ARMY RESEARCH LABORATORY

Effects of Visual and Auditory Cues About Threat Location on Target Acquisition and Attention to Auditory Communications

by Monica M. Glumm, Kathy L. Kehring, and Timothy L. White

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NOTICES

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14. ABSTRACT

This study examined the effects of visual, spatial language and three-dimensional (3-D) audio cues about target location on target acquisition performance and the recall of information contained in concurrent radio communications. Two baseline conditions were also included in the analysis: no cues (Baseline 1) and target presence cues only (Baseline 2). In modes in which target location cues were provided, 100% of the targets presented were acquired, as compared to 94% in Baseline 1 and 95% in Baseline 2. On average, targets were acquired 1.4 seconds faster in the visual, spatial language, and 3-D audio modes than in the baseline conditions, with times in the visual and 3-D audio modes being 1 second faster than those in spatial language. Overall workload scores were lower in the 3-D audio mode than in all other conditions except the visual mode. Less information (23%) was recalled from auditory communications in Baseline 1 than in the other four conditions where attention could be directed to communications between target presentations.

15. SUBJECT TERMS

display; sensory modalities; target acquisition

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1. Introduction

This study was conducted in support of a situational understanding Army technology objective (ATO). The objective of this ATO is to "develop, demonstrate, and transition unit of action Soldier information system interface guidelines that facilitate Soldiers gaining situational understanding and enable planning and acting within the adversary's decision cycle."

The strategy selected to achieve this objective involved the development of models of Soldier-operator functions and tasks via the Improved Performance Research Integration Tool (IMPRINT). The IMPRINT models helped to identify the frequency at which workload levels exceeded a specified threshold, the tasks that contributed most often to these workload peaks, and the mental resources for which concurrent tasks competed. Interviews were conducted with experienced vehicle commanders and gunners to discuss suspected problem areas and potential solutions that might reduce workload and enhance situational awareness (SA). Questionnaires were also administered to derive a prioritized list of critical information requirements (CIRs). Candidate solutions related to the design of the information display were identified based on principles of attention management (Wickens & Hollands, 2000). This study is one of a series of investigations designed to evaluate these potential solutions and a first step in iterative analyses (i.e., modeling and experimentation), which will be performed to assess the effects of these interventions on SA and decision cycle time.

The rationale for the present study was based on the results of an IMPRINT model and analyses of the functions and tasks of the two-person crew (commander-gunner and driver) and squad leader in the infantry carrier vehicle (ICV) (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004). Multiple runs of the model consistently indicated that the commander-gunner frequently experienced instances of high workload. The greatest of these workload peaks were caused by conflicts between tactical communications and other tasks that might be shared by crew members in three- and four-person systems. Conflicting tasks included those associated with maintaining an awareness and understanding of the situation inside and outside the vehicle, such as the task of scanning for threats via the periscope or the battlefield display. According to the Soldiers surveyed, information about the strength, activity, and location of dismounted enemy infantry will be most critical to the commander-gunner of the ICV, as it is to the commander and the gunner of the Bradley fighting vehicle (BFV) (Mitchell et al., 2004). In a line-of-sight environment, the closer the enemy is, the more critical the information. Communications and scanning tasks are the primary means for obtaining this information. Digital communications, which employ the same resources used to perform the scanning task (i.e., visual, motor, and cognitive), were found to overload the commander-gunner more often than voice communications that do not rely on visual resources. Although voice messages would be the most likely mode of communication during engagements and other periods of high activity, digital communications containing critical information are also likely to be exchanged.

Discussions with Soldiers confirmed that communications often conflict with target acquisition and engagement tasks in the BFV. The Soldiers claimed that, as in the BFV, when the commander-gunner of the ICV becomes overloaded, he will most likely ignore those tasks he considers less important and will focus on the task of highest priority. Some Soldiers added that during engagements, they turn off their radio. In such instances, information critical to a present or subsequent engagement might be lost. Providing information about the presence and location of threats in a manner that will facilitate target acquisition rather than compete for mental resources is expected to enhance SA and reduce decision cycle time.

Directional cues on target location might be provided auditorily, visually, or tactilely. Auditory cues can be presented verbally in spatial language (e.g., "5 o'clock") or in 3-D audio sounds that appear to emanate from the clock position of the target. However, some of the Soldiers interviewed expressed concern that auditory cues might be lost amid the din and frequent verbal exchanges that are typical of a combat vehicle environment. The Soldiers were also skeptical about the effectiveness of tactile cues in conveying position information while they are being tossed about their moving vehicle. Some Soldiers preferred visual cues that could be integrated into the sight picture in such a manner as to avoid distraction and obstruction of the scene being scanned.

Auditory cues have been found to be useful in supplementing visual information or alerting the listener to critical information within a visual display (Shinn-Cunningham, Lehnert, Kramer, Wenzel, & Durlach, 1997), but the use of auditory cues in providing spatial information about target location in ground combat vehicles has not been adequately explored. For the most part, research on spatialized audio has focused on its use in aircraft where 3-D audio displays have scored a number of successes. Studies have shown that listeners who must monitor multiple radio communications can selectively attend to one message at a time if messages are presented in different spatial locations. In these studies, dismounted Soldiers (Haas, dePontbriand, Mello, Patton, & Solounias, 2000) and helicopter pilots (Haas, Gainer, Wightman, Couch, & Shilling, 1997) were found to identify and respond to multi-channel radio communications more quickly and accurately with 3-D audio than with existing monaural displays. In the latter study, pilots scored fewer points on a radio communications-identification task when some speech messages were presented to one ear and other messages presented to the opposite ear (i.e., dichotic presentation). Even fewer points were scored when all speech messages were sent to both ears (i.e., diotic presentation).

Spatial information about target location has been found to have positive effects on target acquisition performance and perceptions of workload (Begault, 1993; McKinley, Erickson, & D'Angelo, 1994; McKinley et al., 1995). In one study, commercial airline crew members acquired targets faster using a 3-D audio display than did crew members using a one-earpiece headset; however, no significant differences were found between these auditory displays in the number of targets acquired (Begault, 1993). In another investigation, 3-D audio cues alone did not improve target localization, but when paired with visual cues, the 3-D cues resulted in improvements in time and accuracy, reduced head movement, and lower subjective ratings of workload (Tannen, 2001).

Many studies that have compared the effects of auditory (e.g., 3-D audio and spatial language) and visual cues in the localization of targets during navigation have focused primarily on differences in spatial updating (i.e., the ability of people to keep track of the location of a target mentally without concurrent perceptual cues). In one such study, Loomis, Klatsky, Philbeck, and Golledge (1998) found that distance perception was more accurate with visual cues than with auditory cues, but spatial updating was performed well in both modalities. In another study with blind and blindfolded sighted observers, Loomis, Lippa, Klatzky, and Golledge (2002) again found greater error in distance perception with 3-D audio than with spatial language (e.g., "5 o'clock, 10 meters") for the latter participant group. However, directional errors were greater in the spatial language condition than in the 3-D audio mode. Here, too, spatial updating performance was nearly the same for both auditory conditions. The researchers concluded that once a target location is encoded or represented internally, the representation can be updated as well with either modality. In their report about the results of this research, Loomis and her associates present a two-process model of the task of navigating to a target using the two auditory modes. The two processes they identify are stimulus encoding and spatial update. According to the researchers, encoding of 3-D audio sound involves two substages: perception of the spatial location of the source and then the creation of a spatial image of the source location. Encoding of a spatial language stimulus may or may not require more than one substage, depending on whether a spatial image is formed in the process of converting the verbal directions into meaning. However, regardless of whether the location of the target is cued with 3-D audio sound or a verbal description, the result of encoding these stimuli is a spatial image that continues to exist after the stimulus is no longer present.

The objective of the present investigation was to measure and compare the effects of auditory (speech and non-speech) and visual cues about target location on target acquisition performance and attention to auditory communications. During the study, the participants performed target acquisition tasks while monitoring radio communications in each of five cue conditions: (1) Baseline 1, (2) Baseline 2, (3) Visual, (4) Spatial Language, and (5) 3-D Audio. Baseline 1 represented current limitations in targeting information. In this condition, the participant was not provided any information about the presence or location of targets. In Baseline 2, the participant was provided an auditory alert (bell) when a target was presented but he did not receive any information about where the target was located. In the Visual mode, target location cues were provided by an icon that resembled a one-handed clock without numbers. In the Spatial Language mode, cues were presented verbally in clock positions (e.g., "Target …3 o'clock").

In the 3-D Audio mode, target location was cued by two broadband audio tones that appeared to emanate from the position of the target.

For the current study, it was hypothesized that target detection times would be significantly faster in modes in which information about target location was provided. These improvements in target acquisition performance, however, were expected to be greatest in the Visual mode for two reasons. First, the process of converting the 3-D audio and spatial language stimuli into spatial images may involve more substages than the visual stimulus. Second, auditory resources used in listening to radio communications would not compete for the visual resources used in the perception of the visual cues. Thus, for the same reason, it was also expected that the participants would be able to attend better to radio communications in the Visual mode. The verbal cues provided in Spatial Language were expected to be more disruptive to this latter task than the 3-D Audio cues that were conveyed in sounds and not words.

2. Objectives

The objective of this study was to measure and compare the effects of auditory (speech and non-speech) and visual cues about target location on target acquisition performance and attention to auditory communications.

3. Method

3.1 Participants

The participants were 20 male Soldiers who ranged in age from 22 to 41 years (mean = 30.6 years; standard deviation [SD] = 6.5 years) with from 1.9 to 22.2 years of time in service (mean = 11.1 years; SD = 6.2 years) and a similar amount of time in their military occupational specialty (MOS). Most of the participants were commanders or gunners of the BFV or the M1 tank with an MOS of 19D or 19K, respectively. Fifteen of the 20 participants had seen combat during Operation Desert Storm and/or Operation Iraqi Freedom.

All the participants passed tests of color vision and met visual acuity requirements of 20/20 in one eye and 20/30 in the other eye, corrected or uncorrected. The hearing threshold levels (HTL) of the participants corresponded to Army physical profile H2 which specifies an average HTL of no more than 30 dB, no individual HTL greater than 35 dB at 500, 1000, and 2000 Hz, and no HTL greater than 55 dB at 4000 Hz (U.S. Army, 1991). The participants had otoscopically normal ears (i.e., no blockage or infection), and no history or otologic pathology (i.e., hearing problems) as reported by the participant.

The voluntary, fully informed consent of the persons used in this research was obtained as required by 32 Code of Federal Regulations 219 and Army Regulation (AR) 70-25. The investigators have adhered to the policies for the protection of human subjects as prescribed in AR 70-25.

3.2 Apparatus

3.2.1 Control Station and Target Scenario

The participant's control station consisted of 17-inch[1] Trinitron monitor manufactured by Dell and a joystick manufactured by Saitek (Cyborg 3-D Rumble Force Stick). The participant was seated approximately 25 inches from the monitor (i.e., seat reference point to screen). The monitor presented a 10-degree horizontal field of view (FOV)[1] of the 360-degree field around an imaginary vehicle in which the participant was operating. The joystick controlled the movement of the scene behind crosshairs that were fixed in the center of the visual display. The participant scanned the terrain around the vehicle by twisting the joystick to the left or the right. The farther the hand control was twisted, the faster the movement of the target scene. Movement of the scene behind the crosshairs was limited to the horizontal plane. Each target was an individual dismounted Soldier who was presumed to be an enemy (see figure 1). This choice of target type was based on a prioritized list of CIRs and related threats identified by Soldiers. All personnel targets were situated at a distance of 75 meters from the participant's vehicle. The targets were equal in size and presented along the vertical centerline of the visual display. A hit on the target was recorded when the trigger on the joystick was pulled while the crosshairs were on any portion of the target. The target fell to the ground to indicate to the participant that a hit had been scored. The DiGuy Scenario[2] (Version 5.2.3) developed by Boston Dynamics was used in the development of the target scenarios, the presentation of the target location cues, the interpretation of the input from the joystick, and data collection.

3.2.2 Target Location Cues

Cues about the location of targets were provided in the visual, spatial language (speech), and 3-D audio (non-speech) modes. All cues were 2.5 seconds in duration and their presentation was controlled by a computer. Target location cues were presented once, relative to the 12-o'clock position at each target presentation. The following paragraphs describe these cues and the apparatus that was used to present them.

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[1]This was based on discussions with United Defense Limited Partnership (UDLP) who is responsible for the design of the crew station in the ICV. UDLP provided information about the FOV of the commander's independent viewer (daylight TV sensor) in the BFV A3 (i.e., wide FOV [WFOV]: 10 degrees x 7.5 degrees) and best guess about the FOV of the sight in the ICV (WFOV: 9 degrees circular). At the time of this study, there had not been any decision regarding the FOV of the commander-gunner's sight in the ICV or the size of the flat panel on which the sight image would be displayed. A best guess was that the sight image would be presented on one of the main 15-inch square flat panel displays and, if desired, on a smaller square flat panel called the Crewman's Remote Interface System (CRIS).

[2]DiGuy Scenario is a trademark of Boston Dynamics.

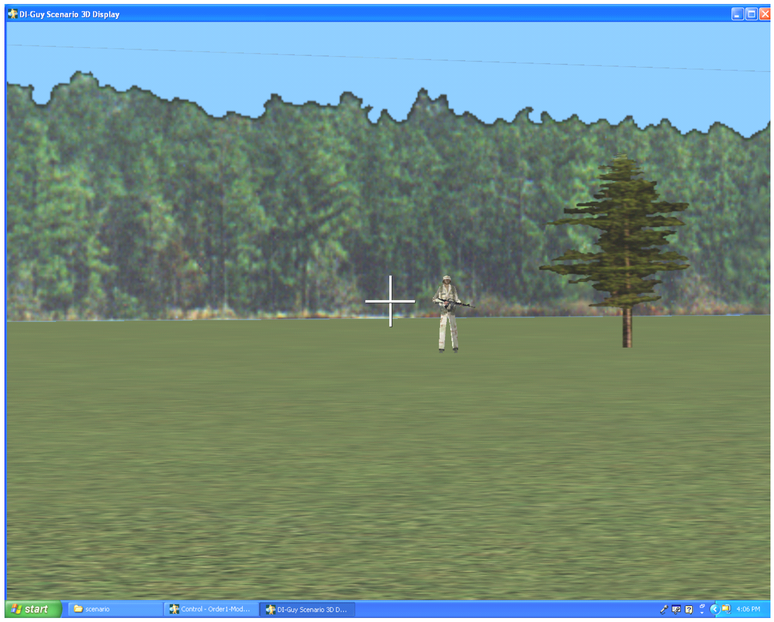

Figure 1. Dismounted enemy soldier within sight image.

(1) Visual. The visual cues about target location were provided by an icon that resembled a one-handed clock without numbers (see figure 2). The direction in which the hand on the clock was pointing indicated the location of the target within the 360-degree field about the vehicle platform. The directions were incremented in hours in the same manner as those cues presented in 3-D audio (non-speech) and spatial language (speech). Ten clock positions were used. No targets were presented at the 12- or the 6-o'clock positions, partly because of front-back reversals that can occur when these cues are presented in the 3-D audio mode (Begault, 1991). The visual icon was 2.5 x 2.5 inches in size and centered at the bottom of the scene displayed on the 17-inch monitor.

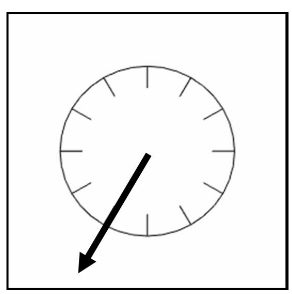

Figure 2. Icon providing directional cue in the visual modality.

(2) Spatial Language (speech). These cues about target location were verbal and were presented in a clock-type format. An example of this type of cue is "Target!…5 o'clock." As with the 3-D audio cue, the total duration of each cue in the spatial language mode was 2.5 seconds. The first and second parts of the cue were each approximately 1.0 second in

duration, separated by 0.5-second pause. All directional cues were pre-recorded in a female voice in contrast to the radio communications that were presented in a male voice.

(3) 3-D Audio (non-speech). These cues about target location were broadband non-speech audio signals. Each audio signal consisted of two 1-second tones that were presented approximately 0.5 second apart for a total duration of 2.5 seconds. The tones were spatialized with a 3-D virtual audio localization (3-DVALS) system manufactured by Veridian Engineering and played on a computer with a generic head-related transfer function recorded on a Kelso electronic mannequin for auditory research (KEMAR) acoustic head.

All cues about the presence and location of targets and other auditory communications were presented to both ears of the participant through stereo earphones manufactured by Sony. All were normalized to 21 dB and noise reduction was applied. The intensity levels of the auditory cues about target location, as measured through an artificial ear, were 73 peak decibels for the Spatial Language cue and 78 peak decibels for the 3-D audio cue. The decibel peaks for the auditory communications ranged from 65 to 70.

3.2.3 Radio Communications and Questionnaires

During each target run in each cue condition, the participant was presented communications through his headphones that simulated tactical information transmitted from command headquarters. These communications were in the form of a situation report (SITREP), although much longer and more detailed than normal. An example of this SITREP is provided in appendix A. The pre-recorded SITREP was the same duration as the target run (i.e., 2.5 minutes) and contained 27 different facts. Ten of the 27 facts were changed at each presentation of the SITREP. A total of 25 SITREPs was prepared and pre-recorded: 20 SITREPs for testing (i.e., four target runs in each of the five experimental conditions) and five SITREPs for training (i.e., two target runs in each condition). After the completion of each target run, the participant was asked to complete a questionnaire that consisted of ten questions pertaining to the information contained in the SITREP. The answers to each question were written and required a one- or two-word response. Each answer was worth two points. If the participant did not provide an answer to a question or the answer was wrong, the participant scored zero points. If the participant omitted a word from an answer that required two words or if one of the words in the answer was wrong, the participant scored one point. The participant had a maximum of 3 minutes to answer the ten questions. The SITREPs and associated questionnaires presented after each run were counter-balanced among the five experimental conditions. An example of the SITREP is provided in appendix B.

3.2.4 The National Aeronautics and Space Administration (NASA) Task Load Index (TLX)

The NASA-TLX was used to assess the participant's experience of workload (Hart & Staveland, 1988). This technique uses rating scales to assess mental, physical, and temporal demands, performance, effort, and frustration. Initially, each of these six workload factors is assigned a weight, based on the responses of the participant to pairwise comparisons. In these comparisons, the six factors are presented in 15 possible pairs, and for each pair, the participant is asked to circle the factor that s/he perceived contributed most to his or her workload experience. The participant then completes rating scales that provide a measure of the magnitude of the workload for each factor. Those factors perceived by the participant to have contributed most to his or her workload experience are given more weight in the computation of an overall workload score. The paired comparisons worksheets and the workload rating scale are provided in appendix C.

4. Procedures

4.1 Experimental Design

The study was a repeated measures, fixed factor design. Five cue conditions were evaluated. These conditions and the independent variables in this study were (1) Baseline 1 (2) Baseline 2 (3) Visual (4) Spatial Language, and (5) 3-D Audio. Cues about target location were provided in the Visual, Spatial Language, and 3-D Audio modes but not in the two baseline conditions. Baseline 1 represented current limitations in targeting information where the participant continuously scanned the terrain around the vehicle for threats without knowing whether threats were present or where they might be located. In Baseline 2, the participant was provided an auditory alert (bell) when a target was presented, but he did not receive any information about the location of the target. The primary purpose of the second baseline condition was to determine if the mere knowledge of the presence of a target would affect performance of the target acquisition task and perceptions of workload. In all conditions except for Baseline 1, the participant's crosshairs automatically returned to the 12-o'clock position after each target presentation. The participant could not move his crosshairs from that position until cued about the presence or location of another target.

The primary task of the participants was to find and engage targets as quickly as possible. Their secondary task was to attend to tactical information contained in SITREPs that were presented auditorily throughout each target run. The dependent variables in this study included measures of primary and secondary task performance and subjective ratings of workload. In the target acquisition task, the dependent variables were time to first shot, the degrees off target center at first shot, and the percentage of hits. For those targets hit, time to hit and the degrees off target center at hit were also recorded. The time to first shot and the time to hit were calculated from the time at which the target was presented to the time of trigger pull. The dependent variable in the secondary task was the total number of points scored on the SITREP questionnaires that were administered after each target run in each condition. Overall workload scores were derived with the NASA-TLX.

One participant was trained and tested at a time. The duration of training and testing for each participant was approximately 4.0 hours. The procedures that were followed for each participant are described in section 4.2.

4.2 Training

Each volunteer was briefed about the purpose of the investigation, the procedures to be followed during the study, and any risks involved in participation. The investigator read a volunteer agreement affidavit aloud to the participant who followed along. If the participant agreed to participate in the investigation, he completed the information requested in the consent form and signed it.

Each participant then completed a demographic questionnaire to obtain pertinent background information. A vision tester manufactured by Titmus Optical Company, Inc. was used to assess the participant's vision at near and far distances to ensure that the participant met visual acuity requirements of 20/20 in one eye and 20/30 in the other eye, corrected or uncorrected. The participant was also required to pass a test for color vision. A hearing test was administered by an audiologist with an AC40 clinical audiometer manufactured by Interacoustics A/S. The participants were required to have an HTL corresponding to Army physical profile H2 (U.S. Army, 1991) or better, otoscopically normal ears, and no history of otologic pathology.

The participant received training in all tasks to be performed during the study in each of the five experimental conditions, including instruction in rating his workload experience using the NASA-TLX. Training also included practice in localizing the 3-D audio cues presented at the ten clock positions. During this portion of the training, the investigator presented 3-D audio tones at each of ten clock positions, starting at the 1-o'clock position and ending at 11 o'clock. After each tone, the investigator stated the clock position at which the tone was presented. This process was repeated two more times. The investigator then presented the 3-D audio tones at each clock position in a randomized order to the participant who identified the clock position of each tone. This process was repeated two additional times.

During training in each of the five experimental conditions, the participant was reminded that his primary task was to find and engage all targets as quickly as possible. If the target did not fall at trigger pull, the target had not been hit and the participant was required to re-engage. The participant was told that his secondary task was to attend to the information contained in the SITREP. He was informed that some of the details in the SITREP would change and that he should not rely on his memory of information contained in previous SITREPs.

Training in each condition included the completion of two target runs, each followed by the questionnaire that assessed the participant's knowledge of the information contained in the SITREP. At the conclusion of training, the participant received practice in rating his workload experience using the NASA-TLX. The order in which the participant received training in each condition was counterbalanced and presented in the same order in which the conditions would be presented to him during the testing period.

4.3 Testing

After a 15-minute rest break, the participant completed four runs in each of the five experimental conditions. Each run consisted of five targets for a total of 20 target presentations. Each of the 20 targets was presented twice at each of the ten clock positions in a random order. Five different random orders of target locations were developed and the presentation of these orders was counterbalanced across the five experimental conditions.

All targets were individual dismounted Soldiers and all represented enemy personnel. Each target was presented for a maximum time of 15 seconds. If a hit was scored, the target fell to the ground to indicate to the participant that the target had been successfully engaged. The target disappeared from the screen after the 15 seconds had elapsed, regardless of whether a hit was scored. The time at which the first target was presented at the start of a target run and the time between subsequent target presentations was varied to reduce expectancy. The time intervals between target presentations were 5, 10, 15, 20, and 25 seconds and the order in which these intervals occurred was counterbalanced. The start of a time interval between target presentations began 15 seconds after the preceding target had been presented, regardless whether or when the participant had scored a hit on that target. Each target run was therefore 2.5 minutes in duration.

Each target run was followed by the questionnaire that assessed the participant's knowledge of information contained in the radio communications. Immediately after testing in each condition, the participant was asked to rate his workload experience using the NASA-TLX.

At the conclusion of testing in all five conditions, the participant was asked to provide his opinions and preferences with regard to the conditions evaluated.

5. Results

5.1 Target Acquisition

It had been hypothesized that target acquisition times in the Visual, Spatial Language, and 3-D Audio modes would be significantly faster than target acquisition times in the two baseline conditions (Baseline 1 and Baseline 2) where no information was provided about target location. These improvements in target acquisition performance were expected to be greatest in the Visual mode for two reasons. First, the process of converting the Spatial Language and 3-D Audio cues into spatial images about target location may involve more substages than the visual stimulus, resulting in an increase in response time and thus time to acquire the target. Second, auditory resources used in attending to radio communications are less likely to compete for visual resources used in capturing visual cues about target location.

To test this hypothesis, separate linear mixed effects model analyses were performed on time to first shot and time to hit. Each analysis included the order of presentation of the cue conditions. The mean times to first shot and mean times to target hit for each of the five experimental conditions are shown in figures 3 and 4, respectively. The similarity between time to first shot and time to hit within each condition merely suggests that, if found, most targets were hit on the first shot.

The results of the analysis on time to first shot indicated a significant main effect of mode (F (4, 472) = 55.596, *p* <.001). The analysis on time to target hit also revealed differences between cue conditions (F (4, 472) = 55.837, *p* <.001).

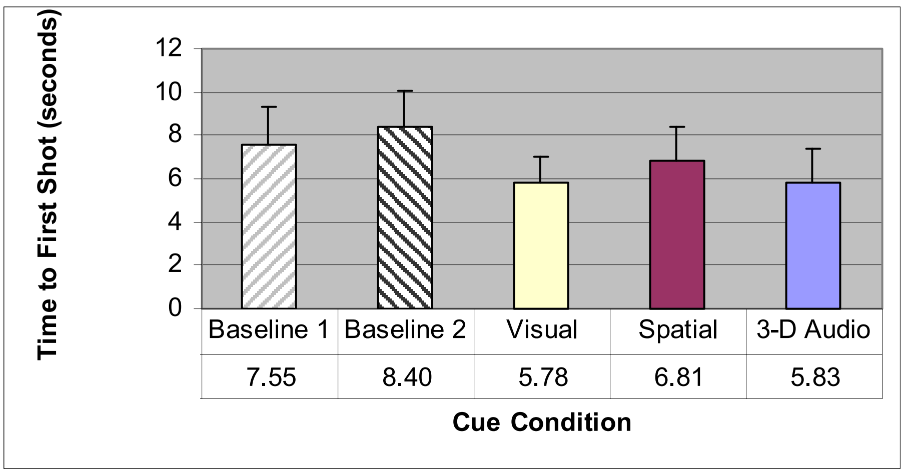

Figure 3. Mean time to first shot.

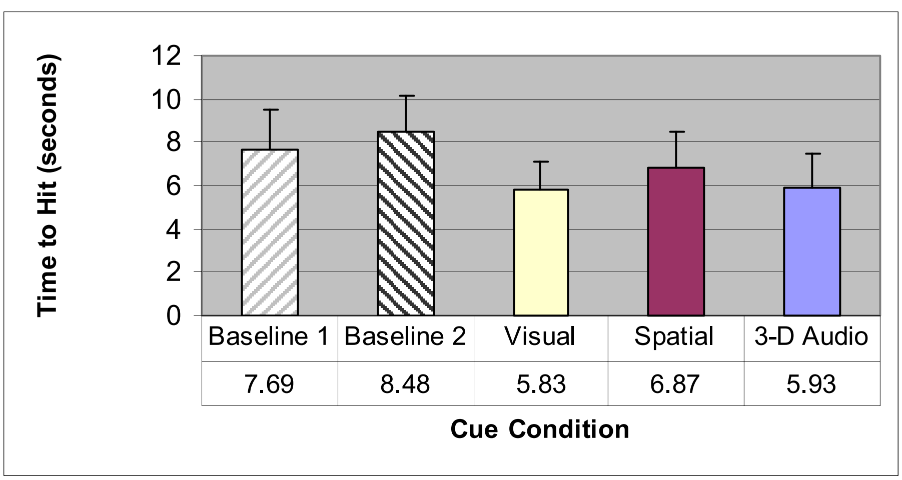

Figure 4. Mean time to target hit.

The results of *post hoc* analyses using the least significant difference (LSD) method are provided for time to first shot and time to hit in tables 1 and 2, respectively. These analyses revealed that, as hypothesized, time to first shot and time to target hit were significantly faster in the Visual, Spatial Language, and 3-D Audio modes than in either of the two baseline conditions. Time to first shot and time to target hit were slower in the Spatial Language mode than in the Visual and 3-D Audio conditions, but no significant differences were found between the Visual and the 3-D Audio modes. The analyses also suggested that time to first shot and time to hit were significantly faster in the Baseline 1 condition than in Baseline 2.

Table 1. Mean difference between modes in time to first shot.

Mode	Baseline 2	Visual	Spatial Language	3-D Audio
Baseline 1	**-0.857 ($p < .001$)**	**1.766 ($p < .001$)**	**0.741 ($p = .001$)**	**1.712 ($p < .001$)**
Baseline 2		**2.623 ($p < .001$)**	**1.598 ($p < .001$)**	**2.569 ($p < .001$)**
Visual			**-1.025 ($p < .001$)**	-0.054 ($p = .800$)
Spatial Language				**0.971 ($p < .001$)**

Bold blocks indicate significant differences.

Table 2. Mean difference between modes in time to hit.

Mode	Baseline 2	Visual	Spatial Language	3-D Audio
Baseline 1	**-0.793 ($p < .001$)**	**1.854 ($p < .001$)**	**0.819 ($p < .001$)**	**1.756 ($p < .001$)**
Baseline 2		**2.647 ($p < .001$)**	**1.612 ($p < .001$)**	**2.548 ($p < .001$)**
Visual			**-1.035 ($p < .001$)**	-0.098 ($p = .647$)
Spatial Language				**0.936 ($p < .001$)**

Bold blocks indicate significant differences.

Figure 5 shows the mean time to first shot and the mean time to hit based on the distance (clock position) of the target from the 12-o'clock position across the five conditions. Generally, the farther the target was from the 12-o'clock position, the farther the slewing distance and thus the longer the time to acquire targets.

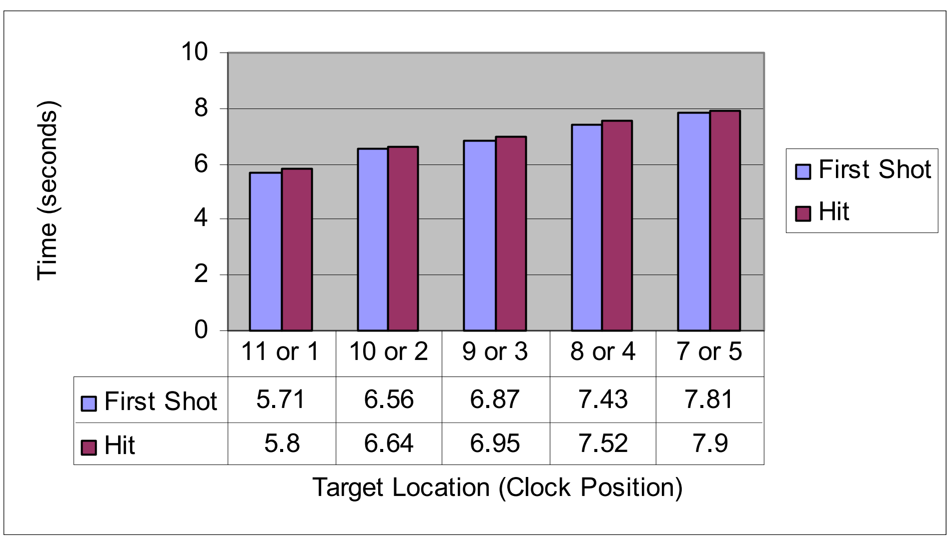

Figure 5. Time to first shot and time to target hit by target location.

The mean degrees off target center at first shot and the mean degrees off target center at hit for each of the five experimental conditions are shown in figures 6 and 7, respectively. The results of the linear mixed effects model analyses that were performed on these data did not reveal significant differences between cue conditions for either the mean degrees off target center at first shot (F (4, 472) = 2.139, *p* =.075), or for the mean degrees off target center at hit (4, 72) = .924, *p* =.445).

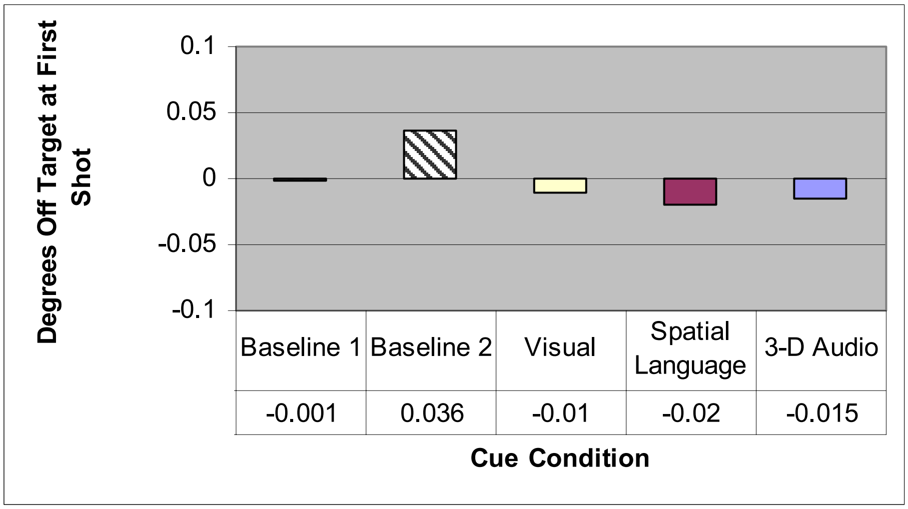

Figure 6. Mean degrees off target center at first shot.

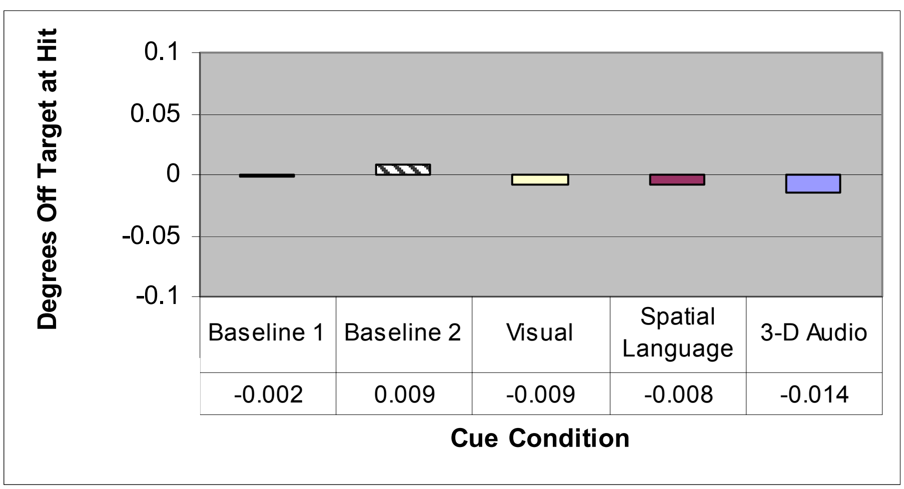

Figure 7. Mean degrees off target center at target hit.

The percentage of hits achieved in each of the five cue conditions is shown in figure 8. The results of the linear mixed effects model analysis indicated a significant difference between modes on this measure of target acquisition performance (F (4, 72) = 5.220, *p* =.001). *Post hoc* analyses indicated that the percentage of hits achieved in the Visual, Spatial Language, and 3-D Audio modes (100%) was greater than that achieved in Baseline 1 (94%) and Baseline 2 (95%).

No significant differences were found between Baseline 1 and the Baseline 2 conditions or between the Visual, Spatial Language, and 3-D Audio modes.

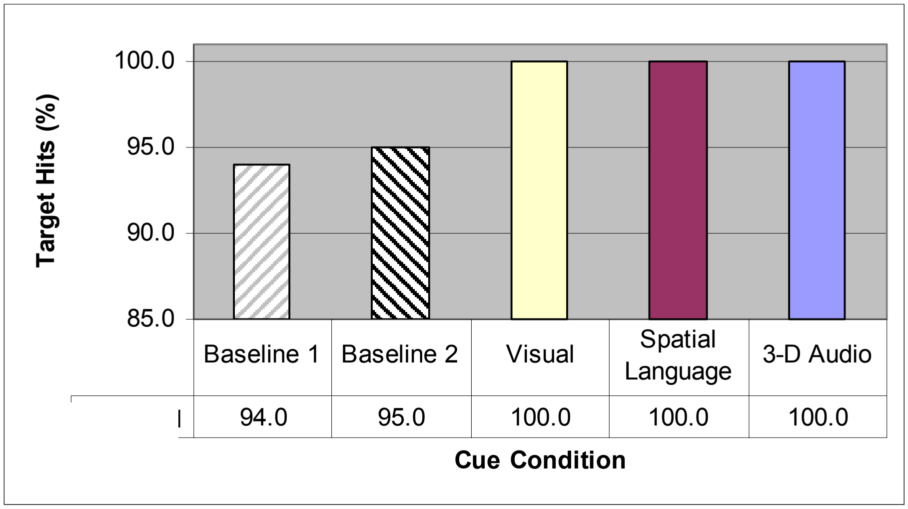

Figure 8. Percentage of target hits.

5.2 Secondary Task Performance (scores on SITREP questionnaire)

It had been hypothesized that the participants would achieve higher scores on questionnaires about information contained in the SITREP in the Visual mode because the visual cues about target location would not compete for auditory resources used when the Soldiers attended to the radio communications. The verbal cues provided in the Spatial Language mode were expected to be more disruptive to the secondary task than 3-D Audio cues that were conveyed in sounds and not words. To test this hypothesis, a linear mixed effects model analysis was performed on the total number of points scored on the SITREP questionnaires in each of the five experimental conditions. The results of the analysis revealed a significant difference between cue conditions ($F(4, 72) = 3.467$, $p = .012$). *Post hoc* analyses indicated that significantly less information was recalled from the SITREPs in Baseline 1 than in the other four cue conditions (see table 3). No differences were found between Baseline 2 and the Visual, Spatial Language, or 3-D Audio modes.

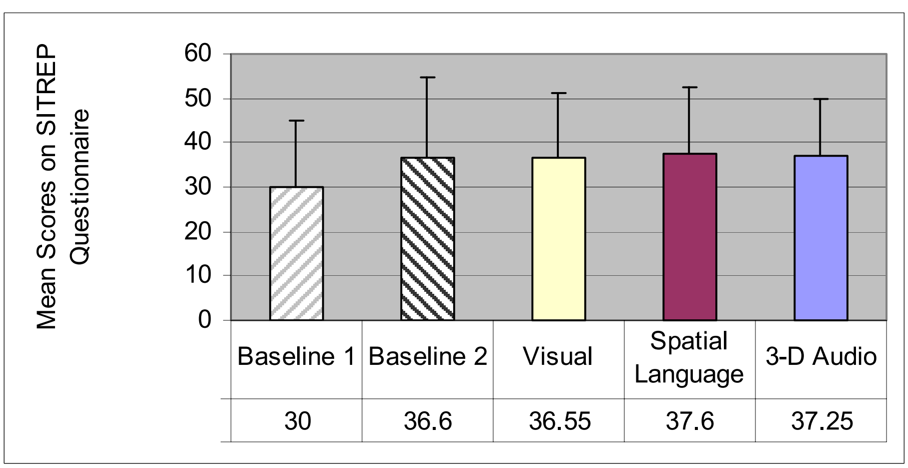

Figure 9. Mean scores on SITREP questionnaire.

Table 3. Mean difference between modes in scores on SITREP questionnaires.

Mode	Baseline 2	Visual	Spatial Language	3-D Audio
Baseline 1	**-6.60 (*p* = .008)**	**-6.55 (*p* = .008)**	**-7.60 (*p* = .002)**	**-7.25 (*p* = .004)**
Baseline 2		0.05 (*p* = .983)	-1.00 (*p* = .678)	-0.65 (*p* = .787)
Visual			-1.05 (*p* = .663)	-0.70 (*p* = .771)
Spatial Language				0.35 (*p* = .885)

Bold blocks indicate significant differences.

5.3 Subjective Workload

The results of a linear mixed effects model analysis on subjective ratings of workload on each of the six workload dimensions of the NASA-TLX (i.e., mental, physical, and temporal demand, performance, effort, and frustration) did not reveal a significant difference between any of the five cue conditions. However, significant differences were found between modes on overall workload scores computed from the weighted ratings on the six workload dimensions ($F(4, 72) = 3.036$, $p = .023$). The mean overall workload score for each condition is shown in figure 10. The results of *post hoc* analyses, shown in table 4, revealed that overall workload scores were significantly lower in the 3-D Audio mode than in all other conditions except the Visual mode.

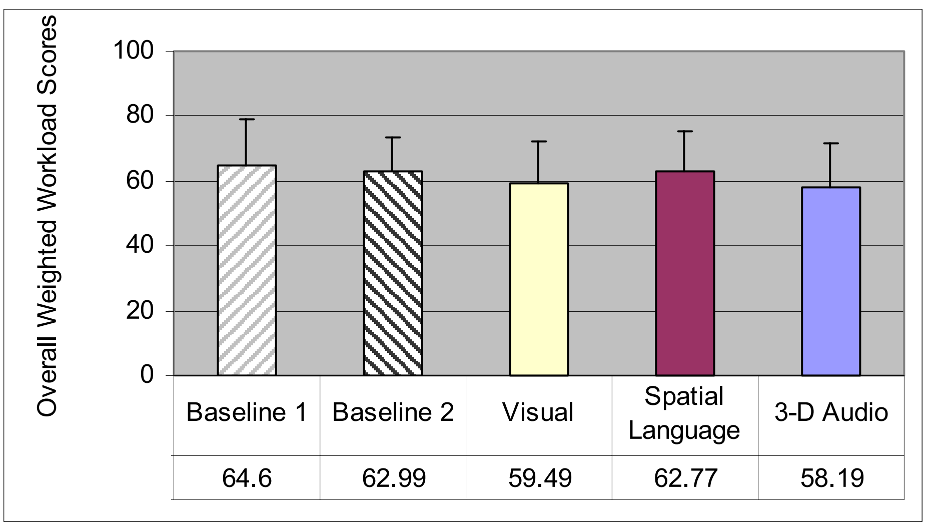

Figure 10. Overall workload scores.

Table 4. Mean difference between modes in overall workload scores.

Mode	Baseline 2	Visual	Spatial Language	3-D Audio
Baseline 1	1.61 (*p* = .459)	**5.11 (*p* = .021)**	1.83 (*p* = .400)	**6.41 (*p* = .004)**
Baseline 2		3.50 (*p* = .110)	0.22 (*p* = .919)	**4.80 (*p* = .030)**
Visual			-3.28 (*p* = .134)	1.30 (*p* = .550)
Spatial Language				**4.58 (*p* = .038)**

Bold blocks indicate significant differences.

5.4 Participants' Preferences and Comments

When asked about which condition they thought was best for acquiring targets while they attended to radio communications, more than half of the participants (53%) selected the Visual mode. The preferences of the remaining participants were split among the 3-D Audio (18%), Spatial Language (12%), Baseline 1 (12%), and the Baseline 2 (5%) conditions. Most of those who preferred the Visual mode believed that the visual cues were more straightforward, required less thought in determining target location, and did not interfere with the radio communications. The reasons some gave for preferring the Spatial Language mode were that it "gets your attention" or that "it is what I'm used to." The latter reason was also given by one participant who preferred the Baseline 1 condition.

When asked about which condition they thought to be the worst for acquiring targets while they attended to the radio communications, half of the participants (50%) selected the Baseline 1 condition. Eighteen percent of the participants believed the Spatial Language mode was the worst, and another 18% chose Baseline 2. Six percent of the participants thought the Visual mode was the worst, and another 6% chose the 3-D Audio mode. Many of those who thought the Baseline 1 condition was the worst noted the lack of information about target location and the need to scan continuously for targets. Most who disliked the Baseline 2 condition also noted the lack of information about target location. Some considered the auditory alert to be "useless," claiming that they found themselves merely waiting for the auditory alert and not focusing on the radio transmissions. Others claimed that there were times when they were slow in responding to the alert. Interference with the radio transmissions and distraction was the reason given most often for their disliking the Spatial Language and 3-D Audio cues. Participants also expressed a lack of confidence in their ability to localize the 3-D Audio sounds to specific clock positions, although all but one participant performed well in pre-tests. One participant who believed the Visual mode was the worst claimed that determining the location of the target "took too many steps" and required him to "look and process before taking action."

Many participants believed that cues about target location should be provided visually and auditorily, not only for backup in case a cue should fail but also when a visual display is unavailable, as would be the case when the commander-gunner is seated with his head outside the vehicle. When the commander-gunner is outside the vehicle, the participants believed that cues about the location of targets should be provided relative to the orientation of his head. When the commander-gunner is seated inside the vehicle, visual cues about target location should be based on the azimuth orientation of the main gun. A number of participants preferred that the auditory cues be provided in 3-D Audio rather than in Spatial Language, but they expressed concern that two speakers were needed to provide the 3-D Audio cues. They claimed that the speakers in their headsets tend to fail and replacements are not readily available. According to the Soldiers, it is not uncommon for crew members to have a headset with only one speaker that works. Speakers are often swapped between crew members to ensure that each has at least one functional speaker.

6. Discussion

In this study, participants hit 100% of the targets presented in the Visual, Spatial Language, and 3-D Audio modes by comparison to 94% in Baseline 1 and 95% in Baseline 2. As hypothesized, target acquisition times were faster in modes where information about target location was provided than in either of the two baseline conditions. On the average, time to first shot in the Visual, Spatial Language, and 3-D Audio modes was 1.4 seconds faster (19%) than in Baseline 1 and 2.3 seconds faster (27%) than in Baseline 2. No difference was found between the Visual and 3-D Audio modes in time to first shot or time to hit, but target acquisition times were 1.0 second faster (15%) in these modes than in the Spatial Language condition. Similarly, no differences were found between the 3-D Audio and Visual modes in overall workload scores, but scores in the 3-D Audio mode were lower than scores in all other cue conditions. On the average, 23% less information was recalled from the SITREPs in Baseline 1 than in the other four cue conditions where attention could be directed to communications between target presentations. No differences were found between Baseline 2 and the Visual, Spatial Language, or 3-D Audio modes in the performance of this secondary task.

Differences found between cue conditions in target acquisition performance might best be compared with the results of an investigation by Simpson et al. (2004). In this latter study, the researchers measured times to visually acquire targets in a simulated flight task in four display conditions that were like those assessed in the current investigation. One of the four conditions provided no information about the presence or location of targets (no display), as in Baseline 1. In a second condition, an auditory alert was provided to signal the presence of a target (as in Baseline 2) but was also accompanied by a visual display that showed target direction and relative elevation (Visual + Audio Alert). In the remaining two conditions, the visual display was supplemented by a non-spatialized verbal cue (Visual + Clock-Coordinate) or a spatialized audio cue (Visual + 3-D Audio). As in the present investigation, Simpson et al. (2004) found that target acquisition times were slower in the first two conditions which were also the only conditions in which targets went undetected. However, pairing the auditory alert about the presence of a target with the visual display showing target location significantly reduced target acquisition times over the “no-display” condition. By themselves, the auditory alerts about the presence of a target provided in the present study were considered “useless” by some participants who observed that on a number of occasions, they were slow in responding to these alerts.

On average, target acquisition times in the Visual and 3-D Audio modes were 24% faster than in Baseline 1 and 31% faster than in Baseline 2. By comparison, Simpson et al. (2004) found an average 25% reduction in target acquisition time between the Visual + 3-D Audio mode and the other conditions they studied. The 1-second difference in target acquisition time found between the Spatial Language condition and the 3-D Audio and Visual modes in the current investigation was also similar to the difference found between the Visual + 3-D Audio mode and the Visual + Clock Coordinate condition in Simpson et al. (2004). In this latter investigation, the researchers did not present any concurrent verbal communications that could potentially interfere with the perception of the verbal cues about target location. Therefore, for the present study, it is believed that the increase in target acquisition time in the Spatial Language condition might be attributable to other factors. First, the 1-second delay in target acquisition time may have been influenced by the structure of the verbal cue. In both studies, words that defined the location of the target were presented in the latter half of the cue, preceded by a verbal alert (e.g., "Target -- 9 o'clock" or "Traffic -- 9 o'clock high..."). A 1-second delay in the receipt of information about the location of a target might be expected to result in a similar delay in the time to acquire the target. However, it is also likely that the encoding of the Spatial Language cue required an additional cognitive step that involved the conversion of the verbal cue about the clock position of the target into a spatial image.

In a more recent study by Haas, Pillalamarri, Stachowiak, and Lattin (in press), target location information was also prefaced by a verbal alert, but the location of the target was presented in plus and minus degrees rather than in clock positions (e.g., "Target -- minus 15 degrees"). Unlike the results of the present investigation, no differences were found between the verbal and 3-D audio cueing techniques in target acquisition time or perceived workload. It is believed that the spatial language cues employed by Haas et al. (in press) may have provided a more immediate indication of whether the target lay to the right or left of 0 degrees, as did the Visual and 3-D Audio cues used in the present study. Here, any additional time and effort spent in the transformation of the Spatial Language cue into meaning may not only have contributed to increases in target acquisition time but also may have offset any potential reductions in perceived workload over baseline conditions.

In the present investigation, no differences were found between the Visual and 3-D Audio modes in either target acquisition performance or workload. The location of the target with respect to the 12-o'clock position was more readily discerned in these modes than in the Spatial Language condition. Given that targets were easy to detect, even at high slew rates, participants may not have felt compelled to localize the target to a specific clock position. Rather, they may have merely slewed in the direction indicated.

Without reliable information about the existence or location of targets, commander-gunners must spend more time scanning the terrain around their vehicle in search of potential threats. The task of detecting and identifying targets can impose significant demands on cognitive resources and attention. Thus, in this study, it was anticipated that while the participants were searching for targets, less attention would be available for acquiring information contained in radio transmissions. Improvements in the performance of this secondary task were expected in conditions where attention could be directed to communications between target presentations. Additionally, it had been hypothesized that improvements would be greater in the Visual mode because the visual cues about target location would not compete for auditory resources used by Soldiers in attending to the radio transmissions. The verbal cues provided in the Spatial Language mode were expected to be more disruptive to this secondary task than the 3-D Audio cues that were conveyed in sounds and not words. However, although many of the participants complained that the auditory cues interfered with the SITREPs, no differences were found between the Visual, Spatial Language, or 3-D Audio modes in the performance of the communications task. Generally, the analysis of secondary task performance appeared to suggest that the less time Soldiers spend scanning for targets, the more time would be available for them to attend to communications between target engagements.

It is believed that if targets had been less conspicuous than they were in the present investigation, target acquisition times in all conditions would have been greater than those that were found. Target acquisition times would still be expected to be faster in modes where target location cues are provided. However, the time to acquire a target would become increasingly dependent on the fidelity of the target location due and the extent to which the cue enables the commander-gunner to narrow the focus of his search. The more time and resources Soldiers spend in the search for targets, the less time and fewer resources they will have available to perform a secondary communications task.

7. Conclusions and Recommendations

In this study, cues that merely signaled the presence of a target did not provide any benefit in target acquisition performance. However, as might be expected, targets were acquired significantly faster when cues were provided about their location. Target acquisition times were faster in the Visual and 3-D Audio modes than they were in the Spatial Language condition, but the advantage that 3-D Audio cues provided in reductions in target acquisition performance and overall workload were not clearly distinguishable from those provided by cues in the Visual mode. Less information was recalled from SITREPs in Baseline 1 than in the other four cue conditions where attention could be directed to the communications task between target presentations. However, contrary to expectations, no differences were found between Baseline 2 and the Visual, Spatial Language, or 3-D Audio modes in the performance of this secondary task.

The results of this investigation are preliminary. Additional studies are needed to explore the advantages and disadvantages of the information presentation techniques assessed in this study and other display alternatives, particularly in the noise and vibration conditions that are typical of the combat vehicle environment. Studies that follow will include an assessment of the effects of tactile displays on target acquisition performance and attention to communications. The modality in which these communications are presented (i.e., auditory and visual) will be included as a factor in these analyses. In these studies, targets will be more embedded in the surrounding terrain to provide a better indication of the fidelity of the target location cues and the effects these cues have on primary and secondary task performance.

The technology that will provide information about target location has not currently been defined, although work is under way to demonstrate such a capability. It cannot be assumed, as it was here, that such a technology will detect 100% of targets with no false alarms. The translation of information from sensors and other intelligence sources into reliable, high fidelity sensory cues about enemy position poses a significant challenge. The potential impact of cue reliability on target acquisition performance and workload with the use of these and other display techniques will need to be explored.

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Appendix A. Situation Report (SITREP) Example

Attention! Some aspects of the current situation have changed that will affect your mission. The following is the latest from Command Headquarters.

The friendly country of Dodge has been overthrown by insurgent religious extremists. The United States has deployed the 3rd STRYKER Brigade Combat Team of the 2nd Infantry Division. This team will link up with and support the remaining elements of the government. The team is currently assembled 3 kilometers west of the airport in the capital city of Aberdeen. The team will conduct reconnaissance operations around the airport prior to securing it for the entry of heavy U.S. forces. Your platoon will proceed to Objective Brown which is 500 meters east of your current assembly point. Other STRYKER platoons will proceed northeast and southeast to their objectives to encircle the airport. You are to arrive at your objective at 0500 hours tomorrow morning. Potential threats on the way to your objective include an ambush along Phaseline Washington. The insurgents have captured tanks from the defense forces and have deployed them around the perimeter of the airport. Your closest supporting unit is dismounted infantry located 100 meters south of the objective. The call sign of this supporting unit is Charlie 1. A friendly artillery unit is currently 2 kilometers north of the airport. The call sign of this unit is Zulu 3. They will await your signal to provide support as needed. Air support will be provided by a squadron of Apache helicopters. Their call sign is Eagle 1. The drop off point for your squad is Peach Hill which is 100 meters south of the objective. The closest enemy unit to the objective is armor, located 200 meters east of the objective. This armor unit is a company-size unit and is currently re-supplying. Dismounted enemy infantry are located throughout the countryside and are armed with RPGs. They have placed landmines near your objective along Church Road.

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Appendix B. SITREP Questionnaire (Example)

Participant # : ______ **Run : ___ Target Set : ___**

Please answer the following questions based on the SITREP you heard during this last target set. Each answer is one or two words. The number in parentheses after the question indicates the number of words in the answer. Examples of one-word answers are “armor” or “NBC.” Examples of two-word answers are “mechanized infantry” or “Charlie Company.” An answer which requires two words can also include a number. Examples of two-word answers with a number are “200 meters” or “Charlie 35.” Each answer is worth 2 points. If you do not provide an answer to a question, or the answer is wrong, you will lose 2 points. If you omit a word from an answer that requires two words, or if one of the words in your answer is wrong, you will lose 1 point.

Question	Answer *(Please PRINT)*
(1) What is the name of the country that has been overthrown? (1)	____________________
(2) In what direction is the STRYKER team from the airport? (1)	____________________
(3) How far is your objective from your current assembly point? (2)	____________________
(4) At what time is your platoon to arrive at the objective? (2)	____________________
(5) What have the insurgents captured from the country’s defense forces? (1)	____________________
(6) What is the call sign of the friendly unit located north of the airport? (2)	____________________
(7) What is the name of the drop off point for the squad? (2)	____________________
(8) How far is the closest enemy unit from the objective? (2)	____________________
(9) In what activity is the enemy unit closest to your objective currently engaged? (1)	____________________
(10) What is the name of the road near your objective where the enemy infantry has placed obstacles? (1)	____________________

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Appendix C. NASA-TLX

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Perfect/Failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort or **Performance**	**Temporal Demand** or **Frustration**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**
Physical Demand or **Performance**	**Temporal Demand** or **Mental Demand**

Frustration or **Effort**	**Performance** or **Mental Demand**
Performance or **Temporal Demand**	**Mental Demand** or **Effort**
Mental Demand or **Physical Demand**	**Effort** or **Physical Demand**
Frustration or **Mental Demand**	

RATING SCALE SHEET

MENTAL DEMAND

Low **High**

PHYSICAL DEMAND

Low **High**

TEMPORAL DEMAND

Low **High**

PERFORMANCE

Good **Poor**

EFFORT

Low **High**

FRUSTRATION

Low **High**

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