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Scaling Robotic Displays: Displays and Techniques for Dismounted Movement with Robots

by Elizabeth S. Redden, Rodger A. Pettitt,
Christian B. Carstens, and Linda R. Elliott

ARL-TR-5174 April 2010

NOTICES

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Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
April 2010	Final	

4. TITLE AND SUBTITLE
Scaling Robotic Displays: Displays and Techniques for Dismounted Movement with Robots

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Elizabeth S. Redden, Rodger A. Pettitt, Christian B. Carstens, and Linda R. Elliott

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
RDRL-HRM-DW
Aberdeen Proving Ground, MD 21005-5425

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-5174

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The purpose of this research was to examine the effects of display type and robotic employment techniques on robotic control during dynamic dismounted Soldier operations. The study took place at Fort Benning, GA, using Soldiers from the Officer Candidate School (OCS) as participants. The employment techniques contrasted stationary bounding operation with operation of the robot while the Soldier was on the move. The two display types were a handheld display (HHD) and a helmet mounted display (HMD). Results indicated that Soldiers performed better with the HHD than they did with the HMD used in this experiment. Their course completion times, driving errors, and the number of times they drove off course were all lower with the HHD. The Soldiers also preferred the HHD to the HMD and rated the workload with the HHD lower. With regard to technique, Soldiers preferred the bounding technique to the continuous movement technique. Fewer driving and off course errors were made and more items were detected with the bounding technique. Finally, until robots become more autonomous in their navigation, robotic control during Soldier movement is beyond the multitasking ability of most Soldiers.

15. SUBJECT TERMS
robots, movement techniques, handheld display, head mounted

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Elizabeth S. Redden
Unclassified	Unclassified	Unclassified	UU	72	19b. TELEPHONE NUMBER (*Include area code*) (706) 545-5493

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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1. Introduction

1.1 Background

Scalability customarily refers to the ability of a process to handle increasing amounts of work or its ability to be readily enlarged (Bondi, 2000). Scalability can also be referred to as the ability of a device to be readily reduced in size, without losing functionality. This is the fourth in a series of experiments designed to investigate scalability of robotic operator controller units (OCUs) for dismounted Soldiers. The first three experiments in this series addressed screen size for the dismounted Soldier's driving camera display (Redden, Pettitt, Carstens, and Elliott, 2008a), controller options for the dismounted Soldier to drive the robot and maneuver the robotic arm (Pettitt, Redden, Carstens, and Elliott, 2008), and multimodal displays for navigation (Redden, Pettitt, Carstens, and Elliott, 2008b). The scalability component of interest concerns how best to accommodate the robotic display process on smaller, lighter OCUs while maintaining functionality, adequate visual properties, and ease of use. The environments of dismounted Soldiers are rugged and physically demanding, and Soldiers must carry their robotic OCUs along with all their protective and fighting equipment in these challenging environments. Relatively large displays typically used in a stationary environment or inside a combat vehicle are not appropriate and could have an adverse impact on dismounted Soldiers' missions. Thus, smaller interfaces are needed for Soldiers operating in the dismounted environment. The key to successful scaling is to consider the range of devices that Soldiers will use (e.g., vehicle-mounted robot control devices, other controller devices) and also their context of use. This approach to scalability of interfaces ensures that training transfer is easily achieved across environments and that interfaces can be tailored to the environment in which they are used.

Two findings in the first experiment demonstrated the need for this follow-on experiment. First, Redden et al. (2008a) found a few areas of concern regarding the use of monocular head-mounted displays (HMDs) for robotic teleoperation. These concerns should be addressed to ensure that perceptual problems such as binocular rivalry and overstimulation do not occur. She and her colleagues recommended further research on factors having a potentially adverse impact on helmet- or goggle-mounted robotic displays if these displays are to be used by the Army for robotic teleoperation. Such factors include interference between the scenes presented to two different eyes, potential problems with prolonged occlusion of one eye, the inability to use compensatory head movements to center the display on the visual field, and the effects of eye dominance on the use of monocular displays. These findings are consistent with the literature on HMDs.

Second, the findings from the Redden et al. (2008a) experiment indicated that smaller devices (i.e., 3.5-in diagonal displays and 6.5-in diagonal displays) can be used to display video sufficient for teleoperation and local surveillance with small, slow-speed robots. This could make more screen space available for other objects (if the total display size is larger than 3.5 in) and enable the use of lower resolution cameras, which would allow faster video processing and lower bandwidth requirements. This finding was limited to users driving robots using a camera display while seated under a tent. Thus, additional robotic tasks (e.g., navigation using map displays) and operating environments (e.g., dismounted on-the-move) need to be investigated.

1.2 Head-Mounted Displays (HMDs)

HMDs were originally developed for remote control of robots in the 1960s (Sutherland, 1968). They have continuously evolved since the 1960s: they are now lighter and have higher resolution, and some are so small they can be clipped onto glasses. They are used everywhere from industrial plants to hospitals to dentist offices. The original concept for use (robotics) has received more emphasis recently and their use for defense-related robots is being championed. Those who are enthusiastic about the use of HMDs argue that they are hands free, have less glare and higher resolution than a handheld display (HHD), and are extremely lightweight. They also emphasize that the HMDs use much less power than other portable displays and meet the light security requirements that are so important to Soldiers. Many in the military advocate their use during dismounted movement, stating that HMDs allow Soldiers to observe information presented on the display while they are conducting dynamic operations. While these are very valid points, it is not clear if HMDs can be used effectively for concentrated monitoring tasks during operational movement. A fundamental question is whether the Soldiers can effectively divide attention between their surroundings (e.g., terrain, indicators of threat) and a display that can partially occlude terrestrial vision, particularly if they are walking over uneven terrain.

HMDs are not without their drawbacks. The following perceptual issues are representative of those found in the literature associated with the use of HMDs (Merhi, Fauugloire, Flanagan, and Stoffregen, 2007; Sheedy and Bergstrom, 2002; Patterson, Winterbottom, and Pierce, 2006):

- Brightness and contrast perceptual consequences can have an adverse impact on vision.
- Both real-world and HMD imagery must be within the user's depth of field, dark focus, and dark vergence.
- Accommodation-vergence synergy and accommodation-vergence mismatch can result in blurred objects and a failure to detect objects. If a stimulus is blurred, a reflexive change in accommodation attempts to resolve the blur. The knowledge that an object exists that is close to the eye may cause accommodation, and specific conscious mental effort can result in a lapse of accommodation. Accommodation also tends to change if there is a change in vergence. This mismatch is frequently reported with HMD use and can create eyestrain or visual discomfort.
- Restricted field of view can impair performance and adversely affect the ability to see the "whole picture."

- Binocular rivalry is a state of competition between the eyes such that one eye inhibits the visual processing of the other eye. The views delivered to the two eyes can be very different with monocular HMDs, because one eye sees the HMD and the other views a real-world scene.
- Eyestrain and blurry vision have been found to occur significantly more with HMDs than with other displays.
- As HMD wearers move their heads, displayed objects in front continue to be in front and this is unnatural. Many wearers try to turn their heads in order to see objects outside of the camera's field of view.
- Motion sickness is commonly found when HMDs are worn by video game users and is often explained as being caused by sensory conflict.

Other problems with HMDs reported in the literature (Cobb, 1999; Cobb and Nichols, 1998; Draper et al., 2001; Patterson et al., 2006; Elliott, Duistermaat, Redden, and van Erp, 2007; Glumm et al. 1998; Krupenia and Sanderson, 2007; McCann, Foyle, and Johnston (1993); National Research Council, 1997; Knight and Baber, 2007; Turner and Carstens, 2007) include the following:

- Competition for the attention of the wearer/attentional tunneling
- Interference with night vision devices
- Occlusion of full field of view if the HMD is not see-through
- Fogging due to weather
- Reduction in wearer situation awareness (SA)
- Reduction in cross-country movement speeds
- Conflict with performance of other critical tasks
- Potential for placing the musculoskeletal system of the head and neck under increased levels of stress
- Known to be nauseogenic. This problem has been found to be even more common with postural instability.
- Decreased likelihood of detecting unexpected events than with standard displays

The National Research Council's Report on Tactical Displays for Soldiers (1997) recommends that if the display occludes the Soldiers' view, then HHDs or wrist-mounted displays should be considered as an alternative to HMDs, because the loss of local SA may be unacceptable.

1.3 Handheld Displays (HHDs)

Personal Digital Assistants (PDA) and other HHDs are becoming mainstays of society. It is difficult to walk down the street without seeing someone peering at their PDA or BlackBerry* as they are walking. However, most individuals who attempt to walk and look at the screen of their HHD have seriously compromised their SA of their surroundings. Furthermore, many HHD screens are difficult to see in the sun because of glare. Also, they are difficult to read due to low resolution, small size, and an unstable view when the user is walking. It appears the most effective way to use HHDs is while the user is stationary. During stationary operations, it appears that HHDs are equally effective or more effective than the HMDs. For example, Scribner, Wiley, Harper, and Kelley (2007) found that Soldiers performed better in terms of enemy target hit performance, time to first shot, and lower enemy engagement rates during defensive shooting (stationary) with a forearm-mounted small display than with an HMD. They did, however, state that the HMD appears to be the best choice for a single task when hands-free convenience is imperative but not when dual-task scenarios, such as shooting and communicating, are expected.

1.4 Techniques for Dismounted Soldier Robotic Operation

A recent literature search on robotic operations reveals that very little has been done in terms of systematic development of tactics, techniques, and procedures (TTPs) for robotic operation by dismounted Soldiers. The Manned-Unmanned Teaming appendix of FM 3-90 (U.S. Army, 2001) alludes to the teaming between dismounted Soldiers and unmanned platforms. It identifies the Small Unmanned Ground Vehicle (SUGV) as an integral part of the fighting team and states that it is not a separate platform added for a specific mission. It is a highly mobile and reconfigurable platform intended for a variety of missions. It further states that manned systems, teamed with unmanned systems, provide the Future Combat Systems (FCS)-equipped Brigade Combat Team Commander with continuous and wide-ranging intelligence, surveillance, and reconnaissance (ISR) capability necessary to accomplish full-spectrum operations. Armed Robotic Vehicles (ARVs) are a family of robotic platforms that have the ability to provide direct fire for offensive operations and force protection in addition to ISR capabilities. ARVs support mounted and dismounted operations by acting as combat multipliers by providing reconnaissance, surveillance, and target acquisition; additional weapons platforms; and limited communications relays, and perhaps most importantly, by assuming risks that Soldiers would otherwise have to assume. An example of a mission is contained in the appendix of FM 3-90. In that mission a dismounted infantry platoon in urban operations teams with ARVs and SUGVs to clear its sector. It is not clear whether the platoon will operate the robots during movement or whether the robotic operator will be stationary during the robotic operation.

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*BlackBerry is a registered trademark of Research in Motion Limited.

A major focus of the Air Assault Expeditionary Force (AAEF) Spiral D Experiment (2008) was to develop TTPs for the employment of a network-enabled small unit and its associated battle command and robotics systems. The experiment was built around an Infantry Brigade Combat Team (IBCT) and was executed by a small unit (Infantry rifle platoon and company headquarters) enhanced by a network and select FCS enablers. The TTPs represent insights gained from the Experimentation Force (EXFOR), technical experts, technology training teams, and analysts. The technique for movement discussed in that document centers on emplacement of the robot by the Soldier and then movement of the Soldier to a covered and concealed position before moving the robot. Movement of the robot along with the squad was discouraged, primarily because the robots used in the experiment violated the light and noise security of the squad.

1.5 Display Type and Movement Condition Interaction

The advocates of HMDs suggest that, under certain operating conditions, an HMD might be best because it provides hands-free operation during movement, reduced glare, and lighter weight than an HHD might. However, the literature suggests that during stationary operations, an HHD might be more practical because of all the perceptual problems associated with using an HMD. Whether the dismounted Soldier is on the move or in a stationary position might moderate the effectiveness of the two display modes. Thus, there may be an interaction between display type and movement condition.

1.6 Overview of Present Research

Our study investigated the effects of display type and robotic employment techniques on robotic control during dynamic dismounted Soldier operations. It took place at Fort Benning, GA, using Soldiers from the Officer Candidate School (OCS) as participants. Two types of employment techniques and two types of displays were used. The employment techniques contrasted stationary bounding operation with operation of the robot while the Soldier was on the move. The two display types were an HHD and an HMD. After training on the operation of the iRobot PackBot system, each Soldier completed planned exercises four times—once with each display type and employment technique combination. The terrain, targets, and hazards were counterbalanced along with the display and movement technique type to control for order effects (e.g., practice, learning, fatigue). Effectiveness of display type and employment technique was evaluated based on objective performance data, data collector observations, and Soldier questionnaires.

2. Method

2.1 Participants

Thirty-six Soldiers from the OCS participated in the study. Their mean age was 26 years and their grades ranged from E4 to E8.

2.2 Instruments, Apparatus, and Techniques

2.2.1 iRobot PackBot Robot

The iRobot PackBot Robot is a portable SUGV reconnaissance and tactical robot that can enter and secure areas that are either inaccessible or too dangerous for humans (figure 1). The PackBot Explorer Robot payload has a rotating pan and tilt head equipped with multiple cameras.

Figure 1. PackBot Explorer Robot.

2.2.2 Robotic Vehicle Displays

Two different display types were used to conduct this experiment. Each display type was plugged into the existing iRobot PackBot Robot control system so that all variables except the displays remained constant.

HHD

The HHD was a PDA-sized display, as shown in figure 2.

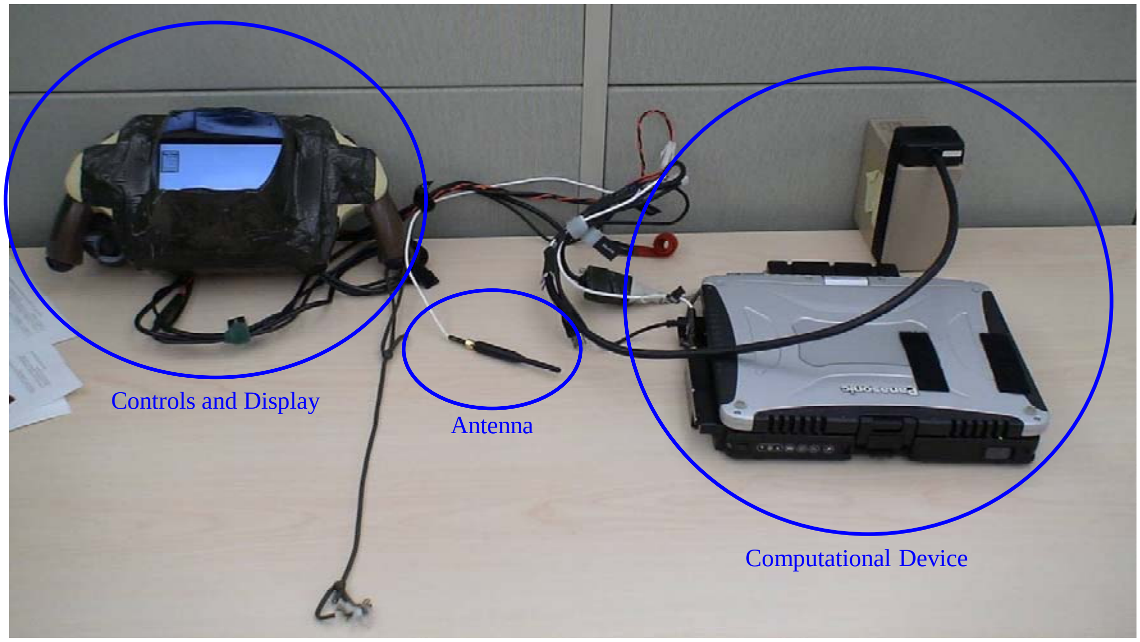

Figure 2. HHD.

This HHD is a modified prototype Esterline-Mason controller that integrates the control inputs and display output. The display is a 6.5-in diagonal screen with 1024 × 768 resolution. The controller was modified so the display could be visible in full sunlight and to provide controls since the integrated controls were not supported by the software. A sunshield was placed around the display and a modified hand controller was added to the unit (figure 3).

Figure 3. Modified display and controls.

The control and display device is carried by the operator. The computational device is placed inside a standard issue day assault pack (figure 4) that is worn by the operator. The antenna is attached to the outside of the pack.

Figure 4. Assault pack and HHD.

HMD

The HMD was a Land Warrior-sized display (1.425 in, 800 × 600 resolution) with super video graphics array (SVGA) input. The system consisted of a modified Tac-Eye goggle-mounted display from Vuzix and a standard game controller. The display position was adjustable up/down and left/right, and each participant was allowed to choose the eye they wanted it on as well as its actual position. The only modifications to this device were that the goggle lens was removed and a sunshield was added to reduce glare (figure 5).

Figure 5. HMD with sunshield.

The computational device is the same one used with the HHD and is placed inside a standard issue day assault pack that is worn by the operator (see figures 2 and 4). The antenna is attached to the outside of the pack.

2.2.3 Questionnaires

- *Demographic Questionnaire*. The demographic questionnaire (appendix A) was developed to collect information pertaining to Soldier characteristics and experience, especially their knowledge of robotic operation.
- *Training Questionnaire*. A training questionnaire (appendix B) was developed to collect information concerning the adequacy of the robotic training, the display training, and the training course. It consisted of semantic differential rating scales and open-ended questions.
- *Post Iteration Questionnaire*. This questionnaire (appendix C) was developed specifically for this experiment and administered during this evaluation. The post iteration questionnaire was designed to be administered at the completion of each trial with each system. The questionnaire consisted of 7-point semantic differential scaled questions and open-ended questions. Questions covered Soldiers' ratings of their performance and experiences with each of the display type and technique combinations. Open-ended questions requested the Soldiers to write their evaluations of the devices.
- *Motion Sickness Assessment Questionnaire (MSAQ)*. The MSAQ was developed by Gianaros and his colleagues (2001) as a result of a series of studies illustrating the dimensionality of motion sickness (appendix D). The authors used exploratory and confirmatory factor analyses of motion sickness descriptors to derive and verify four dimensions of motion sickness, which were defined as gastrointestinal, central, peripheral, and sopite-related. These dimensions of motion sickness were then used to construct the MSAQ, which asks the participant to rate phrases concerning how they feel on a scale of 1 (not at all) to 9 (severely).
- *National Aeronautics and Space Administration (NASA)-Task Load Index (TLX)*. The NASA-TLX is a tool that allows subjective workload assessments by operator(s) working with various human-machine systems (Hart and Staveland, 1988). It uses a multi-dimensional rating procedure that derives an overall workload score based on weighted averages of ratings on six subscales. These subscales include mental demands, physical demands, temporal demands, own performance, effort, and frustration. It can be used to assess workload in multiple human-machine environments. The version of the NASA-TLX used during this experiment was presented to the Soldiers on a computer. Definitions of each scale were provided on laminated paper so the participants could refer to it as they were providing their estimates of the workload associated with each movement condition on the various scales.

- *End of Experiment Questionnaire*. The end of experiment questionnaire (appendix E) required the Soldiers to rank the display and technique combinations and to answer open ended questions about the displays and techniques.

2.2.4 Dynamic Robotic Employment Techniques

Bounding Technique

In the bounding technique, the robot operator is stationary during robot movement. The Soldier moves to the transition point first and then maneuvers the robot past his position to the next transition point. Then the operator moves up to the position of the robot. The operator continues bounding between transition points until reaching the end of the course. This technique requires the use of the camera display to operate the robot (figure 6).

Figure 6. Bounding technique.

Continuous Movement

In the continuous movement technique, the robot operator moves in conjunction with the robot. The robot's position during movement is to the rear of the squad formation. At the first transition point, the robot is called forward to reconnoiter areas that are masked to line of sight. At this point, the operator is located far enough behind the robot so that he must use the camera display to maneuver the robot rather than using line of sight to the robot. Obstacles and other squad members block the operator from seeing the robot directly so that he is forced to use the camera display to maneuver the robot (figure 7).

Figure 7. Continuous movement.

2.2.5 Robotic Course

The robotic course (figure 8) was ~200 m in length. Both the robot and the Soldier teleoperating the robot negotiate the course. The course is designed with obstacles that mask the Soldier's view of the robot, forcing him to maneuver the robot using only the driving camera and display. The obstacles included a tunnel, hills, a covered area, and tents. The course path was approximately 1 m wide and was clearly marked with white engineer tape on the left and right sides. Target silhouettes and simulated improvised explosive devices (IEDs) that could be clearly seen through the driving camera were placed along the course out of the line of sight of the Soldier. Three transition points were marked with red flags. The transition points marked the locations where the Soldier maneuvered the robot from a location behind him to one in front of him in order to reconnoiter the lane for the target silhouettes and simulated IEDs.

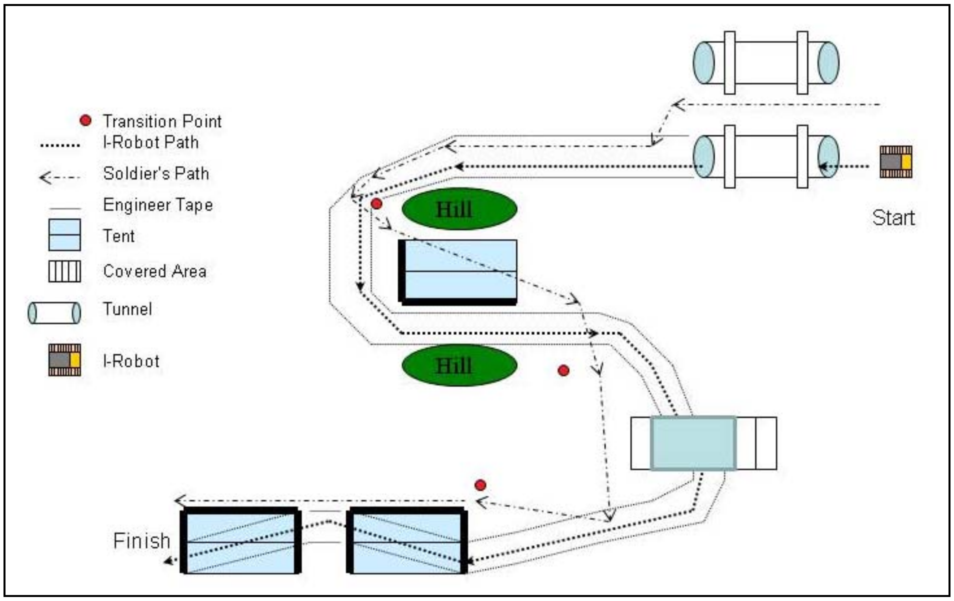

Figure 8. Robotic course.

2.3 Procedures

2.3.1 Demographics

The Soldiers reported in groups of four for one day each. Upon arrival, they were briefed on what was expected of them and how the information they provided would be used. All of the Soldiers consented to participate in the experiment. Each Soldier then completed the demographic questionnaire (appendix A) and was given a roster number.

2.3.2 Training

A representative of iRobot trained the Soldiers to teleoperate the robot using both the HHD and HMD display while conducting both the continuous movement and bounding techniques. They were also trained on the features of the robotic driving course to negate the effect of a potential learning curve. After the training session, Soldiers conducted practice field trials using the robot and displays. They then demonstrated proficiency with the system by performing a series of maneuvers for the trainer. After that, the Soldiers completed the training questionnaire (appendix B).

2.3.3 Experiment Trials

Soldiers were assigned to displays and techniques according to the matrix presented in table 1. The matrix was constructed using all possible orders of movement technique and display combinations, as listed:

Condition A – HHD/bounding technique combination

Condition B – HHD/operator continuous movement technique combination

Condition C – HMD/bounding technique combination

Condition D – HMD/operator continuous movement technique combination

Table 1. Order of treatments.

Roster (Soldier)	**Iteration**			
	1	**2**	**3**	**4**
	Test Condition	**Test Condition**	**Test Condition**	**Test Condition**
1	A	C	B	D
2	B	A	D	C
3	C	D	A	B
4	D	B	C	A
5	A	C	B	D
6	B	A	D	C
7	C	D	A	B
8	D	B	C	A
9	A	C	B	D
10	B	A	D	C
11	C	D	A	B
12	D	B	C	A
13	A	C	B	D
14	B	A	D	C
15	C	D	A	B
16	D	B	C	A
17	A	C	B	D
18	B	A	D	C
19	C	D	A	B
20	D	B	C	A
21	A	C	B	D
22	B	A	D	C
23	C	D	A	B
24	D	B	C	A
25	A	C	B	D
26	B	A	D	C
27	C	D	A	B
28	D	B	C	A
29	A	C	B	D
30	B	A	D	C
31	C	D	A	B
32	D	B	C	A
33	A	C	B	D
34	B	A	D	C
35	C	D	A	B
36	D	B	C	A

This Williams square design controls for effects due to order and also for effects due to preceding device; that is, B does not always follow A (Williams, 1949).

The Soldiers were told that they were acting as a robotic operator and maneuvering through the course as a member of a notional Infantry squad. Their primary task was to use the robot to reconnoiter areas of the route that were not within the visual range of the squad before the squad moved through the area. They were also instructed to find as many items of interest (IEDs [figure 9] and silhouette targets) as possible and move through the course as quickly as possible. At the three transition points on the course, they were instructed to maneuver the robot from the rear of the squad formation to the front in order to reconnoiter areas masked by obstacles. A data collector acting as the squad leader (figure 10) recorded the number of items that were found and recorded the amount of time the Soldier stopped (during the continuous movement technique trials only). Another data collector following the robot recorded the driving errors (number of times the robot ran over or into an object), the number of times the robot went off course (one track drove completely outside the white engineer tape), and the time for completion of the course. The robotic course was negotiated using both the bounding and continuous movement techniques.

After course completion with each display type and technique combination, the Soldiers completed the post iteration questionnaires (appendix C), the MSAQ (appendix D). and the NASA-TLX and waited until the course was ready for the next iteration.

Figure 9. IED on course. (Note: The robot is off course.)

Figure 10. Data collectors.

2.3.4 Post Experiment Questionnaire

Upon completion of all trials with each display and technique combination, the Soldiers were given an end of experiment questionnaire (appendix E) designed for this experiment to assess the degree of acceptance for each combination and their overall preferences.

3. Results

3.1 Demographics

The 36 OCS Soldiers who participated in this experiment averaged 4 years in the military. Some of the subjects were prior service enlisted from a variety of Army fields, including Infantry, Combat Engineer, Intelligence Analyst, and Special Electronic Devices Repairer. Other subjects were recent basic training graduates that enlisted under the college option for OCS. Four of the Soldiers were left-handed and 14 wore prescription lenses. Twenty-eight were right eye dominant. Detailed results from the demographic questionnaire can be found in appendix A.

3.2 Training

The participants were generally positive about the quality and quantity of training on the use of the robot, movement techniques, and displays. Soldiers also rated the practice lane highly. They indicated that learning to drive the robot with the HMD was somewhat harder than learning to drive the robot with the HHD, but the ratings for the training they received on both displays were high. Detailed comments on the training questionnaire can be found in appendix B.

3.3 Experiment Trials

3.3.1 Performance Data

One participant was deleted from the analyses reported in this section; this Soldier was an extreme outlier on all dependent measures. Thus, the sample size used in the analyses in this section is 35.

Course Completion Times

The mean course completion times for each experimental condition are shown in table 2 and figure 11. A 2 × 2 repeated measures analysis of variance (ANOVA) indicates that there was a significant main effect for display [F(1,34) = 11.5, p = 0.002, η^2_p = 0.253]. The main effect for movement was not statistically significant [F(1,34) = 1.74, p = .196, η^2_p = 0.049], nor was the display × movement interaction [F(1,34) < 1.00].

Table 2. Mean course completion times by condition.

Condition	Display	Technique	Mean (s)	SD (s)
A	HHD	Bounding	218	84
B	HHD	Continuous	240	117
C	HMD	Bounding	254	107
D	HMD	Continuous	288	168

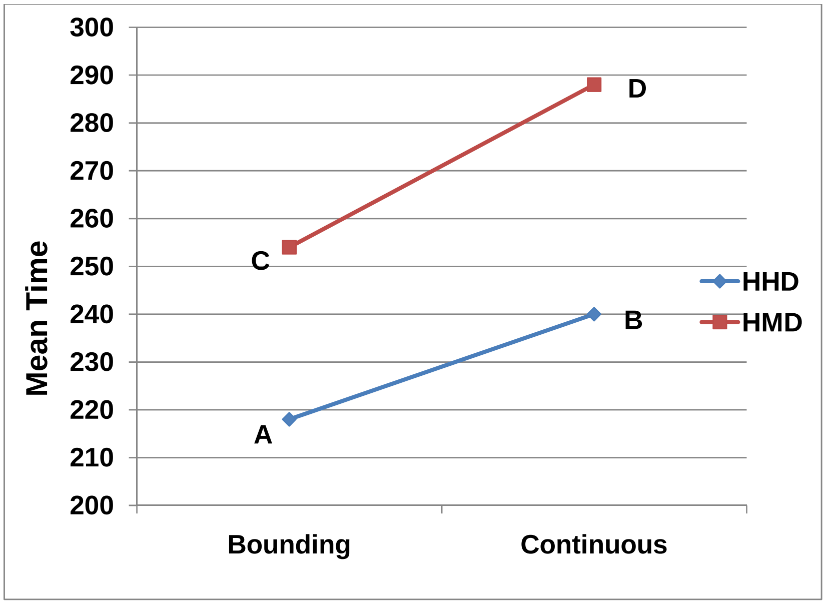

Figure 11. Mean course completion times (seconds).

Driving and Off Course Errors

The mean number of driving errors for each condition is shown in table 3 and figure 12. A 2 × 2 ANOVA indicates that there was a significant main effect for display [$F(1,34) = 5.00$, $p = 0.032$, $\eta^2_p = 0.128$] and for movement [$F(1,34) = 4.63$, $p = 0.039$, $\eta^2_p = 0.120$]. The display × movement interaction was not statistically significant [$F < 1.00$].

Table 3. Mean driving errors.

Condition	Display	Technique	Mean	SD
A	HHD	Bounding	1.89	2.61
B	HHD	Continuous	2.71	2.97
C	HMD	Bounding	3.00	3.06
D	HMD	Continuous	3.74	3.88

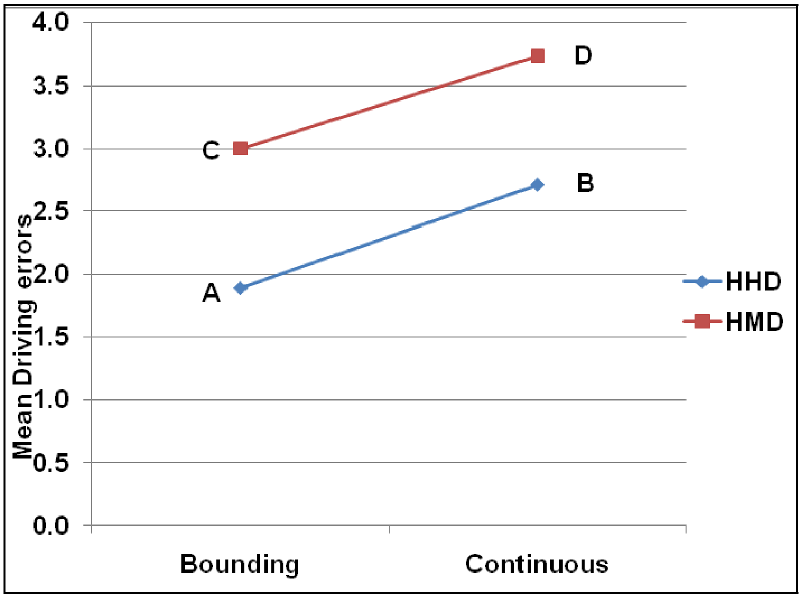

Figure 12. Mean driving errors.

Table 4 and figure 13 show the mean number of times the robot was driven off course in each of the display-movement conditions. Both of the main effects for display [$F(1,34) = 15.6$, $p < 0.001$, $\eta^2_p = 0.315$] and movement [$F(1,34) = 4.30$, $p = .046$, $\eta^2_p = 0.112$] were statistically significant. The display × movement interaction was not statistically significant [$F < 1.00$].

Table 4. Mean number of times off course.

Condition	Display	Technique	Mean	SD
A	HHD	Bounding	2.14	2.43
B	HHD	Continuous	3.31	3.52
C	HMD	Bounding	4.66	4.53
D	HMD	Continuous	5.34	3.61

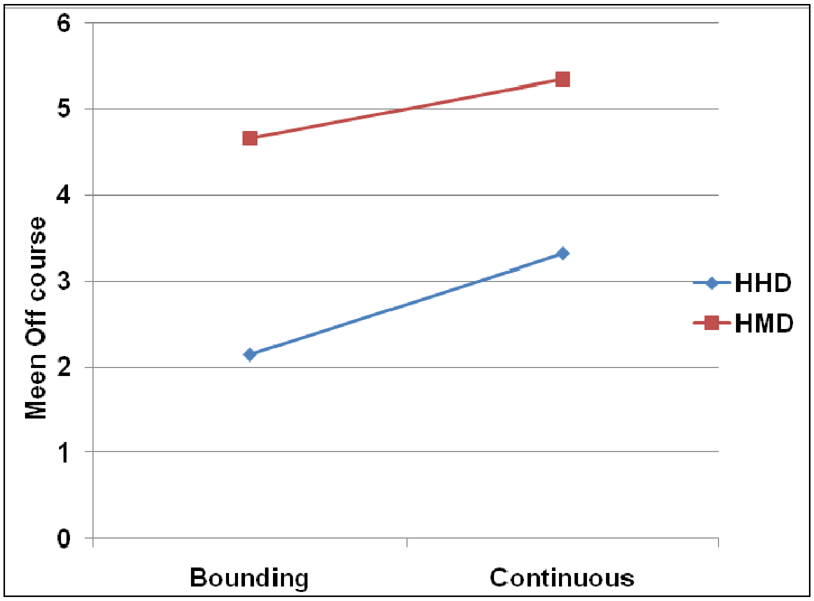

Figure 13. Mean number of times off course.

Robotic Target Detection

The means for the target detection measure (number of items and enemy personnel detected) are shown in table 5 and figure 14. There was no significant main effect for display [$F < 1.00$]. The main effect for movement was statistically significant [$F(1,34) = 4.43$, $p = 0.043$, $\eta^2_p = 0.115$]. The display × movement interaction was not significant [$F < 1.00$].

Table 5. Mean number of items detected.

Condition	Display	Technique	Mean	SD
A	HHD	Bounding	1.63	1.19
B	HHD	Continuous	1.14	1.06
C	HMD	Bounding	1.54	1.09
D	HMD	Continuous	1.31	1.25

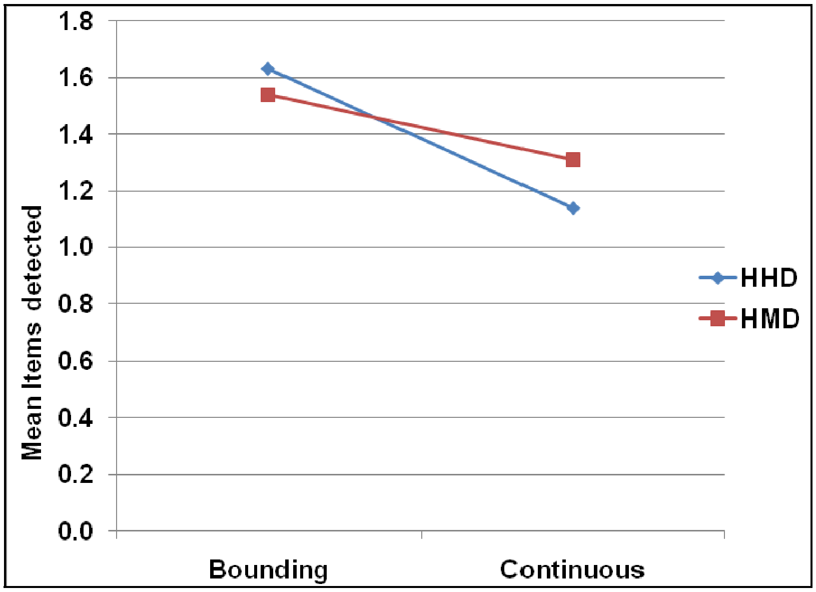

Figure 14. Mean number of items detected.

Stops During Continuous Movement

Two of the dependent variables, number of times that the robot stopped and total time stopped, apply only to the continuous movement conditions. These measurements were an indication of the effect the display configuration had on the ability of the Soldier to continue movement while using the display. More frequent stops and longer stops indicate that the display configuration is adversely affecting the ability of the Soldier to continue movement. The mean number of times stopped for the two display conditions is shown in table 6. A paired samples *t*-test indicates that there was no significant difference between the means: $t(df=34) = 0.17$, $p = 0.864$, $d = 0.04$. Note: Cohen's *d* is an index of effect size, the difference between the means divided by the pooled standard deviation.

Table 6. Mean number of times stopped.

Display	Mean	SD
HHD	4.94	5.27
HMD	5.11	4.29

Table 7 shows the average time stopped with the two display conditions. This time is an accumulation of the running times from each stop. There was no significant difference between the means: $t(df=34) = 0.99$, $p = 0.331$, $d = 0.25$.

Table 7. Total time stopped.

Display	Mean (s)	SD (s)
HHD	28.3	51.4
HMD	41.8	76.2

The distribution of amount of time stopped on the course was highly skewed; most participants stopped for 30 s or less, but a few stopped for several minutes. The time stopped data were transformed to logarithms to obtain a better approximation of normality (Winer, Brown, and Michels, 1991). There was no significant difference between the two display conditions for the transformed data ($t < 1.00$).

Soldiers had to stop frequently and for long periods of time with both display configurations. In effect, many of the Soldiers were unwittingly turning the continuous movement into a bounding movement because they were unable to teleoperate the robot while walking.

3.3.2 Subjective Soldier Data

Post iteration Questionnaire Results

Soldiers rated their abilities to maintain SA of their surroundings highest with the HHD and bounding movement and lowest with the HMD and continuous movement. One Soldier commented that with the HHD, he was able to look around at his surroundings while driving the robot. Another commented that the HMD impeded his SA during continuous movement and blocked him from seeing objects on the ground. Several indicated that they were more aware of their surroundings when they were moving with the bounding technique because they could concentrate on their immediate area as they moved to the next transition point.

Soldiers rated their abilities to move tactically the highest with the HHD and bounding technique and the lowest with the HMD and continuous movement technique. Many Soldiers commented that it was easier to maneuver the robot while they were stationary than while they were moving. One Soldier commented that he had to close one eye to use the HMD and that this made the continuous movement impossible.

There were a total of 23 complaints of eyestrain reported with HMD use and only 4 with HHD use. There were also twice as many complaints of disorientation with HMD use as there were with HHD use. Soldiers complained of competition between their eyes when the HMD was worn and rated the comfort of using the HMD lower than they did that of the HHD. Despite the modified sunshields on both displays, there were still several complaints concerning glare with both displays. However, there were more complaints with the HHD (12 complaints of glare with the HHD on the post iteration questionnaire versus 3 complaints with the HMD). Ratings of the effect of glare on the displays were 3.59 for the HHD and 4.13 for the HMD.

The Soldiers who wore eyeglasses were unable to wear their glasses while using the HMD. There were also numerous comments when the HMD was worn concerning fogging, competition between the two eyes, and display movement causing Soldiers to have to hold the display steady with one hand.

Detailed results from the post iteration questionnaire can be found in appendix C.

Motion Sickness Assessment Questionnaire

Results of the MSAQ indicate that the experiment Soldiers experienced very little, if any, of the symptoms of motion sickness during this experiment. The MSAQ ratings are shown in appendix D.

NASA-TLX

Thirty-three of the 35 participants completed the NASA-TLX inventory after each of the four experimental iterations.

Table 8 and figure 15 show the total workload means for the NASA-TLX for the conditions. The main effect for display was statistically significant [$F(1,32) = 20.2$, $p < 0.001$, $\eta^2_p = 0.387$]. The movement main effect was not statistically significant [$F(1,323) = 3.16$, $p = 0.085$, $\eta^2_p = 0.090$]. The display × movement interaction was not statistically significant [F) < 1.00].

Table 8. NASA-TLX total workload means.

Condition	Mean	SD
A. HHD/Bounding	39.1	16.3
B. HHD/Continuous	41.2	18.2
C. HMD/Bounding	45.4	21.1
D. HMD/Continuous	49.9	19.8

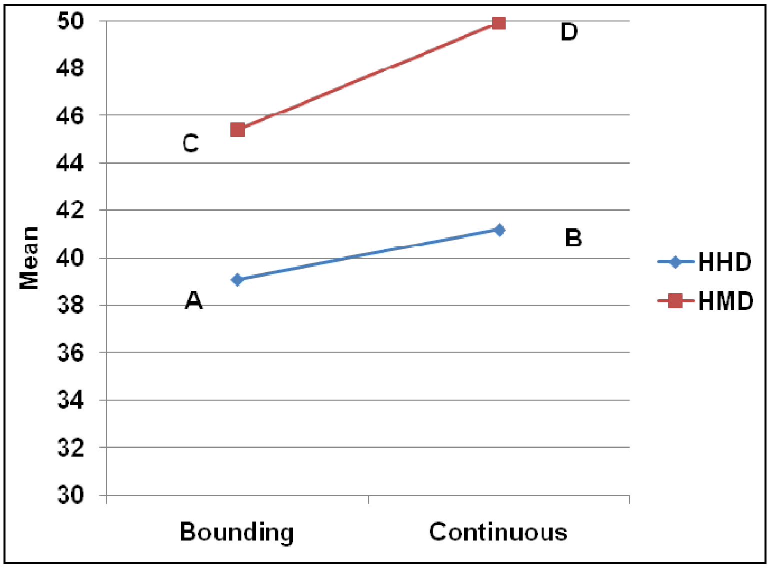

Figure 15. NASA-TLX mean workload scores.

The means for the NASA-TLX subscales for each display type are shown in figure 16 and table 9. With the exception of the Physical scale, the HMD had a higher mean rating than the HHD on all the scales.

Table 9. NASA-TLX scale means.

Scale	HHD		HMD	
	Mean	SD	Mean	SD
Mental	9.74	7.46	11.19	7.75
Physical	3.20	2.98	2.94	3.28
Temporal	7.11	5.95	8.43	6.79
Performance	8.01	5.72	8.87	4.79
Effort	8.94	6.48	9.91	6.00
Frustration	3.72	6.32	6.40	7.25

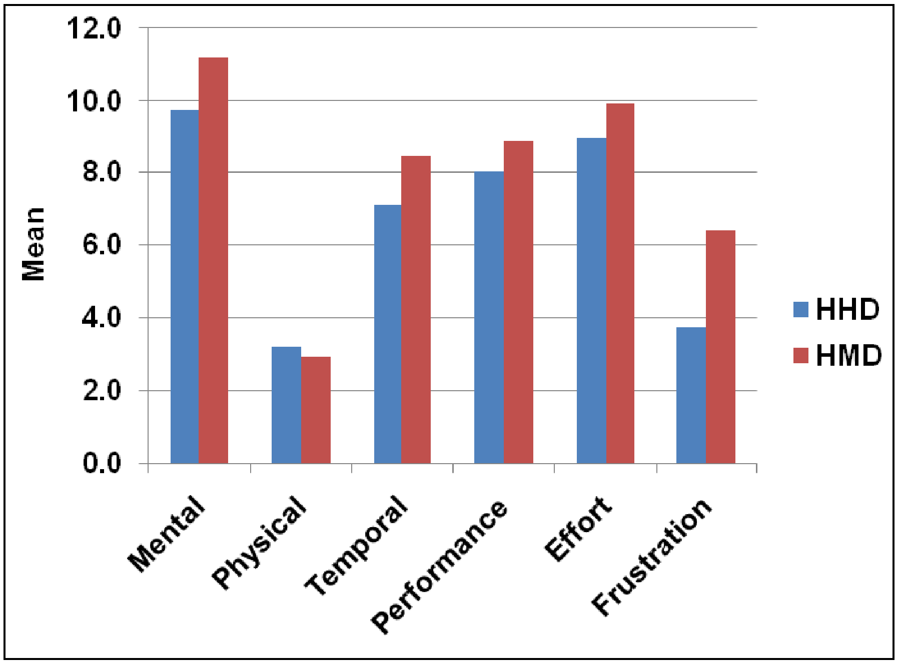

Figure 16. NASA TLX subscale means.

End of Experiment Questionnaire

Soldiers preferred the HHD to the HMD and the bounding technique to the continuous movement technique for the same reasons they listed in the post iteration questionnaires.

Soldiers suggested several improvements for the displays. They suggested a better system for preventing glare or washout with the HHD. Several suggested adding a better sunshield and two suggested that instead of a display that is held flat when using the controls, it would be better to have one that tilts or one that is placed at a 45° angle so the sun does not shine directly on it. For the HMD, they suggested a better mounting system was needed. Problems were experienced with instability, lack of compatibility with glasses, and with distance from the eye.

Detailed results from the end of experiment questionnaire can be found in appendix C.

4. Discussion

4.1 HHD

The experiment results pertaining to the issues associated with the use of HHDs in the literature are as follows:

- Several Soldiers commented that during continuous movement, the requirement to look at the screen of their HHD seriously compromised their SA of their surroundings.
- The screen of the HHD was difficult to see in the sun because of glare (even after the sunshield was added).
- There were only a couple of negative comments concerning the resolution and small size of the HHD.
- Concern was expressed about the fact that the HHD required the use of the hands.

The findings of this experiment supported the findings of Redden et al. (2008a) that smaller display sizes (in this case, a display with a 6.5-in diagonal) are sufficient for teleoperation, which includes detection of objects within the path of the robot that may impede movement. It is important to note that this finding pertains to the display for the driving camera only and is not generalizable to displays for other camera types. For example, wider fields of view and magnification may be needed for other missions, such as a scout mission when the objective is to search for targets outside the path of the robot. This could drive the requirement for higher resolution and a larger screen size for display of that camera's picture and this issue needs to be explored.

4.2 HMD

The experiment results pertaining to the perceptual issues associated with the used of HMDs in the literature are as follows:

- Brightness and contrast were a problem when the HMD was used in the bright sunlight. The addition of an "eyecup" helped, but did not completely alleviate the problem.
- Accommodation-vergence synergy and accommodation-vergence mismatch were not reported as such. However, since this mismatch is frequently reported with HMD use and can create eyestrain or visual discomfort, it may have been the reason for the high number of reported eyestrain incidences.

- The restricted field of view created by wearing the HMD over one eye impaired walking performance during continuous movement and the Soldiers' ability to see objects in their environments.
- Binocular rivalry occurred and created competition between the eyes such that one eye inhibited the visual processing of the other eye. The views delivered to the two eyes were very different with the monocular HMD and many Soldiers reported that they had to close the other eye in order to avoid losing focus.
- Eyestrain and blurry vision were a problem and occurred considerably more often with the HMD than with the HHD.
- As HMD wearers moved their heads, displayed objects in front continued to be in front and this was unnatural. Many wearers tried to turn their heads to see objects outside of the camera's field of view.
- Motion sickness was not reported as a problem with the HMD during this experiment.

Other problems reported with the HMD included the following:

- Occlusion of the full field of view
- Fogging due to weather
- Reduction in wearer SA
- Reduction in movement speeds
- Instability of the HMD mount
- Incompatibility of the HMD with eyeglasses
- Inability to place the HMD at the desired distance from the eye

Soldiers performed significantly worse with the HMD than they did with the HHD on course completion times, driving errors, and the number of times they drove off course. The Soldiers also preferred the HHD to the HMD and rated the workload with the HHD lower. These findings are similar to the findings of Redden et al. (2008a). Redden and her colleagues found that Soldiers completed a leg of their driving course significantly slower with the HMD than they did with the PDA-sized HHD and there was a trend for the Soldiers to perform worse with the HMD on every performance measure.

4.3 Bounding Movement Technique

The bounding movement technique was the preferred movement technique and Soldiers performed best with this technique. Soldiers reported that they were able to teleoperate the robot more efficiently when they were stationary and that they were also able to attend to the environment and find targets more efficiently when they were walking and not having to teleoperate the robot. Thus, their SA of the robot and their SA of their surroundings was better when the bounding movement technique was used.

4.4 Continuous Movement Technique

Soldiers reported that the HMD blocked their view of their surroundings while moving and trying to teleoperate the robot. They also overwhelmingly felt that the continuous movement technique with either display reduced their efficiency of movement and their SA of their surroundings. Movement during robotic control is somewhat analogous to control of multiple robots and appears to require at least a semi-autonomous robot before it will be a realistic technique option. Performance degradation during the continuous movement technique generally came from two sources: event time-line conflicts and attentional limitations. Simultaneous conflicts between requirements for focused attention frequently arose as Soldiers negotiated obstacles themselves while trying to negotiate other obstacles with the robot. Teleoperation alone requires a great deal of operator attention because remote perception is essential and extremely challenging, creating such problems as scale ambiguity, viewpoint mismatch, and lack of motion feedback. (Chen, Haas, Pillalamarri, and Jacobson, 2006). Other problems created by teleoperation include limited view, degraded depth perception, degraded video image, and time delay (latency) (Chen et al., 2006). The camera latencies experienced in this experiment were a continuous source of frustration to the experiment Soldiers and were attributed by the Soldiers to several driving errors and slow task performance. While many of these problems were present when Soldiers operated the robot using the bounding movement technique, they appeared to affect performance more severely during continuous movement because attention was more limited and workload was higher.

5. Conclusions

The Soldiers performed better with the HHD than they did with the HMD used in this experiment. Their course completion times, driving errors, and the number of times they drove off course were all lower with the HHD. The Soldiers also preferred the HHD to the HMD and rated the workload with the HHD lower.

Soldiers preferred the bounding technique to the continuous movement technique. Fewer driving and off course errors were made and more items were detected with the bounding technique than with the continuous movement technique. Until robots become more autonomous in their navigation, robotic control during Soldier movement is beyond the multitasking ability of most Soldiers. As reliable autonomy in robots increases and allows the robot to continue productive movement without human intervention, Soldiers should have more available free time to divert their attention away from the robot and toward their route of movement and their own environment, enabling side-by-side movement.

6. Recommendations

Dixon, Wickens, and Chang (2003) indicate that teleoperation creates a higher workload for the robotic operator than operation of autonomous robots. If simultaneous and close movement of robots with Soldiers is desired, it appears robots will require at least some level of autonomy. However, even with autonomous operation, workload reduction is dependent upon the reliability of the autonomous system (Dixon and Wickens, 2004).

7. References

Air Assault Expeditionary Force (AAEF) Tactics, Techniques and Procedures (TTP) for the Spiral D Experiment; Soldier Battle Laboratory: Fort Benning, GA, 2008.

Army Field Manual FM 3-90 (Tactics), U.S. Army, Washington, DC, 4 July 2001.

Bondi, A. B. Characteristics of Scalability and Their Impact on Performance. *Proceedings of the 2nd International Workshop on Software and Performance*, Ottawa: Ontario, Canada, 2000, pp 195–203.

Chen, J.Y.C.; Hass, E. C.; Pillalamarri, K.; Jacobson, C. N. *Human-Robot Interface: Issues in Operator Performance, Interface Design, and Technologies*; ARL-TR-3834; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2006.

Cobb, S.V.G. Measurement of Postural Instability Before and After Immersion in a Virtual Environment. *Applied Ergonomics* **1999**, *30*, 47–57.

Cobb, S.; Nichols, S. Static Posture Tests for the Assessment of Postural Instability After Virtual Environment Use. *Brain Research Bulletin* **1998**, *47*, 459–464.

Dixon, S. R.; Wickens, C. D. Automation Reliability in Unmanned Aerial Vehicle Flight Control. *Proceedings of Human Performance, Situational Awareness and Automation conference*, Lawrence Erlbaum: Mahwah, NJ, 2004, pp 205–209.

Dixon, S. R.; Wickens, C. D.; Chang, D. Comparing Quantitative Model Predictions to Experimental Data in Multiple-UAV Flight Control. *Proceeding of the Human Factors and Ergonomics Society 47th Annual Meeting*; Santa Monica, CA, 2003, pp 104–108.

Draper, M.; Viirre, E. S.; Furness, T. A.; Gawron, V. Effects of Image Scale and System Time Delay on Simulator Sickness Within Head-Coupled Virtual Environments. *Human Factors* **2001**, *43*, 129–146.

Elliott, L. R.; Duistermaat, M.; Redden, E.; van Erp, J. *Multimodal Guidance for Land Navigation*; ARL-TR-4295; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Glumm, M.; Marshak, W.; Branscome, T.; Wesler, M.; Patton, D.; Mullins, L. *A Comparison of Soldier Performance Using Current Land Navigation Equipment With Information Integrated on a Helmet-Mounted Display*; ARL-TR-1604; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1998.

Gianaros, P. J.; Muth, E. R.; Mordkoff, J. T.; Levine, M. E.; Stern, R. M. A Questionnaire for the Assessment of the Multiple Dimensions of Motion Sickness. *Aviation, Space, and Environmental Medicine* **2001**, *72*, 115–119.

Hart, S. G.; Staveland, L. E. Development of NASA-TLX (Task Load Indices): Results of Empirical and Theoretical Research. In Hancock, P. A., Meshkati N., Eds., Human Mental Workload: Amsterdam: North-Holland, 1988; pp 139–183.

Holm, S. A Simple Sequentially Rejective Multiple Test Procedure. *Scandinavian Journal of Statistics* **1979**, (6), 65–70.

Knight, J.; Baber, C. Effect of Head-Mounted Displays on Posture. *Human Factors* **2007**, *49*, 797–807.

Krupenia, S. Sanderson, P. M. Does a Head-Mounted Display Worsen Inattentional Blindness? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *5*, 2007, pp 1638–1642.

McCann, R. S.; Foyle, D. C.; Johnston, J. C. Attentional Limitations With Head-Up Displays, Jensen R. S., Ed. In *Proceedings of the Seventh International Symposium on Aviation Psychology*, Ohio State University: Columbus, OH, 1993, 70–75.

Merhi, O.; Fauugloire, E.; Flanagan, M.; Stoffregen, T. A. Motion Sickness, Console Video Games, and Head-Mounted Displays. *Human Factors* **2007**, *49*, 920–934.

National Research Council. *Tactical Display for Soldiers: Human Factors Considerations*, National Academy Press: Washington, DC, 1997.

Patterson, R.; Winterbottom, M. D.; Pierce, B. J. Perceptual Issues in the Use of Head-Mounted Visual Displays. *Human Factors* **2006**, *48*, 555–573.

Pettitt, R. A.; Redden, E. S.; Carstens, C. B. *Scalability of Robotic Controllers: An Evaluation of Alternatives*; ARL-TR-4457; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2008.

Redden, E. S.; Pettitt, R. A.; Carstens, C. B.; Elliott, L. R. *Scalability of Robotic Displays: Display Size Investigation*; ARL-TR-4456; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2008a.

Redden, E. S.; Pettitt, R. A.; Carstens, C. B.; Elliott, L. R. *Scaling Robotic Displays: Visual and Multimodal Options for Navigation by Dismounted Soldiers*; ARL-TR-4708; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2008b.

Scribner, D.; Wiley, P.; Harper, W.; Kelley, T. *The Effects of Workload Presented via Visual and Auditory Displays on Soldier Shooting and Secondary Task Performance*; ARL-TR-4224; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Sheedy, J.; Bergstrom, N. Performance and Comfort on Near-Eye Computer Displays. *Optometry and Vision Science* **2002**, *79*, 306–312.

Sutherland, I. A Head-Mounted Three-Dimensional Display. *Proceedings Fall Joint Computer Conference*, AFIPS, *33*, 1968, 757–764.

Turner, D. D.; Carstens, C. B. Future Force Warrior: *Insights from Air Assault Expeditionary Force Assessment*; ARL-TR-4191; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Williams, E. J. Experimental Designs Balanced for the Estimation of Residual Effects of Treatments. Australian *J. Phys. Sci.* **1949**, *A2*, 149–168.

Winer, B. J.; Brown, D. R.; Michels, K. M. Statistical Principles in Experimental Design. McGraw-Hill: New York, 1991.

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Appendix A. Demographics

This appendix appears in its original form, without editorial change.

APPENDIX A

DEMOGRAPHICS

SAMPLE SIZE = 36

MOS

09S	- 7	88H	- 1
11B	- 2	92Y	- 1
21B	- 10	96B	- 1
21C	- 9	OCS	- 1
35F	- 1	NR	- 3

RANK

E2	- 2
E3	- 5
E4	- 18
E5	- 8
E6	- 1
Officer	- 1
NR	- 1

1. What is your age? 26 years (mean) – 19-37 range

2. With which hand do you most often write? Right – 30 Left – 4 NR – 2

3. With which hand do you most often fire a weapon? Right – 31 Left – 4 NR – 1

4. Do you wear prescription lenses? Yes – 14 No – 22

5. If Yes, which do you most often wear? Glasses - 10 Contacts – 3

6. Which is your dominant eye? Right – 28 Left – 8

7. How many months in military? 45 (mean)

8. Using the scale below, please rate your skill level for each of the following activities.

None	**Beginner**	**Intermediate**	**Expert**
1	**2**	**3**	**4**

	MEAN RESPONSE
Land navigation	2.71
Operating ground unmanned vehicles	1.94
Operating unmanned aerial vehicles	1.29
Target detection and identification	2.26

Appendix B. Training

This appendix appears in its original form, without editorial change.

APPENDIX B

TRAINING

SAMPLE SIZE = 36

1. Using the scale below, please rate the training that you received in the following areas:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

	MEAN RESPONSE
How to drive the robot	5.69
Time provided to practice driving the robot	5.18
How to negotiate the robotic course	5.29
How to complete the movement to the objective	5.51
How to use the HMD	5.29
How to use the HHD	5.62
Evaluation of the practice lane	5.29
How to employ the bounding movement technique	5.54
How to employ the continuous movement technique	5.49
How well you expect to perform on the actual course	5.06
Overall evaluation of the training course	5.71

2. What were the easiest training tasks to learn?

Comments	Responses
Movement techniques.	2
Bounding movements with the iRobot.	1
Bounding with the handheld display.	2
Bounding. These were two separate tasks. Running to a point, then driving the robot were the easiest to learn and perform adequately.	1
Using the handheld controllers to operate the robot	2
How to control the robot.	3
Simple robot movements while remaining stationary.	2
I think that the easiest things to learn were to drive while standing still. I think it was easier to learn with the handheld than the mounted.	1
The basic controls and use of the HHD.	1
Driving the robot with the HHD.	7
Learning how to use the HHD.	2
Learning the speed of the robot.	1
Moving the robot left/right.	1
Forward and reverse.	3

Comments	Responses
Handling the robot at higher speeds via the display	1
Identifying obstacles and objects in the path of the robot.	1
I really felt as though with the training and hands-on provided that all tasks were very easy to learn.	1

3. What were the hardest training tasks to learn?

If I had to pick out a difficulty, I would have to say that the lag time in the display makes the tasks harder; however I'm really reaching for a negative there because the tasks were very easy.	1
Adapting to the camera and robot delay and maneuvering the robot via joystick was a bit difficult.	1
It was difficult to learn the HMD display. This was largely due to a connection problem which was slow for download of feed as well as obtaining the movement of the robot.	1
Moving the iRobot while continuously moving.	1
Moving continuously with the HMD.	3
The HMD moving because you had to hold the eyepiece and control it.	1
Using the HMD to view where you are going with the robot because of the difficulty focusing on the display while you are moving and trying to watch where you are going.	1
Bounding with the HMD.	1
Using the HMD - all tasks.	5
Driving the robot with the HMD.	3
I found that it was harder to learn with the HMD versus the HHD and it was also more difficult to not look at the robot when using the HMD display.	1
Learning to drive the HMD while keeping both eyes open.	1
Manipulating the HMD and the controls at the same time.	1
Complex turns and obstacle negotiation along with target identification while moving.	1
Maneuvering the robot, particularly using the head gear.	1
Moving the robot in reverse and right/left reverse.	1
Being able to back up and turn when you run into something.	1
Having the robot make tight turns.	1
Turning the robot.	1
Turning and walking while operating the robot.	1
Navigating from covered to sun exposed areas due to glare.	2
Navigating the robot through narrow corridors.	1
Some of the driving.	1
What was on the screen was closer as it seems.	1

4. What are your comments on the training course?

Comments	Responses
Great training course.	2
It was a good challenging course.	1
The training was awesome; it's good to work with new things.	1
It was fun!!!	2
The training was excellent, but I think that you should factor in the dominant hand in addition to the eye	1
A device that has been manufactured, rather than rigged, might assist with the use of the HMD.	1
A little more time to practice with the robots would have been helpful before hitting the actual course or perhaps a practice run on the course before taking the test.	1
Good course but the trail was kind of difficult to decipher.	1
I think personnel should have a little longer duration to learn how to drive the robot.	2
Incorporate objects to find so user can have examples of what to look for or so user can get trained on what the objects will look like in the camera	1
It was difficult to learn how to use the robot due to the latency.	1
Longer course with a greater various terrain types.	1
The boundaries were hard to see at some point, and I was not sure which direction to take.	1
The course is difficult to navigate in the morning when there is moisture on the grass. The light reflecting off the grass makes it hard to see the engineer tape on the ground. The screen on the display whites out as you are coming out of the tunnel which makes you have to slow or stop until it balances out. The HMD needs to be longer or larger all around to make it easier to focus your eye on the display when you are moving. It also needs something to block sun light from shinning into your eye.	1
The drawback to the training was the "glitches" in the display or the frame rates.	1
The HHD bound was easy because you stood there and moved the robot.	1
Both HMD and HHD were very easy to work with; it will be hard to pick one as the best.	1
This will be very useful for clearing procedures if the HMD were more user friendly.	1
The HHD is just too bulky and it would be difficult to fight with both hands on the monitor.	1
While using the dominant eye is fine in a purely training environment, soldiers need to use the robot with their non-firing eye to facilitate robot operation while carrying a firearm	1

Appendix C. Post Iteration

This appendix appears in its original form, without editorial change.

APPENDIX C

POST ITERATION

SAMPLE SIZE = 36

1. Using the scale below, please rate your ability to perform each of the following **tasks** based on your experience with the display and technique that you just used:

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE			
Condition	**A***	**B***	**C***	**D***
Move the robot in the correct direction	5.26	5.44	4.83	4.40
Avoid obstacles	5.15	5.09	4.49	4.09
Avoid pot holes	4.86	4.86	4.47	3.81
Assess down slopes for navigatability	4.84	4.68	4.66	3.97
Assess side slopes for navigatability	4.68	4.79	4.43	3.89
Identify any other terrain features that might have an adverse effect on the ability of the robot to maneuver through the terrain	4.79	4.91	4.44	3.97
Perform your IMT	5.19	5.04	4.69	4.04
Drive the robot while in a stationary position	5.91	5.58	5.47	4.92
Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	5.00	4.94	4.64	4.26
Anticipate whether the turn radius of the vehicle will allow a turn	4.80	4.97	4.75	4.00
Identify if the robot is on the correct path	5.09	5.29	4.86	4.25
Identify if you are on the correct path	5.46	5.33	4.97	4.54
Navigate far enough ahead to plan route in advance	5.03	4.76	4.91	4.29
Navigate well enough to drive at slowest speeds	5.61	5.74	5.47	5.21
Navigate well enough to drive at medium speeds	5.26	5.37	5.27	4.72
Navigate well enough to drive at fastest speeds	4.60	4.63	4.49	3.77
Finish the course quickly	5.21	5.43	4.86	4.26
Cross a danger area effectively	5.10	5.00	4.84	4.35
Cross a danger area quickly	5.10	5.17	4.71	4.33
Navigate the robot across a danger area	5.40	5.13	4.84	4.40
Ability to maintain situation awareness with this display and technique	4.89	4.58	4.44	3.58
Overall ability to perform the course with this display and technique	5.24	5.25	4.74	4.22
Overall ability to move tactically to the objective with this display and technique	5.29	4.80	4.74	3.97

***A – HHD/bounding; B – HHD/continuous; C – HMD/bounding; D – HMD/continuous**
(Key applies throughout document)

Comments	Responses
A– HHD/bounding	
This was the easiest and most rewarding trial.	1
Robot is very easy to work with.	1
Screen is clear and easy to maneuver.	1
Larger screen allows for greater clarity for seeing upcoming objects.	1
This screen was much easier for me to use and focus on. Having both eyes on the screen helped me to visualize my path better and maintain my orientation.	1
Being stationary while moving the robot allows for a greater speed being implemented to complete the mission.	1
Bounding allowed for more time to concentrate on maneuvering the robot because of being in a stationary position.	2
Bounding is much easier than continuous movement. More difficult to maintain situational awareness while both operator and robot are continuously moving.	1
Having the pack on your back was good and I liked how it was tight against your body so that it wouldn’t flop all around.	1
With HHD it seems a bit less tactical for situational awareness outside the display because we are focused more on the display.	1
Poor quality of picture meant that I identified few of the objects placed on the course.	1
Coming out of a shadowed area into bright light causes the camera to white out momentarily. I had to stop the robot until the light balance adjusted.	1
Sunlight impairs screen sight.	1
The display suffers a lot of glare from sunlight, unless the operator holds it directly up to his/her face (difficult when walking with robot, but less so when stationary), in which case the picture clarity can become sharper than the HMD.	1
B-HHD/continuous	
Controller comfort aside, was very easy to use.	2
Good clarity.	2
It was easier to maneuver today compared to yesterday. There was minimal lag today compared to yesterday.	1
It is ok, however would be nice to have a remote that is geared for someone who's right handed.	1
Fast paced, low visibility depending on terrain.	1
While the bounding technique is more comfortable for me with either device, I prefer the HHD. I performed better with both bounding and continuous movement using this device. For soldiers it is important to maintain situational awareness at all times and the handheld gives us more mobility to assess our surroundings while driving the robot at the same time.	1

Comments	**Responses**
It becomes disorienting maneuvering the robot on a different plane as me because of peripheral and video feed views.	1
Was able to negotiate the course with the robot, but meandered off the path on foot and had difficulty focusing on anything but following the robot, and had I not had the guide, I would have veered off course while guiding my robot.	1
Had to keep both eyes on the screen so I couldn't see what was going on around me.	1
Situational awareness minimal pace man a must to navigate course while maintaining consistent speed.	1
Having most difficulty identifying "IED" type objects from the display.	1
Once again, glare from sunlight severely impeded the effectiveness of the display -- more so than the HMD device.	1
With sun light it is very hard to see the screen, Also the control is very big and hard to handle.	1
Driving controls should be allowed to switch between left and right handed operators.	1
It was hard because the picture on the hand mount would lag	1
C– HMD/bounding	
Easier to manipulate robot while stationary, i.e., bounding technique.	1
Easier to use HMD when bounding because I could rest and focus my vision on the display, and concentrate on moving the robot.	1
Bounding worked very well for me. I experienced very little loss of clarity from sunlight; bounding, then controlling the robot while stationary proved effective.	1
Much easier to move the robot while you are stationary. Bounding makes it easier to observe your own surroundings while moving, as well as makes it easier to effectively control and make observations while you are moving the robot.	1
Task was easy due to the ability to switch eyes when switching tasks.	1
I found this easier than I thought, but I ended up having to hold my eyepiece with my right and use the joystick with my left. This may have been due to the fact that I needed to adjust it more, but I think it did affect my overall performance.	1
Every time that I stopped, I had to readjust the display on my head. While moving I had to hold the display with my right hand so I would be steady and close enough to my eye to avoid eye strain. Also in order to move the robot quickly, I had to close my left eye to avoid losing focus and depth perception in my right eye.	1
I found it hard to always see the white engineer tape.	1
I had to keep one eye closed at all times otherwise I couldn’t see the path correctly.	1

Comments	Responses
Level of difficulty was primarily experienced as I had to navigate w/o my glasses as the head gear was uncooperative.	1
Not able to see when you are in the dark going into the light.	
Screen needs to be bigger than an inch cordless screen mount. Needs to be in night vision.	1
Head mount needs to be strapped better to your head.	1
It was very doable; but there is much room for improvement. The delay was bad, but doable.	1
There was a good amount of lag when the course started but got better as I progressed.	1
D – HMD/continuous	
After driving four times, getting the feel of the remote is easier plus this time there was no lag in the connection between receiving pictures or giving directions which made maneuvering the course easier.	1
It was difficult to multi-task while keeping one eye closed to view the display, but keeping both eyes open was more difficult.	1
From this display I wanted to close the non-dominate eye to more closely watch what I was doing with the robot. I believe the helmet mounted display is best... However in a perfect world, the "robot" view would be superimposed over my regular view to allow me to retain all of my peripheral vision. Also, the camera lens limits the peripheral "vision" of the robot.	1
It is difficult to focus on the head display and still have peripheral. My eyes were severely competing with each other, but it may be due to the fact that the headgear was a prototype and was fitting completely properly.	1
Wearing glasses and having poor vision, I was unable to get the display over my glasses and had to navigate without them. Was able to see the screen fine, but couldn't see where I was going myself very well. Also feel the control of the robot would be vastly increased by giving independent control over each track for tight turns, and better control.	1
The HMD fogs up when you start to sweat because of the heat. The screen could be just a little bit larger so your eyes are not straining to adjust and focus on a small screen. If the eye piece could be moved closer or the peripheral vision of the eye that you are using could be minimized by using a larger cover it would help reduce eye fatigue.	1
I had a lot of difficulty with this movement. When I did the bounding exercise with the HMD I felt really comfortable. I was able to close one eye while I focused on the robots movement. With continuous movement and having to keep both eyes open, I felt extremely disoriented and unable to perform the task comfortably.	1
Better than the handheld, but still distracting and difficult to move personally while operating the robot.	1
It was difficult to keep my navigation on the robot, while trying to navigate my walk.	1

Comments	**Responses**
Very difficult to move constantly and while looking for threats and keeping the robot on course.	1
The glare on the display made it hard to see sometimes.	1
The head display cannot stay stationary while moving.	1
Tunnel still bright; when you come out you can't see very well.	1
The display feed from the camera makes it difficult to identify objects and obstacles in your path until the robot is right on top of it. The camera angle makes it difficult to recognize and navigate slopes, particularly descents.	1
It was kind of hard to work with the delay of the iRobot.	1
I find that the HMD is more difficult because it has to be held while operating with one hand.	1

2. Using the scale below, please rate your ability to perform each of the following **continuous movement tasks** based on your experience with the display and technique that you just used:

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE	
	HHD	**HMD**
Drive the robot while you are performing tunnel maneuver	5.92	5.39
Drive the robot while you are performing the low crawl	4.25	5.00
Drive the robot while you are negotiating the hill	6.00	5.00
Drive the robot while you are climbing the stairs	4.67	5.00
Drive the robot while you are walking	5.70	5.27

HMD	
It was fairly doable.	1
When you're looking through the lens, it's not tight enough on my head.	1
HHD	
Found bounding to be better for control of the robot, as well as being able to observer your surroundings.	1

3. Please check any of the following conditions that you may have experienced during this trial.

Condition	NUMBER OF RESPONSES			
	A	B	C	D
Eyestrain	3	1	10	13
Tunnel vision	3	4	2	4
Headaches	0	0	0	0
Motion sickness	0	0	0	0
Nausea	0	0	0	0
Disorientation	3	4	7	7
Dizziness	0	0	0	0
Competition between eyes for vision of the different scenes at which they are looking	0	2	8	10
Other	1	0	1	4

Comments	**Responses**
A – HHD/bounding	
Became winded from bounding, but it did not impact my ability to drive the robot significantly. Sweat and heat were higher in the bounding exercise, but also didn't play a major factor in driving the robot.	1
B – HHD/continuous	
It is difficult to change focus between robot and my walking path.	1
C – HMD/bounding	
Became very blurry. I couldn't tell if it was me or the equipment.	1
Eyestrain only when using the helmet mounted display. It is difficult to take a look around for yourself and look for the robot at the same time.	1
Felt like my body was still moving when I look through the lens.	1
Getting into bright areas feels like I'm getting hit by a flash bang grenade.	1
Having goggles that fit.	1
The screen kept moving so I had to adjust the screen.	1
D – HMD/continuous	
Head display is easier to carry, but lacks stability.	1
It is easy to become focused on the actions of the robot through the camera.	1
Blurred vision in the eyes with the HMD when sun light was directly in front.	1
It was only because I was trying to look at the display in my screen and the squad leader who was in front of me.	1
Keeping the eye piece steady over my eye.	1
More practical use and training with this gear consistently will help with eye adjustments.	1
Not able to wear glasses.	1
Hard to focus walking and driving robot.	1
Sweat. Severe eye strain because of having to refocus to move and to drive the robot. This led to disorientation.	1

4. Using the scale below, please rate the following characteristics of the display that you just used:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

	MEAN RESPONSE	
	HHD	**HMD**
Resolution (clarity) of the display	4.97	4.74
Size of objects appearing in the display	5.01	4.54
Ability to adjust display	4.44	3.87
Comfort of viewing the display	4.96	3.96
Display brightness	4.94	4.75
Effect of glare on the display	3.59	4.13
Contrast between objects on driving display	4.77	4.49
Display color	4.92	4.87
Comfort of wearing/carrying the display	5.01	4.33
Impact of display on speed of movement	4.76	4.39
Display fogging	5.10	4.78
The effect of the size and shape of the display on mobility of the dismounted Soldier	4.97	4.79
Adequacy of a display of this type for teleoperating a robotic vehicle	5.04	4.66
Impact of display on field of view of the unaided eye	NA	4.18
Impact of display on clarity of vision from the unaided eye	NA	4.29

Comments	**Responses**
HHD	
The joystick maneuvering was in sync with the movement of the robot, with minimal delay, so it was easier to complete the task today.	1
The screen should be changed to a type that isn't affected so badly by sunlight and could also be seen while being held in direct sunlight.	1
The HHD should be much smaller and easier to hold, as well as usability for controlling.	1
Display should be able to tilt to a 45 degree angle to allow soldier to see where he is walking while looking at the display. It would also help reduce sun glare on the screen.	1
Would like to be able to adjust light settings to see from a covered location.	1
Glare impacted maintaining positive position which slowed and or stopped forward movement.	1

Comments	Responses
Display contrast, clarity, and brightness are consistently the most hindering characteristic of the robotic device. Maintaining situational awareness is very difficult, as well.	1
This task was made difficult due to equipment malfunction. The display video was slow with delays. After the correction, the task was doable. Delays were horrific.	1
There were several delays of at least 3 seconds or more from the actual robot movement and the display.	1
Camera had significant delay in refocusing from a dark tunnel, to a brightly lit area, causing movement to temporarily halt.	1
HMD	
HMD is comfortable and effective.	1
I really like the handheld; it has a bigger display and makes it easier to see what is around.	1
The model we were using to test was not mounted very well to our heads and we had to hold it into place. Other than that it was a very good piece of equipment to use.	1
This display is small; however it does have a good picture.	1
I think that this display is small and does not sit well on the person wearing them.	1
The clarity of objects viewed in the display is relatively poor. I had no issues navigating the course [effectively], but I did have problems identifying obstacles and foreign objects.	1
Fairly uncomfortable especially for anyone who wears glasses.	1
I answered neutral for HMD as I had to wear my glasses during the course. As a result, the head gear and eye piece weren't properly aligned.	1
I couldn't use my glasses during this phase as the head gear was uncooperative.	1
The goggles are uncomfortable and the display should be a bit closer to the eye.	1
The screen needs to be adjustable so that is stays where you put it when you're stationary. I had to keep holding it close to my eye just so I could see clearly where I was going. Once I could see clearly and not lose focus in my eye, I was able to drive and react faster.	1
Kept losing focus on display. Also had to keep re-adjusting display.	1
Picture and clarity of robot perspective not as good as could be. The field of view needs to be widened to account for the tunnel vision of the user, especially if the user is in view of the robot.	1
Experienced poor video clarity change when moving from darkness to light.	1
The limited vision from the camera scope made the task difficult. The best way to improve this task is to fix the delay and provide a larger scope from the video camera.	1

5. Using the scale below, what is your **overall rating** of the display and technique combination that you used this iteration?

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

MEAN RESPONSE			
A	**B**	**C**	**D**
5.35	5.37	5.06	4.49

Comments	**Responses**
A – HHD/bounding	
Very easy to move with this device, easy to spot IEDs with this display, much better display than the head mounted display.	2
Driving the robot was easier using the bounding technique because of the time required to concentrate on using the controls and deciphering the footage.	1
Handheld was easy to use in bounding, but I found the HMD more comfortable for continuous movement	1
I prefer the handheld over the mounted piece; it was easier to see things and the feed was faster as well as the reaction to when I was giving directions.	1
Display should be able to tilt up and down to compensate for the glare on the screen from direct sun light.	1
The experience was problematic due to slow video malfunction. After correction, the task was doable. Delays and limited video focus display made the task a bit difficult. You fix these areas and it would be better in accomplishing this task.	1
The handheld control is a little awkward, and camera to screen time was a little slow.	1
B – HHD/continuous	
I think this works very well and I think that with the size of the handheld display makes it easier and clearer to see what is happening or what is in front of you.	1
The equipment was sharp today with minimal delay between joystick controls and the robot, so it was easier to maneuver the robot and complete the assigned task.	1
Difficult to use HHD while walking, using peripheral, and keeping aware of robot location.	1
Glare from the sun seems to affect the HHD more than the HMD. The operator instinctively holds the HHD down in front of them, and sunlight spills down into the display from above as a result. This problem is largely absent with the HMD.	1

Comments	Responses
I would really like to see a different type of unit used for a control once this thing is used by the soldiers. The one being used now is way too big and cannot be seen in sunlight, which is often times where it will need to be seen.	1
C – HMD/bounding	
Overall I think that the handheld has the best display.	1
Head display allows greater situational awareness, especially when actively operating the robot, and the head display is less cumbersome and easier to handle.	1
Loved it.	1
It was good, but it can be improved.	1
Bounding is probably the best way to utilize this device with a dismounted soldier.	1
The HMD provides an effective view using the bounding method; it would be more efficient if one didn't have to use their free hand to adjust the view.	1
HMD + either technique = success.	1
Screen needs to be bigger and you need to be able to block sun light from shinning in your eye from over the top of the display.	1
The head display needs to be a little more secure.	1
D – HMD/continuous	
This is a good tool. This will improve and the functional use of this product will grow.	1
Very useful thing to have around.	1
The HMD has a natural and intuitive feel to it, but I found myself shutting one eye to improve the clarity of the picture, which decreased my situational awareness somewhat.	1
After doing all of the different driving techniques I still prefer the handheld and I prefer the bounding. I found that was the easiest way to maneuver and see clearly.	1
Navigating the robot while walking was difficult, due to double navigation simultaneously. Bound navigation seemed easier to accomplish versus continuous movement navigation.	1
The downside is picture quality and clarity.	1
Did not like using the HMD. It becomes burdensome on the eyes, and I could see it leading to nausea, or vomiting if used for a lengthier period of time.	1
The display needs to be larger to reduce eye strain. Or at least longer to cover your field of view in the eye that you are using.	1
The screen is hard to see into. And the delay time made navigating the robot difficult.	1
The robot has a lot of work until it is ready for combat.	1

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Appendix D. Motion Sickness Assessment

This appendix appears in its original form, without editorial change.

APPENDIX D

MOTION SICKNESS ASSESSMENT

SAMPLE SIZE = 36

1. Using the scale below, please rate how accurately the following statements describe your current state.

1	2	3	4	5	6	7	8	9
Not at all	**<--->**							Severely

Condition	MEAN RESPONSE			
	DISPLAY HHD		DISPLAY HMD	
	A	B	C	D
I felt sick to my stomach	1.07	1.05	1.04	1.04
I felt disoriented	1.69	1.59	1.57	1.88
I felt faint-like	1.03	1.00	1.04	1.04
I felt tired/fatigued	1.37	1.23	1.22	1.08
I felt annoyed/irritated	1.93	1.36	1.39	1.60
I felt nauseated	1.07	1.00	1.09	1.04
I felt sweaty	3.00	2.27	2.35	2.44
I felt hot/warm	2.93	2.59	2.39	2.48
I felt queasy	1.03	1.05	1.09	1.08
I felt dizzy	1.03	1.00	1.09	1.04
I felt lightheaded	1.10	1.18	1.09	1.12
I felt like I was spinning	1.03	1.09	1.09	1.04
I felt drowsy	1.03	1.19	1.04	1.08
I felt as if I may vomit	1.03	1.00	1.04	1.04
I felt clammy/cold sweat	1.10	1.00	1.04	1.04
I felt uneasy	1.27	1.23	1.13	1.44

Appendix E. End of Experiment

This appendix appears in its original form, without editorial change.

APPENDIX E

END OF EXPERIMENT

SAMPLE SIZE = 36

1. Please rank order the display and technique in the order of your preference – with 1 being your favorite, 2 your second choice, etc. (The following are the numbers of times a display and technique combination was chosen over the other three possible combinations.)

Movement and technique combination	Number of time chosen as preferred
HHD and bounding movement	86
HHD and continuous movement	61
HMD and bounding movement	43
HMD and continuous movement	20

Comments	**Responses**
A-HHD and Bounding movement	
This was the best and most comfortable technique to maneuver the robot.	1
Clarity of view was much better.	1
Easiest of all 4 combinations.	3
Allows you to find cover, scout the area you will be moving through, and allows to focus almost entirely on the robot making it easier to maneuver.	1
As a person wearing glasses, was the easiest for me. Was able to see surroundings while navigating the robot at the same time.	1
I liked it a lot.	1
I prefer HHD and this technique the most.	1
It is better because there isn't a glare and the picture looks really good and being in a steady position is pretty simple.	1
That was easier because you are still when you are moving the robot.	1
The best combination. It was very easy to move both myself and the robot without making mistakes.	1
The best in my opinion. While maintaining a steady position during the bounding, I was able to focus my energy on driving the robot.	1
This was the best technique because the screen was larger which allowed the user to spot IEDs and it was easier to bound while carrying the controls for the robot versus moving with the controls on my head.	1
This was my second task. I found it easy to drive the robot using this display. It was easier for me to see what was going on the display. I found this one easier to use and to see what is going on	1

Comments	Responses
This technique is good, should also be geared toward a right handed person as well,	1
Very easy to use, but impractical when it comes to moving and fighting in combat.	1
Almost as good as HMD and continuous movement, except hands were not free.	1
Brightness was the only problem.	1
Good picture on the screen; easier to see what is ahead of you.	1
The bounding was easier than constant movement, but the HHD required both hands and both eyes to use, and eliminated any personal situational awareness.	1
Hands are now obligated to perform robot controls and weapon is maybe an afterthought.	1
It was hard when you had to bound and let the robot catch up with me.	1
Lag was only problem.	1
Only thing that bothers me is that you can't carry a rifle at the same time.	1
The screen had to be adjusted to a new angle so the glare wouldn't show on the screen.	1
If there could be a way to diminish the glare in very sunny conditions that would be beneficial.	1
I did find that the backpack was slightly heavy and bulky.	1
The stuff in there sounded loose and that it may get damaged.	1
B-HHD and Continuous movement	
The best, most preferred by me, easier to navigate.	1
It's easy!	1
I like this, and is easiest with HHD.	1
Was easier to move with the robot and less of a strain on the eyes.	1
Favorite movement technique.	1
A lot easier than HMD.	1
Besides walking while controlling the robot, was able to control and navigate with little problem.	1
I was more aware of my surroundings than when using the HMD. It wasn't difficult to walk and operate the robot.	1
It not that difficult because you are walking when you operate the robot.	1
It was easier to use the HHD while on the move because I can totally shift focus of both eyes and use my peripheral to move. The HMD would not allow this.	1

Comments	Responses
This technique was better than the HMD continuous movement, because you could focus easier on the team leader and controlling the robot at the same time.	1
This was a good technique to use if HHD bounding movement was not available. This was my second preferable setup to accomplish robot tasks.	1
This technique is good, should also be geared toward a right handed person as well. If there could be a way to diminish the glare in very sunny conditions that would be beneficial.	1
Less disorienting than HMD continuous movement. I was able to navigate the course fairly successfully, though at a much slower pace.	1
It was easy to move with the robot, but it was also hard not knowing what was around the blocked area and then you walk up on an IED.	1
A moderately more difficult task to perform.	1
Can’t see what is ahead of you when you are walking because you have to look down at the screen.	1
Glare was also an issue. And I thought this iteration would make it difficult for situation awareness, looking down, instead of up/and around.	1
Hands are now obligated to perform robot controls and weapon is maybe an afterthought.	1
Harder to see objects on the lane while moving, harder to keep on track.	1
Kind of hard to navigate.	1
Once again, easy to use but the display is too big when it comes to combat tactics.	1
This was my first task and was a little less difficult than the HMD moving. I think that walking and driving at the same time is a little more difficult due to wanting to make the robot either stay in front or behind me. I would veer off course.	1
C-HMD and Bounding movement	
Easy to use because I just switch eyes when I need to switch concentration.	1
Easy; not hard to navigate.	1
Easier to control the robot from a stationary position.	1
Bounding was easier with the HMD because hands were free, I was able to focus on the display when I was stopped, and it was a comfortable wear.	2
The HMD allows greater situational awareness while using the robot, is less bulky, requiring only one hand to use, and the eye display is less prone to glare. The bounding technique is also much easier than constant movement.	1
Definitely better than HMD and continuous movement.	1

Comments	Responses
Was much easier to negotiate the course because of being able to bound to your next point, kneel, and then drive the robot to that point. It allowed the user to focus on the course and be able to look for IEDs.	1
I prefer this technique with HMD because you're not moving while you're driving.	1
I found that bounding and then driving the robot easier to do.	1
It gave you enough time to look around at what was going on. It was also less stressful.	1
A slightly more complicated task to perform.	1
Bounding with the HMD wasn't too bad but still hard to walk with the display over my eye.	1
Continuous re-adjusting of the monocle and blurred vision make it difficult to maneuver the robot. The halt does help though.	1
I needed to steady the eye display with one hand and drive with the other, but that may have been because it wasn't properly adjusted.	1
Eye piece cannot go over glasses, which makes observation of your surroundings difficult.	1
Hard to keep display against eye makes it difficult to see camera display and focus on it too.	1
Holding eyepiece was a problem.	1
This was my second one and therefore I still had some issues with the controls. Also, the controller should be smaller and lighter so that you can tether it to you so that you may drop it and engage in fire if needed without taking time to take it off or damage.	1
I found that my situational awareness suffered a bit more with the HMD than the HHD.	1
Initial disorientation but worked it out.	1
It takes a lot of getting use to.	1
It was difficult to focus one eye on the screen and keep the other eye focused on ambience.	1
It was easier to maneuver throughout the course when you had to bound at a position.	1
It's hard to see the picture because it doesn't fit right.	1
Much easier to control robot as opposed to continuous movement.	1
Needs to be a little more stationary.	1
Stopping made it easier to focus on what the display was showing.	1
The picture on the screen was small and hard to recognize what obstacles were in the way.	1

Comments	Responses
This technique is good, but should also be geared toward a right handed person as well. The head mount for covering the dominant eye needs to cover the whole eye because you tend to close the other eye to see more clearly into the video camera since there is still come light that filters through.	1
This was my last task and was easier than the others. It was easier to maneuver once I was bounded and the remote responded well. I did have to hold the eyepiece with one hand and maneuver with the other which was a little on the challenging side and would not be beneficial in a fight because both hands would be occupied.	1
You had to hold the eyepiece.	1
D-HMD and Continuous movement	
It was easier because you are walking.	1
It's easy to see where the robot is going.	1
Quite easy, always had one eye free to see where you're going.	1
Was very difficult to move with the robot and look out both eyes at the same time.	1
Can't focus on walking and driving both at same time.	4
It was harder to focus on the screen and also watch where you're going at the same time.	1
Did not like this technique at all because it caused me to miss IEDs because I had to focus on the movement of my team leader and try to drive the robot while looking for IEDs.	1
Depth perception was a little off.	1
Harder to control with the eye piece moving around.	1
Harder to see objects on the lane while moving, harder to keep on track.	1
Holding eyepiece was a problem.	1
I didn't enjoy this one at all. I couldn't maintain my orientation having to move and keep my eyes focused on two separate things at the same time.	1
I think that the eye display may be harder to see because it moves. I prefer the bounding technique because you're not walking and trying to watch the screen. I also keep my other eye closed while using the HMD method so walking while driving is hard.	1
It was difficult to focus one eye on the screen and keep the other eye focused on ambience.	1
It took longer to focus on the display, and the frustration factor was higher because I had trouble staying on course when I couldn't clearly see the display.	1
Of all four, it is the most difficult.	1

Comments	Responses
I personally veered off course several times and had difficulty with IMT while using the robot.	1
The hardest of tasks to perform.	1
The most difficult for me as I was unable to wear my glasses, so moving was difficult while trying to pay attention to what the robot was seeing.	1
The process was complicated, and movement made using the display difficult.	1
This technique really needs the whole dominant eye covered; you tend to walk into the direction of the movement of the equipment and you might even risk an accident since you automatically close the other eye to get a more detail visual of where the vehicle is going.	1
This was my third task and was the worst. During this one the communication between the remote and the robot was not good at all. There was a large delay in feed for the camera as well as when I tried to give it direction. I would slightly push up and nothing would happen so I pushed harder it took time and then the robot would take off fast. Even pushing left or right had the same effect.	1
Too difficult to focus on both tasks and switching concentration.	1

2. What suggestions do you have for ways to increase the effectiveness of the displays?

HHD

I think the HHD was great.	1
I thought it was really good; I would make no changes.	1
It was excellent, I liked it best.	2
It was great.	1
Keep it the same.	3
Liked the larger screen size and that you could see it while wearing glasses.	1
A wider field of view would increase the accuracy.	1
As it is, I don't see a practical advantage to carrying the display if in fact an HMD can be fitted and mounted hands free.	1
Better camera resolution/display.	1
It needs to be less bulky and heavy.	2
Get rid of it, it is too bulky, cumbersome, distracting and heavy, and requires both hands and eyes to use.	1
Make the controller not as awkward to hold.	1
Make the controller smaller.	9

Comments	**Responses**
Create a smaller platform. The display wouldn't need to be so big if it worked more efficiently with various lighting.	1
Make the unit usable with only one hand.	4
Having a better shielded display that cuts the glare off of the display regardless of the position of the handheld.	1
Reduce glare.	4
Find a way to block more sunlight from the HH screen. Sunlight was a factor that was kind of making things more hard.	1
Use a display screen that can tilt to reduce glare from sun light on the screen.	1
HMD	
Found the HMD view most effective.	1
A mount similar to our NVG mounts where the monocle remains steady and you can focus out the blur.	1
Better stability for the head display; constantly had to adjust view.	1
Eyepiece needs to be more secure.	4
It can be difficult to keep the eyepiece adjusted properly while moving.	1
Make the eyepiece cover your whole eye.	1
Proper fit and adjustment. I had to hold the eyepiece in place and use the controls.	
Create a better fitting headpiece, so the display can fit snugly against the eye.	2
I really don't know how to keep the display from moving while you're walking unless you worked on the mount and found a way to tighten it up.	1
Be closer to the face rather than as far as it was,	1
Increase the size of the display to eliminate competition between your eyes wanting to focus on where you are walking.	1
Lessen the effect of sunlight on the display, and the focus factor for leaving a dimly lit area to a brightly lit area should be quicker.	1
Make it so that you can still see out of the glasses but also make the glasses tinted so that the displays camera appears on the tinted lens.	1
Make the display area bigger.	2
Stiffer armature to prevent wobbling, better mounting system than the goggles, and a focusing feature to adjust diopters for soldiers with glasses.	1
More glass friendly.	2
More soldier level mounting adjustments to set up display for individual eyes.	1
Move the display closer to the eye or create a clear HUD similar to aircraft HUD.	1
Not really good for combat. Can't see the area around you and see what the robot sees.	1

Comments	Responses
Something to improve the clarity and brightness of the display.	1
Talk to the Sony corporation and let them come up with something for a display and control device.	1
The arm that attaches the display to the goggles needs to be more ridged so it would stay in place easier.	1
The camera completely obstructs your vision. Open the area up around the camera to improve the user's peripheral vision. This might also improve the user's ability to drive the robot.	1
The display is less panoramic.	1
Better communications between remote and robot! Better fitting is about the only thing I can think of.	1
Better equipment.	1

3. What suggestions do you have for ways to increase the effectiveness of the movement techniques?

Bounding / Bounding movement	
Bounding was the most effective. No suggestions.	1
It was excellent, I liked it best.	1
It was great; I enjoyed it.	1
Nothing. It is already two separate tasks.	1
Pretty good as it is, unless there are malfunctions and you have to go back to the unit.	1
Going shorter bounding distances.	1
It was effective, but using the unit without being able to see it more, would probably assist in training.	1
Lag occurred more frequently.	1
Making the gear that you are wearing lighter is about the only way to improve this one.	1
Mainly gear issues affected this technique.	1
Operate the system as a crew served weapon with both an operator and an assistant to provide security for operator.	1
Continuous movement	
It was a good training.	1
Being forced to look at other thing while navigating the robot. Looking up and down a lot would increase the reality of using the unit.	1

Comments	Responses
Have the robot beside or slightly in front of you. You would be able to see the robot when you aren't really using it, so you wouldn't have to keep watching your display to move it.	1
Movement with the hand held display.	1
Mainly gear issues affected this technique.	1
Not preferable, sorry.	1
Without a guide to follow while focusing on using the robot, it is easy to veer personally off course.	1
Walk at a speed you would actually move at rather than a person setting your pace.	1

4. Please provide suggestions on ways to improve the driving course.

I thought everything looked good.	1
It was a good challenging course.	2
Add obstacles.	2
Better marching system.	1
Doing the course on a not so bright day.	1
For beginners, make the course on sand, so the terrain would be easier to see and navigate.	1
Sharper turns, sand/dirt areas and objects to avoid should be added.	1
Longer lane for driving to get more comfortable, smaller IEDs to make it harder or in the ground.	1
Make it level or give it a little more hill for training.	2
Make it longer.	3
Different terrain.	2
More elevation changes.	1
More in depth as far as how to move in confined areas and how to make sharper turns.	1
Raise the boundaries a little so it is evident the path to take.	1
The engineer tape is more difficult to see on the ground through the camera. Raise the tape four or five inches off the ground.	1
Would be useful to be able to independently move the tracks to make tighter turns. Would also be excellent to make the cam adjust light settings so it can see form a hidden position.	1

5. Please provide suggestions on ways to improve the driving lanes that you negotiated?

Comments	Responses
It was a good challenging course.	2
A greater emphasis on the identification of foreign objects in the display.	1
Additional iterations would build confidence in individual ability to successfully navigate course and help to build speed.	1
Cut tall grass.	2
Cut grass in certain areas in the tunnel. Raising boundaries will also solve the problem.	1
I think that the lens should have the camera inside the lens to make it easier to see.	1
I would see if there is something better to outline the course with, sometimes it is difficult to see the engineer tape.	1
Use something that does not reflect light as much as engineer tape does when it gets bright. When driving into sunlight the screen whites out and makes it hard to see the tape.	1
Make it harder; it was not anywhere near challenging enough or realistic enough for me.	1
More obstacles.	2
More hills, holes.	1
Put more obstacles in the lane. Rocks, sandbags, or maybe the use of stairs.	1
Would be better to make it longer with varying terrain types.	1

List of Symbols, Abbreviations, and Acronyms

AAEF	Air Assault Expeditionary Force
ANOVA	analysis of variance
ARVs	Armed Robotic Vehicles
EXFOR	Experimentation Force
FCS	Future Combat Systems
HHD	handheld display
HMDs	head-mounted displays
IBCT	Infantry Brigade Combat Team
IEDs	improvised explosive devices
ISR	intelligence, surveillance, and reconnaissance
MSAQ	Motion Sickness Assessment Questionnaire
NASA	National Aeronautics and Space Administration
OCS	Officer Candidate School
OCUs	operator controller units
PDA	Personal Digital Assistants
SA	situation awareness
SUGV	Small Unmanned Ground Vehicle
SVGA	super video graphics array
TLX	Task Load Index
TTPs	tactics, techniques and procedures

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