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

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NOTICES

Disclaimers

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14. ABSTRACT

This study examined the effects of tactile, visual, and auditory (spatial language and three-dimensional [3-D] audio) cues about threat location on target acquisition and the recall of information presented in visual and auditory communications. On average, participants hit 98% of the targets presented when cued about the location of targets compared to 64% in a baseline condition (no cues). When target location cues were provided, time to first shot was an average 26% faster; 23% more information was recalled from the auditory and visual communications, and overall workload scores were 17% lower. On average, time to first shot in the visual and spatial language modes was 13% faster than in the tactile condition and 26% faster than in the 3-D audio mode. Overall workload scores were an average 14% higher in the 3-D audio mode than in the other conditions in which target location cues were provided. Communications modality did not have a significant effect on either the amount of information recalled from the communications or on target acquisition. No interactions were found between communications modality and cue condition. However, on average, 10% more information was recalled from communications when target location cues were provided in the visual mode than in the other cue conditions.

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display; sensory modalities; target acquisition

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1. Introduction

Future combat vehicle systems will be lighter in weight and the size of their crews will be potentially reduced from three to two. Communication and target acquisition tasks that are currently shared by two crew members could become the responsibility of one: the commander-gunner. Task and workload analyses have shown that the commander-gunner will often become overloaded when he attends to auditory or digital communications while scanning for threats and engaging targets (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004).

According to the multiple resource theory, two tasks can be time shared more efficiently if these tasks do not share the same perceptual modality and employ different working memory codes (Wickens, 2002). Although different sensory modalities may be used in the acquisition of targets and information presented in radio transmissions, both tasks can impose high demands on cognitive resources and attention. Target detection and identification require a search through long- and short-term memory stores, as do the interpretation and prioritization of auditory or visual information about the battlefield. If information is to be recalled, it must be rehearsed for transfer to working memory (Wickens & Hollands, 2000). As task demands increase and attentional resources employed in these processes are depleted, performance of one or both tasks is expected to decrease.

As technologies advance, Soldiers will be provided far more information about the battlefield than they are provided now. The combat advantage that information can provide is well recognized, but as the amount of information the Soldier must process increases, so does the potential for cognitive overload. In an effort to reduce the burden on over-taxed resources and increase the speed and accuracy with which Soldiers capture, interpret, and act upon information, Army researchers are investigating different techniques for displaying information that Soldiers have identified as critical. High on Soldiers' lists of information requirements is enemy location.

Information about the location of enemy threats or targets might be provided in an auditory, visual, or tactile modality. Auditory cues might be presented verbally in spatial language (e.g., "5 o'clock") or in three-dimensional (3-D) audio sounds that appear to emanate from the location of the target in space. Research about collision avoidance in aircraft has found reductions in target acquisition time and perceived workload when target location cues were provided in 3-D audio (Begault, 1993; McKinley, Erickson, & D'Angelo, 1994; McKinley, D'Angelo, Haas, Perrot, Nelson, Hettinger, & Brickman, 1995; Simpson et al., 2004) or when 3-D audio and visual cues were paired (Tannen, 2001). In one such study, Simpson et al. (2004) measured times to visually acquire targets in a simulated flight task in four display conditions. One of the four conditions provided no information about the presence or location of targets (No Display). In a second condition, a non-spatialized auditory alert (i.e., chirp) was provided to signal the presence of a target but was also accompanied by a visual traffic advisory system (TAS) display that showed the relative altitude and direction of the target (Visual + Audio Alert). In the third condition, the visual display was supplemented by a verbal cue that provided target location information in clock positions (Visual + Clock-Coordinate). A spatialized audio chirp indicating target direction and a verbal cue indicating relative altitude supplemented the visual display in the fourth condition (Visual + 3-D Audio). The researchers found that target acquisition times were slower in the first two conditions, which were also the only conditions in which targets were 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. Simpson et al. (2004) also found an average 25% reduction in target acquisition time between the Visual + 3-D Audio mode and the other conditions they studied. Target acquisition time was 1 second slower in the Visual + Clock Coordinate condition than in the Visual + 3-D Audio mode. The researchers concluded that response times to a visual TAS could be significantly reduced if a non-spatialized clock-coordinate audio display were added; however, even greater reductions in response time could be achieved if the visual display were supplemented with a spatialized 3-D audio display.

Many studies that have compared the effects of auditory (e.g., 3-D audio and spatial language) and visual cues in localizing 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 cues than with spatial language cues (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 on the results of this research, Loomis and his 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 updating. 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 "linguistically" converting the "utterance" 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 has been presented.

Research has shown that tactile displays may offer a viable alternative to auditory and visual displays of information, particularly in situations when the auditory and visual channels are heavily loaded. Tactile cues have been found useful in alerting operators to unexpected, high priority events (Calhoun, Draper, Ruff, Fontejon, & Guilfoos, 2003) and an acceptable substitute for auditory alerts as a redundant cue to visual alerts (Calhoun, Fontejon, Draper, Ruff, &

Guilfoos, 2004). Calhoun et al. (2004) found that in situations when visual load was high, reaction times to tactile cues were faster than reaction times to visual alerts and as fast as those to auditory cues. Like auditory cues, tactile cues do not require the operator to look in any particular direction to receive the information. Research suggests that tactile cues can enable the performance of multiple tasks better than visual cues can. In one study, a tactile cue elicited faster reaction times in the detection of system faults than a visual cue and was less disruptive in the performance of concurrent tracking and visual monitoring tasks (Calhoun, Draper, Ruff, & Fontejon, 2002). In another study, the performance of helicopter pilots in counteracting the effects of drift was less affected by a secondary cognitive task when a tactile display was used to provide direction information (Van Erp, Veltman, Van Veen, & Oving, 2003). In other investigations, improvements in navigation performance and reductions in workload were found with tactile displays compared to visual displays (Chiasson, McGrath, & Rupert, 2003; Van Erp, Meppelink, & Van Veen, 2002).

The present study was the second in a series of investigations conducted in support of a Situational Understanding Army Technology Objective (SU ATO). The objective of this ATO is to "develop, demonstrate, and transition unit of action (UoA) soldier information system interface guidelines that facilitate soldiers gaining situational understanding and enable planning and acting within the adversary's decision cycle."

The first study examined the effects of one visual and two auditory cues (i.e., spatial language and 3-D audio) about threat location on target acquisition performance and the recall of information presented in concurrent auditory communications (Glumm, Kehring, & White, 2005). 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 compared to 94% in baseline 1 and 95% in baseline 2. No differences were found between the 3-D audio and the visual modes in target acquisition time or perceived workload. However, on the average, target acquisition times were 1 second faster in the 3-D audio and visual modes than they were in the spatial language condition. The only differences found between conditions in the performance of the secondary communications task was between baseline 1, in which participants were required to continuously scan for targets, and the other four cue conditions where attention could be directed to communications between target presentations.

The present study extended the earlier investigation of alternate displays for cueing target location to the tactile mode and included the modality in which communications are presented as a second factor. In this study, the participants monitored auditory or visual communications while performing target acquisition tasks in each of five cue conditions: (1) baseline, (2) visual, (3) spatial language, (4) 3-D audio, and (5) tactile. As in the initial investigation, it was assumed that the technology that provided cues about target location detected 100% of the targets with no false alarms. Targets were less conspicuous than they were in the initial study to encourage the participant to use the cue to localize the target to a specific clock position rather than merely slew in the direction indicated. Thus, the speed at which a target is acquired would depend primarily on the fidelity of the target location cue and the size of the area to be searched. The following was hypothesized for this study:

H1: Reaction times (time from cue presentation to movement of crosshairs) will be faster when target location cues provide an immediate indication about the direction to slew to acquire the target in the shortest distance. Reaction times will be slower in the Spatial Language mode than in the Visual, 3-D Audio, and Tactile modes because some additional processing will be required to determine slewing direction. Reaction times among the latter three modes are not expected to be significantly different.

H2: Time to slew (i.e., time to first shot minus reaction time) will be faster for cues that provide a more direct indication of the clock position of the target and less uncertainty about target location (i.e., Visual and Spatial Language) than for cues where the clock position is not as clearly specified (i.e., 3-D Audio and Tactile).

H3: Cue condition is not expected to affect shooting accuracy or result in a significant difference between time to first shot and time to hit. If a target is found, it will normally be hit on the first shot, regardless of cue condition.

H4: Time to first shot and time to hit will be faster for cues that provide a more direct indication of the clock position of the target (i.e., Visual and Spatial Language) than for indirect cues where the clock position is not as clearly specified and, thus, more prone to errors in localization (i.e., 3-D Audio and the Tactile). Time to first shot and time to hit will be faster in the Visual mode than in the Spatial Language condition because of slower reaction times in the latter mode. No differences will be found, however, between the 3-D Audio and the Tactile modes on these measures of target acquisition performance.

H5: More information will be recalled when communications are presented auditorily than visually because the information contained in the visual situation reports (SITREPs) is less likely to be captured when the SITREPs are presented during the visually intensive target acquisition process.

H6: More information will be recalled from the SITREPs for cues that provide a more direct indication of the clock position of the target (i.e., Visual and Spatial Language) because time to acquire will be faster than indirect cues (i.e., 3-D Audio and Tactile) and more time and attention will be available for rehearsal of the information.

2. Objectives

The objective of this laboratory study was to measure and compare the effects of visual, auditory (i.e., spatial language and 3-D audio), and tactile cues about target location on target acquisition performance and the recall of information presented in visual and auditory communications.

3. Method

3.1 Participants

The participants were 20 male Soldiers who ranged in age from 21 to 41 years (mean *[M]* = 31.8 years; standard deviation *[SD]* = 5.2 years) with from 3.3 to 21.9 years of time in service (*M* = 12.1 years; *SD* = 4.8 years) and a similar amount of time in their military occupational speciality (MOS). Most of the participants were commanders or gunners of the Bradley fighting vehicle (BFV) or the M1 tank with an MOS of 19D or 19K, respectively. Thirteen of the 20 Soldiers had completed one to two tours in Iraq, and ten of the 13 had seen combat during their tour(s).

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 of 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 (CFR) 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 a computer monitor (17 inch[1], Dell Trinitron[2]) and a joystick manufactured by Saitek (Cyborg 3D Rumble Force Stick). The participant was seated approximately 25 inches from the computer monitor (i.e., seat reference point to screen). The monitor presented a 10-degree horizontal view[1] of the 360-degree field about the vehicle in which the participant was theoretically operating. The joystick controlled the movement of the scene behind crosshairs, which was fixed in the center of the visual display. The participant was able

[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 field of view of the commander's independent viewer (daylight TV sensor) in the BFV A3 (i.e., wide field of view [WFOV]: 10 degrees x 7.5 degrees) and best guesses about that of the sight in the ICV (9 degrees circular). At the time of this study, there had not been any decision regarding the field of view 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 flat panel displays and, if desired, on a smaller square flat panel called the crewman's remote interface system (CRIS).

[2]Trinitron is a registered trademark of Sony.

to scan the 360-degree field 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. An azimuth indicator was provided at the bottom of the target scene to show the direction in which the main gun was pointing (see figure 1). The indicator was similar to that incorporated along the turret ring of the BFV; however, the azimuths were provided in clock positions rather than in mils to preclude the need for conversions.

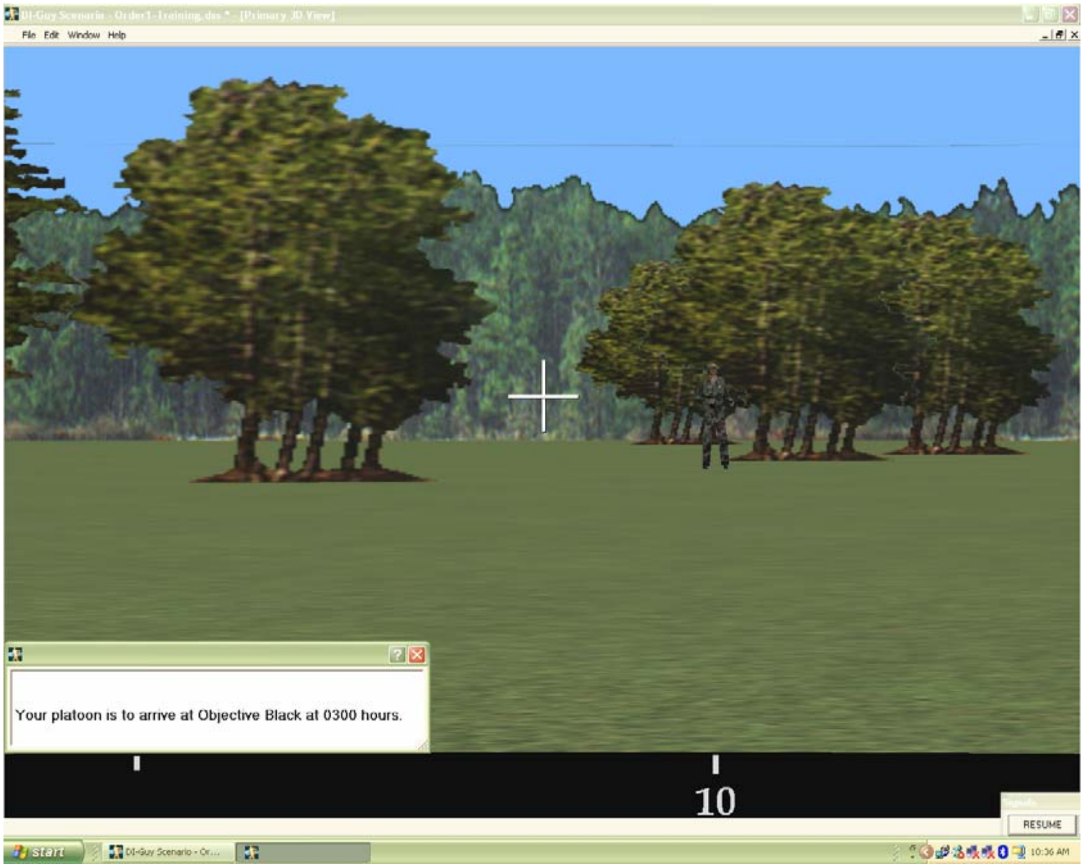

Figure 1. Target scene with azimuth indicator and SITREP segment.

Each target was an individual dismounted Soldier who was presumed to be an enemy. This choice of target type was based on a prioritized list of critical information requirements and related threats identified by subject matter experts (SMEs). All targets were located 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[3] (version 5.2.3) by Boston Dynamics was used in the

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

development of the target scenarios, 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), 3-D Audio (non-speech), and Tactile modes. All cues were 2.5 seconds in duration and their presentation was controlled by computer. Target location cues were presented once for each target presented, relative to the 12-o'clock position. The following describes these cues and the apparati that were used to present them:

(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. Target locations were incremented in hours like those cues presented in Spatial Language and 3-D Audio. Ten clock positions were used. No targets were presented at the 12-o'clock or the 6-o'clock positions, partly because front-back reversals can occur when these cues are presented in the 3-D audio mode (Begault, 1991). The visual icon was 2.5 by 2.5 inches and appeared at the bottom of the screen just above the azimuth indicator.

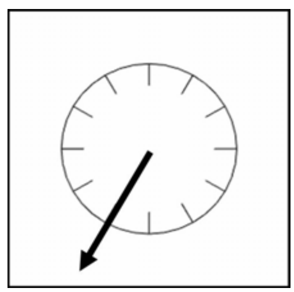

Figure 2. Icon providing directional cue in the visual modality.

(2) Spatial Language (speech). These cues about target location were verbal and presented in a clock-type format. An example of this type of cue is "5 o'clock…5 o'clock." The total duration of each verbal cue was 2.5 seconds with the first and second parts of the cue each about 1.0 second in duration and 0.5 second apart. The cues were pre-recorded in a female voice in contrast to the auditory communications that were presented in a male voice.

(3) 3-D Audio (non-speech). These spatialized target location cues were non-speech audio signals. Each audio signal was 2.5 seconds in duration, consisting of two, 1.0-second tones that were 0.5 second apart. The tones were spatialized with a Veridian Engineering 3-DVALS[4] (3-D virtual auditory localization system) audio engine so that each tone appeared to emanate from a different clock position. The spatialization used generic head-related transfer

[4]3-DVALS is a registered trademark Veridian Corporation.

functions (HRTF) developed by the U.S. Air Force using a Kelso Electronic Mannequin for Auditory Research (KEMAR) acoustic head.

(4) Tactile. A tactile signal indicating the clock position of a target was transmitted by one of ten electromechanical vibrators or tactors. The tactors were developed by the Massachusetts Institute of Technology (MIT) under the Collaborative Technology Alliance (Lockyer, 2004). Each tactor was approximately 1.5 cm in diameter and connected by wire to a remote unit that incorporates a 9-volt battery. The tactors were incorporated into a belt that the participant wore around his torso. The belt was adjusted with Velcro[5] to accommodate the circumference of the participant's torso. The belt had 24 small pockets in which the tactors were placed to align them with each of the ten clock positions. The belt was attached to suspenders that could be adjusted to maintain the belt at the desired position. Each tactile signal consisted of two, 1.0-second vibrations presented 0.5 second apart for a total duration of 2.5 seconds. The vibrations were low in intensity and similar to those emitted by a cellular phone.

3.2.3 Communications and Questionnaires

The auditory and visual communications presented during the target engagement periods were in the form of a SITREP. The auditory communications were pre-recorded in a male voice and presented monaurally to the participant through stereo earphones (Sony MDR 7506). All auditory cues and SITREP communications were normalized to 21 dB and noise reduction was applied. The intensity levels of the auditory cues and the SITREP communications were the same as those in the preceding investigation (Glumm et al., 2005). These intensity levels, as measured through an artificial ear, were 73 peak dB for the spatial language cue and 78 peak dB for the 3-D audio cue. The decibel peaks for the auditory communications ranged from 65 to 70. Given that all auditory cues were easily detected above the auditory communications, audiologists do not consider the differences in decibel peaks between the spatial language and the 3-D audio cues to be of any consequence.

The visual communications were displayed in a text box at the lower left of the target scene in Microsoft sans serif 12-point bold font (see figure 1). Each SITREP consisted of 15 individual sentences or segments (see appendix A). The number of words in each sentence ranged from 6 to 13 words. Each sentence was presented one at a time for 5 seconds with a 5-second time interval between sentence presentations. The time to speak the longest 13-word sentence at a normal rate of speech ranged from approximately 4 to 5 seconds. Given a maximum sentence length of 13 words, a display time of 5 seconds accommodated a reading speed of approximately 156 words per minute (2.6 words per second) and was below the average 8th grade reading speed of 200 words per minute (3.3 words per second) (Boff & Lincoln, 1988). The 15 sentences in each SITREP contained a total of 20 items of information about the current battlefield. Ten of the sentences contained one item of information and five of the sentences contained two items. Ten of the 20 items of information (50%) changed in each SITREP presented. The total duration of each SITREP was 2.5 minutes (150 seconds). The first sentence in the SITREP was presented 5 seconds after the start of each target set. A total of 25 SITREPs were prepared and pre-

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[5]Velcro is a registered trademark of Velcro USA, Inc.

recorded: five SITREPs for training in each of the five cue conditions and 20 SITREPs for testing (i.e., two target sets in each of the ten experimental conditions).

After the completion of each target set, the participant was asked to complete a questionnaire that consisted of ten questions pertaining to the information contained in the SITREP. An example of this questionnaire is provided in appendix B. The answers to each question were written and required a one- or two-word written response. Each answer was worth 2 points. If the participant did not provide an answer to a question or the answer was wrong, the participant scored 0 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 1 point. The participant had a maximum of 3 minutes to answer the ten questions. The order of presentation of the SITREPs and associated questionnaires was counterbalanced.

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 computing 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 5X2 fixed factor design with cue condition and SITREP communications modality all as within-subject effects. The five cue conditions evaluated in this study were (1) baseline, (2) spatial language, (3) visual, (4) 3-D audio, and (5) tactile. The Baseline cue condition represented current limitations in targeting information where the participant continuously scans the terrain around the vehicle for threats without knowing whether threats are present or where they might be located. In all conditions except for Baseline, the participant's crosshairs automatically returned to the 12-o'clock position after each target presentation. The participant was not able to move his crosshairs from that position until cued about the 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 recall information contained in SITREPs that were presented in one of two communications modalities throughout each target set. The two SITREP communications modalities were (1) auditory and (2) visual.

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. Other measures of target acquisition performance included reaction time (i.e., time from cue presentation to movement of the crosshairs) and time to slew (i.e., time to first shot minus reaction time). The dependent variable in the secondary task was the total number of points scored on the SITREP questionnaires that were administered after each target set in each condition. Overall workload scores were computed from subjective ratings on each of six dimensions of workload obtained with the NASA-TLX.

One participant was trained and tested at a time. The duration of training and testing for each participant was approximately 5.7 hours. The procedures that were followed for each participant are described next.

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 his participation. The investigator read the volunteer agreement affidavit aloud to the participant who followed along. If the participant agreed to participate in the investigation, he completed the information on the last page of the affidavit and signed it. A demographic questionnaire was then administered to the participant to obtain pertinent information about his background (see appendix D).

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 with an AC40 clinical audiometer manufactured by Interacoustics A/S. The participants were required to have HTLs corresponding to Army physical profile H2 (U.S. Army, 1991), otoscopically normal ears, and no history of otologic pathology.

Each participant was trained and tested in performing the target acquisition tasks in each of the five cue conditions in one of the two SITREP communications modalities before being trained and tested in the other. The order of training and testing in each cue condition and communications modality was counterbalanced.

During the initial training period, the participants were instructed in rating their workload experience using the NASA-TLX. They also received practice in localizing the tactile and 3-D audio cues presented at the ten clock positions. For each of these modes, the investigator presented cues at each of ten clock positions, starting at the 1-o'clock position and ending at 11 o'clock. After each cue, the clock position at which the cue was presented was displayed on the participant's monitor. This process was repeated two more times. The investigator then presented the cues at each clock position in a randomized order to the participant who identified the clock position of the target. This latter process was repeated two more times.

During training in each SITREP communications modality, 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 information contained in the SITREP and that he would be asked to recall information from the SITREP after each target set. He was informed that some of the details in the SITREP would change in each SITREP presented and that he should not rely on his memory of information contained in previous SITREPs.

Training in each SITREP communications modality included the completion of one run in each of the five cue conditions for a total of ten runs and practice in using the NASA-TLX in rating the workload experience. Each run consisted of two target sets. Each target set was followed by the questionnaire that assessed the participant's knowledge of the information contained in the SITREP.

4.3 Testing

After a 15-minute rest break, the participant completed one test run in each of the five cue conditions in the SITREP communications modality in which he was just trained. Before each run, the participant was reminded that his primary task was to find and engage each target as quickly as possible and that the secondary task was to remember information contained in the SITREP.

As during training, each test run consisted of two target sets. Each target set consisted of five targets for a total of ten target presentations. The targets were presented once in each of ten clock positions in a random order. Five different random orders had been developed for testing and the presentation of these orders counterbalanced among the experimental conditions. Each target was presented for a maximum duration of 20 seconds. Regardless whether the target was hit, the target disappeared from the screen after the 20 seconds elapsed. The time at which the first target was presented at the beginning of a target set and the time between subsequent target presentations was varied to reduce expectancy. The time intervals between target presentations were randomized in 4-second increments ranging from 4 to 20 seconds, and these orders were counterbalanced among the experimental conditions. The start of a time interval between target presentations began 20 seconds after the preceding target had been presented, regardless of the time in which the participant scored a hit on that target. The total duration of each target set was 2.6 minutes (160 seconds).

Each target set was followed by the questionnaire that assessed the participant's knowledge of the information contained in the SITREP that he had just received. After each run in each cue condition, the participant was asked to rate his workload experience using the NASA-TLX.

A 1-hour lunch break was provided before completion of training and testing in the second communications modality. At the conclusion of testing in all conditions, the participant completed a questionnaire to obtain his opinions and preferences with regard to the conditions evaluated (see appendix E).

5. Results

5.1 Target Acquisition

5.1.1 Reaction Time

It had been hypothesized that reaction times (time from cue presentation to movement of the crosshairs) would be faster when target location cues provided an immediate indication about the direction to slew to acquire the target. Reaction times were expected to be slower in the Spatial Language mode than in the Visual, 3-D Audio, and Tactile conditions because some additional processing would be required to determine slewing direction. Reaction times among the latter three modes were not expected to be significantly different.

To test this hypothesis, a linear mixed model analysis was performed on reaction times in those conditions where cues about target location were provided. The analysis did not reveal a significant effect of communications modality on reaction time ($F (1, 22) = 0.171$, $p = .68$), or an interaction between communications modality and cue condition ($F (3, 22) = 1.408$, $p = .24$). However, the analysis did indicate a significant effect of cue condition ($F (3, 22) = 29.481$, $p < .001$). The means and standard deviations in reaction time in each cue condition are shown in figure 3 along with the results of the *post hoc* analyses using the least significant difference (LSD) method, which are denoted by the letters that are shown within each bar in the chart. Like letters indicate that there are no significant differences between the cue conditions. The mean differences between cue conditions are provided in table 1. As hypothesized, reaction time was an average 30% slower (0.3 seconds) in the Spatial Language mode than in the Visual, 3-D Audio, and Tactile conditions. No significant difference was found among the latter three modes.

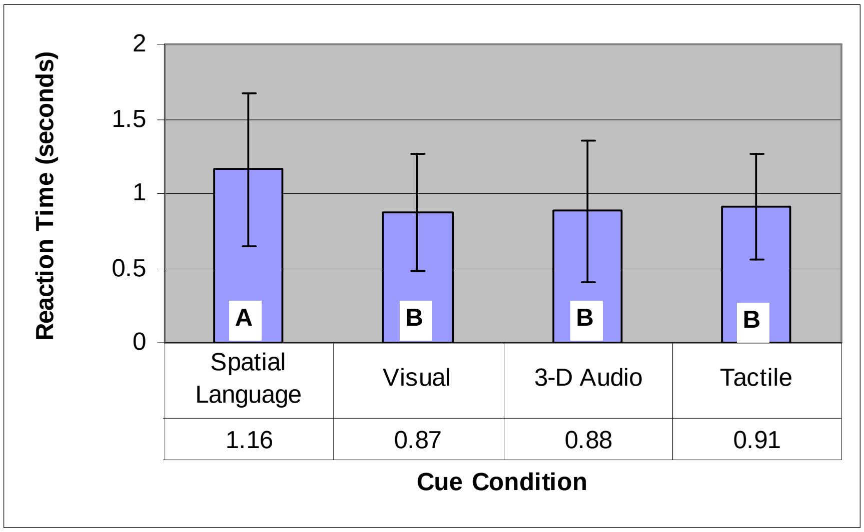

Figure 3. Mean reaction time by cue condition.

Table 1. Mean difference between cue conditions in reaction time.

Mode	Visual	3-D Audio	Tactile
Spatial Language	**.282 (*p* = <.001)**	**.276 (*p* = <.001)**	**.250 (*p* = <.001)**
Visual		-.006 (*p* = .86)	-.031 (*p* = .38)
3-D Audio			-.025 (*p* = .48)

Bold blocks indicate significant differences.

5.1.2 Time to Slew

It had also been hypothesized that time to slew to the location of the target (i.e., time to first shot minus reaction time) would be faster for cues that provided a more direct indication of the clock position of the target (i.e., Visual and Spatial Language). Slewing time would be faster in these latter conditions because there would be less uncertainty about the clock position to which to slew than there would be for indirect cues where the clock position was not as clearly specified (i.e., 3-D Audio and Tactile).

To test this hypothesis, a linear mixed model analysis was performed on time to slew in those conditions where cues about target location were provided. The analysis did not reveal a significant effect of communications modality on time to slew (F (1, 22) = 2.009, p = .16) or an interaction between communications modality and cue condition (F (3, 22) = 0.503, p = .68). However, the analysis did indicate a significant main effect of cue condition (F (3, 22) = 71.121, p < .001). The means and standard deviations in time to slew in each cue condition are shown in figure 4 along with the results of the *post hoc* analyses. The mean differences between cue conditions are provided in table 2. As hypothesized, time to slew to target averaged 24% faster (1.8 seconds) in the Visual and Spatial Language modes than in the 3-D Audio and Tactile conditions. No significant difference was found between the Visual and the Spatial Language modes; however, time to slew in the Tactile mode was 17% faster (1.4 seconds) than in the 3-D Audio condition.

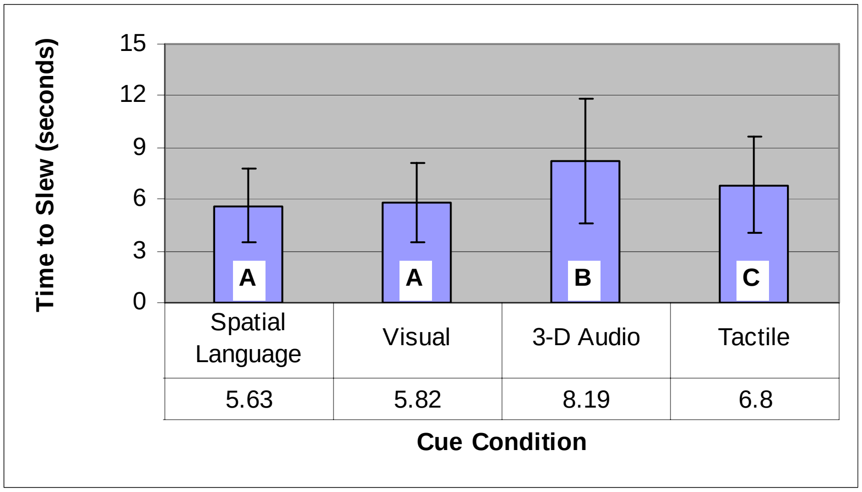

Figure 4. Mean time to slew by cue condition.

Table 2. Mean difference between cue conditions in time to slew.

Mode	Visual	3-D Audio	Tactile
Spatial Language	-.183 (*p* = .34)	**-2.557 (*p* = <.001)**	**-1.171 (*p* = <.001)**
Visual		**-2.374 (*p* = <.001)**	**-.988 (*p* = <.001)**
3-D Audio			**1.386 (*p* = <.001)**

Bold blocks indicate significant differences.

5.1.3 Time to First Shot and Time to Hit

It was hypothesized that time to first shot and time to hit would be faster for cues that provided a more direct indication of the clock position of the target (i.e., Visual and Spatial Language) by comparison to indirect cues where the clock position was not as clearly specified (i.e., 3-D Audio and the Tactile). It was believed that cues that did not provide a direct indication of clock position would be more prone to errors in localization resulting in longer search times. It was also hypothesized that time to first shot and time to hit would be faster in the Visual mode than in the Spatial Language condition because of slower reaction times in the latter mode. No differences were expected in time to first shot or time to hit between between the 3-D Audio and the Tactile conditions.

The results of the analysis of time to first shot were similar to those for time to hit. The analyses did not reveal an effect of communications modality on time to first shot (F (1, 24) = 0.170, *p* = .68) or hit (F (1, 24) = 0.257, *p* = .61) or an interaction between communications modality and cue condition for time to first shot F (4, 24) = 0.719, *p* = .58) or hit (F (4, 24) = 0.560, *p* = .69). However, the analyses did indicate a significant main effect of cue condition on time to first shot (F (4, 24) = 91.362, *p* < .001) and hit (F (4, 24) = 85.791, *p* < .001). The means and standard deviations in time to first shot and time to hit in each cue condition are shown in figure 5 along with the results of the *post hoc* analyses. The mean differences between cue conditions are provided in tables 3 and 4. The analyses revealed that time to first shot and time to hit were slower in the Baseline condition than in all modes in which cues about target location were provided. In accordance with the hypothesis, time to first shot in the Visual and Spatial Language modes was an average 38% faster (4.2 seconds) than in the Baseline condition, 26% faster (2.3 seconds) than in the 3-D Audio mode, and 13% faster (1.0 second) than in the Tactile condition. Time to first shot was 15% faster (1.4 seconds) in the Tactile mode than in the 3-D Audio condition. However, contrary to hypothesis, no significant difference was found between the Visual and the Spatial Language modes. It appears that although reaction time to the spatial language cue was approximately 0.3 second slower than reaction time to the visual cue, participants may have compensated for some of the lost time with a 0.2-second faster time to slew to target.

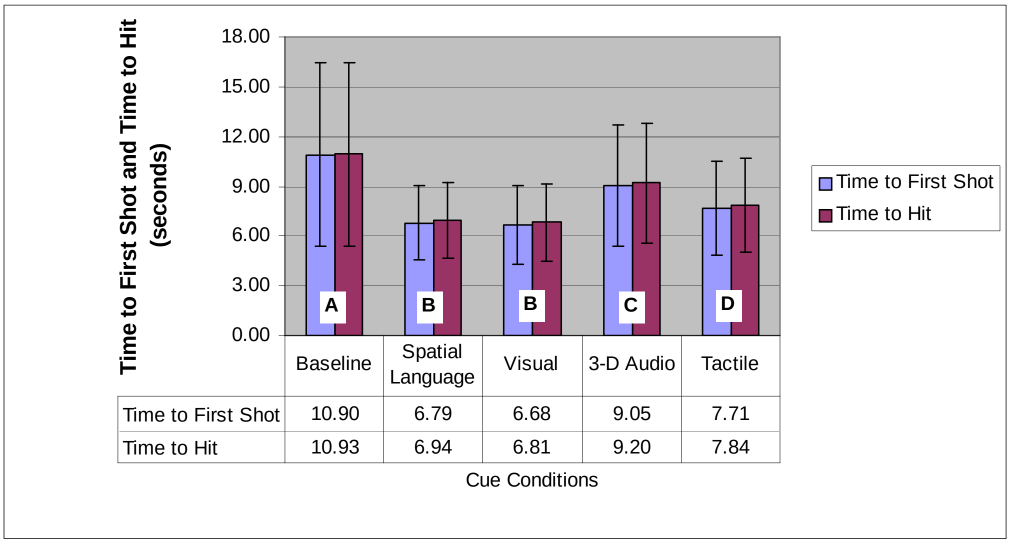

Figure 5. Mean time to first shot and mean time to target hit by cue condition.

Table 3. Mean difference between cue conditions in time to first shot.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**4.111 (*p* = <.001)**	**4.214 (*p* = <.001)**	**1.846 (*p* = <.001)**	**3.187 (*p* = <.001)**
Spatial Language		.103 (*p* = .66)	**-2.265 (*p* = <.001)**	**-.924 (*p* = <.001)**
Visual			**-2.368 (*p* = <.001)**	**-1.027 (*p* = <.001)**
3-D Audio				**1.341 (*p* = <.001)**

Bold blocks indicate significant differences.

Table 4. Mean difference between cue conditions in time to hit.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**3.988 (*p* = <.001)**	**4.121 (*p* = <.001)**	**1.727 (*p* = <.001)**	**3.089 (*p* = <.001)**
Spatial Language		.133 (*p* = .57)	**-2.261 (*p* = <.001)**	**-.899 (*p* = <.001)**
Visual			**-2.394 (*p* = <.001)**	**-1.032 (*p* = <.001)**
3-D Audio				**1.362 (*p* = <.001)**

Bold blocks indicate significant differences.

5.1.4 Degrees Off Target Center at First Shot and Hit

Cue condition was not expected to have an effect on shooting accuracy or result in a significant difference between time to first shot and time to hit. If a target was found, it would normally be hit on the first shot, regardless of cue condition.

To test this hypothesis, linear mixed model analyses were performed on degrees off target center at first shot and degrees off target center at hit. As expected, the results of the analyses did not reveal a significant effect of cue condition on degrees off target center at first shot ($F(4, 24) = 1.237$, $p = .30$) or at hit ($F(4, 24) = 0.338$, $p = .85$). There was also no indication of an effect of communications modality on shooting accuracy at first shot ($F(1, 24) = 0.555$, $p = .46$) or at hit ($F(1, 24) = 1.207$, $p = .27$) or an interaction between communications modality and cue condition for first shot $F(4, 24) = 0.937$, $p = .44$) or hit ($F(4, 24) = 0.365$, $p = .83$).

5.1.5 Percent Hits

The means and standard deviations for the percentage of target hits achieved in each of the five cue conditions are shown in figure 6. The analysis did not reveal a significant effect of communications modality ($F(1, 24) = 0.798$, $p = .37$) or an interaction between communications modality and cue condition ($F(4, 24) = 0.273$, $p = .90$). However, the analysis did indicate a significant effect of cue condition ($F(4, 24) = 100.935$, $p < .001$). *Post hoc* analyses revealed that the percentage of hits achieved in the Baseline condition (64%) was significantly lower than that achieved in the Spatial Language (100%), Visual (100%), Tactile (98%), and the 3-D Audio (93%) modes (see table 5). The analyses also indicated that the percentage of hits achieved in the 3-D Audio mode was significantly lower than that achieved in the Visual, Spatial Language, and Tactile conditions, but no differences were found among the latter three modes.

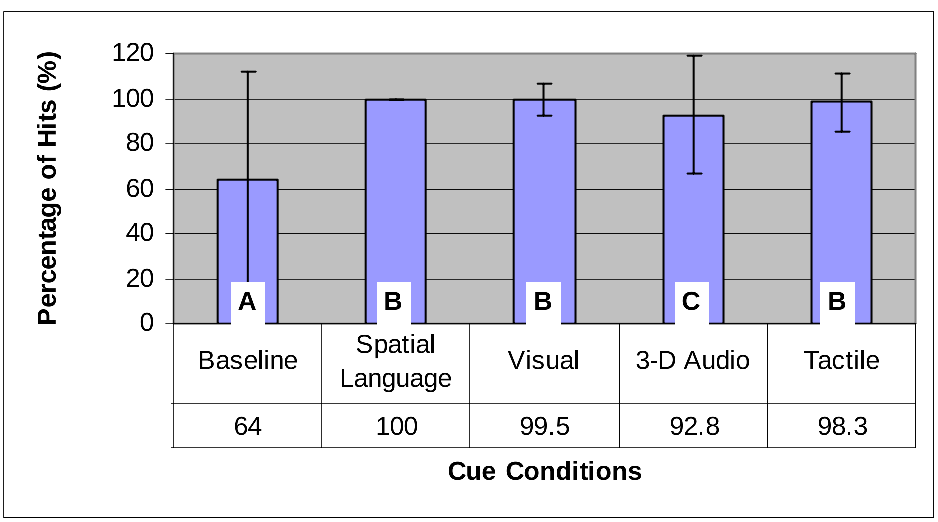

Figure 6. Mean percentage of target hits by cue condition.

Table 5. Mean difference between cue conditions in the percentage of targets hit.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**-36.0 (*p* = <.001)**	**-35.5 (*p* = <.001)**	**-28.7 (*p* = <.001)**	**-34.2 (*p* = <.001)**
Spatial Language		-0.5 (*p* = .82)	**7.2 (*p* = .001)**	1.7 (*p* = .42)
Visual			**6.7 (*p* = .002)**	1.2 (*p* = .56)
3-D Audio				**-5.5 (*p* = .01)**

Bold blocks indicate significant differences.

5.2 Secondary Task Performance (scores on SITREP questionnaire)

It had been hypothesized that more information would be recalled when communications were presented auditorily than visually because the information contained in the visual SITREPs would be less likely to be captured when the SITREPs were presented during the visually intensive target acquisition process. It had also been hypothesized that more information would be recalled from the SITREPs for cues that provided a more direct indication of the clock position of the target (i.e., Visual and Spatial Language) than for indirect cues (i.e., 3-D Audio and Tactile). Target acquisition times would be faster for cues that provided a more direct indication of the clock position of the target and, therefore, more time and attention would be available for rehearsal of the information presented in the SITREPs for later recall.

To test these hypotheses, a linear mixed model analysis was performed on the number of points scored on the SITREP questionnaires. Contrary to hypothesis, the results of the analysis did not reveal a significant effect of communications modality (F (1, 24) = 023, p = .88), nor were any interactions found between communications modality and cue condition (F (4, 24) = 1.080, p = .37). However, the results of the analysis did indicate a significant effect of cue condition (F (4, 24) = 14.435, p < .001). The means and standard deviations in points scored in each cue condition are shown in figure 7, along with the results of the *post hoc* analyses. The mean differences between cue conditions are provided in table 6. The findings indicated that, on average, 23% less information was recalled from the SITREPs in the Baseline condition than in modes where the location of targets was cued, and more information was recalled in the Visual mode than in all other cue conditions. Compared to the Visual mode, 8% less information was recalled in the Spatial Language condition, 9% less in the Tactile mode, 12% less in the 3-D Audio condition, and 39% less in the Baseline. No differences were found among the Spatial Language, Tactile, and 3-D Audio modes on this measure.

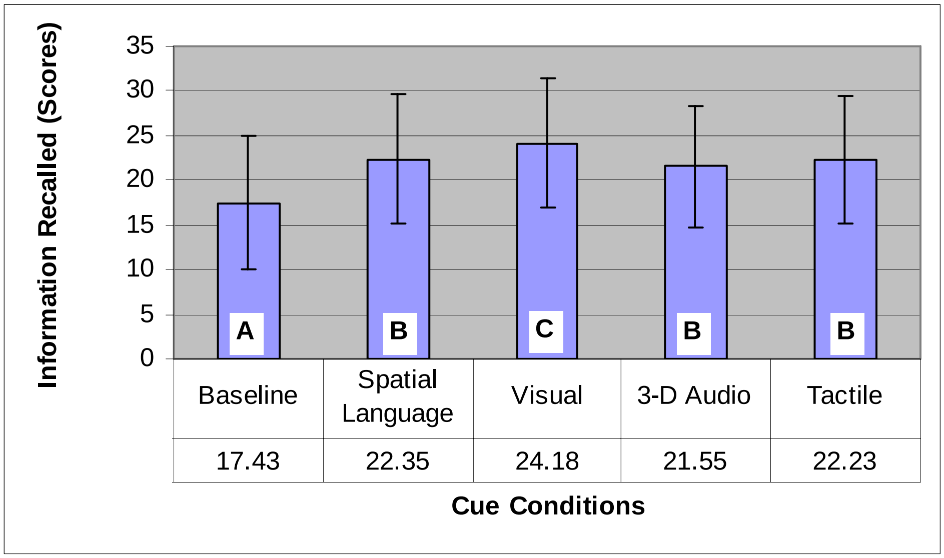

Figure 7. Mean scores on SITREP questionnaire.

Table 6. Mean difference between cue conditions in scores on SITREP questionnaires.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**-4.93 (p = <.001)**	**-6.75 (p = <.001)**	**-4.13 (p = <.001)**	**-4.80 (p = <.001)**
Spatial Language		**-1.83 (p = .05)**	.80 (p = .39)	.13 (p = .89)
Visual			**2.63 (p = .005)**	**1.95 (p = .04)**
3-D Audio				-.68 (p = .47)

Bold blocks indicate significant differences.

5.3 Subjective Workload

Separate linear mixed model analyses were performed on subjective ratings of workload on each of the six subscales of the NASA-TLX (i.e., mental, physical, and temporal demand, performance, effort, and frustration). A linear mixed model analysis was also performed on overall workload scores that were derived from ratings on each of the six subscales. The analyses revealed a significant effect of SITREP communications modality on ratings of temporal demand (F (1, 24) = 4.555, p = .03) where ratings on this subscale were higher in the visual communications modality than they were in the auditory modality (mean difference = 24.65). The modality in which the SITREPs were presented did not have a significant effect on ratings on any of the other six dimensions of workload or on overall workload scores, and no interactions were found between communications modality and cue condition.

The analyses revealed a significant effect of cue condition on subscale ratings of physical demand (F (4, 24) = 3.644, p = .007), temporal demand (F (4, 24) = 2.751, p = .03), effort (F (4, 24) = 3.379, p = 0.01), and frustration (F (4, 24) = 3.611, p = .008). However, no differences were found between cue conditions in subjective ratings of mental demand (F (4, 24) = 1.775, p = .14) or performance (F (4, 24) = 0.945, p = .44). A significant effect of cue condition was also found for overall workload scores (F (4, 24) = 12.928, p < .001). The means and standard deviations in subscale ratings of work-load and overall workload scores for each cue condition are shown in figures 8 through 12 along with the results of the *post hoc* analyses. The mean differences between cue conditions are provided in tables 7 through 11. As indicated in figure 8, ratings of physical demand were higher in the Baseline condition where participants slewed continuously in search of targets. As shown in figure 9, ratings of temporal demand were also higher in the Baseline condition than in all other modes except Spatial Language. However, ratings of temporal demand in the Spatial Language mode were not significantly higher than those in the Visual, 3-D Audio, and Tactile conditions. Figure 10 shows that ratings of effort were higher in the Baseline condition than in the Visual and Tactile modes but not significantly higher than those in the Spatial Language and 3-D Audio conditions. Ratings of effort were higher in the 3-D Audio mode than in the Visual condition but were not different from ratings of effort in the other cue conditions. As shown in figure 11, ratings of frustration were significantly higher in the Baseline condition than in all other modes except 3-D Audio, and ratings of frustration were higher in 3-D Audio than in the Tactile condition. However, ratings of frustration in the latter two modes were not significantly different than ratings of frustration in the Spatial Language and Visual conditions. As shown in figure 12, overall workload scores were higher in the Baseline condition than in all other modes except 3-D Audio. Overall workload scores in 3-D Audio were an average 14% higher than in the Spatial Language, Visual, and Tactile conditions but no significant differences were found among the later three modes.

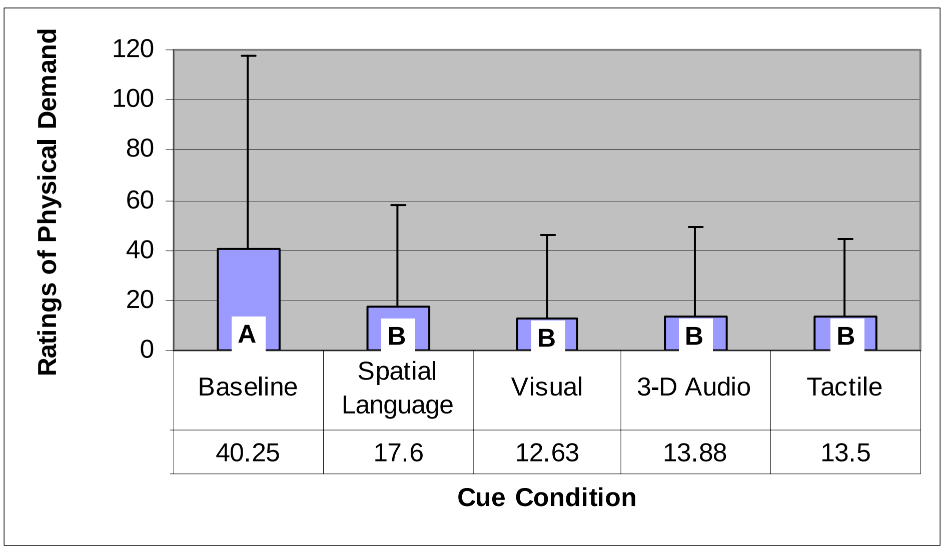

Figure 8. Mean ratings of physical demand by cue condition using NASA-TLX.

Table 7. Mean difference between cue conditions in subjective ratings of physical demand.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**22.65 (*p* = .01)**	**27.63 (*p* = .002)**	**26.38 (*p* = .003)**	**26.75 (*p* = .002)**
Spatial Language		4.98 (*p* = .57)	3.73 (*p* = .67)	4.10 (*p* = .64)
Visual			-1.25 (*p* = .89)	-.88 (*p* = .92)
3-D Audio				.38 (*p* = .97)

Bold blocks indicate significant differences.

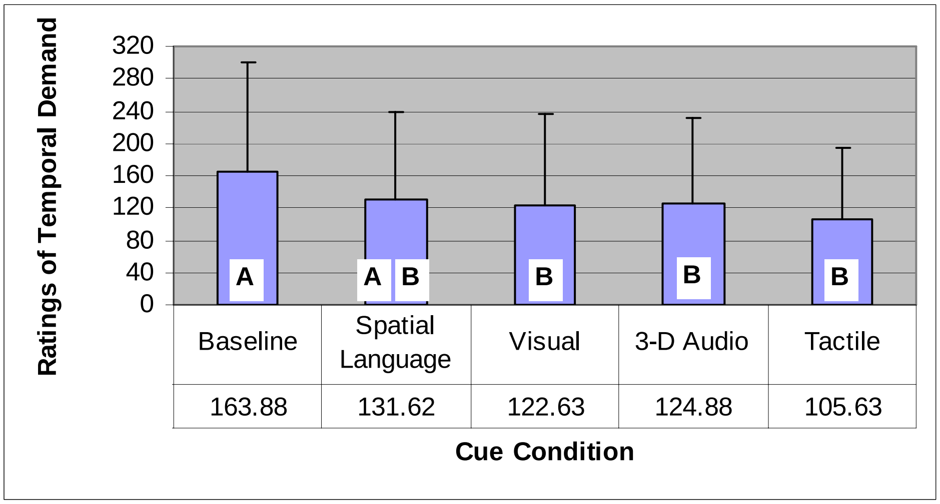

Figure 9. Mean ratings of temporal demand by cue condition using NASA-TLX.

Table 8. Mean difference between cue conditions in subjective ratings of temporal demand.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	32.26 (*p* = .08)	**41.25 (*p* = .03)**	**39.00 (*p* = .03)**	**58.25 (*p* = .002)**
Spatial Language		8.99 (*p* = .63)	6.74 (*p* = .71)	25.99(*p* = .16)
Visual			-2.25 (*p* = .90)	17.00 (*p* = .35)
3-D Audio				19.25 (*p* = .29)

Bold blocks indicate significant differences.

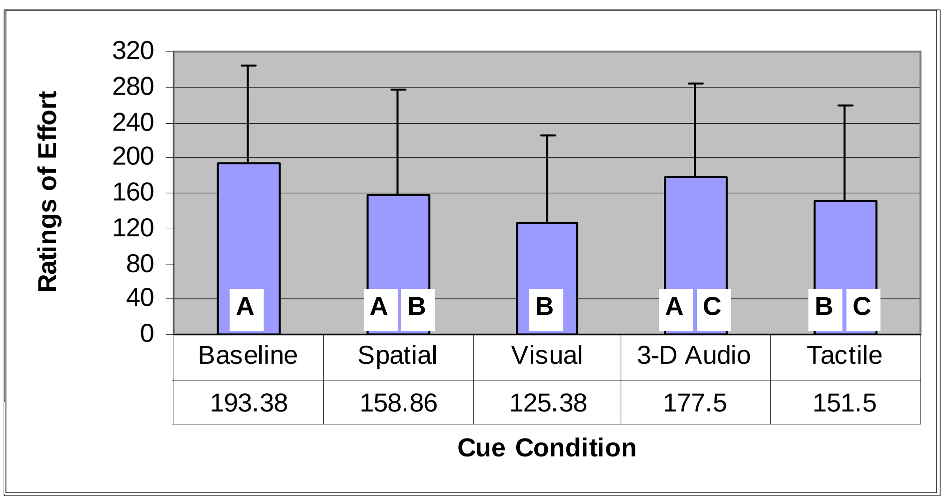

Figure 10. Mean ratings of effort by cue condition using NASA-TLX.

Table 9. Mean difference between cue conditions in subjective ratings of effort.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	34.51 (*p* = .09)	**68.00 (*p* = .001)**	15.88 (*p* = .43)	**41.88 (*p* = .04)**
Spatial Language		33.49 (*p* = .10)	-18.64 (*p* = .36)	7.36 (*p* = .71)
Visual			**-52.13 (*p* = .01)**	-26.13 (*p* = .19)
3-D Audio				26.00 (*p* = .19)

Bold blocks indicate significant differences.

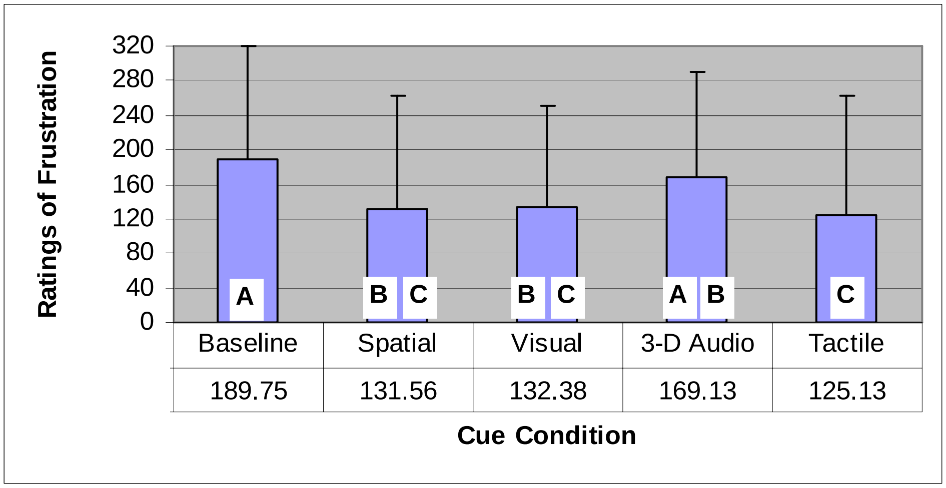

Figure 11. Mean ratings of frustration by cue condition using NASA-TLX.

Table 10. Mean difference between cue conditions in subjective ratings of frustration.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**58.19 (*p* = .007)**	**57.38 (*p* = .007)**	20.63 (*p* = .33)	**64.63 (*p* = .003)**
Spatial Language		-.82 (*p* = .97)	-37.57 (*p* = .08)	6.43 (*p* = .76)
Visual			-36.75 (*p* = .08)	7.25 (*p* = .73)
3-D Audio				**44.00 (*p* = .04)**

Bold blocks indicate significant differences.

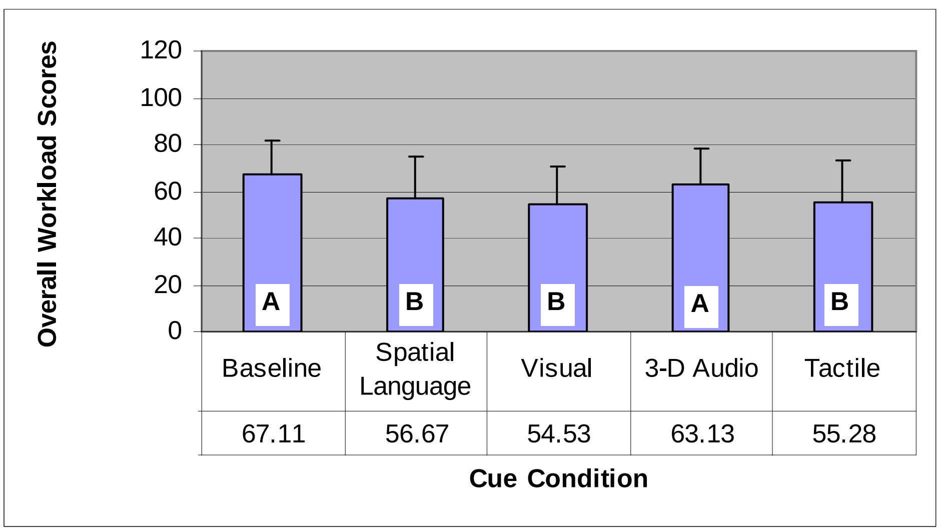

Figure 12. Mean overall workload scores by cue condition using NASA-TLX.

Table 11. Mean difference between cue conditions in overall workload scores.

Mode	Spatial Language	Visual	3-D Audio	Tactile
Baseline	**10.44 (*p* = <.001)**	**12.58 (*p* = <.001)**	3.98 (*p* = .07)	**11.83 (*p* = <.001)**
Spatial Language		2.14 (*p* = .33)	**-6.46 (*p* = .003)**	1.40 (*p* = .52)
Visual			**-8.60 (*p* = <.001)**	-.74 (*p* = .73)
3-D Audio				**7.86 (*p* = <.001)**

Bold blocks indicate significant differences.

5.4 Participants' Preferences and Comments

The participants ranked the five cue conditions from "1" to "5" based on how helpful they believed the cues were in finding targets (1 = most helpful; 5 = least helpful). The results were as follow: 1 - both Visual and Spatial Language conditions, 2 - Tactile mode, 3 - 3-D Audio, and 4 - Baseline. Most participants perceived that it was easier to remember the information contained in the SITREP communications when the information was presented auditorily in the Baseline and the Visual modes, and visually in the Spatial Language and 3-D audio conditions. Similarly, most believed that the visual communications interfered with target acquisition in the Baseline and Visual conditions and that the auditory communications interfered with target acquisition in the Spatial Language and 3-D Audio modes. Only five participants believed that the SITREP communications interfered with their ability to acquire targets in the Tactile mode. Of these five, three thought the visual communications interfered with their ability to acquire targets and two believed that the auditory communications were more disruptive.

6. Discussion

On average, participants hit 98% of the targets presented when cued about target location compared to 64% in the Baseline condition. In conditions where target location cues were provided, time to first shot was an average 26% faster (2.7 seconds) than Baseline, 23% more information was recalled from the auditory and visual communications, and overall workload scores were 17% lower. As hypothesized, targets were acquired faster in the Visual and Spatial Language modes than in the 3-D Audio and Tactile conditions. On average, time to first shot was 13% faster (1.0 second) in the Visual and Spatial Language modes than in the Tactile condition and 26% faster (2.3 seconds) than the 3-D Audio mode. However, contrary to expectations, the analysis did not reveal a significant difference between the Visual and Spatial Language conditions. In an earlier study, Glumm, Kehring, and White (2005) found that time to first shot was 1 second slower in the Spatial Language mode than in the Visual and the 3-D Audio conditions. These latter findings were similar to those of Simpson et al. (2004) who did not present any concurrent verbal communications that could potentially interfere with the perception of the verbal cues about target location. Therefore, it was believed that the difference in target acquisition time between the Spatial Language condition and the Visual and 3-D Audio modes may have been attributable to other factors. First, the 1-second delay in target acquisition in the Spatial Language mode may have been influenced by the structure of the verbal cue. As in the study by Simpson et al. (2004), 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, Glumm et al. (2005) also believed that increases in target acquisition time in the Spatial Language mode might be attributable to additional processing requirements.

When Haas, Pillalamarri, Stachowiak, and Lattin (2005) presented target location information in plus and minus degrees (e.g., “Target minus 15 degrees”), no differences were found between the verbal and the 3-D audio modes. Glumm et al. (2005) surmised that the verbal cues employed by Haas et al. may have provided a more immediate indication of whether the target lay to the left (i.e., minus) or right (i.e., plus) of 0 degree as might a 3-D audio sound that appears to emanate from one or the other direction in space. A cue that merely states the clock position of a target may require additional processing in determining the location of the target relative to one’s heading or the position of the main gun. According to Loomis et al. (2002), the result of the encoding of a 3-D audio or a spatial language cue is a spatial image. Although there has been considerable debate about whether the mental imagery created is spatially displayed or depictive (Pylyshyn, 2002), the steps that must be taken in forming this imagery and the accuracy of the image that is created are expected to influence target acquisition time.

For the present investigation, the researchers restructured the spatial language cue to minimize differences between cues in the time in which target location information was presented by replacing the verbal alert with information about the location of the target (i.e., “9-o’clock – 9 o’clock”). Measures of reaction time (i.e., time from cue presentation to movement of the crosshairs) and time to slew to target (i.e., time to first shot minus reaction time) were also obtained to gain further insight into factors that might contribute to differences among cueing techniques in target acquisition time. As hypothesized, the results of the analyses indicated that reaction time was slower (0.3 second) in the Spatial Language mode than in the Visual, 3-D Audio, and Tactile conditions. However, this relatively small increase in reaction time in the Spatial Language mode did not thoroughly account for the 1-second increase in time to first shot found in the earlier study.

Like the Visual cue, the 3-D Audio and Tactile cues provided a more immediate indication of whether the target lay to the left or right of the 12 o’clock position, and no differences were found between these conditions in reaction time. However, participants appeared to experience greater difficulty in localizing the targets to a specific clock position in the 3-D Audio and Tactile modes than in the Visual and Spatial Language conditions. On average, time to slew to the target in the latter two modes was 16% faster (1.1 seconds) than in the Tactile condition and 30% faster (2.5 seconds) than in the 3-D Audio mode. No difference was found between the Visual and Spatial Language conditions on this measure. These findings support the hypothesis that time to slew would be faster for cues that provide a more direct indication of the clock position of the target and, thus, less uncertainty about target location than cues that did not clearly specify clock position. Time to slew in the Tactile mode was 17% faster (1.4 seconds) than in the 3-D Audio condition where the magnitude of errors in target localization were observed to be greater. The less confident the participant may have been in his choice of clock position, the more likely he was to reduce slewing speed as he approached the location at which he thought the target might be. The greater the error in determining target location or the greater the difference between the perceived and actual clock position of the target, the longer the search time and, thus, the longer the time to slew to target.

The problems experienced by participants in localizing targets to a specific clock position in the 3-D Audio mode may have been related to the generic HRTFs used to spatialize the tones for the current study. People respond differently to different HRTFs, and performance in the 3-D Audio mode may have been improved if the HRTFs had been tailored to each participant. In the previous investigation, Glumm et al. (2005) did not find a significant difference between the Visual and 3-D Audio modes in time to first shot. Targets were easily detected in this earlier study even at high rates of slew and participants may have merely slewed in the direction indicated by the cue rather than attempting to localize the target to a specific clock position. In the present investigation, however, targets were well camouflaged and the percentage of targets hit in the 3-D Audio and Baseline conditions was significantly less than that achieved in the earlier study. A comparison of target acquisition performance between the Glumm et al. (2005) and the present investigation revealed a significant interaction of study and cue condition for both the percentage of targets hit (F (3, 10) = 85.883, p < .001) and the time to first shot (F (3, 10) = 64.875, p < .001). In the previous study, participants hit 100% of the targets presented in the 3-D Audio mode by comparison to 93% in the present investigation. The percentage of hits achieved in the Baseline condition dropped from 94% to 64%. By contrast, 100% of the targets presented in the Visual and Spatial Language modes were hit in both studies. In the present investigation, mean time to first shot increased by more than 3 seconds in both the 3-D Audio mode and the Baseline condition. In the Visual mode, time to first shot increased by approximately 1 second; however, no difference was found between the two studies in time to first shot in the Spatial Language mode. It is believed that the restructuring of the verbal cue eliminated the delay in the receipt of information about target location and helped to offset an increase in target acquisition time similar to that found in the Visual mode.

Table 12. Mean time to first shot and percent hits by cue condition in Glumm et al. (2005) and present study.

	Time to First Shot (seconds)		**Percent Hits (%)**	
	Glumm et al. (2005)	**Present Study**	**Glumm et al. (2005)**	**Present Study**
Baseline	94	64	7.55	10.95
	F (1, 4) = 94.408, p<.001		F(1, 4) = 126.014, p<.001	
Visual	100	100	5.78	6.69
			F (1, 4) = 52.998, p<.001	
Spatial Language	100	100	6.79	6.81
			F(1, 4) = .304, p = .58)	
3-D Audio	100	93	5.83	9.07
	F(1, 4) = 266.428, p<.001		F(1, 4) = 32.402, p<.001	

In the present study, it had been hypothesized that more information would be recalled from the auditory SITREPs because the information contained in the visual SITREPs were less likely to be captured when they were presented during the visually intensive target acquisition process. As would be expected, the analysis of participant responses to the post-test questionnaire indicated that most participants believed that the visual SITREPs interfered with target acquisition in the Baseline and Visual conditions and that the auditory SITREPs interfered with target acquisition in the Spatial Language and 3-D Audio modes. Similarly, most perceived that it was easier to remember the information contained in the SITREPS when the information was presented auditorily in the Baseline and the Visual modes, and visually in the Spatial Language and 3-D audio conditions. Nevertheless, the analysis did not reveal a significant effect of communications modality on either target acquisition performance or on the amount of information recalled from the SITREPs, and no interactions were found between communications modality and cue condition. The only indication of a potential conflict between tasks in their competition for visual resources was found in the analysis of subjective ratings of workload where ratings of temporal demand were higher when time and attention were divided between reading the visual SITREPs and the visual acquisition of targets.

Research and related literature about memory indicates that information must be rehearsed if it is to be retained (Wickens & Hollands, 2000). Therefore, it was hypothesized that more information would be recalled from the SITREPs in the Visual and Spatial Language modes because of a decrease in target acquisition time and an increase in the time and attention that could be allocated to the rehearsal of the information. This hypothesis, however, was only partially supported by the results of the analysis indicating that more information was recalled in the Visual mode than in the Spatial Language, 3-D Audio, and Tactile conditions. No differences were found between the latter two modes and the Spatial Language condition in performance of the secondary communications task. In the Visual mode, participants recalled 8% more information than in they did in the Spatial Language condition, 9% more than in the Tactile mode, 12% more than in 3-D Audio, and 39% more than in the Baseline condition. It is believed that any additional cognitive processing that may have been involved in converting the verbal cue into a spatial image or correcting for errors in slewing direction may have been sufficiently disruptive to interfere with the capture and rehearsal of the information presented in the SITREPs.

As might be expected, subjective ratings of physical demand were higher in the Baseline condition where participants were required to scan continuously for targets. Overall workload scores were higher in the 3-D Audio mode than in the Visual, Spatial Language, and Tactile conditions, but no differences were found among the latter three modes. The similarity in subjective ratings of effort expended, frustration, and overall workload scores in the Baseline and 3-D Audio conditions may reflect the level of difficulty participants experienced in localizing targets in the latter mode. The greater the error in localizing targets, the longer the search time, and the narrower the gap between cue conditions in perceived workload.

7. Conclusions and Recommendations

The participants' ranking of the cue conditions examined in the present investigation was reflected in their performance of the target acquisition task. Reaction time was slower in the Spatial Language mode than in the other cue conditions, but no difference was found between the Spatial Language and Visual modes in time to slew to target or time to first shot. Time to slew to target and time to first shot were faster in the Spatial Language and Visual modes than in the Tactile and the 3-D Audio conditions. No difference was found between the latter two modes in reaction time but time to slew to target and time to first shot were faster in the Tactile mode than in the 3-D Audio condition. Although the 3-D Audio cue still proved to be better than no cue at all, time to acquire was slower and the percentage of hits achieved was lower than in the Spatial Language, Visual, and Tactile conditions.

It is suspected that reaction time to the spatial language cue was slower than reaction times to the visual, tactile, and 3-D audio cues because the latter cues provided a more immediate indication of the direction to slew to acquire the target. Time to slew and time to first shot were faster for the visual and spatial language cues because they provided a more direct indication of the clock position of the target than the 3-D audio or the tactile cues. Although the 3-D audio and the tactile cues may have provided a clear indication of whether the target lay to the left or right of the 12 o'clock position, some additional processing was needed to localize the sound or vibration to a specific clock position. A mental replay of the 3-D audio or tactile cue may not have portrayed the location of the sound or vibration as accurately as a mental snapshot of the visual icon or memory of the clock position stated in the verbal cue. Difficulty in localizing targets at a specific clock position in the 3-D Audio mode may have also been attributable to the particular HRTFs used to spatialize the sounds in the current investigation.

A comparison of the results of the present study with those of an earlier investigation suggests that target acquisition times in the 3-D Audio mode were affected as much by the reduction in the salience of the target as times in the Baseline condition. In the present study, time to first shot was 3 seconds slower in both the Baseline and the 3-D Audio mode than in the earlier investigation in which targets were easier to detect. By comparison, time to first shot in the Visual condition only increased by 1 second. No differences were found between the first and second studies in time to first shot in the Spatial Language mode where the restructuring of the verbal cue may have offset an increase similar to that found for the Visual mode.

The findings of the present investigation suggest that some portion of the 1-second increase that was found in the previous investigation for time to first shot in the Spatial Language mode was attributable to a delay in reacting to the verbal cue. In the current investigation, the increase in reaction time in the Spatial Language mode appears to support the notion by Loomis et al. (2002) that encoding of the verbal cue might require an additional cognitive step that involves conversion of the cue into a spatial image. The remainder of the 1-second increase in time to first shot found in the earlier study may be attributable to the structure of the verbal cue and the delay in the receipt of information about target location.

Although the analyses of primary and secondary task performance did not reveal any interactions between communications modality and cue condition, it should not be concluded that the same would be found in other situations. In the Visual mode, for example, the attentional demands of the secondary task and the potential for task conflict would likely increase if the visual cues were less intuitive, the SITREPs longer and more complex, or the visual communications presented on a separate display. It is likely that more information was recalled from communications in the Visual mode than in the other cue conditions because there were fewer cognitive steps involved in determining both the slewing direction and the clock position of the target and, thus, more time and attention available for capturing and rehearsing the information contained in the SITREPs.

The results of this investigation are preliminary. Additional studies are needed to further 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.

Although the technology needed to detect targets and provide target location cues is not currently defined, research to quantify the advantages that such information can provide and to identify presentation techniques that yield the greater benefit, is an important first step. For the purpose of the present study, it was assumed that such a technology would detect 100% of the targets with no false alarms. However, it is recognized that the translation of information from sensors and other intelligence sources into reliable, high fidelity sensory cues about enemy position poses a significant challenge, where failure to ensure the dependability of such cues can present a host of concerns and other research issues.

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Appendix A. Situation Report (SITREP[6]) Example

1. Your objective is 500 meters east of your current assembly point.
2. Your platoon is to arrive at objective Brown at 0500 hours.
3. Threats on the way to your objective include an ambush
4. Closest supporting unit is infantry, 100 meters from objective.
5. Call sign of closest supporting unit is Charlie 1.
6. Friendly artillery unit is 2 kilometers north of airport.
7. Call sign for air support unit is Eagle 1.
8. Drop off point for squad is Peach Hill, 100 meters south of objective.
9. Closest enemy unit to the objective is armor.
10. Closest enemy unit is 200 meters from your objective.
11. Closest enemy unit is company-size.
12. Closest enemy unit to your objective is resupplying.
13. Enemy infantry in countryside are armed with RPGs.
14. Enemy has placed landmines near your objective
15. Enemy has placed obstacles near objective along Church Road.

[6]The 20 items of information underlined are those that changed in deriving the 25 SITREPs. Only 10 of these items were changed in each version of the SITREP.

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Appendix B. SITREP Questionnaire Example

Participant # : ______ Cue/Communications Mode: __/__ Target Set : ___

SITREP Questionnaire

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 that 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 your objective? (1)	________________________
2. How far is the objective from your current assembly point? (2)	________________________
3. At what time is your platoon to arrive at the objective? (2)	________________________
4. What type of threat might you encounter on the way to your objective? (1)	________________________
5. What is the name of the place where the squad is to dismount? (2)	________________________
6. What is the call sign of your closest supporting unit? (2)	________________________
7. What type of enemy unit is closest to the objective? (1)	________________________
8. How far is the closest enemy unit from the objective? (2)	________________________
9. In what activity is the enemy unit that is closest to your objective currently engaged? (1)	________________________
10. What is the size of the enemy unit that is closest to your objective? (1)	________________________

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Appendix C. NASA-TLX

RATING SCALE DEFINITIONS

Title	End Points	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

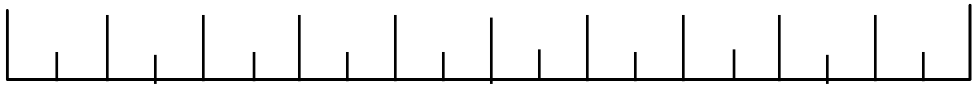
Frustration

or

Mental Demand

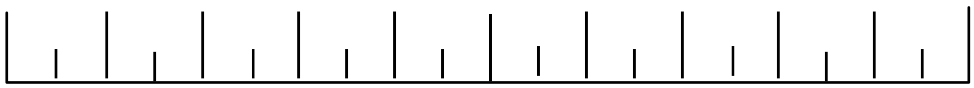
RATING SCALE SHEET

MENTAL DEMAND



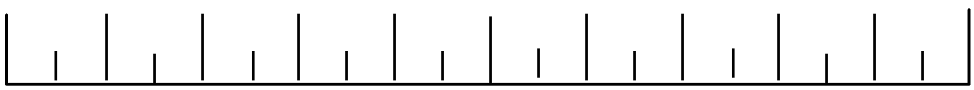
Low **High**

PHYSICAL DEMAND



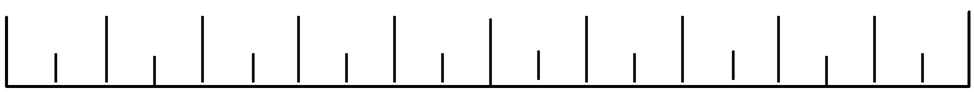
Low **High**

TEMPORAL DEMAND



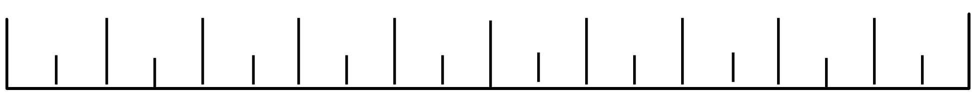
Low **High**

PERFORMANCE



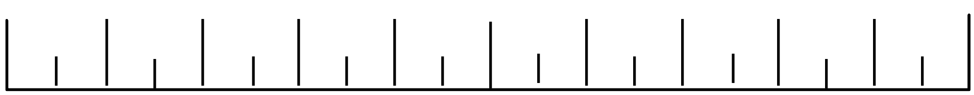
Good **Poor**

EFFORT



Low **High**

FRUSTRATION



Low **High**

Appendix D. Demographic Questionnaire

Please answer the following questions. The information you provide will be considered privileged and will be protected.

1. Participant No: ____

2. Age: _________ years

3. Rank: ___________________

4. Military Occupational Specialty (MOS): _________________

5. Time in Service: ______years ________ months

6. Time in MOS: _______years ________ months

7. Are you left- or right-handed?

   Left-Handed [ ] Right-Handed [ ]

8. How often do you play video- or computer games?

   Never [ ]
   Sometimes [ ]
   Often [ ]
   All the time [ ]

9. Vehicle Experience and Crew Positions Held *(Check all that apply):*

	Commander	Gunner	Loader	Driver
Bradley Fighting Vehicle	[ ]	[ ]	[NA]	[ ]
M1 tank	[ ]	[ ]	[ ]	[ ]
Other *(Please specify)* ___________	[ ]	[ ]	[ ]	[ ]

10. Combat Experience:

Geographic Area *(Check all that apply)*		Duration of Tour	Did you see combat? *(Circle either Yes or No)*		**If "Yes"** *(Please specify duty position during combat)*
Bosnia	[ ]	___years ___months	Yes	No	______________
Afghanistan	[ ]	___years ___months	Yes	No	______________
Iraq 1 (Desert Storm)	[ ]	___years ___months	Yes	No	______________
Iraq 2 (Iraqi Freedom)	[ ]	___years ___months	Yes	No	______________

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Appendix E. Post-Test Questionnaire

Participant No.: ____

1. Please rank *each* of the five cue conditions from 1 to 5 based on the order that you thought each was helpful in finding targets (1 = Most Helpful, 5 = Least Helpful):

Baseline	[ ]
Visual	[ ]
Verbal	[ ]
3-D Audio	[ ]
Tactile	[ ]

2. For each of the five cue conditions, in what communications modality was it easier to remember the information contained in the SITREPs?

Baseline	Auditory [ ]	Visual [ ]	No Difference [ ]
Visual	Auditory [ ]	Visual [ ]	No Difference [ ]
Verbal	Auditory [ ]	Visual [ ]	No Difference [ ]
3-D Audio	Auditory [ ]	Visual [ ]	No Difference [ ]
Tactile	Auditory [ ]	Visual [ ]	No Difference [ ]

3. Did the *auditory* SITREPs interfere with your ability to acquire targets in any of the five cue conditions?

Baseline	Yes [ ]	No [ ]
Visual	Yes [ ]	No [ ]
Verbal	Yes [ ]	No [ ]
3-D Audio	Yes [ ]	No [ ]
Tactile	Yes [ ]	No [ ]

4. Did the *visual* SITREPs interfere with your ability to acquire targets in any of the five cue conditions?

Baseline	Yes [ ]	No [ ]
Visual	Yes [ ]	No [ ]
Verbal	Yes [ ]	No [ ]
3-D Audio	Yes [ ]	No [ ]
Tactile	Yes [ ]	No [ ]

5. How often did you use the azimuth indicator in each of the five cue conditions?

Baseline	Never [ ]	Sometimes [ ]	Often [ ]	All the time [ ]
Visual	Never [ ]	Sometimes [ ]	Often [ ]	All the time [ ]
Verbal	Never [ ]	Sometimes [ ]	Often [ ]	All the time [ ]
3-D Audio	Never [ ]	Sometimes [ ]	Often [ ]	All the time [ ]
Tactile	Never [ ]	Sometimes [ ]	Often [ ]	All the time [ ]

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