize auditory sensitivity, protection from noise and communication ability. Additionally, a standard was recently developed for the measurement of auditory localization. However, there is still disagreement about how to predict the relationship of auditory ability to overall situation awareness and performance. Recently, researchers have attempted to demonstrate the impact of degraded hearing on operational performance. If communication is verbal, degradation of hearing increases errors and cognitive load. We will discuss this research, and efforts to develop operational measures of situation awareness for use in the evaluation of novel auditory situation awareness aids.

Keywords: auditory situation awareness, measurement, detection, communication, localization

1. Introduction

Endsley defines situation awareness as, “The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [1]. This term is especially relevant to military personnel for whom the knowledge and comprehension of relevant elements in the current environment and prediction of future events is essential for survival. Auditory situation awareness refers to the auditory elements of one’s environment that are necessary to comprehend it and to predict future events. Auditory information interacts with other perceptual information and top-down cues to aid in overall situation awareness.

2. Hearing protection versus auditory situation awareness

The levels of noise encountered during common military operations are typically unsafe; that is, steady-state noise that averages above 85 dB A and impulsive noise above 140 dB peak. For example, the weapon-fire of an M16 rifle measures 157 dB peak [2]. Similarly, measurements of the M60
machine gun average 155 dB peak. Larger weapons produce even higher peak levels of impulsive noise; the M72A3 antitank weapon and the M119 Howitzer, produce levels of 182 and 183 dB peak at the gunner position. The steady-state noise levels of tracked vehicles, such as the Abrams and the Bradley, exceed levels of 105 dB (A-weighted) at the driver position when moving. Noise levels in the cockpit of a UH60 Blackhawk helicopter measure at106 dB A. Even wheeled vehicles produce levels above 85 dB A in the cab compartment, meaning that longer trips should require hearing protection [2]. This problem is not limited to the U.S. Army, as even higher levels of steady-state noise (133-153 dB A) have been measured on the flight deck of a carrier when an F22 is taking off [3].

With such high noise levels, it is no surprise that hearing loss and tinnitus are significant problems for the military. Tinnitus and hearing loss are the two most common disability compensations for veterans [4]. The U.S. Government Accountability Office (GAO) reports that hearing loss is the most prevalent occupational health disability in the Department of Defense (DoD), costing the VA approximately 1.102 billion in 2005 alone [5].

In the Army, the Army Hearing Program mandates the monitoring and protection of hearing [6]. Soldiers are required to have an annual audiogram and Department of the Army civilians regularly exposed to noise have the same requirement. Hearing protection is required for steady-state noise levels above 85 dB A, and for impulsive noise levels above 140 dB peak. However, soldiers are often reluctant to wear hearing protection because of the perception that doing so reduces auditory situation awareness [7]. For this reason, the military has issued a number of devices that offer hearing restoration or “hear through” capabilities. These include two types of hearing protector: 1) those that incorporate a passive acoustic valve that is level dependent; and 2) those that incorporate an electronically-modulated sound transmission pass-through circuit in a battery-powered device. To distinguish hearing protectors that offer hearing restoration from those that only attenuate sound, we will refer to them here as hearing protection and enhancement devices (HPEDs). Tactical communications and hearing protection systems also offer hearing restoration in addition to hearing protection and communications. We will refer to them here as TCAPS (tactical communications and hearing protection systems).

Although the failure to protect one’s hearing can result in a permanent threshold shift, it can also affect one’s auditory situation awareness by causing temporary threshold shifts [8]. Therefore, despite the perception that it is better to maintain auditory situation awareness by foregoing hearing protection in the short-term, one is subject to impaired hearing via temporary threshold shifts. However, it is difficult to convey this danger to young warfighters, as hearing loss is invisible and seems a remote possibility. To the degree possible, it is important to give the warfighter both hearing protection and auditory situation awareness. What follows is a discussion of how to measure auditory situation awareness as a function of head-worn equipment such as HPDs, HPEDs, and TCAPS.

3. Auditory fitness for duty

Fitness for duty is a term used by medical personnel when assessing whether a current employee is, or is not, able to perform essential job functions. Although it is a medical term, some of the same questions apply to both auditory situation awareness and auditory fitness for duty. What auditory capabilities are required for one’s job? What auditory information is necessary in order to maintain auditory situation awareness?

Currently, all soldiers are required to have an annual pure tone audiogram. The hearing profile of the soldier is categorized in one of four categories, from H1-Normal to H4-Significantly Impaired, according to the criteria in AR 40-501 [6; 9]. Any profile greater than H1 requires further evaluation by an audiologist. If a soldier’s audiometric thresholds exceed the maximum levels allowed by the H2 profile, he or she is required to have a Military Administrative Retention Review (MAR2). The MAR2 is the process used to make a decision about whether to retain, reclassify, or separate a soldier with a medical condition from active duty, ostensibly on the basis of the soldier’s ability to perform his/her duties.
Although the Medical Review Board makes the ultimate decision on the disposition of a hearing-impaired soldier, a very important component of this decision is the recommendation made by the audiologist responsible for the hearing evaluation of the soldier. One tool used to make this assessment is the SPeech Recognition In Noise Test (SPRINT). The percentile score derived from this test, combined with years of service [10] is used to make a determination about a soldier’s ability to return to duty and any necessary restrictions [9].

Military audiologists are often tasked with determining whether a warfighter is “fit for duty” within an audiological framework. There is a lot of pressure to grant medical waivers, and very little upon which to make this judgment. A commander may argue that a soldier’s expertise is of value and his or her hearing loss is of no consequence for a particular military occupational specialty (MOS). The audiologist is responsible for preventing further hearing loss by reducing the soldier’s further exposure to noise. In many cases, the operational context provides significant challenges to the auditory situation awareness of even normal hearing persons. Noise presents an even greater challenge for those with a hearing impairment. Understanding the degree of hearing required for operational efficacy is a challenge for both audiologists and those who evaluate protective equipment.

4. Measurement of auditory situation awareness

We start with simply assessing the effect of hearing protection or noise on hearing thresholds, speech communication and auditory localization. Degraded auditory sensitivity results in higher thresholds, lower speech recognition scores and reduced spatial accuracy. However, soldiers may not need perfect auditory sensitivity. In the field, soldiers commonly compensate for ambiguous auditory information by repeating commands, using hand signals and confirming auditory information visually. Military leaders complain that psychophysical measures of auditory performance give little information on the actual impact of equipment and hearing loss on operational performance. Recently, researchers at Virginia Tech developed and implemented a test battery of field measures of the effects of TCAPS and HPEDs on auditory situation awareness [11; 12; 13]. Their measures formed the acronym DRILCOM, and included assessments of the ability to detect, recognize, identify, localize and communicate sounds. For example, for detection, thresholds were measured for the detection of a bolt click and an AK-47 burst presented in a 40 dB A pink noise background. The Recognition/Identification test requires the listener to recognize and identify a target sound signal presented with two other signals. Communication was measured as the difference in the speech to noise ratio (SNR) required to correctly recognise speech, relative to bare ear. Auditory localization was measured for a dissonant chord presented at two signal levels and in two levels of background noise. Localization was measured for both the horizontal azimuth and vertical elevation as a function of hearing protector use. Although this test methodology has not been adopted for widespread use, the concept of DRILCOM is useful as an acronym describing the elements of auditory situation awareness. What follows is a description of the standardized methodology used to assess these characteristics.

4.1 Measurement of the ability to detect, recognize and identify sounds

The attenuation of hearing protectors reduces one’s ability to detect sounds. Therefore, the established method for measuring the attenuation of hearing protectors can serve as a way to quantify its effect on auditory detection. The method for measuring the real-ear attenuation of hearing protectors is outlined in ANSI/ASA S12.6 [14], and is commonly known as the REAT standard. To evaluate the effectiveness of hearing protection, one measures the level of sound at the listener’s hearing threshold with and without the hearing protector, and the difference is used to compute the noise reduction rating of the device.

The intent of passive hearing protection is to reduce the level of sound that reaches the listener and necessarily decreases detection. To counter these effects, the military often uses HPEDs and TCAPS to restore ambient hearing. The REAT measurement standard is not appropriate for the measurement
of the protective attenuation of devices designed to provide minimal attenuation at threshold levels. To measure the level-dependent attenuation of HPEDs and TCAPS, one uses an auditory test fixture. Rather than measure the difference in threshold, one measures the difference in the level recorded by the auditory test fixture as a function of hearing protector use [15]. Thus, REAT provides a measure of the reduction in auditory sensitivity for HPEDs and TCAPS, and the test fixture measurements provide a measure of the protection provided by a device.

Currently, we ignore the problem of measuring recognition and identification. When there is prior knowledge of the target sound, the levels required for detection are correlated with the levels required for recognition and identification. The operational environment, however, consists of an unpredictable and infinite set of sounds in an indeterminate background context. Recognition and identification necessarily vary as a function of their similarity to the environmental context and detection does not necessarily predict recognition or identification [16; 17]. Further, in the context of a complex operating environment, with multiple perceptual cues, and a heavy cognitive workload, one may not attend to all relevant information. We thus assume that detection is necessary for recognition and identification, it is not necessarily sufficient. However, because we are not currently able to account for all of the factors that drive the recognition and identification of sound sources, we limit our measures to detection.

4.2 Measurement of speech communication

The mantra, “Shoot, move, and communicate” is standard military doctrine [18]. Therefore, an element of auditory situation awareness is the intelligibility of speech communication. There are many ways of measuring speech intelligibility [19]; however, the degree to which the speech corpus and acoustic context match the operational environment limits their generalizability. However, it has been found that tests that use monosyllabic speech items can be used to predict performance on other speech materials, so while they do not directly predict performance, they do allow for relative comparisons [20; 21]. For this reason, the Modified Rhyme Test (MRT), as specified in ANSI/ASA S3.2 [22] is used for most evaluations of military communications equipment.

4.3 Measurement of auditory localization

Although HPEDs and TCAPS provide hearing restoration by design, there is still a general perception that use of these devices impairs overall auditory situation awareness [23]. This may be due to a loss of auditory spatial sensitivity. Studies consistently show that head-worn equipment impairs auditory localization performance [24; 25]. Consequently, the research and development of new helmets and TCAPS have included evaluations of their effects auditory localization performance [26; 27; 28; 29].

Although there is a consensus that auditory localization is important for auditory situation awareness, there has been no established criteria for acceptable auditory localization performance. First, the need for auditory spatial awareness varies with MOS and operational environment. Second, the methods used to measure auditory localization vary significantly across laboratories, resulting in data that does not easily compare. Two common measures are percent correct, and magnitude of localization estimate error. The measure of percent correct depends on the number of loudspeakers in the response set and functions as a closed set. If there is a small set of loudspeakers, the probability of correct guessing is higher. There are still several factors that may bias participants if localization error magnitude is used. For example, if the loudspeakers are visible, participants may still be biased to respond by pointing at one of the available visual targets. Further, the participant is limited by the resolution of the response mechanism; if potential responses are 5° apart, error magnitude will be influenced accordingly. Depending on the size of the loudspeaker array, the availability of visual cues and the resolution of responses, the differences between these two measurements can be substantial. Other differences in response method can have significant effects on the data. For example, Iyer et al. [30] compared the accuracy of responses collected using head-pointing, a 2-D tablet display and
a hybrid of both methods. Errors were greatest for the 2-D tablet responses and least for the head-pointing method. Surprisingly, the hybrid method reduced errors relative to the tablet method.

Because of the need for comparable data across laboratories, researchers affiliated with military auditory research have been working to develop a standard method for assessing the effects of head-worn devices on auditory localization accuracy. We have formed an American National Standards working group (S3/94) and written a draft standard, “BSR/ASA S3.71-201X Methods for measuring the effect of head-worn devices on directional sound localization in the horizontal plane” is in preparation. Currently experiments are underway to assess the inter-laboratory variability of the data collected using these methods.

5. Measuring operational auditory situation awareness

If only we could directly measure the impact of auditory situation awareness on operational performance! There have been numerous attempts to quantify the effects of auditory capabilities on operational performance. The most well known is that of Garinther and Peters [31], who measured performance and subjective workload as a function of speech intelligibility. The task was to fire upon targets as instructed by a commander who was speaking over an intercom system. Using a “chopping” technique, they systematically removed portions of the speech signal to achieve each of five speech intelligibility levels (0%, 25%, 50%, 75% and 100%). Operational effectiveness, measured as the number of targets correctly fired upon and the response latency was not significantly affected by speech intelligibility until levels were degraded to 50%. However, participants reported that subjective workload increased linearly as a function of intelligibility. While the data are convincing, it is not surprising that response accuracy for a task that requires comprehending spoken instructions is affected by decreased speech intelligibility. Arguably, soldiers could use alternate means to identify targets, should speech communication be limited.

Weatherless, et al. [32] measured the navigation performance of persons concurrently responding to a verbal task. They filtered the speech items to simulate three levels of hearing ability. Participants completed the verbal task at each of these hearing levels while navigating and while standing still. Not surprisingly, as hearing levels decreased, performance on the verbal task was impaired. When the navigation task was added, verbal performance in the hearing-impaired conditions was even lower. However, there were no significant changes in the navigation task, suggesting that the effects of hearing loss are mostly restricted to speech communication.

Warfighters are trained to operate in teams and squads. Communication is an essential part of team effectiveness. Therefore, it is expected that the effects of hearing loss would be observed for an operational task that requires team cooperation. Ben Sheffield and his colleagues [33; 34] developed a clever experiment using hearing simulators and competitive paint ball teams. Soldiers from the 101st Airborne were equipped with hearing loss simulators that adjusted hearing to each of four levels, from normal to profound deafness. They then participated in a combat exercise requiring multiple fire teams with different levels of hearing loss to progress through a series of waypoints in a wooded area as quickly as possible without being eliminated by enemy gunfire. Researchers were surprised to observe increased survival as a function of increased hearing loss; this seemed to be due to participants, when deafened, taking protective measures such as hiding and avoiding contact in order to ensure their own survival. However, when the measure of performance was lethality (number of hits/kills), impaired hearing had a significant impact on efficacy.

A limitation of this study is that all members of the team were given the same level of hearing impairment. Further, unlike hearing impaired persons, this impairment was sudden, not allowing the individuals to develop compensatory strategies. This resulted in some amusing incidents, such as when a team member yells at the team leader, telling him to visually scan for the other team members when in the hearing impaired condition, so that hand signals could be used to replace verbal communication. They also found that hearing loss had a greater effect on the performance of experienced teams, suggesting that they are more effective in their use of communication to achieve objectives.
In a study by Keller et al. [35] experienced U.S. Navy personnel served as the study participants and were required to monitor information from multiple sources and respond appropriately to communications initiated by investigators playing the roles of other personnel involved in a realistic Naval scenario. Speech intelligibility was systematically controlled by identifying the speech to noise ratio (SNR) required to obtain intelligibility levels of No Loss, 80%, 60% and 40% for each participant. One of the hypotheses of this experiment was that individuals would employ compensatory strategies when speech communication is challenged by noise. The number of “repeat-back requests”, and the change in utterance amplitude was used as a measure of compensation. The number of repeat-back requests increased as intelligibility decreased, with the exception of the 40% intelligibility condition. They surmise that repeat-back requests decreased for the 40% intelligibility condition because some of the commands were missed entirely. Despite the SNR being kept constant for each intelligibility condition, utterance amplitude was also increased, clear evidence of the participants’ attempts to counter poor speech intelligibility.

One of the more interesting behaviours observed for this experiment was that of eye gaze. As intelligibility decreased, the amount of time spent fixated on “white space” or areas with little or no information increased. This is the result of “vision narrowing”, a compensatory technique that allows a person to focus their attention on speech comprehension. Although this narrowing can have beneficial effects for speech comprehension, it also increases the chance of missing other relevant visual information.

Warfighters will attempt to achieve their mission, regardless of difficulty, until they are unable to do so. Overall, operational performance did not decrease significantly until speech intelligibility was 60% or less. This illustrates the difficulty of developing operational tasks that reflect the true impact of poor auditory situation awareness. There was clear evidence that the impaired hearing increased task difficulty significantly, even though performance was only partially affected.

6. Development of a simulated test platform

The measurement of auditory situation awareness continues to be a challenge for military researchers. There is no single representative military context, thus limiting the broad generalization of research findings to other contexts. There continues to be the problem of “so what?”, when it comes to assessing hearing protection or hearing loss. How much auditory situation awareness is required for operational efficacy?

One strategy may be to develop representative test environments for use in performance evaluations. U.S. Army Research Laboratory is working with the U.S. Army Training and Doctrine Command to identify the components and tasks that are desirable for the next generation combat crew environment. The objective is to develop a representative test platform for use in all evaluations of performance, allowing use to compare the effects of new equipment and technology on crew station performance.

Another strategy is to adapt current technologies to create communications equipment that compensates for the limitations of the military environment. Auditory situation awareness will always be limited by the noise-induced “hearing impairment” of noise hazards in the military environment. By using the same strategies used to assist hearing impaired persons, such as speech-to-text capabilities, multimodal alerts and signal redundancy, it may be possible to circumvent the limitations of human auditory capabilities.

REFERENCES


