The Effect of Various Display Modalities on Soldier Shooting and Secondary Task Performance

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ABSTRACT

The study examined the effects of auditory and visual displays, with and without an auditory alert cue (AAC), on a friend or foe shooting task and secondary task performance. Visual display conditions were: a forearm-mounted display (FMD), 2) a helmet-mounted display (HMD), 3) an FMD with an AAC, and 4) an HMD with an AAC. Results indicated that shooting performance was hindered by the use of an HMD. Shooting errors while performing a dual task were minimized with the use of an AAC for the secondary task. Additionally, of all display conditions, shooting errors were highest with the HMD, and lowest with the FMD with an AAC.

1.0 INTRODUCTION

The Army Vision states that U.S. forces will achieve overmatching combat power by leveraging information to enhance maneuver, firepower, protection, and leadership. This enhancement will be enabled by timely and accurate situational understanding (SU). Interface design solutions are being sought for information systems that enhance soldier performance, SU, and decision cycle performance.

1.1 Army Problem

One of the Army's challenges for the dismounted soldier is to optimize Soldier combat performance considering the impact of processing additional information. Information handling is a process that includes perception, encoding, processing, and output. Information can be presented in many modalities including aurally, visually, and even in tactile mode. Project Manager (PM) Land Warrior and the Future Force Warrior program at the US Army Natick Soldier Center have made significant progress in solving technical issues with wearable information systems that provide information to the soldier. These future wearable information systems will provide: 1) enhanced communication (squad radio and intra-squad communications), 2) enhanced navigation features, 3) weapon-sensor connectivity (to allow viewing of targets indirectly), and 4) other data access such as MOS-related (Military Occupational Specialty) data or emergency medical information. The dismounted warrior has several basic job elements that are often combined to create the real-world scenario of workload for the soldier. These can be simply summarized by listing the basic

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functions of "move", "shoot", "communicate", "gain intelligence", and "make good decisions." The workload demands of using such systems in complex environments are not fully understood. Failure to understand the impact of new high-tech weapons and information systems of the future may bring less than optimal soldier performance. Systems must be designed with the target population's capabilities, limits, and environments in mind.

1.2 Goal of the Study

The goal of this study was to discern if there are shooting and secondary task performance differences caused by various secondary task display modality types and auditory alert cues used by a soldier while shooting under additional workload. Various displays were used to provide secondary task workload while the soldier was engaged in a shoot-don't shoot friend or foe target scenario. The basic question of how to present information to the soldier while they are shooting has not been addressed in terms of displays and shooting performance. There are several variables regarding visual displays that may affect soldier-performance such as size, weight, resolution, brightness, occlusion, and mounting position (for hands-free operation). The latter two variables will be addressed in this paper. Two displays were selected that were likely to be used on future wearable information systems. Both displays were suitable for hands-free operation. Specifically, the two systems chosen were a Helmet Mounted Display (HMD) and a forearm mounted display (FMD). These two displays have been the most popular in military design communities concerned with wearable information systems. Additionally, the auditory alert cue was crossed with the visual displays to determine if the effect of an alert allowed better performance in any of the dependant measures. The purpose of this study was to examine the effects of various displays with and without an auditory alert cue for shooting and secondary task performance.

1.3 Multi-Tasking while Shooting

Increased levels of cognitive tasking are inevitable and some tasks will be performed simultaneously with shooting tasks. The most demanding and crucial form of multi-tasking for the dismounted infantry soldier is likely to be a scenario where a soldier is shooting or being shot at while having to attend to pertinent information. Many tasks can be mixed to formulate the battle demand on a soldier's attention. However, the fire-fight is thought to be the most stressful, highest-demand scenario. The effect of cognitive load on shooting performance has been studied to some extent by the Army Research Laboratory in recent years (Scribner & Harper, 2001; Scribner, 2002; Kelley & Scribner, 2003). The fundamental purpose of this research was to show that when the soldier is overburdened mentally there is a decrease in soldier lethality.

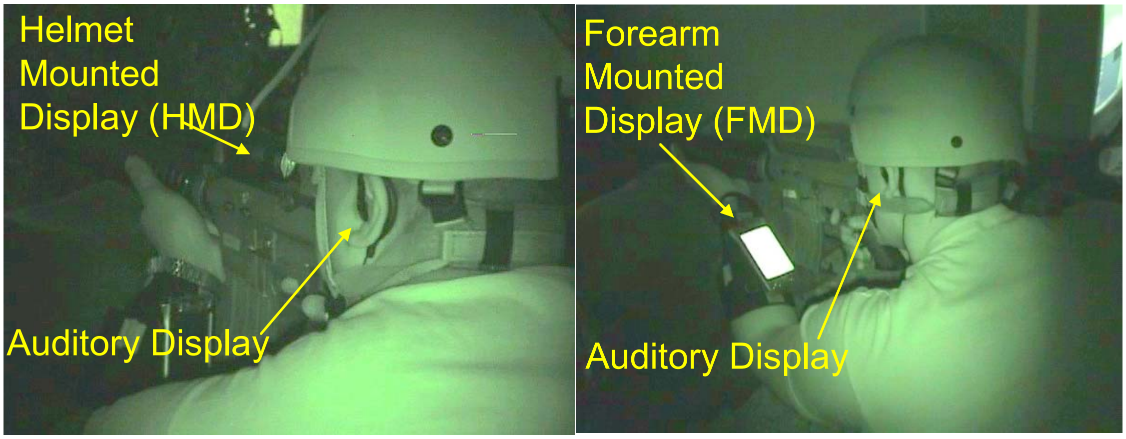

Figure 1. Visual and Auditory Equipment Worn.

Fratricide rates increase with higher levels of workload induced by such systems (Scribner, 2002). The current study was designed to address the workload issue for different display modalities for optimal shooting and secondary task performance. Visual and auditory displays are often categorized as "secondary" task displays when viewed in context of a shooting scenario. Some critics state that a soldier will reduce his workload instantly by "flipping" that HMD out of the way during a fire-fight. This may be true but, there are many emergency messages, warnings, and changes in rules of engagement that could be communicated to a soldier via this system just prior to or during a fire-fight scenario. On the design side, there are many designers that consider both an HMD and an FMD (figure 1) viable options to choose from. One of the main concerns designers have with HMDs are that they may be flipped out of the way making them useless or that they may hinder a soldier's vision, reducing ability in target engagement tasks. HMDs also add more head weight which can contribute to neck muscle fatigue. FMDs don't create neck muscle fatigue nor require being moved out of the way of direct vision, and can be accessed easily with a quick downward glance with the eyes. On the other hand, HMDs are readily accessible visually and provide a large field of view due to their proximity to the eye.

1.4 Hypotheses

1) The efficiency of the visual system would yield improved soldier verbal secondary task performance over the auditory system.
2) The effect of an auditory cue with visual displays would yield improved soldier primary and secondary task performance due to more efficient task switching (Wickens, 1984).
3) The location of the FMD with a *moderate visual scan angle* but most importantly, an *uncluttered visual field* would improve shooting performance.

2.0 METHOD

The experimental protocol was approved by the US Army Research Laboratory Human Use Committee. Twelve US Army soldiers volunteered for this study. They were all MOS 11B, dismounted infantryman, met requirements for 20/30 visual acuity, and were all experienced and recently qualified with the M16A2 service rifle. This study was conducted at Aberdeen Proving Ground in a shooting simulator commonly known as DISALT, or Dismounted Infantry Survivability and Lethality Testbed. The subjects entered the shooting simulator, donned all equipment used in the study, and were briefed on the nature of the study. As part of the experiment, each subject wore all display equipment through all trials to eliminate equipment weight and feel differences. When the HMD was not used, it was "flipped" up to eliminate visual obscuration of the target set. Subjects trained basic shooting, friend or foe shooting discrimination, and math addition problems to asymptotic performance.

The shooting task consisted of a randomized 24-target pop-up scenario using friendly (brown) and enemy (black) E-type silhouettes (figure 2). Half of the targets were friendly and half were enemy. Ranges consisted of 75, 100, 150, 200, 250, and 300-meters. There were right, center, and left target positions for each range. Target exposure time was 3 seconds with a 2-second inter-target interval. Soldiers were in a foxhole supported kneeling position for all trials. De-militarized M16A2 rifles with iron sights and simulated recoil were used for this study. Subjects were instructed to shoot their best as their primary task priority, and to solve as many math problems as possible for their secondary task priority. Subjects were exposed to a counter-balanced presentation of all experimental conditions. All shooting data was recorded and stored on the host computer of the shooting simulator system. A general weapon zero was performed electronically and stored for use in all trials.

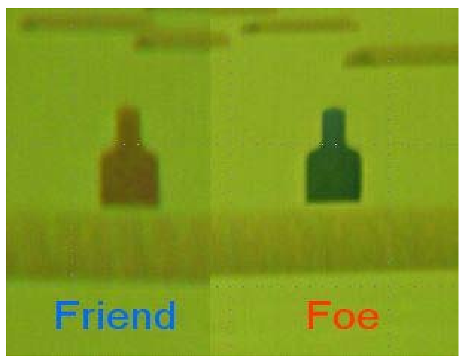

Figure 2. Target Silhouettes.

2.1 Display Modalities and Secondary Task

The five methods of presenting secondary task workload were: 1) aural, 2) visual only using the FMD, 3) visual only using the HMD, or 4) visual with an auditory cue using the FMD, and 5) visual with an auditory cue using the HMD. Auditory displays may be monaural, binaural, or even provide a three dimensional spatial component for enhanced understanding. Audio presentation via ear "buds" were worn in the ear and used for comparison of secondary task performance. For auditory mode, each math problem presented consisted of a spoken math problem followed immediately by a brief response cue tone, indicating that the test participant could respond. There was a sixth condition in which no secondary task (single shooting task,) was presented during the shooting trial, this baseline condition would be used for simple comparison and not be included in the statistical analysis. For the visual mode, the entire math problem was presented on the FMD or HMD for a time equal to the time required for the spoken math problem in the aural mode. For all modes, the subject had 2.5 seconds to speak the correct answer or it was scored as an error. Twenty math problems were presented, each a double-digit plus a single-digit problem always requiring a carrying operation. This "moderate" level of secondary task workload was found to be suitable for sensitivity to primary task performance such as friend-or-foe shooting scenarios (Scribner & Harper, 2001). The number of math problems correctly solved was calculated to score this secondary task.

2.2 Experimental Design

The design was a 1x6 repeated measures design using a Latin-square to provide a counter-balanced presentation order to minimize learning effects. Independent variables were display type and by auditory alert cue presence. A series of 2x2 and 1x3 ANOVAs were performed to compare visual displays by AAC, no-cue visual displays compared to auditory, and finally, visual displays with compared to auditory. Dependant variables included enemy targets hit, reaction time, total error, friendly fire error, enemy not engaged error, and secondary task performance.

3.0 RESULTS

3.1 Visual Display by Cue Comparisons

A series of 2x2 repeated measures ANOVA analyses were performed for all dependant variables to examine the aspects of visual display-only by cue performance. The independent variable levels were visual display type (FMD or HMD) by auditory cue (present or not). Total error rate (the sum of friendly fire error and enemy targets not engaged) yielded significant differences for display type ($p<.05$). The results are shown below in figure 3. Friendly fire error rate yielded significant results ($p<.02$) for cue condition. This data is shown below in figure 4.

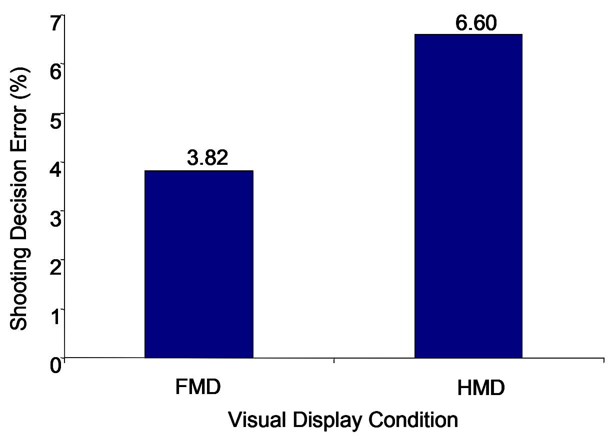

Figure 3. Shooting Decision Error by Visual Display.

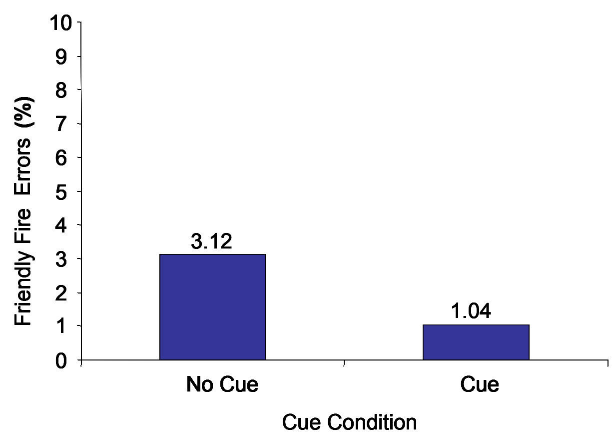

Figure 4. Friendly Fire Errors by Cue.

3.2 Auditory Compared to Visual Displays with No Cue

A series of 1x3 repeated measures ANOVA analyses were performed for all dependant measures. The independent variable levels were visual display type (Auditory, FMD-No Cue, and HMD-No Cue). Reaction time, shown in figure 5, yielded significant differences for type of display used ($p<.03$). Post-Hoc analyses determined that differences were significant between Auditory and HMD-No Cue conditions.

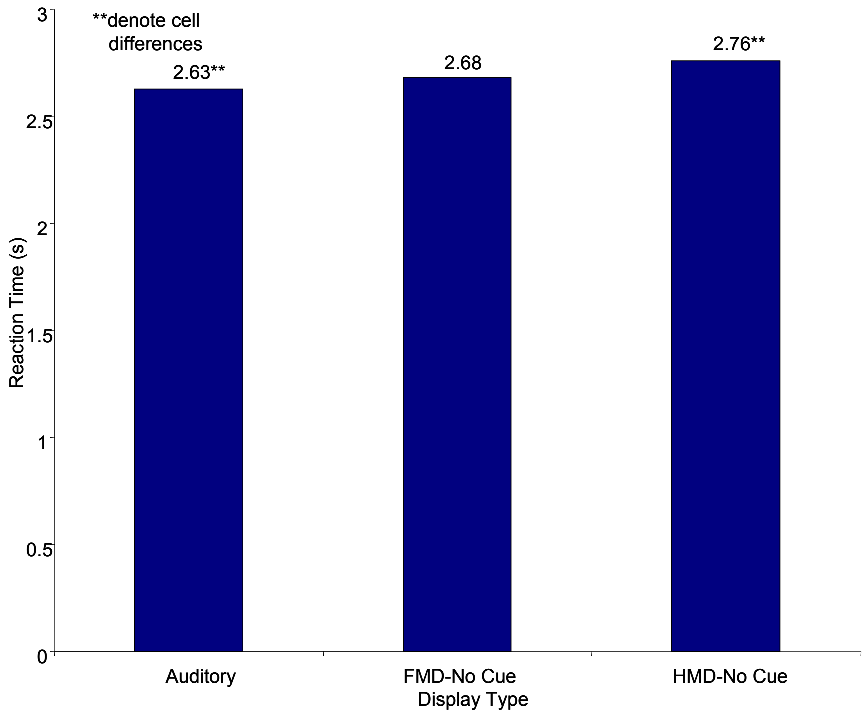

Figure 5. Reaction Time by Display Type.

Secondary task completion rate analysis revealed a significant difference (p=.05), seen below in figure 6. Post-hoc analyses determined that the auditory condition was significantly lower than the HMD-No Cue condition.

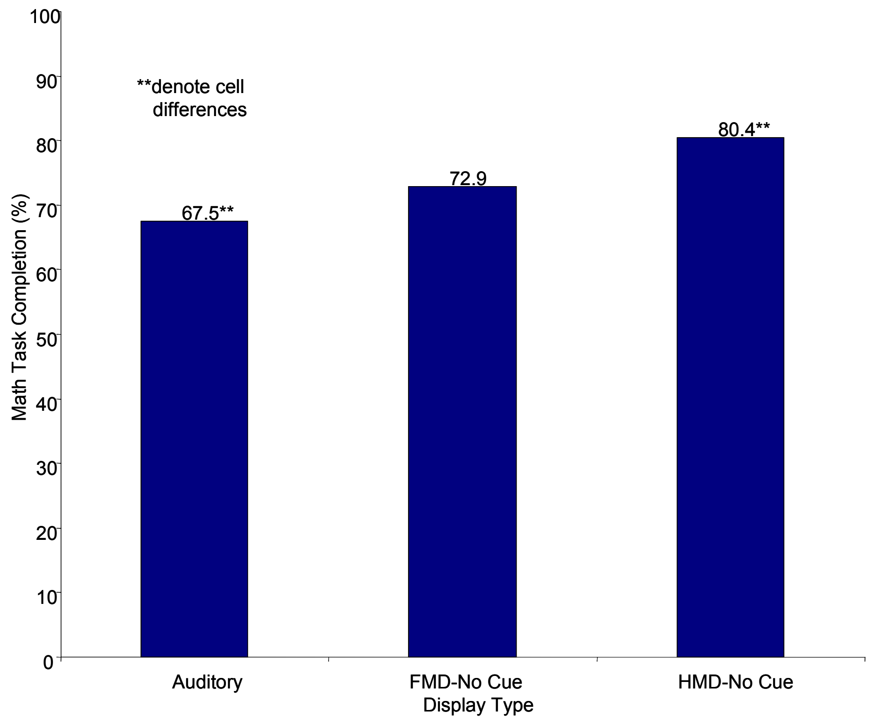

Figure 6. Math Problems Completed by Display Type.

3.3 Auditory Compared to Visual Displays with Cue

A series of 1x3 repeated measures ANOVA analyses were performed for all dependant measures. The independent variable levels were visual display type (Auditory, FMD+Cue, and HMD+Cue). Enemy hit percentage yielded significant differences for type of display used ($p<.04$). Post-Hoc analyses determined that differences were significant between Auditory and HMD+Cue conditions as seen below in figure 7. Single shooting task hit percentage data was added strictly for visual comparison to a baseline shooting task.

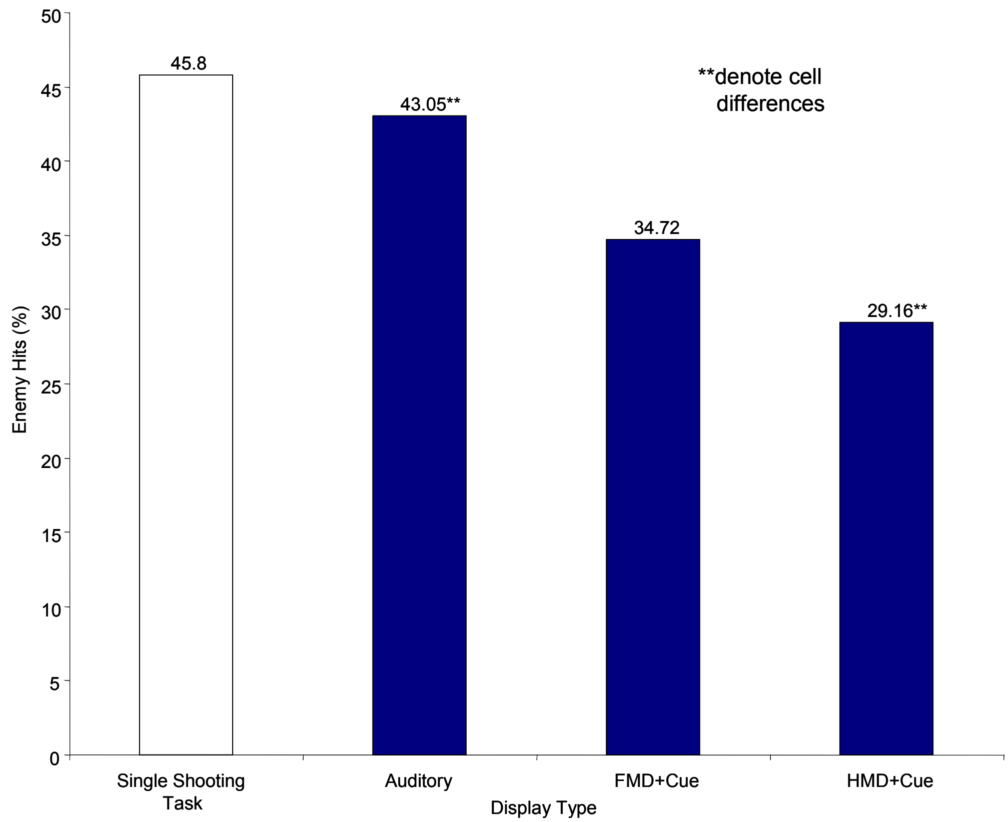

Figure 7. Enemy Hits by Display Type.

For secondary task completion rate analysis revealed a significant difference (p=.05), seen below in figure 8. Post-hoc analyses determined that the HMD+Cue was significantly better than the auditory condition.

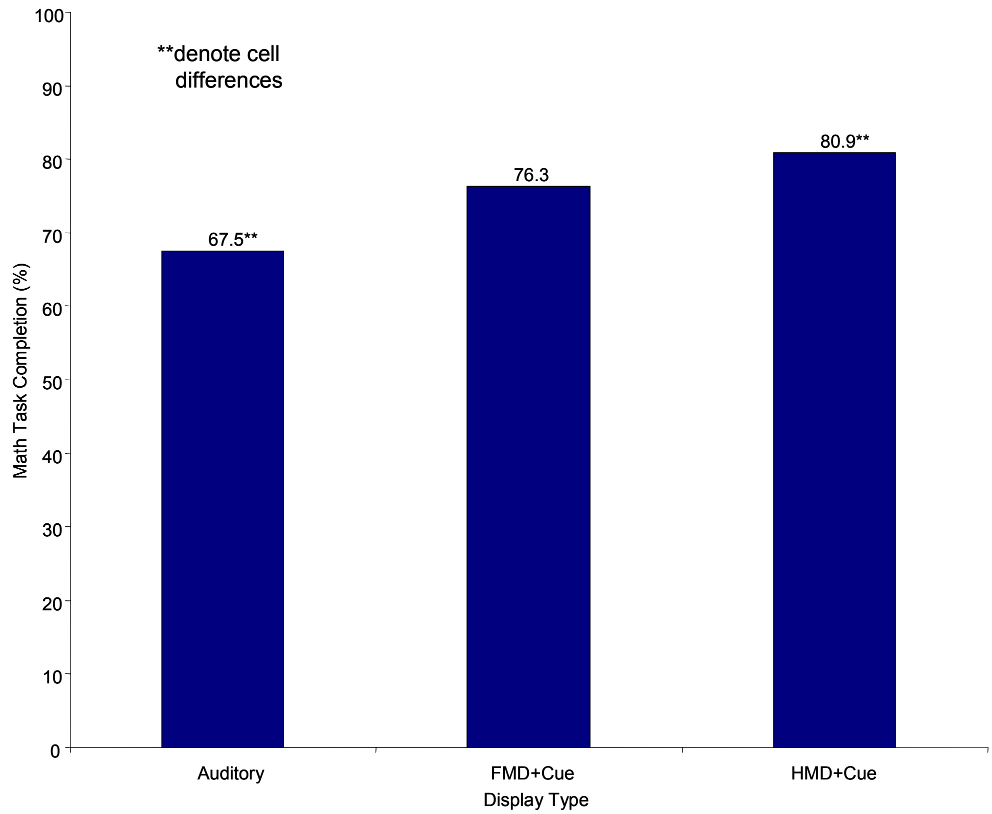

Figure 8. Math Problems Completed by Display Type.

DISCUSSION

The data show that when comparing visual displays and cue presence the FMD was superior to the HMD in reducing overall shooting error. Additionally, the auditory cue reduced friendly fire error. When three displays were compared to each other, the HMD (No Cue and Cue) showed superior secondary task performance (math problems completed), whereas, the auditory display showed superior primary task performance (enemy targets hit) when compared to HMD+Cue. Additionally, the auditory display showed superior performance in reaction time to HMD-No Cue. It appears that the auditory display provided the best hit percentage. The HMD when used with shooting as a secondary task display was a poor performer. The FMD, however, failed to show difference from either the auditory or HMD display in any of the simple 1x3 comparisons. The FMD with an auditory alert cue was the best possible choice for a trade-off between the primary and secondary tasks under a dual task shooting scenario.

Sound human factors design dictates that information be provided in auditory mode when information is simple in nature or if it tends to fall into a warning or alert category. It appears that the HMD is the best choice for a single, complex visual task where hands-free convenience is imperative, but not for use when dual-task scenarios such as shooting or self-defence are expected. When in a target engagement or shooting task, the soldier's visual field should be clear of anything but critical information. Information should be as easy to access and process as possible. Where possible, the use of both auditory and visual icons should be explored. When information cannot be presented as an icon, easy to understand visual presentation should be used to eliminate lengthy information uptake and processing requirements. Because fratricide is more probable under conditions of high workload, it is imperative that future warrior systems be assessed for workload demand on soldiers under all operational scenarios.

5.0 REFERENCES

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