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Robotic Telepresence: Perception, Performance, and User Experience

by Linda R. Elliott, Chris Jansen, Elizabeth S. Redden, and Rodger A. Pettitt

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14. ABSTRACT
Two experiments examined the effectiveness of telepresence features during indoor and outdoor beyond-line-of-sight robot reconnaissance missions. In the first experiment, Soldier participants controlled a reconnaissance robot with two controllers developed by TNO Human Factors: one with and one without telepresence capabilities. Telepresence capabilities included a stereo visual display and a head-mounted camera that was guided by operator head movements. Soldiers performed equivalent search and identification tasks with each controller interface. Measures included indices of performance (e.g., time, accuracy), workload, situation awareness, and user-based ratings and feedback. Results from the first experiment indicated that while Soldiers preferred the telepresence system, performance outcomes were similar in both conditions. The second experiment was based on more challenging task demands and investigated the additional contribution of three-dimensional (3-D) audio capability for audio-based localization tasks. Results indicated that the 3-D audio combined with the head-track camera control enhanced audio-based search tasks. Feedback from Soldiers was overall positive. Suggestions for improvement included a more lightweight portable system, higher visual clarity, and enhanced ease of use.

15. SUBJECT TERMS
flexible display, wearable display, forearm display, robot performance, telepresence, teleoperation, situation awareness, robot navigation, Soldier performance, Army, robot, controllers

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1. Introduction

1.1 Purpose

Small ground robots, such as the PackBot and TALON, have been widely used by warfighters to hunt for terrorists and perform all types of reconnaissance duties (Axe, 2008). Their rugged small size and video capabilities make them very effective for non-line-of-sight reconnaissance (e.g., search and assessment) tasks in darkness or dangerous context, and their widespread use reduces the human risk in combat reconnaissance missions. While their contributions to Soldier performance and well-being have been established, many vital robot tasks have been identified as high workload tasks given Army operational context (Mitchell, 2005; Mitchell and Brennan, 2009). In addition, many tasks have been identified that can lead to failure (e.g., damage to operator, robot, and/or rescue victim) (Scholtz et al., 2004). Exploratory missions in which the robot operator must teleoperate the robot while also attending to the environment in order to gain intelligence result in especially high operator workload (Chen et al., 2008). Such missions require many abilities, such as driving, sensing, and information evaluation, in order to perform successfully while maintaining situation awareness (SA).

Improved robot display and control capabilities as associated with telepresence technology have been shown to support performance and reduce operator workload. Telepresence has been defined as "a human-computer-machine condition in which a user receives sufficient information about a remote, real-world site through a machine so that the user feels physically present at the remote, real-world site" (Aliberti and Bruen, 2006). Telepresence often includes capabilities for a more naturalistic perception of information, such as stereo vision, panoramic view, and stereo audio (Den Breejen and Jansen, 2008; Jansen et al., 2012).

In addition to a more naturalistic display of perception information, telepresence also often includes more intuitive control capabilities such that operator movements or gestures are translated in a naturalistic fashion. The intent is to increase ease of perception and control and thus provide the robot controller with a greater ability to attend to aspects of SA (Van Erp et al., 2006; Van Breda and Van Erp, 2006). In this report we describe two experiments using telepresence capabilities for beyond-line-of-sight control of a ground robot for military reconnaissance missions.

1.2 Telepresence

Telepresence technology can enable operator performance through sensory and performance capabilities that allow the operator to feel "present" in robot teleoperation tasks. In regular ground teleoperations, an unmanned ground vehicle (UGV) typically transmits video to an operator control station that displays the video on a computer screen. The operator then teleoperates the UGV, usually by using a joystick or gaming controller (e.g., handheld button controls). In contrast, telepresence capabilities incorporate features such as immersive three-dimension (3-D) vision, 3-D audio, and head-driven camera movement controls. These features are expected to allow the operator more seamless perception and manipulation within the environment and higher SA (Van Erp et al., 2006; Jansen et al., in review). Visual search, object identification, and object manipulation are expected to be improved through enhanced camera capabilities (e.g., resolution, video streaming, camera scope, movement, and focus). Normally in telepresence, the operators wear a head-mounted display (HMD) and head tracker to allow them to move the camera through head movements as if they were seeing through the robot's "eyes." This capability has also been demonstrated in a portable binocular format (Jansen, 2006). Three-dimensional audio capability has been developed and demonstrated for robot control tasks (Keyrouz and Diepold, 2007) and is expected to contribute to performance across a variety of military missions.

Many applications for telepresence capabilities have been developed and demonstrated. Telepresence technologies have been instantiated in medical surgical operations (Alexander and Maciunas, 1999; Faust, 2007; Haidegger and Benyo, 2008; Sankaranarayanan et al., 2007; Schostek et al., 2009) and for remote patient care (Hu, 2008; Schmidt and Holmes, 2007). They have also been demonstrated in a broad variety of settings for purposes as diverse as service to the public (Gong, 2008), control of humanoid robots (Seo et al., 2006), construction and vehicle teleoperation (Fong et al., 2001; Sasaki and Kawashima, 2008), ocean exploration (Manley, 2008; Martinez and Keener-Chavis, 2006), National Aeronautics and Space Administration (NASA) team member support (Goza et al., 2004), museum learning tools (All and Nourbakhsh, 2001), reconnaissance and rescue (Zalud et al., 2006), insect telepresence (All and Nourbaskhsh, 2001), and space operations (Foing and Ehrenfreund, 2008; Landis, 2008).

Immersive telepresence has also been demonstrated for field operations that are more directly relevant to military operations, including situations such as search and rescue, forestry, mine operations, remote security guard, and reconnaissance. To date, results are mixed but show promise. Ryu and colleagues (Ryu et al., 2006) report advancements in networking that allow greater distances in remote teleoperation of robot security guards. Hai-zhou and his colleagues (2000) describe the development of a telepresence system for outdoor mobile robots, consisting of a wide-screen display, remote driving steering wheel, camera pan and tilt, and dual 3-D cameras.

While the system was demonstrated to be functional, there were no empirical comparisons of the telepresence to a non-telepresence controller. Halme and his colleagues (Halme et al., 1999; Halme, 2010) investigated several levels of telepresence for field tasks, ranging from "full" telepresence (i.e., stereovision, sound, 2-degree-of-freedom [2-DOF] head tracking) to partial combinations: monovision (i.e., monovision, sound, 2-DOF head tracking), monitor-based (i.e., image on screen, sound, 2-DOF head tracking), manual (i.e., image on screen, sound, 2-DOF manual camera control), and baseline (image on screen, sound, fixed camera). Sound was previously determined to significantly enhance performance. Halme et al. applied these controllers to several different mission-relevant tasks, such as corridor driving, driving in unknown territory, loading tasks, maneuvering tasks, off-road driving, and fast driving. All conditions were associated with better performance than the condition with the manual camera control, which was eliminated from further comparisons. The authors report driving times were somewhat shorter, and there were fewer errors when using the head tracker; however, tests of significance or effect sizes were not reported. There was some evidence that the stereo vision also contributed to better performance. Operators could only accomplish driving in unknown terrain in the conditions with head tracking, as they could not recover from being lost with only a fixed camera.

In general, the monocular vision performed as well as the stereo; however, this may have been because of the higher resolution of the monocular display. Overall, results showed that effectiveness of capabilities depended on the task demands, the opportunities for training and practice (operators improved considerably with all conditions after practice), and the degree of novelty of the task (e.g., operators facing unknown territory or performing a task as a novice). Generally, the head tracking was found to assist in various tasks, while stereo vision may need further improvements in resolution. Further research is ongoing to integrate telepresence features with semi-autonomous capabilities in various work operations (Suomela and Halme, 2001; Suomela, 2004).

Telepresence prototypes for military applications are being developed for a number of military purposes, such as search and disposal of improvised explosive devices (IEDs) (Getlin, 2009; Greenemeier, 2010; Neerincx, in review). Prototypes under development also include a remote sentry with directional 3-D spatial audio to detect, localize, and track vehicle targets (Overland, 2005; Vaudrey and Sachindar, 2003). While these capabilities were successfully demonstrated, they were not compared with any existing system. In another effort, immersive telepresence was expected to enable higher driving speeds when compared to current small Army UGVs (Yamauchi and Massey, 2008). In that study, the immersive teleoperation was based on an HMD and head-aimed cameras. The combination of telepresence and semi-autonomous obstacle avoidance was mounted on an iRobot Warrior UGV prototype and also on a ruggedized radio-controlled gas-powered car. Researchers reported that this system enabled operators to drive at full speed (estimated top speed of 30 mph) while making turns, and that Soldiers reported increased SA. However, the head-controlled camera was not associated with faster times than a fixed-camera view; both performed very well. Researchers speculated that the telepresence, along with semi-autonomous driver assist capability, will prove more effective as higher speeds are attained. Again, there is further need to systematically compare telepresence features, and specific combinations of features, as they apply to specific tasks.

In this report we describe two experiments. In experiment 1, we focused on the combination of stereo vision and head tracking capability for reconnaissance tasks that did not require 3-D audio. A recent study investigated the effectiveness of 3-D visualization on robot control performance (Pettijohn et al., 2009). In their study, seven Soldiers performed target search and identification tasks in a variety of settings (finding targets buried in rubble or placed in a dark cave, route reconnaissance, etc.) and object manipulation (placing a chemical sensor very near the target, removing obstacles surrounding the target, etc.). Stacked LCD displays produced stereo video when used with passive polarized glasses. Researchers found that Soldiers performed search tasks much faster (22%–47% time savings) with the 3-D system and reported that the 3-D system greatly enhanced their depth perception and overall performance. Three-dimensional visualization was also associated with better performance and Soldier preference in other Army robot control tasks (Bodenhamer, 2007; Pettijohn et al., 2007). However, other results were mixed with regard to contribution of stereoscopy on performance; these results suggest that effectiveness will depend on factors such as task demands and image resolution (Lee and Kim, 2008).

For our first experiment, we investigated the utility of the stereo vision combined with head tracking for indoor and outdoor ground search. For this task scenario, all items were placed on the ground to enable some comparison with results from a previous study using a similar baseline system (Pettitt et al., 2010). After training on the operation of the robotic system, each Soldier completed indoor and outdoor reconnaissance tasks using the telepresence interface and the baseline controller interface commonly used in current operations. The terrain and hazards were counterbalanced along with the interface conditions to control for practice effects. Display conditions were evaluated based on objective performance data, data collector observations, and Soldier questionnaires.

From experiment 1, we developed a plan for further investigation for experiment 2. For experiment 2, we created a more challenging search environment where items were placed above ground as well as on the ground to better explore the utility of the head-driven camera. We also added the 3-D audio capability and corresponding audio search task demands. The full telepresence condition consisted of stereo vision, 3-D audio, and head-tracked camera controller. The baseline telepresence used monovision, monoaudio, and a joystick camera controller. A third condition used monovision, monoaudio, and the head-tracked camera controller. Soldiers performed an audio search task, an SA search task, and a movement control task where tasks and conditions were counterbalanced. Measures included objective performance data, data collector observations, and Soldier questionnaires.

2. Experiment 1

In this section, we describe experiment 1, where we examined operators' experience and performance while using robot telepresence capability during indoor urban and outdoor cross-country reconnaissance missions. Soldier participants controlled a reconnaissance robot, developed by TNO[*] Defence, Security and Safety – Human Factors, to search and identify various items of interest. Each Soldier performed equivalent search tasks, once using a robot controller interface with telepresence capability and once without the telepresence. This allowed us to assess the relative contribution of telepresence to robot performance with regard to navigation, search and identification of items, and situation assessment. After task performance, Soldiers provided structured descriptions of user experiences and systematic feedback regarding operational issues.

2.1 Method

2.1.1 Scenario

For this experiment, there were two visual search tasks. For the indoor reconnaissance, operators were requested to search each room in a building and locate and identify each item of interest. They were then requested to describe what activity was most likely happening and would likely occur next, through inference given the particular items found. For the outdoor reconnaissance, operators were requested to search for various items of military interest while navigating a route outdoors in relatively rough terrain.

2.1.2 Participants

Twenty Soldiers were recruited from the Officer Candidate School (OCS) to participate in the study. Solders included those with prior service as well as those who entered OCS directly from college. Sixteen Soldiers were able to participate fully; other sessions had to be cancelled, primarily because of weather.

2.1.3 Equipment and Instruments

The robot (Generaal) used during the experiment was developed by TNO to demonstrate telepresence capabilities. Two interface designs for robot control were compared for navigation and search and identification tasks (i.e., TNO interface design with and without the telepresence features). Routes for indoor and outdoor reconnaissance were developed to systematically evaluate robot control performance.

2.1.3.1 The Generaal. The Generaal UGV is a six-wheeled vehicle developed by TNO for research and development purposes (figure 1). It has a pan-tilt-roll camera sensor system, consisting of stereo vision and 3-D audio. It typically runs for about 2 h, depending on situation and task demands. Sensor and control signal communication is IP based (5.8-GHz wireless local area network), with an open development architecture. The Generaal UGV has ultrasonic collision sensors, with telepresence experience provided by the stereo vision and 3-D audio. It has performed well in indoor obstacle-rich environments.

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[*]Netherlands Organisation for Applied Scientific Research, Toegepast-natuurwetenschappelijk Onderzoek.

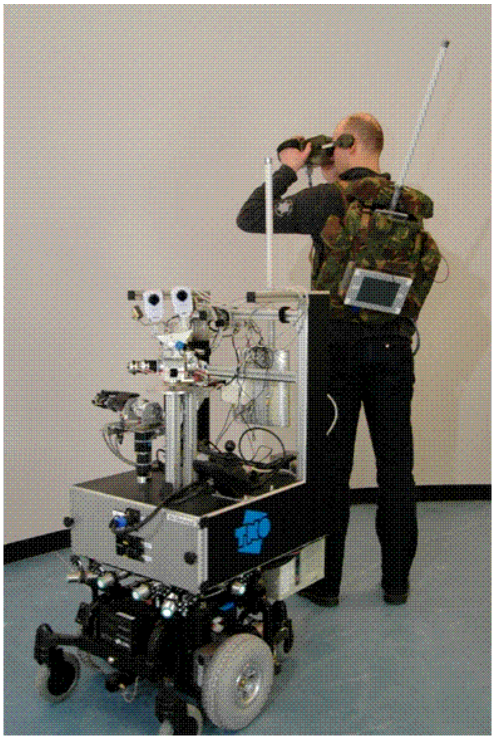


Figure 1. The Generaal robot and a binocular controller.

2.1.3.2 The Generaal Telepresence Controller. The Generaal control unit (figure 2) included head tracking equipment that enabled stereo vision and 3-D audio. The stationary control unit usually includes a steering wheel and foot pedals for vehicle control, and vehicle rotation was controlled by rotating the control unit's chair. Optional force feedback on the operator-induced rotation of the vehicle can be provided to the operator by corresponding rotation of the control unit's chair. However, in this experiment, we used a more portable laptop system with a gaming controller device; therefore, the telepresence capability was limited to the head-mounted controls and stereo vision. The 3-D audio capability was not assessed in this initial experiment. Image resolution was 320 × 240 for the left as well as the right eye. Weight of the unit was 950 g. Important for performance is the cumulative delay in the whole system. For this system, the lag of the video image is estimated at 100–150 ms. The total delay consists of the lags in head tracking measurements, transmission of those values to the robot, turning the pan-tilt-roll, encoding the video image, sending it via the wireless comm, decoding the image again, and presenting it on the HMD. Figure 2 shows on the laptop screen the same image as the Soldier sees on the HMD.

Figure 2. The Generaal controller with head-mounted telepresence.

2.1.3.3 TNO Baseline Interface. The operator interface used to control the TNO systems was instantiated on a laptop and based on software that emulates SSC Pacific's Multi-Robot Operator Control Unit (Powell et al., 2008). An example screenshot of the interface is found in figure 3. The robot's location, driven path, goal points, and sensor data (i.e., map data) are overlaid on an aerial image. Real-time video from the robot is also displayed. Function-button mapping was rather simple: one stick controller for left-right-forward-backward control of the robot, another stick controller for up-down-left-right control of the sensor unit.

Figure 3. Snapshot of laptop interface.

2.1.3.4 Outdoor Route Reconnaissance Course. The outdoor route reconnaissance course (figures 4 and 5) was located at the Molnar MOUT (Military Operations in Urban Terrain) site in Fort Benning, GA. It consisted of two separate but equivalent routes. Each route included three waypoints and totaled a length of 180 m. Various types of IEDs, mortar rounds, and mines that could be seen by the driving camera were placed along each route (figure 6). An equal number of small and large items were placed along each route, with equivalent locations on the route, resulting in items that were small and near, small and farther away, large and near, and large and farther away. Operators were located out of line of sight of the robot in a stationary position inside a tent located outside the building. Data collectors followed behind the robot as it traversed the course. Soldiers were assigned to devices and routes in a counterbalanced manner to obviate any effects due to a particular route.

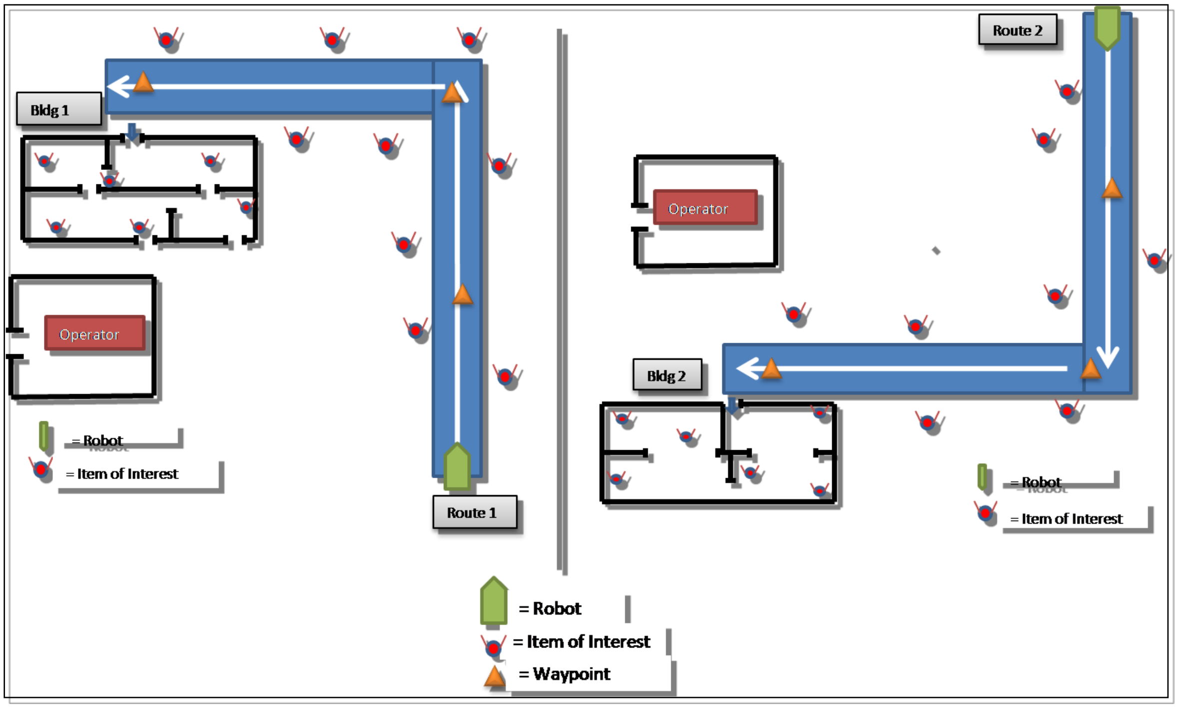


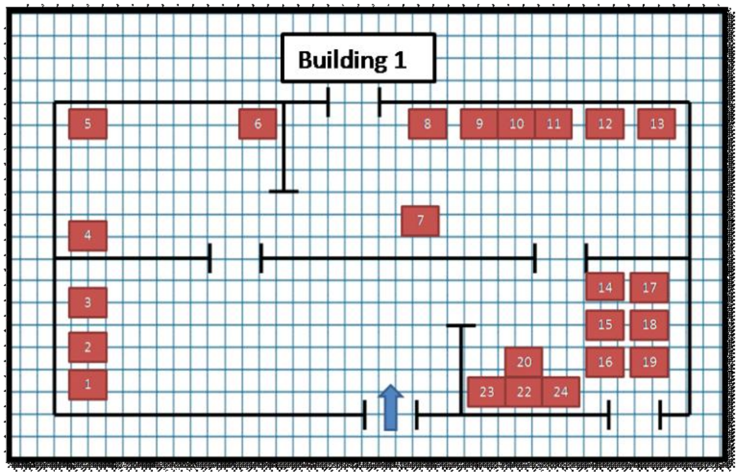
Figure 4. Outdoor route reconnaissance course diagram.

Figure 5. Outdoor route.

Figure 6. Examples of outdoor items of interest.

2.1.3.5 Building Reconnaissance Course. The building reconnaissance course (figure 7) was also located at the Molnar MOUT site. For this experiment, we used two one-story buildings, which were similar in size, with the same number of rooms and similar floor plans. Rooms in the buildings had tables, chairs, and other furnishings. Over 20 mock-up IEDs, weapons, and other items of interest were placed along each building route. The building routes differed in theme in that items of interest indicated a different purpose. In one building, the setting portrayed enemy interrogation of prisoners (i.e., a prisoner-of-war [POW] theme); the other portrayed enemy plans and materials related to a suicide terror attack on New York City (see items listed in figure 7 and examples of items in figure 8). Soldiers were assigned to devices and indoor routes to counterbalance the effects of route differences.

Item	Description
1	Diet Pepsi Caffeine Free Can bomb
2	Diet Coke bomb
3	Diet Pepsi Can bomb
4	Land Mine Grey
5	Land Mine Green and Tan
6	Land Mine Tan
7	Cardboard box
8	picture of statue of liberty
9	Suicide bomber vests
10	Suicide bomber vests
11	Suicide bomber vests
12	Briefcase bomb
13	Map with New York circled
14	Timer
15	6v Battery
16	Wire
17	Initiation Device
18	PDA
19	Cell Phone
20	Pipe Bomb
21	82mm Mortar round
22	122mm Projectile
23	130mm Rocket round



Item	Description
1	Cardboard box
2	PDA
3	Fan
4	AK47
5	AK47
6	AK47
7	RPG
8	12v Battery
9	Jumper cables
10	Chair
11	Table
12	Lamp
13	Wire
14	Rope
15	Wire
16,17	ACU uniform
18	Bedding
19	Bloody rags
20	Tortured dead body
21	Sandbag over head
22	Chair
23	Bedding

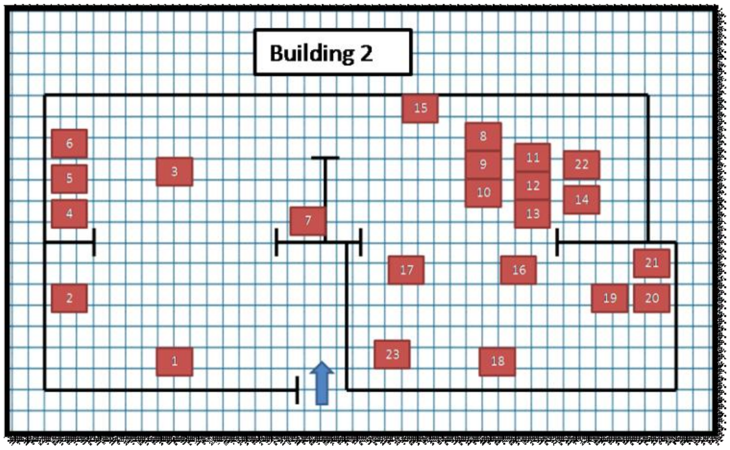


Figure 7. Building reconnaissance courses and items of interest within each building.

Figure 8. Examples of building items of interest.

2.1.4 Procedures

2.1.4.1 Soldier Orientation. The Soldier participants reported in groups of four for 1 day each, from 0800 to 1800 daily. After arrival, they received a roster number for identification throughout the evaluation. The Soldiers were oriented on the purpose of the study and their participation. They were briefed on the objectives, procedures, equipment, reconnaissance course, and reconnaissance tasks. They were asked to review an operations order that provided a context for the reconnaissance mission. Experimenters answered any questions the Soldiers had concerning the experiment. The Soldiers were also told how the results would be used and the benefits the military could expect from the investigation.

2.1.4.2 Demographics. Soldiers were requested to provide demographic data about their physical characteristics and military experience, including their knowledge of operating remote-controlled vehicles. The demographic sheet and data summary are provided in appendix A.

2.1.4.3 Training. No specialized experience was required from the requested Soldiers. A representative from the U.S. Army Research Laboratory (ARL) presented an overview of the experiment, reconnaissance courses, and task demands. Representatives from TNO introduced the Soldiers to the use of the robot control systems. Soldiers were given hands-on training on a particular interface immediately before using the interface. During the hands-on training, Soldiers performed the reconnaissance tasks on indoor and outdoor training courses that provided practice on all task demands. Training evaluation questions were included in the postiteration questionnaire regarding adequacy of training and requests for comments and suggestions.

2.1.4.4 Task Execution. After Soldiers completed training on a particular interface, they completed the outdoor and then the indoor route with that interface. Soldiers were given 20 min to complete each route, and all performed within the time limits. During task execution, a TNO experimenter and an ARL experimenter observed Soldier performance, recorded performance measures, and noted any issues.

The entire route reconnaissance course consisted of the outdoor route followed by the indoor route. There were two equivalent entire routes; the Soldiers navigated a different route with each robot interface. They were instructed to search for items of interest and locate waypoints for the outdoor route. The Soldiers were provided a map of the route on their operator interface with the waypoints of the route marked. The map display included a list of potential items that might be present on the course, but there was no indication of the specific items that were placed along the route. When the Soldier found an item of interest, he or she would tell the data collector, select the item from the list, and use the controller to take a picture of the item. Soldiers drove to each waypoint while performing the search, and when a waypoint was reached, they notified the data collector. Upon reaching the last waypoint, the robot was returned to the starting point by a TNO experimenter.

A data collector accompanied the robot to report start and stop times, times off course, and driving errors. Another data collector was present at the operator station to record the number of objects found and reported performance measures. Upon completing the iteration (i.e., an entire route reconnaissance), the Soldiers moved to a questionnaire area to fill out questionnaires concerning the exercise just completed (see appendix A) and to fill out a NASA task load index (TLX) (see appendix B) concerning the level of workload experienced.

Once Soldiers completed the first iteration, including the questionnaires, they joined the other Soldiers in a waiting area. Soldiers were requested, emphatically, to refrain from discussing their experience among themselves. Experimenters were nearby to monitor and enforce this request. Soldiers remained in the waiting area until they were called for their second iteration, which proceeded in the same way as the first iteration. After both iterations were completed, Soldiers filled out an end-of-experiment questionnaire (see appendix A). The Soldiers took ~2 h to complete both iterations, with all data collection accomplished in ~8 h in a single day. All Soldiers were available throughout the 8 h.

2.1.5 Experiment Design

This experiment was a within-subjects design with two levels of robot control interface (with and without telepresence). The order of treatments and assignment of Soldiers to routes were counterbalanced according to table 1. As the table shows, Soldiers were processed in pairs. First, Soldier 1 performed iteration 1. After Soldier 1 completed his or her first iteration and while he or she was providing feedback, Soldier 2 performed iteration 1. After Soldier 2 completed a first iteration and while he or she was providing feedback, Soldier 1 performed a second iteration. After Soldier 1 completed a second iteration and while he or she was providing feedback, Soldier 2 completed a second iteration (and so on).

Table 1. Order of treatments and lanes.

Weekday	Roster (Soldier)	First Iteration			Second Iteration		
		Order	Interface	Route	Order	Interface	Route
Monday	1	1	L	1	3	T	2
	2	2	T	1	4	L	2
	3	5	L	2	7	T	1
	4	6	T	2	8	L	1
Tuesday	5	9	T	1	11	L	2
	6	10	L	2	12	T	1
	7	13	T	2	15	L	1
	8	14	L	1	16	T	2
Wednesday	9	17	L	2	19	T	1
	10	18	T	2	20	L	1
	11	21	L	1	23	T	2
	12	22	T	1	24	L	2
Thursday	13	25	T	2	27	L	1
	14	26	L	1	28	T	2
	15	29	T	1	31	L	2
	16	30	L	2	32	T	1
Friday	17	33	L	2	35	T	1
	18	34	T	2	36	L	1
	19	37	L	1	39	T	2
	20	38	T	1	40	L	2

Note: T = with telepresence; L = laptop without telepresence.

2.1.6 Measures

Measures included performance, workload, and Soldier evaluations.

2.1.6.1 Performance Measures. Performance measures included the following:

- Route reconnaissance course completion time

- Building reconnaissance course completion time
- The number of driving errors on each course
- The type and number of correct objects found on each course
- Accuracy of movement to designated waypoints

2.1.6.2 Workload. The NASA-TLX requires the rater to examine multiple combinations of dimensional levels (measured on six subscales: mental demands, physical demands, temporal demands, own performance, effort, and frustration) and derive an overall workload score (Hart and Staveland, 1988). In addition, the Soldier evaluations included ratings of difficulty for specific tasks. Further description of the TLX is included in appendix B, and the Soldier evaluations are included in appendix A.

2.1.6.3 Situation Awareness. After each iteration, Soldiers completed a questionnaire that listed all objects in the building that were identified by the Soldier as recorded by the data collector. The Soldiers were requested to consider the purpose of the building, select the answer that best described that purpose, and provide a rationale for their answer, including a description of what the occupants were planning to do.

2.1.6.4 Soldier-Based Evaluations. Soldiers completed two postiteration questionnaires and one final questionnaire. Questionnaires inquired about the operator's experience with the controller units, overall assessments, and comments. The questionnaires were designed to elicit Soldiers' opinions about their performance and experiences with each control system. The questionnaires asked the Soldiers to rate the devices on a seven-point semantic differential scale ranging from "extremely good/easy" to "extremely bad/difficult." Copies of each questionnaire are included in appendix A.

2.1.7 Data Analysis

Descriptive statistics were calculated for each measure. Performance data was analyzed using repeated measures analysis of variance (ANOVA). Follow-on pairwise comparisons were calculated using Holm's Bonferroni procedure (Holm, 1979) to control for family-wise error rates. Partial eta squared (η^2_p), an index of effect size, was computed for each ANOVA.[*]

[*]Holm's Bonferroni correction: The *p* value required for significance is based on the number of *t*-tests calculated. Take the *t*-test with the smallest *p* value and divide your alpha (typically .05) by *k*, the number of paired comparisons. The partial eta squared is the proportion of the the effect + error variance that is attributable to the effect.

2.2 Results

2.2.1 Participant Demographics

Twenty Soldiers were recruited from the OCS at Fort Benning. Of these, complete data were collected on 16 Soldiers. Soldiers were primarily male (two were female). The average age was 25. Nine of the Soldiers had previous military experience, averaging 8 months. All reported familiarity and daily use of computers. Two reported previous experience with electronic military displays, and three reported experience with (civilian) robotic systems. Most reported low (none or beginner) experience for operating robot systems. Detailed results are listed in appendix A.

2.2.2 Training

Soldiers reported high satisfaction with all aspects of training. The mean ratings regarding training are provided in table 2. Ratings (seven-point scale) ranged from 5.81 (outdoor reconnaissance) to 6.44 (overall concept). Detailed results are provided in appendix A. Soldiers reported that the easiest tasks to learn were tasks associated with the camera controls and driving. The more difficult tasks were associated with coordination of driving, searching, and taking pictures. Also, Soldiers reported that using specific camera movement controls on both systems was more difficult to learn.

Table 2. Mean ratings for aspects of training.

Training	Mean Response		
	No. of Soldiers	Telepresence	Laptop
Completeness of introductory training	16	6.31	6.31
Comprehension of overall concept of the robot	16	6.31	6.44
Outdoors: How to drive	16	6.19	6.25
Outdoors: Time provided to practice	16	6.13	6.06
Outdoors: How to perform reconnaissance	16	5.81	6.13
Building: How to drive	16	6.19	6.19
Building: Time provided to practice	16	6.06	6.00
Building: How to perform reconnaissance	16	6.13	6.25
Overall training evaluation	16	6.13	6.38

2.2.3 Performance Outcomes

2.2.3.1 Performance on Building Reconnaissance. Overall, Soldiers performed well using either system when performing indoor reconnaissance.

- **Number of items detected**. The mean number of items found for the baseline laptop condition was 22.19 (standard deviation [sd] = 1.05) compared to 21.75 (sd = 1.00) for telepresence. This difference was not statistically significant ($F = 1.05$; df 15, $p = 0.32$,

η^2_p = 0.06). Performance also did not vary between the two buildings. With the laptop system, the means were 22.22 (bldg. 1) and 21.87 (bldg. 2); with the telepresence system, means were 21.25 (bldg. 1) and 22.25 (bldg. 2).

- **Number of items correctly identified**. The mean number of items correctly identified for the laptop was 20.62 (sd = 1.82) compared to 20.12 (sd = 2.65) for telepresence. This difference was not statistically significant (F = 0.38; df 15, p = 0.55, η^2_p = 0.025).

- **Time to complete**. Soldiers' time to complete the building reconnaissance was not significantly different between laptop and telepresence conditions (F = 0.34, df = 15, p = 0.57, η^2_p = 0.22). The mean time for the laptop was 9.39 min (sd = 2.49) and 10.03 min (sd = 1.34) for the telepresence system.

- **Driving errors**. The number of driving errors within the building was not significantly different between the laptop and telepresence conditions (F = 0.01, df = 15, p = 0.91, η^2_p = 0.001). The mean number of errors for the laptop was 2.31 (sd = 2.02) and 2.38 (sd = 1.41) for the telepresence system.

Figure 9 provides summary results for the building reconnaissance performance measures.

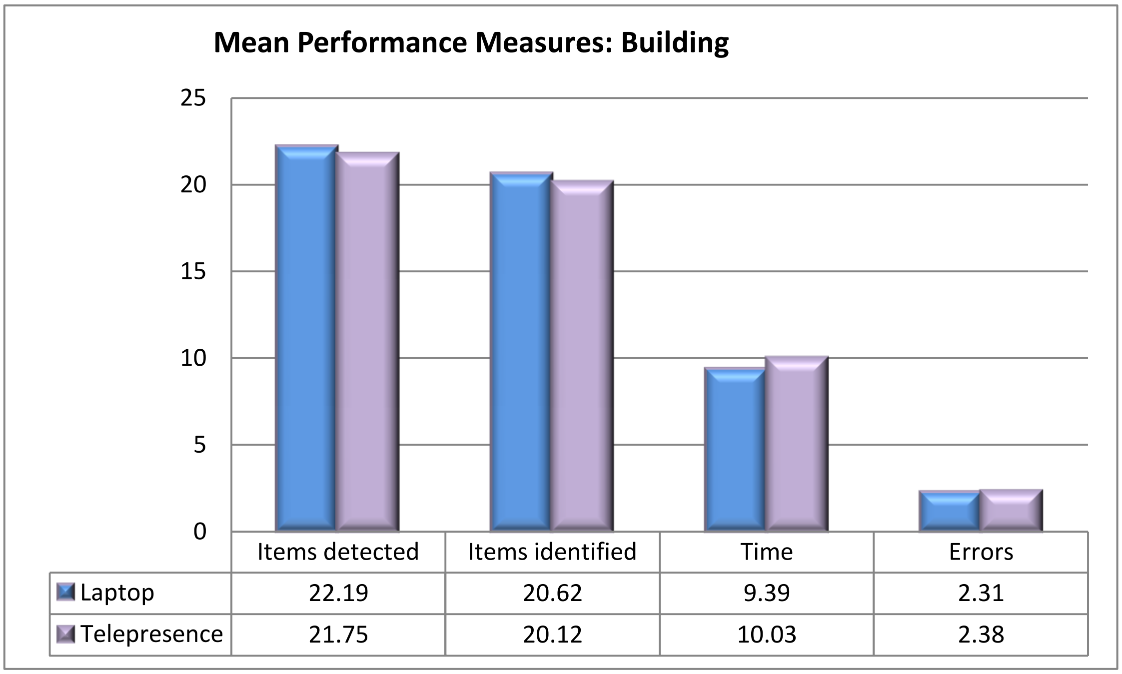


Figure 9. Mean measures of building reconnaissance performance for laptop and telepresence conditions.

2.2.3.2 Performance on Outdoor Reconnaissance. Overall, Soldiers performed well using either system when performing outdoor reconnaissance.

- **Number of items detected**. The mean number of items detected for the laptop system was 5.37 (sd = 2.09) and for telepresence, 4.50 (sd = 1.63). The difference approached significance (F = 3.69, df = 15, η^2_p=0.20, p = 0.07). It should be noted that the eta-square effect size value is considered moderate (from 0.20 to 0.40).

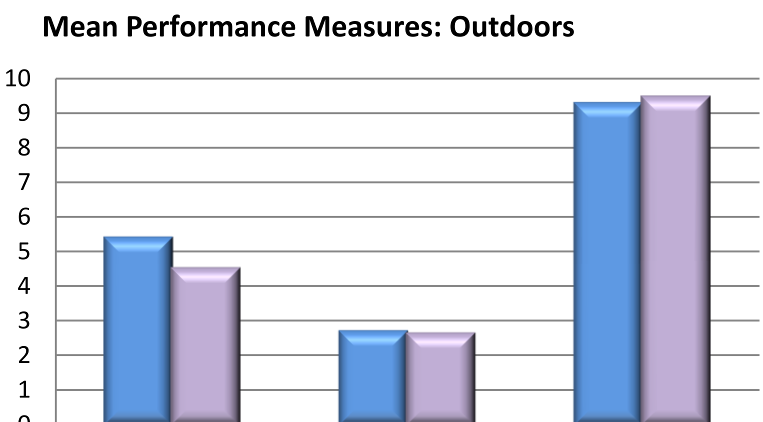
- **Number of items correctly identified**. Data collectors recorded the number of items that were detected but incorrectly identified. Mean values were very low and equivalent among the two systems; the laptop was 0.50 (sd = 0.73) and telepresence was 0.50 (sd = 1.03).

- **Number of waypoints**. This is the number of waypoints that the operator correctly navigated and identified. For the laptop system, the mean was 2.68 (sd = 0.48); for telepresence, the mean was 2.62 (sd = 0.50). This difference was not significant (F = 0.14, df = 15, η^2_p = 0.00; p = 0.72).

- **Time to complete**. The mean time to complete the outdoor course with the laptop was 9.24 min (sd = 3.24); the mean time for telepresence was 9.45 min (sd = 2.57). This difference was not significant (F = 0.16, df = 15, η^2_p = 0.01, p = 0.69).

- **Driving errors.** There were no outdoor driving errors reported for either system condition.

Figure 10 provides summary results for the outdoor reconnaissance performance.



	Items detected	Waypoints	Time
Laptop	5.37	2.68	9.24
Telepresence	4.5	2.62	9.45

Figure 10. Mean measures of outdoor reconnaissance performance for the laptop and telepresence conditions

2.2.4 Soldier-Based Assessments

2.2.4.1 Postiteration Soldier-Based Assessments. Means for all ratings of the laptop and telepresence conditions for outside and inside reconnaissance conditions are provided in appendix A. Ratings were grouped and averaged for particular functions. For example, items pertaining to moving or controlling the camera were clustered to obtain overall ratings for camera control. Table 3 provides means for these item groupings.

Table 3. Mean Soldier ratings for telepresence and laptop systems by indoor and outdoor task context.

Task	No. of Soldiers	Mean Response			
		Outdoors		Indoors	
		Tele	Laptop	Tele	Laptop
Camera control	16	5.22	5.12	5.10	5.14
Moving the robot	16	4.81	5.64	5.41	5.59
Visual identification	16	4.64	5.05	5.06	5.38
Overall Assessments					
Finish the course quickly	16	4.75	5.19	5.44	5.25
Find improvised explosive devices	16	4.25	4.94	5.94	6.31
Maintain situation awareness	16	5.25	5.25	5.25	5.12
Overall ability to perform this reconnaissance	16	4.94	5.62	5.56	5.64

Results appear to indicate a general trend in favor of the laptop; however, the differences were generally small. Only the difference between telepresence and laptop for moving the robot outdoors was statistically significant (p = 0.026). In addition, all ratings were averaged to produce an overall mean for each Soldier for each condition (i.e., laptop-outside, laptop-building, telepresence-outside, telepresence-building). The repeated measures general linear model resulted in an F statistic of 2.93 (df = 3, $\eta^2_p = 0.16$, $p = 0.04$); the means are portrayed in figure 11. Follow-on paired comparison tests showed that no particular comparison was statistically significant.

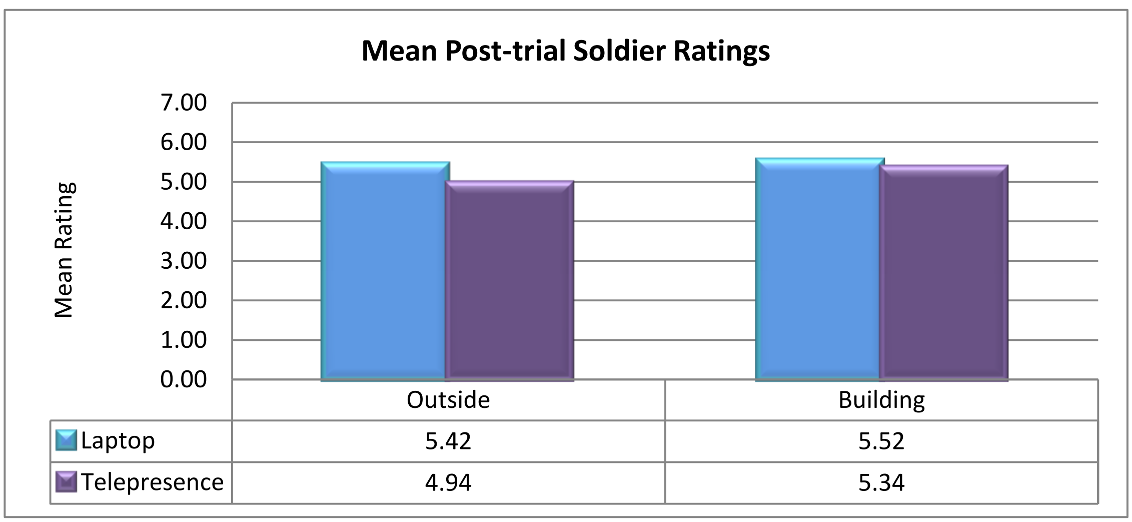


Figure 11. Mean overall ratings for laptop and telepresence for indoor and outdoor performance.

2.2.4.2 Soldier Reports of Discomfort. Table 4 provides a summary of Soldier reports of various symptoms of discomfort. Telepresence was associated with a higher number of reported symptoms, particularly for eyestrain. Comments* regarding the telepresence display consisted of dry eyes (1), poor image quality (3), tunnel vision (1), camera alignment (1), slight motion sickness (1), and "a little blurry for the first 5 seconds" (1).

Table 4. Summary of reports of discomfort.

Symptoms	No. of Responses	
	Telepresence	**Laptop**
Eyestrain	9	3
Tunnel vision	2	0
Headaches	0	0
Motion sickness	3	1
Nausea	1	0
Disorientation	4	2
Dizziness	0	0
Competition between eyes for vision	4	0
Any other problems?	2	0

2.2.4.3 SA Measure. Soldiers responded to questionnaire items that asked their opinion as to what was going on in the buildings and which items led them to their conclusions. These items were used to assess three factors of their SA: perception, comprehension, and projection (Endsley, 1995). Results are provided by building because each building had a different set of items and a different theme.

- **Perception**. First, it should be noted that the primary indicator of SA, attributable to the robot and display capabilities, is the number of items that were detected and correctly identified. As summarized previously in the performance measures section, all Soldiers performed well, with little difference between laptop and telepresence. The mean number of items found for the laptop system was 22.19 (sd = 1.05) compared to 21.75 (sd = 1.00) for telepresence. Performance did not vary between the two buildings. Also, the mean number of items correctly identified for the laptop was 20.62 (sd = 1.82) compared to 20.12 (sd = 2.65) for telepresence. This difference was not statistically significant (F = 0.38; df 15; $\eta^2_p = 0.025$; $p = 0.55$).
- **Comprehension**. Soldiers were good at diagnosing the building situations and providing a plausible rationale (i.e., comprehension). Soldiers were asked what they thought was happening inside the building before the reconnaissance. For the building with the POW theme, 100% of the Soldiers responded correctly (e.g., relevant to POWs) regardless of display condition. Soldiers were less in agreement with regard to the IED building: only

* The number of Soldier reports is provided after each comment.

62% of the Soldiers provided the subject-matter expert (SME)-chosen response (i.e., relevant to a terror attack); however, most of their responses were similar in theme.

- **Projection.** Soldiers were also asked what they thought would occur in the building in the near future (i.e., projection) with regard to the enemy plans. For the question regarding future intent, Soldiers were asked to provide two responses. For the building with the POW theme, 86%–89% of the Soldiers provided a correct response, with no difference between display conditions. For the building with the IED theme, 88% of the Soldiers provided at least one correct response.

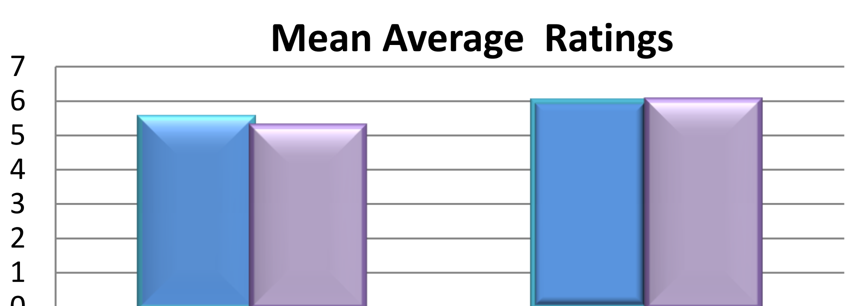
  Soldiers were also asked which items in the building led them to their conclusion. These responses were compared to the list of items identified by an SME. There was more variance in these responses; 67% of the Soldiers agreed with the SME in the laptop condition, and 72% agreed with the SME in the telepresence condition for the POW-themed building. Soldiers agreed on certain core items (e.g., tortured dead body, bloody rags, bedding, battery, jumper cables) but varied in their selection and interpretation of other items. For the IED building, 56% of Soldiers agreed with the SME in the telepresence condition compared to 65% in the laptop condition. Most Soldiers did provide a plausible rationale for their particular selection of items. For example, while "cardboard box" was not identified as critical to the correct situation assessment, those Soldiers who did select the box as a relevant item also inferred that the box represented an intent to pack and move. Similarly, some Soldiers inferred from the presence of weapons and arms that the enemy was surprised and would return to the building later.

2.2.4.4 End-of-Experiment Soldier-Based Evaluations of Controller Characteristics. Mean Soldier evaluations of controller characteristics are provided in table 5. In general, the laptop had slightly higher ratings for display characteristics, while the telepresence condition had some slightly higher ratings for controller features. However, these differences are not likely to be significant.

In order to perform tests of significance, ratings pertaining to displays and to controller features were averaged separately (figure 12). Repeated measures ANOVA analyses were not significant for the display ratings, $F = 1.050$ (df = 16, $\eta^2_p = 0.06$, $p = 0.32$), or for the controller ratings, $F = 0.02$ (df = 16, $\eta^2_{p,} = 0.00$, $p = 0.88$).

Table 5. Mean ratings of controller characteristics.

Controller Characteristics	Mean Response		
	No. of Soldiers	Telepresence	Laptop
Resolution (clarity)	16	5.25	5.81
Size of objects appearing in the display	16	5.25	5.38
Ability to adjust display	15	4.60	4.87
Comfort of viewing	16	4.75	5.81
Display brightness	16	5.25	5.81
Display glare	16	5.63	5.13
Contrast between objects on the driving display	15	5.53	5.47
Display color	15	5.47	5.67
Comfort of using display	16	5.31	5.69
Number of controls	16	5.88	5.50
Control locations	16	6.25	5.94
Size of individual controls	16	6.25	6.13
Complexity of controls	16	6.25	5.88
Ability to use controls without activating other controls	16	5.94	6.12
Size of entire control unit	16	6.56	6.56
Adequacy of this control unit for teleoperation	16	6.00	6.20
Ease of controlling camera (viewing direction)	16	5.38	5.31
Overall assessment of this control unit	16	5.75	5.81



	a	b
Laptop	5.5	5.96
Tele	5.23	5.99

Figure 12. Means of averaged ratings for display and controller features.

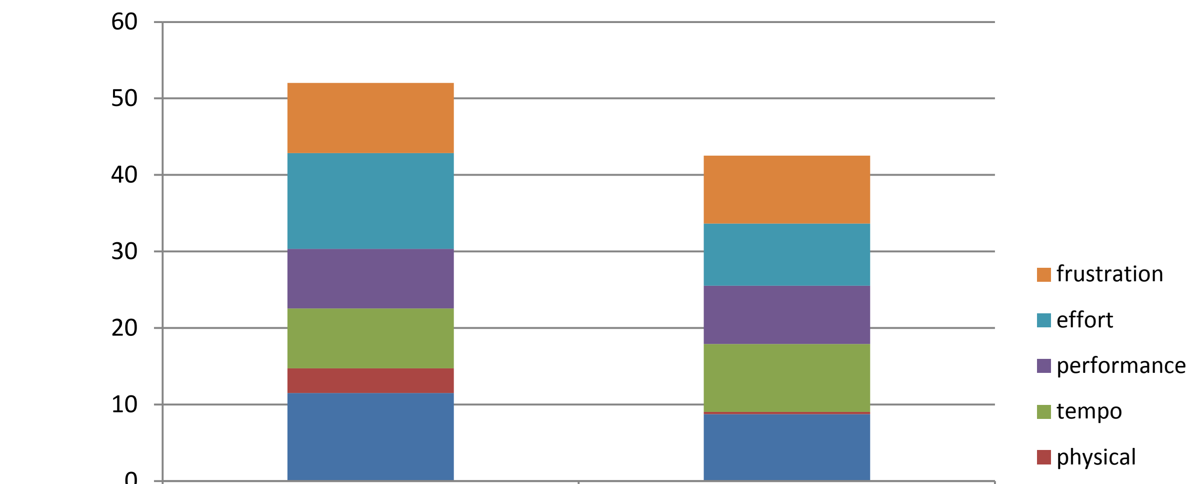
2.2.4.5 End-of-Experiment Soldier-Based Evaluations for Task Performance. Mean ratings for ease of performing tasks are provided in table 6. In general, ratings were slightly higher for the laptop, with the exception of overall ratings for building reconnaissance.

Table 6. Mean ratings for ease of performing tasks.

Task	**Mean Response**		
	No. of Soldiers	**Telepresence**	**Laptop**
Avoiding obstacles	16	5.31	6.13
Assessing terrain for navigability	16	5.81	6.06
Driving straight route	16	5.25	6.13
Driving multiple waypoints	16	5.44	6.06
Looking for objects of interest	16	5.50	5.69
Identifying objects	16	5.44	5.75
Scanning surroundings	16	5.75	5.56
Maneuvering corners	16	5.50	5.88
Maintaining situation awareness	16	5.31	5.87
Overall building reconnaissance	16	5.81	5.63
Overall outdoor reconnaissance	16	5.06	6.00

Ratings were averaged separately for the laptop and telepresence conditions. The mean rating for laptop was 5.82 (sd = 0.61) and telepresence was 5.43 (sd = 0.99). This difference was not significant ($F = 1.76$, df = 16, $\eta^2_p = 0.10$, $p = 0.20$).

2.2.4.6 Workload: NASA-TLX. Mean ratings for the NASA-TLX workload scales are provided in figure 13. Paired *t*-test comparisons were significant for effort (telepresence was significantly higher at $p = 0.005$) and total workload (telepresence mean of 52.0 was significantly higher than the laptop mean of 42.53, at $p = 0.05$).



	Telepresence	Laptop
frustration	9.14	8.88
effort	12.53	8.1
performance	7.75	7.63
tempo	7.84	8.84
physical	3.24	0.29
mental	11.51	8.78

Figure 13. Mean NASA-TLX workload ratings.

2.2.5 Soldier Comments and Suggestions

Soldiers provided numerous comments throughout data collection in response to open-ended questions. All comments are listed in appendix A, organized by questionnaire. The following tables consolidated comments across all questionnaires in order to categorize the comments with regard to (a) favorable, (b) concerns, and (c) suggestions for improvement.

2.2.5.1 Favorable Comments. Table 7 provides favorable Soldier comments in general order of the number of comments.

Table 7. Summary of favorable comments.

Comment Category	No. of Comments: Telepresence	No. of Comments: Laptop
Easy to use (in general).	11	16
Overall system (great system, etc.).	6	2
Easy to use indoors.	9	2
Easy to see indoors.	7	3
Easy to see through robot eyes.	6	0
Easy to maneuver.	3	2
Easy to maneuver indoors.	2	0
Easy to use outdoors.	4	3
Easy to identify objects.	2	0
Easy to use camera.	2	1
Red and green lines make it easy to orient camera.	0	1
Re-center button is very helpful for quick correction.	0	1
Controls sensitive, responsive.	2	0
Navigation easier after practice.	2	1
Telepresence more effective indoors, particularly to maneuver and have situation awareness.	2	0
Movement speed of the robot was excellent (easy to control; responsive).	1	0
Stereo vision was helpful.	2	0
Controls easy to use.	1	0
Map display very useful.	0	1
Prefer controller to telepresence.	0	1
The "1" button to re-center the eyes to the body was very useful.	0	1
More comfortable, felt less time pressure.	1	0
Better for indoors.	2	0
Better for outdoors.	0	1
Better for observations.	2	0
More familiar.	0	1

2.2.5.2 Concerns. Table 8 provides Soldier comments of concern in general order of the number of comments.

Table 8. Summary of concerns.

Comment Category	No. of Comments: Telepresence	No. of Comments: Laptop
Video resolution (poor, lower, etc.).	11	4
Slight disorientation during quick head movements; head movements difficult while moving quickly; camera jumped around; difficult to adjust camera; hard to keep camera steady.	7	0
Camera moves too quickly, jerky, would freeze.	0	6
Headpiece bulky and rear cords constrained movement.	4	0
Difficult to maneuver and search at same time.	0	3
Nausea.	3	0
Camera controls too sensitive.	0	2
Hard to see when looking down at my feet.	2	0
Lag between operator and camera movements.	0	2
Difficult to maneuver robot indoors around turns.	4	0
Rough terrain made movement difficult.	2	0
Not for urban ops.	2	0
Lag between operator and robot motions.	1	0
Camera height (too high) hard to know if on course.	1	0
Robot seemed to veer when moving forward and looking around at same time.	1	0
Navigation with headset required switching back to map to drive to waypoints, but then can't see IEDs.	1	0
Alignment of head movement and camera: "The alignment of me facing forward with the robot eyes facing forward with the robot body was gradually drifting out of alignment. This meant that after some time, I would face front, but the robot was not facing straight ahead but off to the side, and I would have to re-calibrate the robot to face front."	1	0
Robot kept spinning in circles on its own.	1	0
Camera would freeze and system rebooted.	1	0
Had to be recalibrated.	1	0
Commands entered (such as "view satellite map" button) wouldn't work.	1	0
Difficult to maintain SA outdoors while moving. Controls did not feel smooth.	0	1
Controls confusing, hard to keep track of each button function.	0	1
Smaller size of rooms, thus more difficult to maneuver indoors.	1	0
Rooms seemed smaller than they really were.	1	0
Taking pictures hard, because had to switch screens and select a category.	1	0
Robot bulky, hard to maneuver.	1	0
Bumpy terrain contributed to slight motion sickness, resolved by mono.	1	0
Don't need stereo, mono is good.	1	0
Laptop map good for outdoors recon.	0	1
Controller and display did not feel like one unit.	0	1
Sometimes hard to see antennas, made it hard to navigate turns.	1	0
Too small (display).	0	1
Waypoint ID difficult because of two maps (toggling between).	1	0

2.2.5.3 Suggestions. Table 9 provides Soldier comments of suggestions in general order of the number of comments.

Table 9. Summary of suggestions.

Comment Category	No. of Comments: Telepresence	No. of Comments: Laptop
Needs bigger video and smaller map.	0	12
Increase size of camera display.	0	7
Improve resolution.	8	5
Needs zoom function.	4	6
Put a small map display at the bottom of the telepresence screen.	5	0
Invert the Y axis of the camera controls.	0	4
Need ability to customize screen, change size of displays, etc.	0	2
Use a head-mounted sensor to direct the robot's eyes, but let the user view the video (mono) on a laptop screen. Resolution was much better on the screen.	2	0
Would like more control of volume on the handset, especially when going over rocks.	1	0
Prevent video freezing.	1	0
Fix camera drift, so that forward is always forward.	2	0
It would help a lot if I could make the robot have slight turns of its head at first. Then its head moves faster as I push the controller harder or hold it down longer.	0	1
Adding 360° ability would enable the robot to navigate around turns better. Hard to judge how far you can swing out.	0	2
Add rear camera.	0	1
The camera – there needs to be a sound effect or some kind of indication or flashing light or something to confirm I took a picture. Sometimes a small image of the photo I took would appear, and when there were several pictures to take at once it was unclear if I got the picture or if the button didn't push or what.	0	1
Make camera control less sensitive.	1	1
Have camera higher off the ground.	0	1
Make camera less jumpy when head is moved.	1	0
Add option like tapping the "eyes left" stick twice to make the robot look 90° left.	0	1
Make predefined functions, such as "right face," "left face," etc.	0	1
Mount from ceiling.	1	0
Attach the cord so it does not slip or get caught.	1	0
Put list of objects on both views.	1	0
More contrast between colors.	1	0
Wider peripheral view.	1	0
Lighter headpiece.	1	0
Don't need stereo.	1	0
Add keyboard for control (as well as joystick).	0	1

2.2.5.4 Overall Preference. Table 10 provides the number of Soldiers preferring the telepresence or the laptop system overall. While Soldiers had some concerns with the telepresence and often rated it less highly for current characteristics and capabilities, 9 of the 17 Soldiers preferred the telepresence display.

Table 10. Number of Soldiers preferring each system.

No. of Responses in Favor of:	
Telepresence	**Laptop**
9	6

2.3 Summary and Discussion

In this preliminary investigation, we explored the relative utility of two telepresence capabilities (head tracking and stereo vision) for indoor and outdoor reconnaissance tasks. Two robot controllers, developed by TNO, were compared: (1) a baseline laptop controller that used a gaming joystick for robot and camera control and (2) a partial telepresence controller that used a head-mounted camera controller and stereo vision.

Overall results showed little difference in task performance measures between the two controllers. Soldiers performed well with both types of controllers for detection and identification of items, driving performance, and driving speed (i.e., course completion time). Soldier evaluations were also similar, rating both systems favorably. There were, however, more reports of Soldier eyestrain with the telepresence system and higher values for estimates of workload. Reports of eyestrain, headache, or motion sickness have been associated with telepresence, similar to experiences of virtual reality, and compounded by technical issues, such as camera lag or interocular adjustments regarding the stereo display (Van Erp et al., 2006). Soldiers commented that the visual display was not as clear with the stereo vision (telepresence system) compared to the laptop, and that they preferred the higher clarity of the mono display (laptop system). They also commented that the telepresence system was heavy and bulky on the head.

While Soldiers performed well with both controllers, they also provided many comments with regard to how each system could be improved. All of the Soldiers suggested that the laptop controller have a larger camera display to take up more of the laptop screen. In this study, the 4-in camera screen size was made to be equivalent to a U.S. laptop-based robot controller display (i.e., the MOCU, multirobot operator control unit). Other common suggestions were to improve resolution and add a zoom function to both displays. In addition, they suggested adding a map to the telepresence display and inverting the Y axis of camera controls for the laptop display. It should be noted that, comments withstanding, more of the Soldiers preferred the telepresence controller to that of the laptop. Comments appeared to acknowledge the potential of the telepresence approach once certain improvements are made to it.

As a result of this study, several improvements have been made to the telepresence controller. The synchronization between left and right stereoscopic channels has been improved. In addition, the visual quality for each channel has a higher pixel resolution. TNO is also improving procedures to verify depth perception.

In the next experiment (2), task demands will be tailored to better assess telepresence capabilities. For example, in the current experiment, the visual search task included only items placed on the ground. To better investigate ease of camera control, we will place items in a variety of locations such that the robot camera will have to look up, around, and behind objects. In addition, we will include a visual tracking task, where the robot controller will be asked to track and identify the movements of a human confederate who will move about while placing and picking up items. The robot controller will have to describe these movements and behaviors. The stereo vision capability will be further evaluated through an object manipulation task. In addition, task demands will also evaluate 3-D audio relative to mono audio capabilities; the robot controller will be asked to quickly locate audio signals.

3. Experiment 2

Experiment 2 builds upon experiment 1 through the investigation of stereo vision and head tracking capabilities for a visual search task. In this experiment, the visual search task included items that were located above the robot as well as items placed on the ground. In addition, 3-D audio capability was also compared to mono audio for an audio-based target localization task. While search tasks are primarily visual in cognitive demand, in combat situations there are many vital cues that are auditory in nature and often indicate a threat or need for attention.

3.1 Method

3.1.1 Scenario

For this experiment, we developed two indoor reconnaissance tasks. In the first reconnaissance task, we placed various items of military interest (e.g., various ordinances as in experiment 1) within an indoor environment simulating a military room-clearing task. Items were placed in various locations, on the ground and also above the robot. For this task, we associated particular items with an audio cue. For each search task, a single audio cue was activated. The operator was required to search for the particular item associated with the audio cue as quickly as possible. They were then instructed to approach the item as close as possible without disturbing it.

In a second task, various items were placed in the room, some of which were distinguished with a distinct audio cue. For this task, operators were requested to search for all items and build a mental map of as many items as they could remember. They were then requested to indicate, on a paper map, which items they remembered in particular locations.

3.1.2 Participants

Twenty-two Soldiers were recruited from the OCS to participate in the study. Solders included those with prior service as well as those who entered OCS directly from college. Eighteen Soldiers were able to participate fully; other sessions had to be cancelled, two due to time constraints and two due to discomfort (e.g., nausea).

3.1.3 Equipment and Instruments

3.1.3.1 The Generaal UGV. The same robot used during experiment 1 (Generaal) was used in this experiment (see experiment 1 for description). In this experiment, we also used the Generaal's 3-D audio capability. Figure 14 shows the robot and stereo vision and stereo audio features.

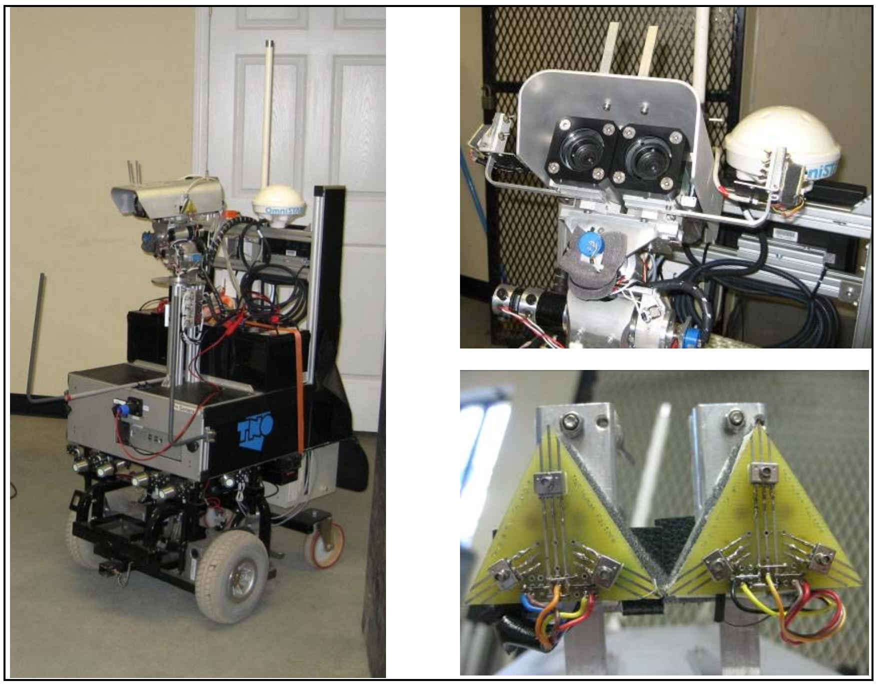


Figure 14. Unmanned vehicle "Generaal" stereo vision and 3-D audio features.

In figure 14, the left panel shows the vehicle with a forwardly directed red-tipped pointer at the mid-front for approaching targets, vertical antennas for visual assistance in close maneuvering, and a sensor unit on a pan-tilt-roll motion platform with 3-D audio and stereo visual sensors. The sensor unit is enlarged in the upper-right panel, in the microphone array placed in their 3-D audio position, at either side of the stereo cameras. The lower-right panel shows how the two microphone arrays were placed in the middle position right above the stereo cameras, to get a directional mono sound.

The TNO Generaal is a manually controlled UGV with a fast and powerful pan-tilt-roll camera or sensor system that can accurately mimic human head movements (Jansen et al., 2010). On top are two cameras for providing stereo vision at the control station and two microphone arrays that can be positioned at either side for spatial 3-D audio or next to each other in front, thereby functioning as a mono audio condition. The horizontally positioned, forwardly directed pointer in front of the vehicle was the reference point for the participants in approaching the target as closely as possible.

3.1.3.2 The Generaal Telepresence Controller. The same Generaal control unit used during experiment 1 was used in this experiment. However, 3-D audio reception was also included. The text displays used in experiment 1 were not necessary in this experiment. Figure 15 shows the controller; the dual image is shown on the laptop. The user sees the integrated stereo view of the laptop image.

Figure 15. Telepresence controller (image displayed on laptop).

3.1.3.3 Building Reconnaissance Course. The building reconnaissance course (figure 16) was located at ARL's Human Research and Engineering Directorate facility at the McKenna MOUT site, Fort Benning, GA. One building with several rooms was further segmented using padded partitions. Rooms in the building had tables, chairs, computers, and other furnishings.

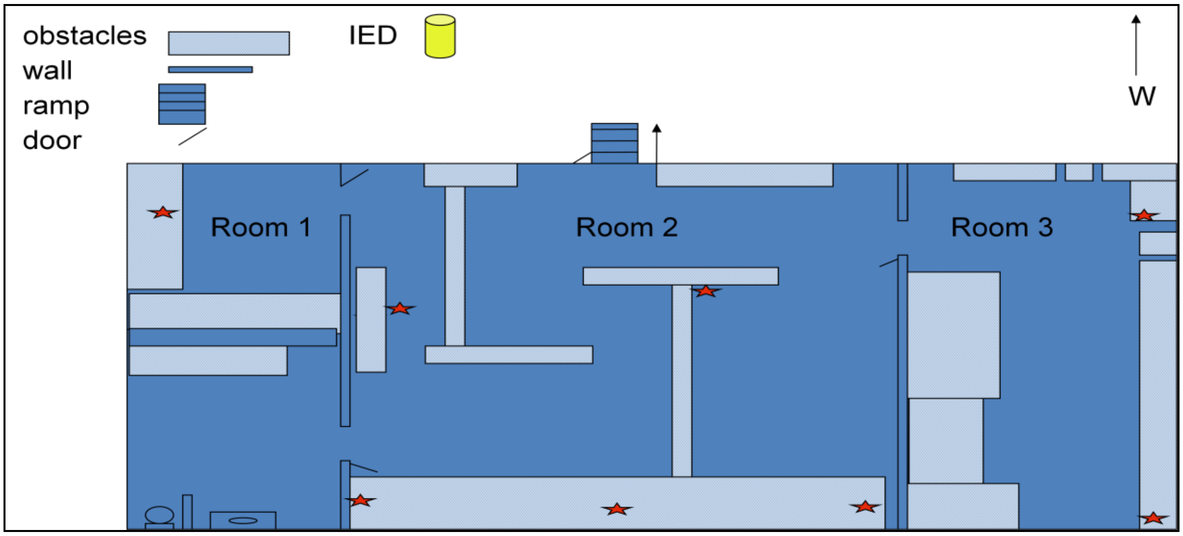


Figure 16. Indoor route reconnaissance course.

Figure 17 shows the general layout, with positioning of target items for the audio search task. It provides a map of the target environment depicting the robot's starting location, the decoy and practice targets (gray boxes), and real targets (F and I were used in practice trials). Targets K and J are in a room adjacent to the larger room with the other targets. The gray T-shapes subdivided the larger room. Figure 18 shows a panoramic view in which some targets are marked by labels and arrows.

Eleven possible target objects varying in size were positioned at different height levels in the reconnaissance environment. The underlined items were used as targets in the experimental trials; the italic items were used in the practice trials; and items A, C, and K were decoy targets that were never used. Wires and speakers were included for these three as well.

(A) Soda can bomb on a table

(B) <u>Hand grenade on the ground</u>

(C) Soda can bomb on the ground

(D) <u>Hand grenade near the ceiling</u>

(E) <u>Semtex on the ground</u>

(F) *Bomb shell on a table*

(G) <u>Pipe bomb on the ground</u>

(H) <u>Semtex with timer on a chair</u>

(I) *Mine on a water container*

(J) <u>Land mine on a high cupboard shelf</u>

(K) Land mine on a high cupboard shelf

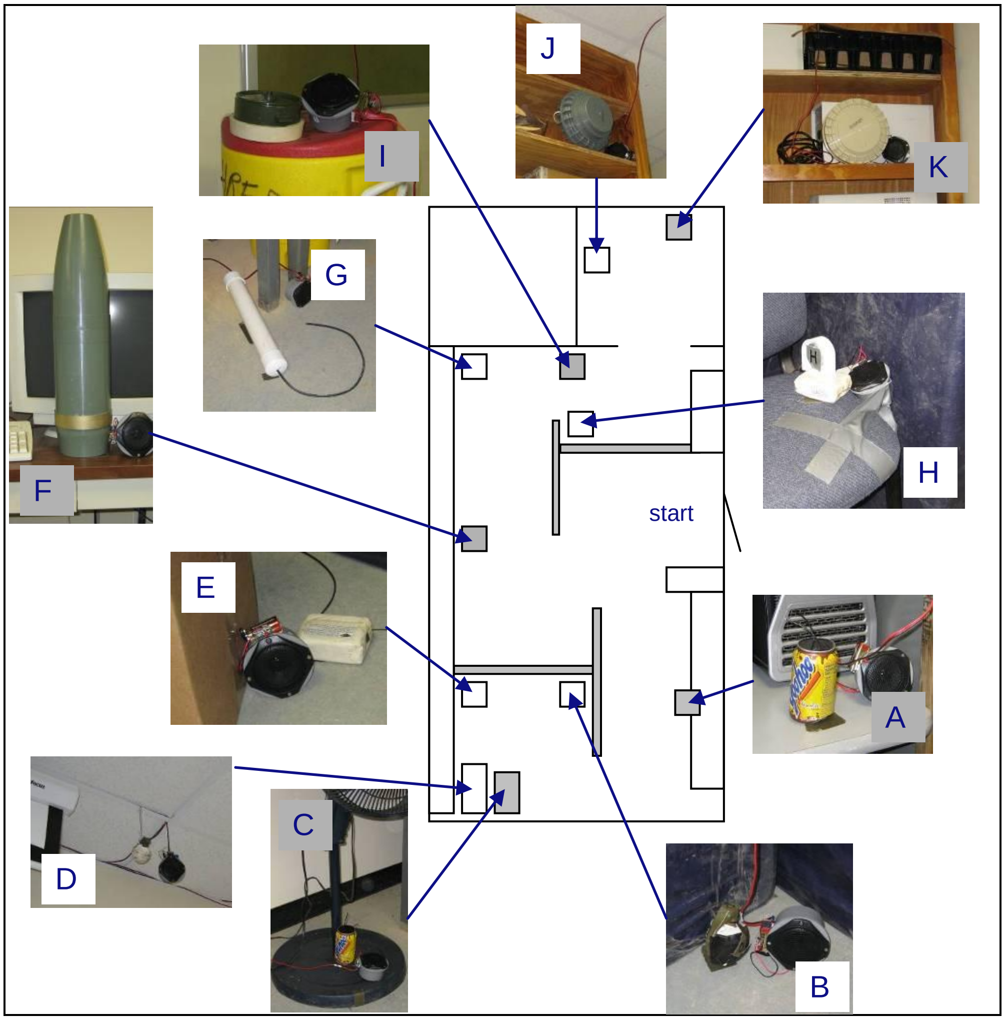


Figure 17. Room configuration and locations of audio target search items.

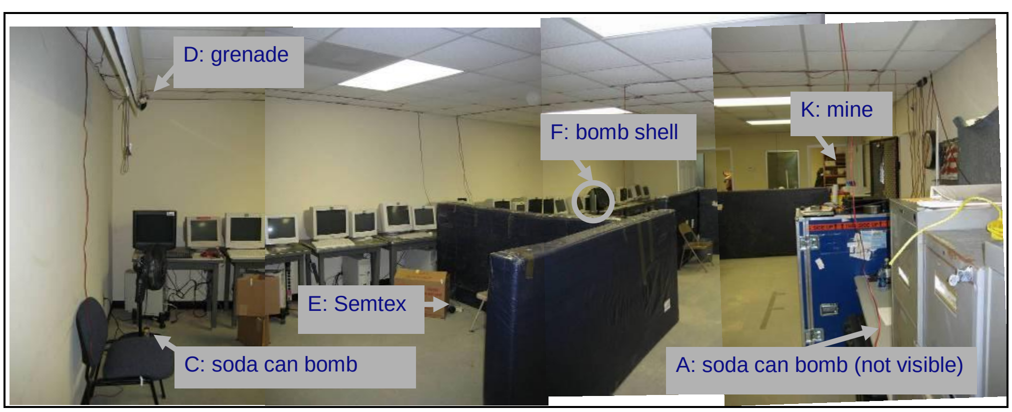


Figure 18. Panoramic view on the target environment.

The control station was located in a tent next to the building of the reconnaissance environment (figure 19). The control station consisted of a user interface with an NVIS nVISOR HMD (stereo or mono), an Xsens MTi motion sensor as a head tracker, stereo headphones, and a Logitech Dual Action game controller.

Figure 19. Reconnaissance environment and tent with control station.

3.1.3 Procedures

3.1.4.1 Soldier Orientation. The Soldier participants reported in groups of four for 1 day each, from 0800 to 1800 daily. After arrival, they received a roster number to identify them throughout the evaluation and protect privacy information on the data sheets. The Soldiers were oriented on the purpose of the study and their participation. They were briefed on the objectives, procedures, equipment, the reconnaissance course, and reconnaissance tasks. Experimenters answered any questions the Soldiers had concerning the experiment. They were also told how the results would be used and the benefits the military could expect from the investigation. For this experiment, all Soldiers volunteered to participate and signed consent forms (appendix C).

3.1.4.2 Demographics. Soldiers were requested to provide demographic data about their physical characteristics and military experience, including their knowledge of operating remote-controlled vehicles. The demographic sheet and data summary are provided in appendix A.

3.1.4.3 Training and Task Demands. No specialized experience was required from the requested Soldiers. A representative from ARL presented an overview of the experiment, the reconnaissance courses, and task demands. Representatives from TNO trained the Soldiers on the use of their robot control systems. Soldiers were given hands-on training on the TNO controller immediately before using the interface.

The detailed instructions entailed a directed walk through the task environment, during which the TNO researcher pointed out the 11 locations and corresponding items that could be used as targets (only 6 of those were used as real targets, 2 were used for practice, and 3 were decoys). They were also introduced to the robot and its sensor system and trained on how to operate it using the joystick control. Then they practiced maneuvering the robot (turn around, make a 90° right turn, go through a doorway, make a turn in that room, and return) and sensors (look left, right, up, and down) while having a direct view of the robot. The participants were shown the extensions at the lateral front side of the robot that assist in maneuvering the robot. They were instructed to make sure that the robot did not collide with any object, furniture, wall, etc. The second part of the instruction was at the control station. The three user interface setups were explained. For each setup, the participant performed a practice trial to a practice target. This was done in the same order of the three setups as used in the experimental trials, with F, I and again F as practice targets, respectively.

Before starting the experimental task, the participant was informed about the possible occurrence of motion sickness when using HMDs. The experimenter explained the first symptoms and explicitly asked the participant to take a break if these symptoms were experienced. If these symptoms become more severe after continuation, the researchers would stop this Soldier's participation in the study.

For the SA task, the Soldiers did not receive further training on the controllers because the SA tasks were performed after all audio search tasks were completed. For the SA task, Soldiers were not walked through the rooms but were told there would be many target items and to visually search for as many as possible, trying to remember each item and its location. Training evaluation questions were included in the postiteration questionnaire regarding adequacy of training and requests for comments and suggestions. Soldiers indicated high satisfaction with training. A seven-point scale from extremely bad to extremely good showed the mean rating for verbal training was 6.28 and for the practice session, 6.17. Tasks related to head-mounted camera control were reported to be easiest to learn. Tasks related to joystick control of movement were reported as more difficult.

3.1.4.4 Task Execution. After Soldiers completed training on a particular interface, they completed the audio search task with each controller condition in counterbalanced order. At the beginning of each trial, the robot was placed at the starting position. The trial started with the presentation of a repetitive sound from one of the target locations ("help . . . help," every second). The participant was instructed to locate where the sound was coming from by identifying the object that was positioned next to the speaker making the sound. Once identified, the participant had to maneuver the robot to approach the object as closely as possible by minimizing the distance between the object and a pointer attached at the front of the robot. The maximum allotted time was set at 10 min for each trial. If a participant would have needed more than these 10 min for more than four trials, he or she would be excluded from further participation.

The participant was told these objects were considered IEDs, therefore it was of the utmost importance that they correctly identify the target as fast as possible. Corrections were allowed; the final identification was used for performance measurements. After identification, the participants were told they should immediately continue to approach the target. During this approach it was most important not to collide with the target object. They should approach the object as closely as possible, and they were informed that we would use time to final approach as a performance measure.

During task execution, a TNO experimenter and an ARL experimenter observed Soldier performance, recorded performance measures, and noted any issues.

After all Soldiers completed the audio search task, they rotated through the SA task. Twenty-two items were placed throughout the rooms. Operators were requested to search the rooms, taking note of all items of interest, and to try to remember all items and their locations. They were then given a diagram that specified the various locations where the items were placed, provided with a pictorial list of the items (figure 20), and asked to indicate which items were clearly remembered to be at particular locations.

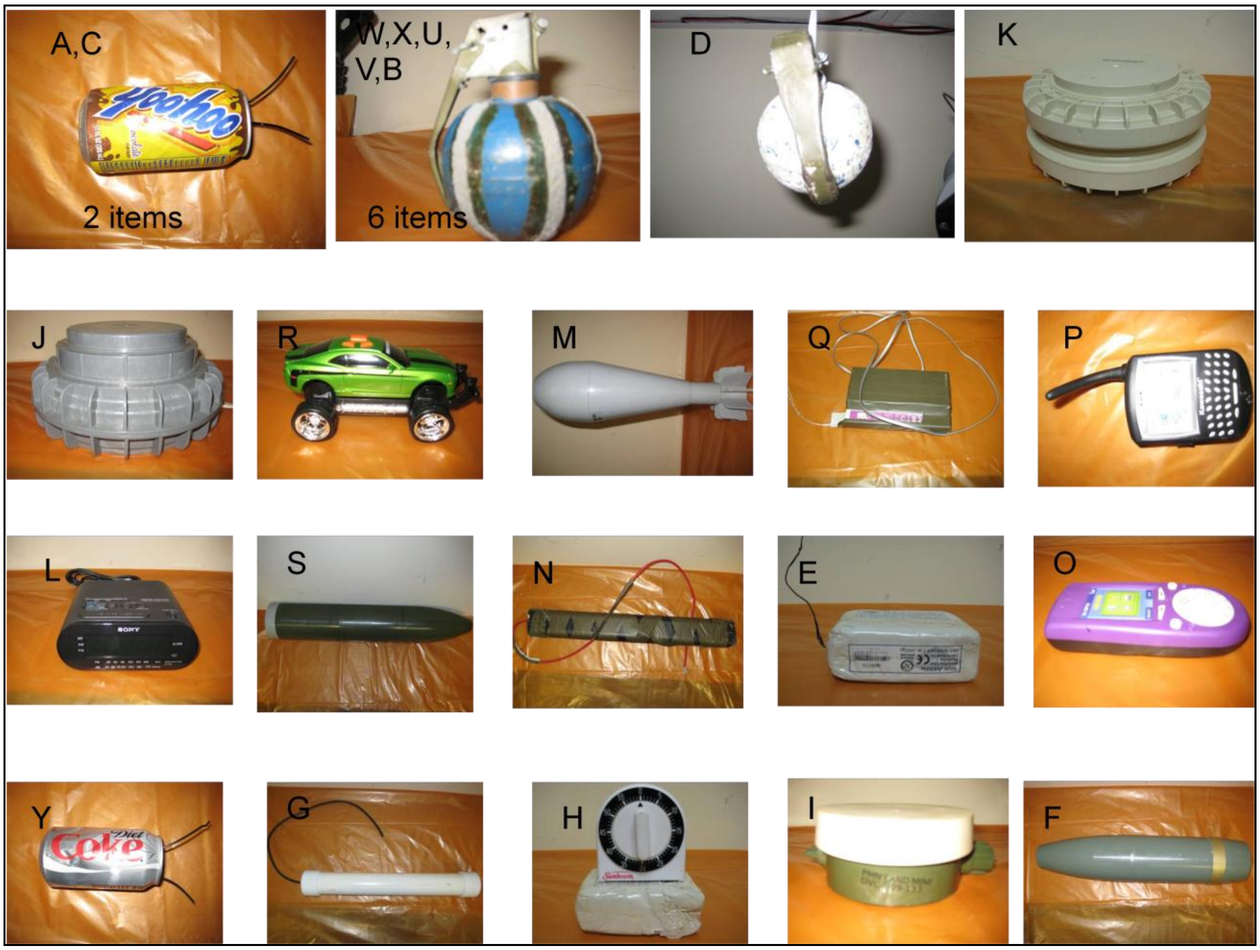


Figure 20. SA search task items.

A data collector accompanied the robot to report start and stop times, times off course, and driving errors. Another data collector was present at the control station to record the number of objects found and report performance measures. Upon completing the iteration, the Soldiers moved to a questionnaire area to fill out questionnaires concerning the exercise just completed (appendix A) and to fill out a NASA-TLX concerning the level of workload experienced (appendix B).

Once Soldiers completed the audio search task, including the questionnaires, they joined the other Soldiers in a waiting area. Soldiers were requested, emphatically, to refrain from discussing their experience among themselves. Experimenters were nearby to monitor and enforce this request. Soldiers remained in the waiting area until they were called for their SA task. After both tasks were completed, Soldiers filled out an end-of-experiment questionnaire. For the Soldiers, participation in this experiment took ~2 h to complete both iterations, with all data collection accomplished in ~8 h in a single day. All Soldiers were available during the 8 h.

3.1.4 Experiment Design

This experiment was a within-subjects design with three levels of robot control interface for the audio search task:

- MJ (Mono Joystick): Mono audio and video on HMD, with joystick control for robot movements and heading of camera sensor system. Operators must control the camera with the joystick; in addition, they were asked not to move their heads.
- MH (Mono Head Tracking): Mono audio and video on HMD, with joystick control for robot movements and head tracking for directing the sensor system.
- T (Telepresence): Stereo audio and video on HMD, with joystick control for robot movements and head tracking for directing the sensor system.

Each participant performed the sound detection task 18 times. We did not include the first four participants because their training was somewhat different. Participant 14 dropped because of nausea. Each of the six targets was used for each of the three conditions. After each trial, the participant switched to one of the other two experimental conditions. For example, participant 5 started with MH in the first trial to detect target B, switched to MJ in the second trial to detect target D, then to T for target H, then continued with MH for the fourth trial for localization of target G, etc; in this example, the pattern of MH-MJ-T repeated for all 18 trials. The pattern was counterbalanced between participants (table 11). Participant 22 had to stop because of motion sickness.

Table 11. Assignment of participants to repeating pattern of user interface setups.

Participant No.	Order of Condition Presentations
10, 15, 20	MJ – MH – T
11, 16, 21	MJ – T – MH
5, 8, 12	MH – MJ – T
7, 18	MH – T – MJ
6, 13, 19	T – MJ – MH
9, 17, (22)	T – MH – MJ

The order of targets was the same for each participant: B, D, H, G, B, E, H, J, D, J, E, B, D, H, G, E, G, J. This target order guaranteed that all targets were used a single time for all three user interface setups. We controlled for practice effects and for confounding effects for combinations of target and user interface by varying the order in which user interface setups were presented among participants while keeping the order of targets the same for all participants. Table 12 shows the order of trials for participant 5 as an example.

Table 12. Representative target presentation for operator 5.

Trial	User Interface Setup	Target ID
Practice 1	MH	F
Practice 2	MJ	I
Practice 3	T	F
1	MH	B
2	MJ	D
3	T	H
4	MH	G
5	MJ	B
6	T	E
7	MH	H
8	MJ	J
9	T	D
10	MH	J
11	MJ	E
12	T	B
13	MH	D
14	MJ	H
15	T	G
16	MH	E
17	MJ	G
18	T	J

For the SA search task, there were only two controller conditions: full telepresence and baseline, presented in a within-subjects experiment design. Each Soldier performed the SA search task with each controller condition, in counterbalanced order. Soldiers performed in pairs, such that when Soldier 1 completed his/her first condition, they then proceeded to the questionnaire station to provide feedback, while Soldier 2 begins his/her first condition. Soldier 1 then returns to complete the second condition, and so on.

3.1.5 Measures

Measures included aspects of performance, workload, and Soldier evaluations.

3.1.5.1 Performance Measures. Performance measures included the following:

- Audio search course completion time
- Time to approach each target item
- Distance to each target item
- The type and number of correct objects found for the audio search task
- The type and number of correct objects and locations for the SA task

3.1.5.2 Workload. The NASA-TLX requires the rater to examine multiple combinations of dimensional levels and derive an overall workload score (Hart and Staveland, 1988). In addition, the Soldier evaluations included ratings of difficulty for specific tasks. A further description of the TLX is included in appendix B, and the Soldier evaluations are included in appendix A.

3.1.5.3 Situation Awareness. After the SA task, Soldiers completed a questionnaire that provided locations of all items in the building. They were also provided with a picture of each type of target item (all were different), each indicated by a letter. Each Soldier was asked to indicate which items were placed in each location. They were asked not to guess but to list only the items they were fairly certain about.

3.1.5.4 Soldier-Based Evaluations. Soldiers completed a postiteration questionnaire after each task, and one final questionnaire. Questionnaires inquired about the operator's experience with the controller units, overall assessments, and comments. The questionnaires were designed to elicit Soldiers' opinions about their performance and experiences with each of the control systems. The questionnaires asked the Soldiers to rate the devices on a seven-point semantic differential scale ranging from "extremely good/easy" to "extremely bad/difficult." Copies of each questionnaire are included in appendix A.

3.1.6 Data Analysis

Descriptive statistics were calculated for each measure. Performance data were analyzed using repeated measures ANOVA. Follow-on pairwise comparisons were calculated using Holm's Bonferroni procedure (Holm, 1979) to control for family-wise error rates. Partial eta squared (η^2_p), an index of effect size, was computed for each ANOVA (see footnote on p. 15).

3.2 Results

3.2.1 Audio Search Task

3.2.2 Time to Find Target Item

Figure 21 provides the mean times and standard deviations for time to approach target items for each controller condition. Time was shortest for full telepresence and longest for the mono joystick condition. Two-way repeated measures ANOVA of both display type and target type showed significant differences among the means for display ($F(2,14) = 12.42$, $p = 0.00$, $\eta^2_p = 0.64$) and for targets ($F(5,11) = 15.14$, $p = 00$, $\eta^2_p = 0.873$). In addition, the interaction between display type and targets, while not significant using the p-level (due to df), had a very high effect size, indicating that displays were particularly effective for some targets ($F(10,6) = 2.43$, $p = .14$, $\eta^2_p = .80$). Follow-on Holm's Bonferroni paired comparison tests for audio search times are provided in table 13.

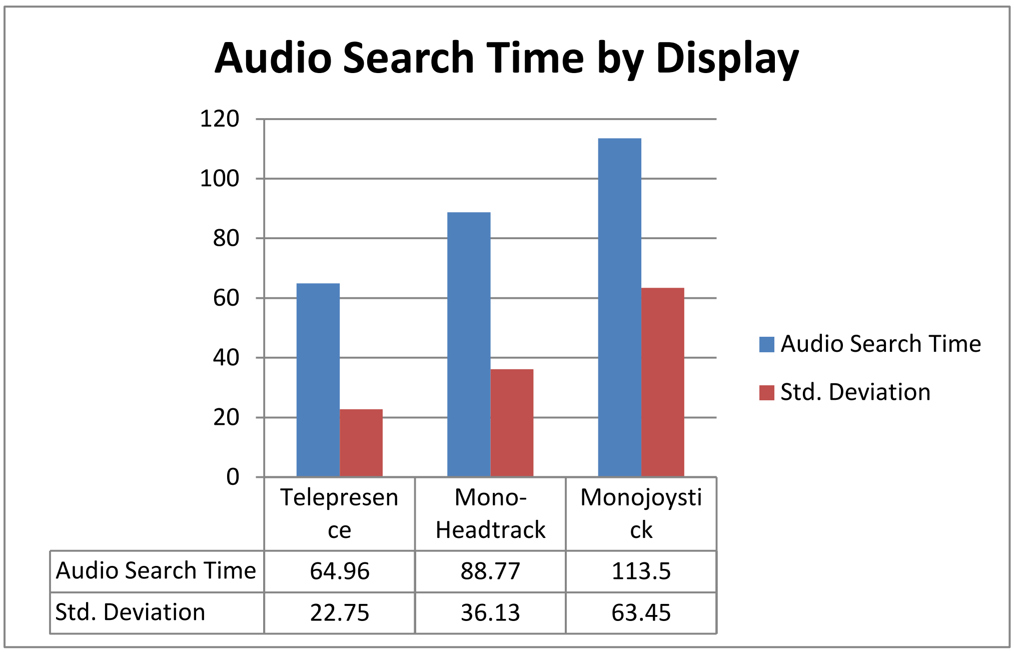


Figure 21. Mean time and standard deviations for time to approach for each controller condition.

Table 13. Holm's Bonferroni paired comparisons for mean times (audio search task).

Pair	*t*	df	Obtained *p*	Required *p*
Telepresence vs. mono joystick	4.345	15	0.001[a]	0.05
Telepresence vs. mono head track	4.232	15	0.001[a]	0.0167
Mono joystick vs. mono head track	2.337	15	0.034	0.025

[a] Met requirements for statistical significance.

Figure 22 provides the mean audio search time by display and target.

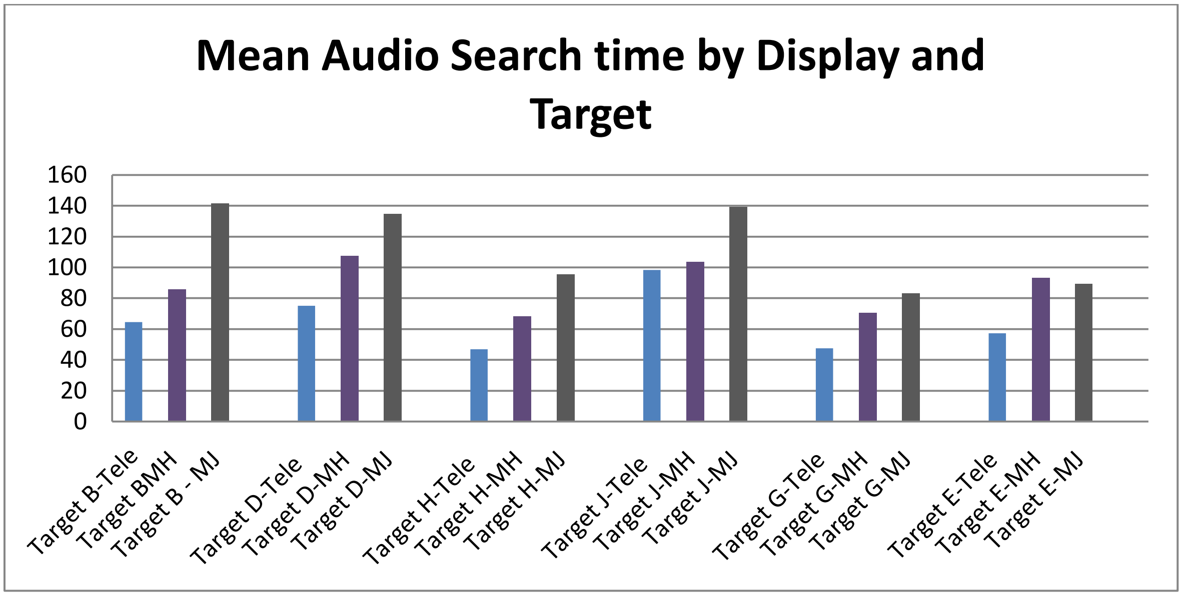


Figure 22. Mean audio search time by display and target.

3.2.3 Time to Approach Target Item

A repeated measure ANOVA on time to target identification included both display and target as variables in order to assess degree of interaction. It indicates a main effect for display ($F(2,14) = 15.18$, $p =.000$, $\eta^2_{p} = 0.68$) and a main effect for target ($F(5,11)= 10.07$, $p =.001$, $\eta^2_{p} = 0.82$). While the interaction term p-value was not significant, the effect size was very high ($F(10,6) = 1.66$; $p = 0.276$, $\eta^2_{p} = 0.73$). Effects can be seen in figure 23. Post-hoc Holm's Bonferroni results are provided in table 14. All comparisons were significant.

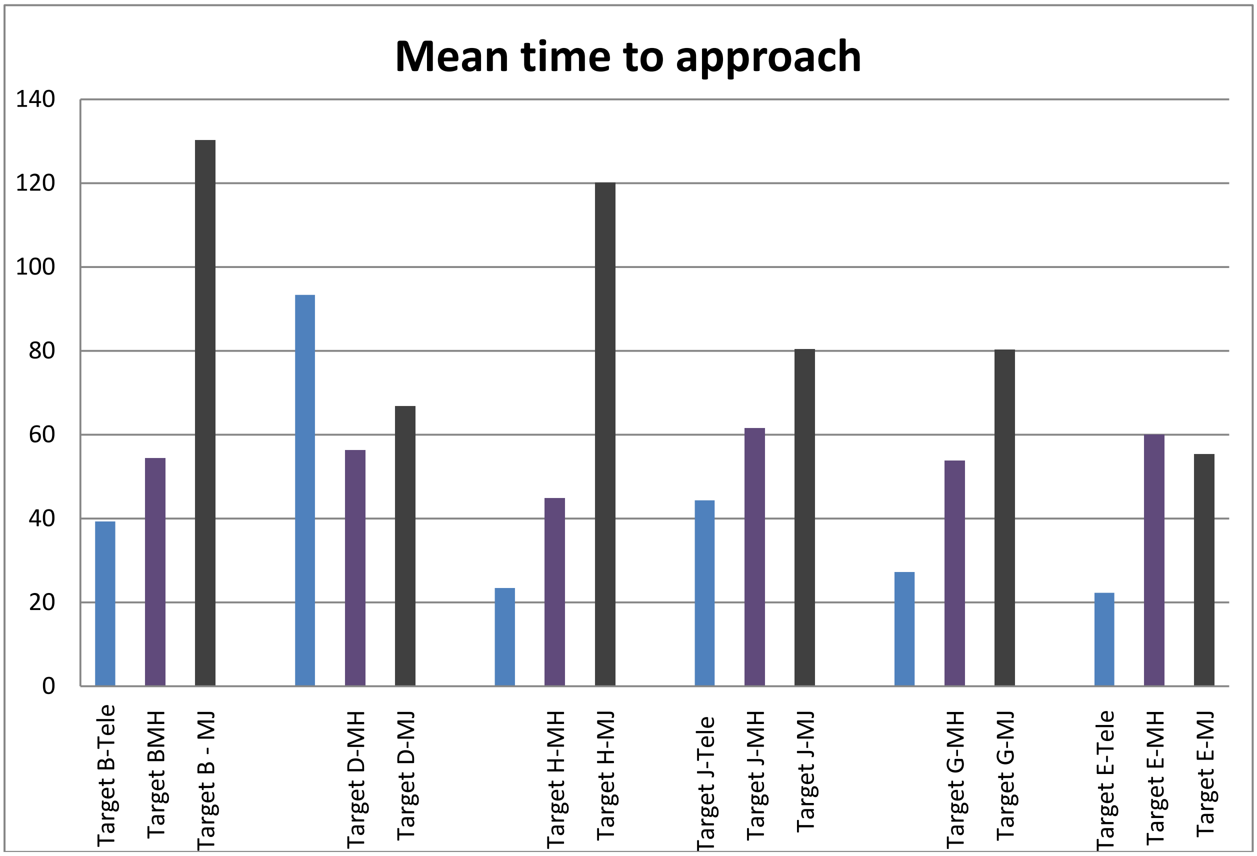


Figure 23. Mean time to approach.

Table 14. Holm's Bonferroni paired comparisons for mean time to approach (audio search task).

Pair	*t*	df	Obtained *p*	Required *p*
Telepresence vs. mono joystick	5.159	15	0.000[a]	0.05
Telepresence vs. mono head track	3.387	15	0.004[a]	0.0167
Mono joystick vs. mono head track	2.932	15	0.010[a]	0.025

[a] Met requirements for statistical significance.

3.2.4 Percentage of Correct Target Identifications

Table 15 shows the percentage of targets correctly identified by display. Two-way ANOVA shows that the differences due to display conditions are significant ($F(2,14) = 9.51$, $p = 0.002$, $\eta^2_p = 0.58$). In addition, differences due to target are significant ($F(5,11) = 4.104$, $p = 0.024$, $\eta^2_p = 0.651$), and while the interaction term was not significant, the effect size was very high ($F(10,6) = 3.30$, $p = 0.08$, $\eta^2_p = 0.846$). Post-hoc Holm's Bonferroni indicate that the telepresence was significantly higher in percentage of correct identifications.

Figure 24 illustrates the interaction. Telepresence was generally associated with higher percentages but was particularly helpful for some targets.

Table 15. Percent correct identifications by display and target.

Pair	*t*	df	Obtained *p*	Required *p*
Telepresence vs. mono joystick	3.496	15	0.003[a]	0.05
Telepresence vs. mono head track	3.873	15	0.002[a]	0.0167
Mon-joystick vs. mono head track	0.689	15	0.502	0.025

[a] Met requirements for statistical significance.

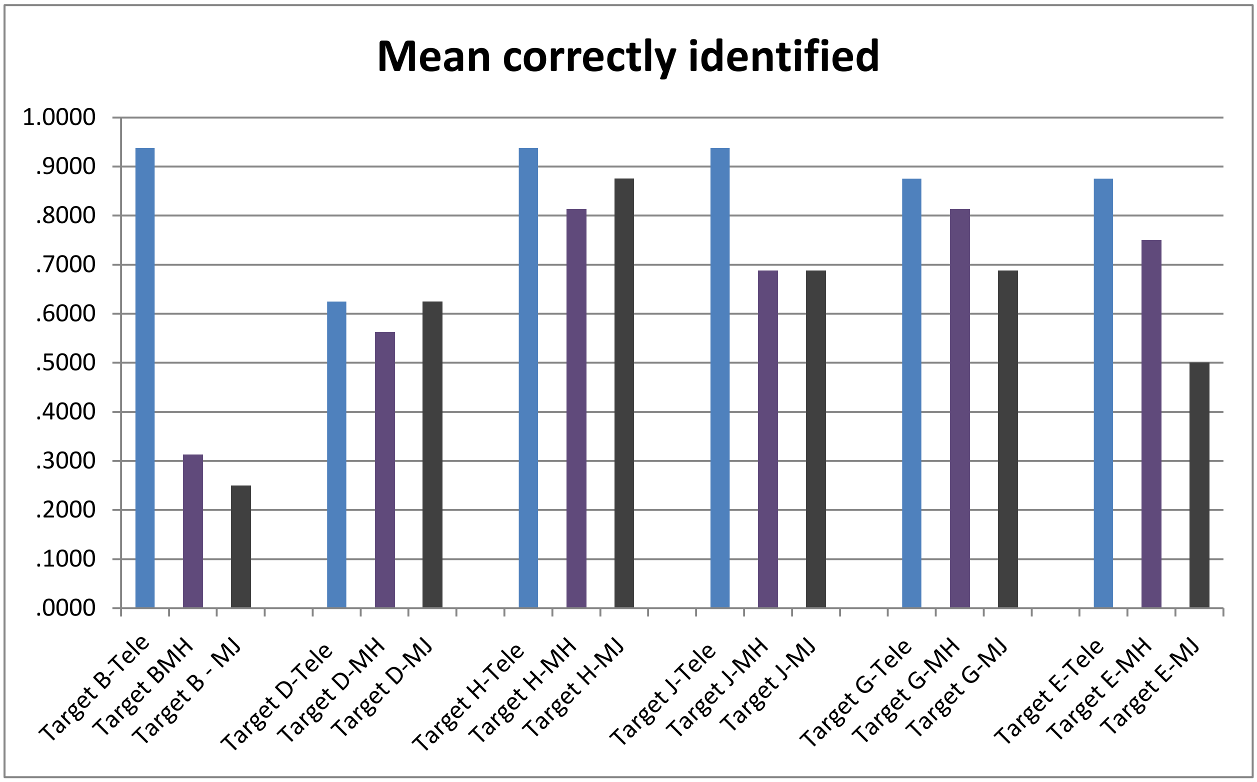


Figure 24. Percentage of targets correctly identified by display and target.

3.2.5 Distance to Target Item

Data collectors observed and measured the distance from the robot camera to the target after the target was approached. Mean distances for each condition are listed in figure 25. Differences due to display type were not significant ($F(2,13) = 0.258$, $p = 0.776$, $\eta^2_p = 0.038$). Differences due to target type were significant ($F(5,10) = 52.84$, $p = 0.00$, $\eta^2_p = 0.96$). The interaction term was not significant; however, the effect size was very large ($F(10,5) = 2.441$, $p = 0.168$, $\eta^2_p = 0.83$). Means and standard deviations are listing in appendix A.

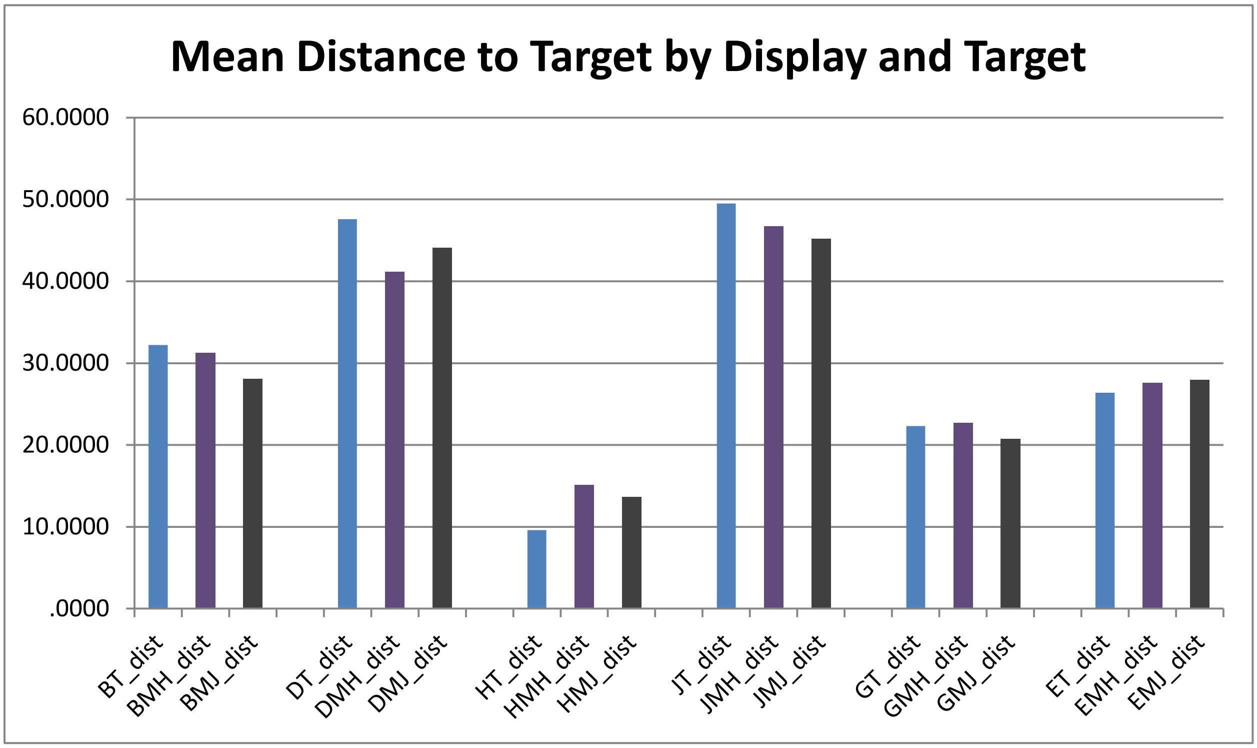


Figure 25. Mean distance to targets by display condition and target.

3.2.6 Mean Driving Errors

A repeated measures ANOVA of display and target showed a significant difference due to display ($F(2,13) = 5.14$, $p = 0.02$, $\eta^2_p = 0.44$) but not for targets ($F(5,10) = 2.36$, $p = 0.12$, $\eta^2_p = 0.54$) or their interaction ($F(10.5) = 1.67$, $p = 0.29$, $\eta^2_p = 77$). However, effect sizes are large (see figure 26). Means and standard deviations are listed in appendix A.

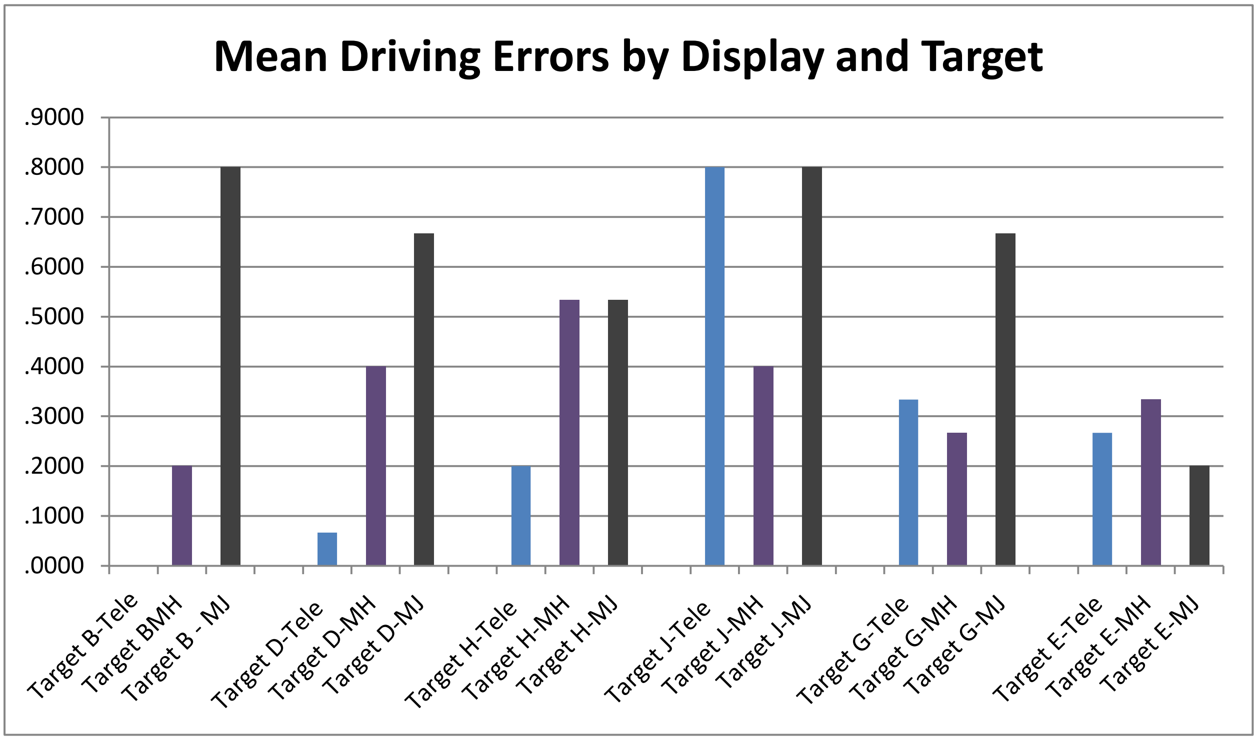


Figure 26. Mean driving errors by display and target.

3.2.7 Spatial Ability Assessment

Spatial ability was assessed through the Cube Comparisons Test* (Ekstrom et al., 1976). This test measures the ability to mentally rotate a line drawing of a 3-D cube. Soldiers were allotted 3 min to mentally rotate and respond to 21 test items. The dependent measure is the correct identification of the mental rotation of each test item from a series of forced-choice line drawings. Soldiers read the instructions and performed sample items prior to the test. They were encouraged not to guess, as the final score is calculated by subtracting the number wrong from the number correct. Scores ranged from 0 to 19, with a mean of 7.22 (sd 4.79).

Spatial ability correlated significantly with audio search measures. For telepresence audio search times, spatial score (spa) correlated –.52 (p = 0.02); for mono joystick, spa correlated –.65 (p = 0.00), for mono head tracking, spa correlated –.65 (p = .00). The spa was entered as a covariate in repeated measures analyses of display and audio search time. There was a significant interaction between display and spa (F = 4.67, p = .025), as reflected in the different correlation values between spa and audio search times for the different display conditions. The correlation with performance was lowest for telepresence, with the implication that telepresence allowed participants with lower spa to perform somewhat better than the other conditions. This can be seen in figure 27, where Soldiers with low spa performed much faster in the telepresence condition as opposed to the other conditions.

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*Copyright 1962, 1976 by Educational Testing Service.

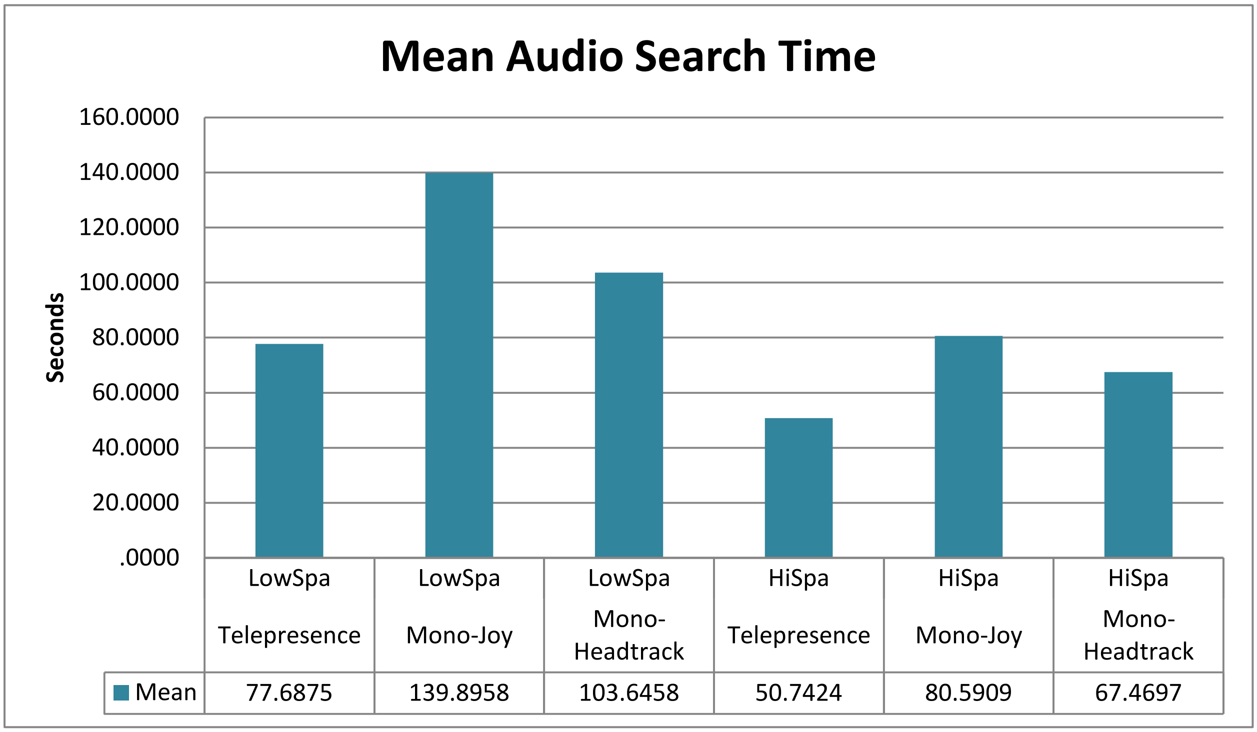

Figure 27. Mean audio search times by spa and display.

3.2.8 NASA-TLX Workload Ratings

Soldiers provided direct ratings of the NASA-TLX workload scales. Mean ratings are provided in figure 28. Differences were significantly different for mental workload ($F(2,15) = 20.98$, $p = 0.00$, $\eta^2_p = 0.74$); effort ($F(2,15) = 9.44$, $p = 0.00$, $\eta^2_p = 0.56$), and frustration ($F(2,15) = 7.82$, $p = 0.01$, $\eta^2_p = 0.51$). While the F test for temporal demand was not significant ($F(2,15) = 3.38$, $p = 0.06$), the effect size was moderately high ($\eta^2_p = 0.31$). Follow-on Holm's Bonferroni comparisons are provided in table 16. The performance subscale is not a measure a workload but a self-assessment of how well each operator rated his or her performance.

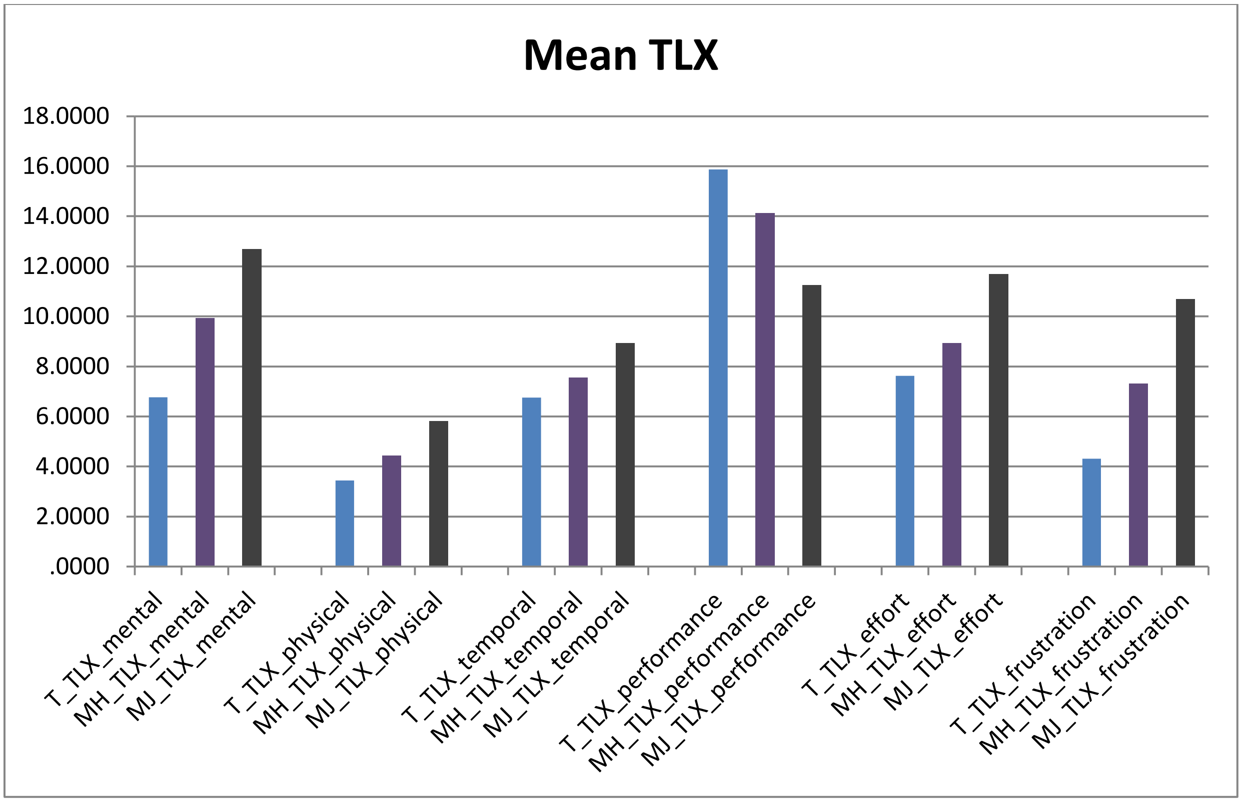

Figure 28. Mean NASA-TLX workload ratings by display.

Table 16. Paired comparison t-tests with Holm's Bonferroni criteria.

Mental	***t***	**df**	**Obtained *p***	**Required *p***
Tele – mono head track	–3.03	16	0.008[a]	0.05
Tele – mono joystick	–6.22	16	0.000[a]	0.0125
Mono head – mono joy	–4.23	16	0.001[a]	0.025
Effort	—	—	—	—
Tele – mono head track	–1.267	16	0.22	0.05
Tele – mono joystick	–3.85	16	0.001[a]	0.025
Mono head – mono joy	3.92	16	0.001[a]	0.0125
Frustration	—	—	—	—
Tele – mono head track	–2.998	16	0.009[a]	0.05
Tele – mono joystick	–4.079	16	0.001[a]	0.025
Mono head – mono joy	3.053	16	0.008[a]	0.0125

[a] $p < .05$, two-tailed.

3.2.9 Soldier Feedback

3.2.9.1 Task Difficulty Ratings. Soldier responses to questionnaires are provided in full in appendix A. Table 17 provides mean responses to items regarding task difficulty ratings for each display condition. Ratings ranged from 1 = extremely difficult to 7 = extremely easy. Soldier comments expressed higher difficulty with the mono condition to locate the targets and higher difficulty with the joystick to maneuver the robot. This is also reflected in the ratings, such as the ratings for capability to locate target objects by sound location.

Table 17. Mean ratings of ease/difficulty for tasks.

Task	Mean Response		
	Telepresence	Mono/Head Tracking	Mono/Joystick
Move the robot in the desired direction	6.11	5.74	4.63
Avoid obstacles	5.42	5.00	3.95
Turn around	5.32	4.95	4.53
Maneuver around corners	5.42	5.11	4.47
Back up	5.11	4.74	4.58
Hear the target sound (sound volume)	5.47	4.58	4.11
Locate target objects by sound location	5.47	3.89	3.26
Locate target objects by sight	6.00	5.79	4.89
Find targets quickly	5.42	4.79	3.89
Know your location in the room	5.95	5.89	5.53
Remember target locations	5.63	5.47	5.21
Move quickly	5.47	4.84	4.26
Maneuver probe close to the IED object (when requested)	5.63	5.32	4.74

Items regarding movement of the robot (items 1, 2, 3, 4, 5, 9, 12, 13) were averaged to create a more reliable overall assessment of robot maneuverability. Overall means ranged from 4.38 (mono joystick), to 5.05 (mono head track), to 5.49 (telepresence). The overall within-subjects F-test was significant ($F(2,36) = 16.68$, $p = 0.00$, $\eta^2_p = 0.48$). Paired comparison t-tests with Holm's Bonferroni criteria are listed in table 18. All paired comparisons met the criteria for significance.

Table 18. Paired comparison *t*-tests with Holm's Bonferroni criteria.

Robot Control: Movement	*t*	df	Obtained *p*	Required *p*
Tele – mono head track	–3.04	18	0.007[a]	.05
Tele – mono joystick	–4.28	18	0.000[a]	.0125
Mono head – mono joy	–4.26	18	0.000[a]	.025

[a] $p < .05$, two-tailed.

3.2.9.2 Display/Control Characteristics. Soldier responses to questionnaires are provided in full in appendix A. Table 19 provides mean responses to items regarding display/control characteristics for each display condition. Ratings ranged from 1 = extremely ineffective to 7 = extremely effective. In general, ratings were higher for the telepresence controller condition and lowest for the mono joystick condition. A repeated-measures ANOVA of the overall rating for each controller unit (item 10) resulted in $F(2,34) = 10.15$, $p = 0.000$, $\eta^2_p = 0.37$.

Table 19. Mean ratings of effectiveness for display characteristics.

Display/Control Characteristics	Mean Response		
	Telepresence	Mono Head Tracking	Mono Joystick
Resolution (clarity) of the display	5.33	5.28	5.11
Precision of camera movement control	5.44	5.22	5.11
Sensitivity of camera movement control	5.17	4.94	4.67
Time lag of camera movement control	4.83	5.06	4.88
Controlling camera and movement at the same time	5.72	5.67	4.53
Capability to hear sound (volume)	5.50	5.17	4.83
Capability to locate sound (direction)	5.33	4.00	3.33
Overall ease of use	5.94	5.50	4.72
Adequacy of this control unit for tele-operating a robot	5.67	4.94	4.61
Overall assessment of this control unit	5.78	5.00	4.39

Paired comparison *t*-tests of the overall assessment item are listed in table 20. Results were significant for each comparison.

Table 20. Paired comparison *t*-tests with Holm's Bonferroni criteria.

Overall Assessment	*t*	df	Obtained *p*	Required *p*
Tele – mono head track	2.83	17	0.01[a]	0.05
Tele – mono joystick	3.65	17	0.00[a]	0.0125
Mono head – Mono joy	2.37	17	0.03[a]	0.025

[a] $p < .05$, two-tailed.

3.2.9.3 Relevance of Capabilities to a Reconnaissance Mission. Soldiers were also asked to rate (1 = extremely bad to 7 = extremely good) to what extent the following features would contribute to a recon mission. Results are listed in table 21. The 3-D audio, stereo vision, and head-track camera all received high mean ratings.

Table 21. Mean responses to relevance of each feature for a reconnaissance mission.

Features	Mean Response
3-D audio	6.56
Stereo vision	6.22
Head-tracked camera	6.06
Mono audio	3.67
Mono vision	4.11
Joystick camera	4.56

When asked which controller condition was preferred, 13 of 18 responses were in favor of the telepresence condition. Reasons provided for the preference are included in table 22.

Table 22. Consolidated comments regarding display characteristics.

Soldier Comments Regarding Telepresence	No. of Responses
Just seemed easier to use.	2
Easier for sight.	1
Easier to locate target.	1
Firing arm is free for use.	1
Natural.	1
The most impressive, allowing a quicker assessment of the situation and greater ease of maneuver.	1
Easier to locate and identify objects while being able to move your head (as part of the camera/stereo vision). I felt the 3-D audio was very precise and so was the head tracking feature.	1
3-D audio helped a lot for target identification when multiple units were in the same area.	2
3-D audio helped to locate the direction of the sound a lot faster.	1
Because I was naturally inclined to move my head with the 3-D view. With video games, I was used to the joystick, but the television for that is farther away and less impressive; with this system, it was much easier to use the head tracking.	1
I didn't notice an appreciable difference in terms of the stereo vision increasing my depth perception. This may have been mainly attributable to the poor quality of the display.	1
Felt the most precise. I could move quickly and fluidly through the course.	1
Easiest overall control of box and easiest ability to listen to where the sound was coming from.	2
The head tracking was extremely helpful in the overall maneuvering of the robot.	1
It combined the head movement along with the stereo audio. That was a huge plus.	1

3.2.9.4 Soldier Discomfort. Soldiers indicated whether they experienced any negative symptoms from the controller task. Results, listed in table 23, indicate that several symptoms were experienced by several Soldiers.

Table 23. Number of Soldiers reporting each symptom (telepresence).

Symptoms	No. of Responses
Eyestrain	8
Tunnel vision	0
Headaches	8
Motion sickness	5
Nausea	5
Disorientation	0
Dizziness	4
Competition between eyes for vision of the different scenes at which they are looking	4
Other	7

Soldier comments regarding the symptoms are included in table 24.

Table 24. Comments regarding symptoms.

Soldier Comments Regarding Telepresence	No. of Responses
Some discomfort from weight.	1
The headset hurt my head (too heavy/hard/tight) and created discomfort.	4
Fatigue.	1
Hands started to tingle with the increase of above symptoms (headaches, motion sickness, nausea, dizziness).	1
I was only able to do tasks in groups of three before nausea set in. After each break, I was able to resume, but the nausea came back at a faster rate each time.	1
Headaches may be due to seeing double during the breaks. Also, there was some lag at one point.	1

Results indicate that the issues of eyestrain, headache, and motion sickness persist, as does need for improvements to the head-mounted design to make it lighter. Results also indicate the need for further improvements to resolution and reduced time lag in camera control.

4. Overall Discussion and Conclusions

In the first experiment, we compared visual telepresence features (e.g., head-controlled camera, stereo vision) with the more commonly used laptop interface for robot control. This first experiment demonstrated that telepresence capabilities were as effective as current laptop-based controllers and were very well appreciated by users. However, results suggested effectiveness will vary because of task demands. In addition, Soldiers provided many suggestions for design improvements.

The second experiment used task demands more fully matched to telepresence capabilities. In the second investigation, we further examined the utility of the head tracking and stereoscopic features for more visually demanding indoor reconnaissance tasks. We also investigated the utility of 3-D (vs. mono audio) in audio localization tasks. Robot controller tasks included visual navigation with audio localization, depth perception, and overall SA perception. Several telepresence features were associated with higher performance.

4.1 Visual Navigation and Audio Localization

For this task, operators were given a tour of the indoor facility and training on robot control and navigation. They then searched the rooms while the controller condition varied from (a) mono joystick (mono audio and mono stereo, with joystick control), (b) mono head track (mono audio and mono stereo with head track camera control), and (c) telepresence (stereo audio and stereo video with head track camera control). There were significant differences among conditions with regard to audio search time. The telepresence condition was associated with the fastest mean time (62.08 s), which was significantly faster than the mono head track condition (82.70 s), which in turn was significantly faster than the baseline mono joystick condition (105.56 s). Telepresence was also associated with a higher mean percentage of correct identifications (80.7 % compared to 64.9% and 57.8%) with differences being more pronounced for some targets.

In addition, mean ratings of NASA-TLX workload for task 1 were significantly lower than the mono head track condition for mental workload and frustration. In turn, mean ratings of mental workload and frustration for the mono head track condition were significantly lower compared to the baseline mono joystick condition. Mean ratings of workload effort were significantly higher for the baseline mono joystick condition when compared to the mono head track and telepresence conditions. Thus, in task 1, the telepresence condition was associated with faster and better performance and lower experience of workload. The head track condition was associated with improved performance and lower workload compared to the mono joystick. The addition of stereo audio and vision further improved performance and lowered workload when added to the head track capability.

4.2 Depth Perception

Operators were asked to maneuver the robot as close to the target as possible without touching it. The stereo vision feature was expected to assist in this task; however, mean differences among the display conditions were quite similar.

4.3 Impact of Spatial Ability

Spa was found to be a direct contributor to robot control performance and also a moderator of the effects of display on performance. Spatial ability correlated significantly with audio search measures. For telepresence audio search times, spa correlated –0.52 ($p = 0.02$); for mono joystick, spa correlated –0.65 ($p = 0.00$); and for mono head tracking, spa correlated –0.65 ($p = .00$). These differences among the correlations were significant. The spa was entered as a covariate in repeated measures analyses of display and audio search time. There was a significant interaction between display and spa ($F = 4.67$, $p = .025$), which is reflected in the different correlation values between spa and audio search times for the different display conditions. The correlation with performance was lowest for telepresence, with the implication that telepresence allowed participants with lower spa to perform somewhat better than did the other conditions.

4.4 Soldier Discomfort

While refinements to telepresence software were conducted to minimize discomfort, some Soldiers reported symptoms of eyestrain, headaches, motion sickness, nausea, and dizziness. These symptoms may be due to factors related to stereo vision (e.g., competition between eyes, time lag in camera movements). There were also comments with regard to the weight and fit of the headset.

4.5 Soldier Feedback

The Soldiers provided feedback through structured semantic differential rating scales (e.g., task difficulty, ease of use, comfort, effectiveness) and verbal/written comments. For ratings of task difficulty and SA, the telepresence condition was rated more favorably for all items (13 out of 13). Eight of the items referred to maneuvering the robot (e.g., move the robot in the desired direction, avoid obstacles, turn around) and were averaged to create a more reliable measure for analysis. Overall means regarding the ease of robot maneuvering indicated the telepresence condition was associated with significantly easier robot maneuvering compared to the mono head track condition, which in turn was associated with significantly higher ratings of ease than the mono joystick condition.

Soldiers also rated characteristics of each display condition, such as display resolution, precision, sensitivity, etc. In general, the telepresence condition was associated with the highest ratings (9 of 10), with the exception of time lag. Telepresence ratings were notably higher than mono head track or mono joystick for capability to hear sound volume (5.50 vs. 5.17 vs. 4.83), capability to locate sound (5.33 vs. 4.00 vs. 3.33), overall ease of use (5.94 vs. 5.50 vs. 4.72), adequacy for teleoperation (5.67 vs. 4.94 vs. 4.61), and overall assessment of the controller (5.78 vs. 5.00 vs. 4.39). Paired comparison *t*-tests of the overall assessment item found significant differences for each condition paired comparison. In addition, with regard to contributions to an operational reconnaissance mission, 3-D audio was rated much higher than mono audio (6.56 vs. 3.67), stereo vision was rated much higher than mono vision (6.22 vs. 4.11), and the head track camera was rated much higher than the joystick (6.06 vs. 4.56).

When asked which controller condition was preferred, 13 of 18 responses were in favor of the telepresence condition. Reasons provided for the preference included overall ease of use, and in particular, ease of visual search and target localization. Comments included descriptions of the telepresence as "intuitive," "easy," and "second nature." They noted that the telepresence allowed the hand/arm to be free and a quicker assessment of the situation. The 3-D audio combined with the head track capability was particularly valued for the audio localization task. Soldiers reported they could not localize with the mono audio, and that robot movement and maneuvering was more difficult using the joystick.

While Soldiers performed well with both controllers having telepresence features, they also commented on how a telepresence system could be improved. A primary issue is eyestrain and motion sickness. Another common theme is that of physical discomfort from the weight and bulk of the head track equipment. Some Soldiers reported that the 3-D audio could be further improved in that it was difficult to tell if a noise was coming from above or below. Soldiers also suggested additional capabilities, such as a rear vision camera, a more effectively placed probe, crash/collision sensors, greater field of view, and camera zoom capabilities. They also noted that the system would have to be integrated with a combat helmet to be effective in operations.

In summary, the telepresence capabilities are promising, but further improvements are indicated. Significant differences in workload and performance were noted, particularly with regard to usefulness of the remote 3-D audio capability. Results also showed the benefit of head tracking even when in the mono audio condition, reflecting the importance of head movement for sound localization, as found elsewhere (Toshima and Aoki, 2009). However, reports of eyestrain, headache, or motion sickness are still experienced by more users with telepresence, similar to experiences of virtual reality, and compounded by technical issues, such as camera lag or interocular adjustments regarding the stereo display (Kolasinski, 1995; Van Erp et al., 2006).

Soldiers were favorably impressed with the potential that current systems represent. Further efforts are now underway to address these improvements and investigate each aspect of telepresence with regard to their contributions to performance in different task demand scenarios.

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Appendix A. Detailed Descriptive Results

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

A-1 - Experiment 1: Demographic Results (N = 18)

MOS		RANK	AGE	DUTY POSITION
09S -	15	E4 – 5	25 years (mean)	OCS - 18
11B -	1	E5 – 4		
14J -	1	OCS – 9		
15A -	1			

1. How long have you served in the military? _8_ months (mean)

2. How long have you had an infantry-related job? _3_ months (mean) (N=1)

3. How long have you been deployed in a combat area? _12_ months (mean) (N=1)

4. With which hand do you most often write? _17_ Right _1_ Left

5. With which hand do you most often fire a weapon? _17_ Right _1_ Left

6.a. Do you wear prescription lenses? _10_ No _8_ Yes

b. If so, which do you most often wear? _5_ Glasses _3_ Contacts

c. Which is your dominant eye? _12_ Right _4_ Left _2_ NR

d. Do you have any vision related problem? _15_ No _3_ Yes

If so, what? Color vision deficiency, astigmatism (2)

7.a. How often do you use a computer?

_0_ Never _0_ Infrequently _2_ Sometimes _16_ Daily

b. How often do you use a computer on a weekly basis?

_3_ 1-10 hrs _9_ 11-20 hrs _4_ 21-30 hrs _2_ More than 30 hrs

8. Do you have experience with any type of digital or electronic military displays (e.g., FBCB2, fire control systems FB (ITAS, IBAS, LW, etc.)? _16_ No _2_ Yes

9.a. Have you ever used a robotic system? _15_ No _3_ Yes

b. If so, what type? PLC (Programmable Logics Controller), civilian robots,

c. Please describe the conditions under which you used the robotic system.

Industrial/Manufacture.	1
College/classroom environment,	1
We built and controlled our own robot in high school and then battled each other.	1

10. Please rate your skill level for each of the following activities?

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

ACTIVITY	MEAN RESPONSE
Operating ground unmanned vehicles	1.11
Operating aerial vehicles	1.28
Target detection and identification	1.78
Playing commercial video games	2.83
Training with Army video simulations	1.83
Using Microsoft Office products	3.17

A-2 - Experiment 1: Performance Data for Indoor and Outdoor Reconnaissance Tasks

PERFORMANCE DATA from Observers

DETECTIONS. In this set of data, all items that were detected were counted, whether they were correctly identified or not.

Recon Items : Building = B (DETECTIONS)					
		Laptop		Telepresence	
		N	Mean	N	Mean
1	Soda Can bomb (diet pepsi)	8	1.00	8	1.00
2	Soda Can bomb (diet coke)	8	1.00	8	1.00
3	Soda Can bomb (diet pepsi)	8	1.00	8	1.00
4	Land mine Grey	8	1.00	8	1.00
5	Land mine green and tan	8	1.00	8	1.00
6	Land mine tan	8	1.00	8	1.00
7	cardboard box	8	1.00	8	1.00
8	picture of Statue of Liberty	8	.75	8	.50
9	suicide bomber vest	8	1.00	8	1.00
10	suicide bomber vest	8	1.00	8	1.00
11	suicide bomber vest	8	1.00	8	1.00
12	map with New York circled	8	.88	8	.75
13	briefcase bomb	8	1.00	8	1.00
14	Timer	8	1.00	8	1.00
15	6v battery	8	1.00	8	1.00
16	Wire	8	1.00	8	1.00
17	initiation device	8	1.00	8	1.00
18	PDA	8	1.00	8	1.00
19	cell phone	8	.88	8	1.00
20	pipe bomb	8	1.00	8	1.00
21	82mm mortar round	8	1.00	8	1.00
22	122mm projectile	8	1.00	8	1.00
23	130mm rocket round	8	1.00	8	1.00
M_ALL (total)		8	22.5000	8	22.25
M_ALL (%)		8	0.98	8	0.97
Valid N (listwise)		8		8	

Recon Items : Building = C (DETECTIONS)					
		Laptop		Telepresence	
		N	Mean	N	Mean
1	cardboard box	8	1.00	8	1.00
2	PDA	8	1.00	8	1.00
3	Fan	8	1.00	8	1.00
4	AK47	8	1.00	8	1.00
5	AK47	8	1.00	8	1.00
6	AK47	8	1.00	8	1.00
7	rpg	8	1.00	8	1.00
8	12v battery	8	.88	8	1.00
9	jumper cables	8	1.00	8	1.00
10	chair	8	1.00	8	1.00
11	table	8	1.00	8	1.00
12	lamp	8	1.00	8	1.00
13	wire	8	.75	8	.63
14	rope	8	1.00	8	.88
15	wad of wire	8	.63	8	.13
16	ACU uniform	8	1.00	8	1.00
17	ACU uniform	8	1.00	8	1.00
18	bedding	8	1.00	8	1.00
19	bloody rags	8	1.00	8	1.00
20	naked mannequin	8	1.00	8	1.00
21	sandbag over head	8	.75	8	.88
22	chair	8	.88	8	.75
23	bedding	8	1.00	8	1.00
M_ALL (total)		8	21.8750	8	21.2500
M_ALL (%)			0.95		0.92

IDENTIFICATIONS. In this set of data, only items that were correctly identified were counted.

Recon Items :Building = B (IDENTIFICATIONS)					
		Laptop		Telepresence	
		N	Mean	N	Mean
1	Soda Can bomb (diet pepsi)	8	1.00	8	1.00
2	Soda Can bomb (diet coke)	8	1.00	8	1.00
3	Soda Can bomb (diet pepsi)	8	1.00	8	1.00
4	Land mine Grey	8	.75	8	.63
5	Land mine green and tan	8	.25	8	.75
6	Land mine tan	8	.63	8	.63
7	cardboard box	8	1.00	8	1.00
8	picture of Statue of Liberty	8	.75	8	.50
9	suicide bomber vest	8	1.00	8	1.00
10	suicide bomber vest	8	1.00	8	1.00
11	suicide bomber vest	8	1.00	8	1.00
12	map with New York circled	8	.88	8	.75
13	briefcase bomb	8	1.00	8	1.00
14	Timer	8	1.00	8	1.00
15	6v battery	8	1.00	8	.75
16	Wire	8	.88	8	.50
17	initiation device	8	.50	8	.63
18	PDA	8	.63	8	.50
19	cell phone	8	.88	8	.50
20	pipe bomb	8	1.00	8	.88
21	82mm mortar round	8	.88	8	1.00
22	122mm projectile	8	.88	8	1.00
23	130mm rocket round	8	1.00	8	1.00
M_ALL (total)			19.87	8	19.0000
M_ALL (%)			0.86	8	0.83
Valid N (listwise)		8	8	8	1.00

Recon Items : Building = C (IDENTIFICATIONS)					
		Laptop		Telepresence	
		N	Mean	N	Mean
1	cardboard box	8	1.00	8	1.00
2	PDA	8	.88	8	1.00
3	Fan	8	1.00	8	1.00
4	AK47	8	1.00	8	1.00
5	AK47	8	1.00	8	1.00
6	AK47	8	1.00	8	1.00
7	rpg	8	.88	8	1.00
8	12v battery	8	.88	8	1.00
9	jumper cables	8	1.00	8	1.00
10	chair	8	1.00	8	1.00
11	table	8	1.00	8	1.00
12	lamp	8	1.00	8	1.00
13	wire	8	.63	8	.63
14	rope	8	1.00	8	.88
15	wad of wire	8	.63	8	.13
16	ACU uniform	8	.88	8	1.00
17	ACU uniform	8	1.00	8	1.00
18	bedding	8	1.00	8	1.00
19	bloody rags	8	1.00	8	1.00
20	naked mannequin	8	1.00	8	1.00
21	sandbag over head	8	.75	8	.88
22	chair	8	.88	8	.75
23	bedding	8	1.00	8	1.00
M_ALL (total)		8	21.3750	8	21.2500
M_ALL (%)			0.93		0.93

Performance in BUILDINGs: Total time, Number of driving errors

	N	Minimum	Maximum	Mean	Std. Deviation
Laptop_Bldg_time	16	4:28:00	15:00:00	9:39:11.250	2:49:30.032
Laptop_Bldg_errors	16	0	7	2.31	2.024
Telepresence_Bldg_time	16	6:22:00	12:45:00	10:02:14.999	1:32:10.490
Telepresence _Bldg_errors	16	0	6	2.38	1.408
Valid N (listwise)	16				

Performance OUTSIDE: Time, Driving errors, Waypoints, Off-course, False detects

	N	Minimum	Maximum	Mean	Std. Deviation
Laptop _Outside_time	16	3:57:00	14:07:00	9:24:07.500	3:24:11.678
Laptop _Outside_errors	16	0	0	.00	.000
Telepresence _Outside_time	16	5:12:00	14:30:00	9:45:44.999	2:57:37.290
Telepresence _Outside_errors	16	0	0	.00	.000
Laptop _wpt_all	16	2.00	3.00	2.6875	.47871
Telepresence _wpt_all	16	2.00	3.00	2.6250	.5000
Laptop _#times off course	16	0	0	.00	.000
Telepresence _#times off course	16	0	1	.06	.250
Laptop _# false detects	16	0	2	.50	.730
Telepresence _# false detects	16	0	4	.50	1.033
Laptop _# false detects corrected	16	0	2	.13	.500
Telepresence _# false detects corrected	16	0	1	.06	.250
Valid N (listwise)	16				

OUTSIDE: Targets, % detected, mean distance of detected targets

	Laptop			TELEPRESENCE		
	N	**Mean**	**Std. Deviation**	**N**	**Mean**	**Std. Deviation**
Outside_1	16	.63	.500	16	.25	.447
1_distance	10	16.60	7.214	4	27.50	8.660
Outside_2	16	.56	.512	16	.19	.403
2_distance	9	13.00	5.292	3	14.67	4.619
Outside_3	16	.31	.479	16	.44	.512
3_distance	5	6.60	1.673	7	7.71	3.498
Outside_4	16	.44	.512	16	.19	.403
4_distance	7	10.86	3.532	3	11.00	6.928
Outside_5	16	.44	.512	16	.19	.403
5_distance	7	7.00	3.215	3	11.00	4.583
Outside_6	16	.75	.447	16	.56	.512
6_distance	12	13.92	6.127	9	14.33	3.775
Outside_7	16	.75	.447	16	.75	.447
7_distance	12	20.42	5.534	12	17.42	4.680
Outside_8	16	.37	.500	16	.31	.479
8_distance	6	10.83	4.401	5	11.80	3.271
Outside_9	16	.44	.512	16	.75	.447
9_distance	7	11.71	4.957	12	10.83	2.443
Outside_10	16	.69	.479	16	.87	.342
10_distance	11	15.91	9.279	14	17.93	9.000
Total Targets	16	5.3750	2.09364	16	4.5000	1.63299

A-3 - Experiment 1: Post-Iteration Questionnaire Results

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

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

TELEPRESENCE: OUTDOORS							
	N	**Mean**	**Std. Deviation**	**Skewness**		**Kurtosis**	
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**
Move the robot in the correct direction	16	4.4375	1.26326	-.293	.564	-.872	1.091
Avoid obstacles	16	4.3125	1.19548	.108	.564	-1.598	1.091
Avoid potholes	14	4.2143	1.12171	.276	.597	-1.310	1.154
Identify any other terrain features that makes it difficult to maneuver through the terrain	16	4.7500	1.23828	.060	.564	-.962	1.091
Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	15	4.1333	1.06010	.116	.580	-1.557	1.121
Anticipate whether the turn radius of the vehicle will allow a turn	16	4.8750	1.45488	-.942	.564	.249	1.091
Identify if the robot is on the correct path	16	5.1250	1.82117	-1.270	.564	.418	1.091
Navigate far enough ahead to plan route in advance	16	5.5625	1.26326	-.614	.564	-.638	1.091
Navigate well enough to drive at slowest speeds	15	5.7333	1.03280	-.282	.580	-.917	1.121
Navigate well enough to drive at medium speeds	14	5.6429	1.27745	-.759	.597	-.286	1.154
Navigate well enough to drive at fastest speeds	14	5.0000	1.66410	-.818	.597	-.394	1.154
Finish the course quickly	16	4.7500	1.39044	-.680	.564	.318	1.091
Find IEDs and other objects of interest	16	4.2500	1.61245	-1.009	.564	.135	1.091
Navigate to next waypoint	16	4.8125	1.60078	-.989	.564	.523	1.091
Take pictures	15	5.9333	1.66762	-1.479	.580	1.059	1.121
Control the camera (viewing direction)	4	5.2500	1.70783	-.753	1.014	.343	2.619
Make robot understand you	10	5.2000	1.54919	-.188	.687	-1.276	1.334
Being aware of the direction the camera is pointed within it is not centered on the front of the robot	4	4.7500	1.25831	-1.129	1.014	2.227	2.619
Move the camera direction	12	6.0833	1.44338	-2.349	.637	6.264	1.232
Maintain situation awareness	16	5.2500	1.65328	-1.366	.564	1.726	1.091
Overall ability to perform this reconnaissance	16	4.9375	1.28938	-1.149	.564	.341	1.091

TELEPRESENCE: OUTDOORS							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Move the robot and camera angle at the same time	12	4.6667	1.92275	-.812	.637	-.664	1.232
Maintain direction to way-point while searching for items	12	5.1667	1.46680	-1.171	.637	.686	1.232

Laptop: OUTDOORS							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Move the robot in the correct direction	16	5.3125	1.13835	-.708	.564	.717	1.091
Avoid obstacles	15	5.1333	1.40746	-.802	.580	.361	1.121
Avoid potholes	14	5.0000	1.70970	-1.293	.597	1.516	1.154
Assess down slopes for navigability	6	4.8333	1.47196	.418	.845	-.859	1.741
Assess side slopes for navigability	6	4.8333	1.47196	.418	.845	-.859	1.741
Identify any other terrain features that makes it difficult to maneuver through the terrain	16	5.6875	.94648	-.352	.564	-.471	1.091
Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	14	4.1429	1.35062	-.736	.597	.890	1.154
Anticipate whether the turn radius of the vehicle will allow a turn	15	4.6667	1.71825	-.278	.580	-1.293	1.121
Identify if the robot is on the correct path	16	5.5625	1.45917	-1.318	.564	1.295	1.091
Navigate far enough ahead to plan route in advance	16	5.8125	1.22304	-.844	.564	.167	1.091
Navigate well enough to drive at slowest speeds	15	6.3333	.81650	-.740	.580	-1.022	1.121
Navigate well enough to drive at medium speeds	15	6.0667	1.09978	-1.635	.580	3.411	1.121
Navigate well enough to drive at fastest speeds	14	5.5714	.93761	-1.546	.597	3.852	1.154
Finish the course quickly	16	5.1875	1.04682	-.422	.564	-.201	1.091
Find IEDs and other objects of interest	16	4.9375	1.65202	-.698	.564	-.743	1.091
Navigate to the next waypoint	16	5.8750	1.36015	-1.198	.564	.647	1.091
Take pictures	16	6.5625	.81394	-2.348	.564	6.262	1.091
Control the camera (viewing direction)	4	5.2500	1.25831	1.129	1.014	2.227	2.619
Make the robot understand you	10	6.3000	.94868	-.742	.687	-1.640	1.334
Being aware of the direction the camera is pointed within it is not centered on the front of the robot	4	4.7500	1.89297	-1.659	1.014	2.615	2.619
Move the camera direction	12	5.2500	1.48477	-.312	.637	-1.270	1.232

Laptop: OUTDOORS							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Maintain situation awareness	16	5.2500	1.18322	-.276	.564	.361	1.091
Overall ability to perform this reconnaissance	16	5.6250	.80623	-.027	.564	-.130	1.091
Move the robot and the camera angle at the same time	11	4.9091	1.57826	-.379	.661	-1.823	1.279
Maintain direction to way-point while searching for items	12	4.9167	1.50504	-.024	.637	-1.463	1.232

Comments	**No. of Responses**
TELEPRESENCE: OUTDOORS	
Great piece of equipment while in the field.	2
Easily maneuvered and easily identified objects.	2
Much easier to move and adjust camera.	1
Easier and more efficient than the Laptop.	1
Moving the camera and robot at the same time was much easier with this device.	1
Poor resolution of "mono" led to some misidentification. Neverthe-less, well completed. Controls very sensitive and responsive, and had no trouble perfectly substituting robot's eyes for mine.	1
I wish there was a way to control volume on the handset. It was a bit loud at times, especially when going over portions of dense conglomerations of rocks.	1
Slight disorientation while head movement was quickly changed.	1
Head movements were most difficult to function while moving quickly.	1
Began to get nauseated often in the later part of the outdoor. I felt as if there was a lag between my motions and the actual motions the robot was making.	1
Most of the difficulties I had were more with the robot, but the camera system at times jumped around and it could be a little confusing as to where the camera is pointing in relation to the robot.	1
Difficult to adjust camera direction at times.	1
Sometimes camera detail not as precise. Camera quality also not as good.	1
Camera is a lot harder to keep steady and control with the robot.	1
With camera sitting so high on the robot, it was difficult for me to watch where the robot was going, and if it was staying on course (going where I thought it was going).	1
I had trouble navigating the inside course mainly because of the turn going into the torture room. I am not sure if the headset display was more difficult to use around the corner, but I did think it was easier to search for items while moving the robot.	1
The robot seemed to veer when I moved forward and also looked around. Do the wheels return to zero or do they stay angled to continue turning? It threw me off during Telepresence. Overall, however, I felt as though the Telepresence definitely helped to identify threats. Navigation was a bit tricky,	1

Comments	No. of Responses
but is manageable with practice. Also, the rough terrain made movement difficult.	
The terrain was difficult on the steering.	1
Telepresence was actually worse for the outside reconnaissance. This is only due to the fact that the video resolution of the Telepresence headset device display is terrible. I couldn't clearly see the IEDs, etc., although I have perfect vision, and it was much easier to identify the items by simply watching the video on the monitor.	1
To navigate to the waypoints with Telepresence, I had to keep switching back to the map, and drive to the next point. I can't see IEDs and other items while I'm driving in "map" mode. Why not just have a small map at the bottom of the screen? Then I can see where I am, and view the surroundings at the same time.	1
There was not a large advantage of using Telepresence outside because there was plenty of room and time to look around. The difference in maneuverability and situation awareness didn't become clear until the indoor reconnaissance.	1
1st problem: The alignment of me facing forward with the robot eyes facing forward with the robot body was gradually drifting out of alignment. This meant that after some time, I would face front, but the robot was not facing straight ahead but off to the side, and I would have to re-calibrate the robot to face front. This was extremely confusing and bothersome. Front should always be front. When I face straight ahead, I want my robot facing straight ahead.	1
2nd problem: There were repeated errors with the robot. Little worked as it should. Robot kept spinning in circles on its own. Camera would freeze, and computer had to be re-booted. Commands entered (such as "view satellite map" button) wouldn't work. When I push a button or command the robot, I need it to carry out that action IMMEDIATELY, and WITHOUT FAIL. Actually, an anomaly can be overcome as long as the robot is reacting consistently. This robot was not consistent; I could never trust it to move or look at the directions I was trying to command it.	1
Suggestion: use a head-mounted sensor to direct the robot's eyes, but let the user view the video (mono) on a Laptop screen. Resolution was much better on the screen, "stereo vision" was cool, but it did nothing to help me see. As a result, I operate in mono the whole time because in stereo it would be right on top of an item and still not see it until I switched to mono.	1
Difficult to see objects on ground in general, let alone when moving.	1
Display quality made it hard to distinguish what an object was at more than 6 feet out. Objects tended to blend in with terrain.	1
Laptop: OUTDOORS	
Very easy to use.	2
With practice, this style could be mastered.	1

Comments	No. of Responses
The movement speed of the robot was excellent. I tried different speeds which turned out to be very easy to handle.	1
Navigation outdoors is much easier when a map is present to orient off of, especially when the direction of travel is clearly marked.	1
This system while not having the “cool” factor of the headset is easier to use. The control system is very similar to many video games. And, considering the age group of those who will be using it if the military adopts it, this control scheme will already feel familiar. The only change I would recommend is an option to invert the Y-axis of the camera controls.	1
I would prefer the ability to have the camera axis not be inverted (up=up). At times the camera did not respond to my commands or was jumpy.	1
Used to having a big picture with a little map. Also, focusing on smallness of picture made it more difficult to hit waypoint and steer camera.	1
I found that maintaining situational awareness while moving to be difficult. The controls with video did not feel smooth.	1
Difficult to look for objects outside because it was unclear where the limits of the course were. A zoom function would have helped outdoors.	1
It would be easier to operate if when you pushed up on the controller the camera went up and down when you pressed down.	1
Moving the robot was the most difficult part. The camera was moving much too quickly (for small motions as well). It would help a lot if I could make the robot have slight turns of its head at first. Then its head moves faster as I push the controller harder or hold it down longer. Short, jerky movements of the head took a lot of getting used to.	1
The controller’s vision is very sensitive. I think the sensitivity could become more acute, sharper.	1
Controllers were too sensitive on the camera side of things.	2
Lagging of the camera was hardest part of navigation. Sometimes it would freeze up and it can lead to losing orientation.	1
For both iterations the video freezing made the recon frustrating.	1
Adding 360 degrees ability would enable the robot to navigate around turns better. Hard to judge how far you can swing out.	1
Also, there was a huge lag between the image on my screen and the commands I was inputting into the controls. When I tell the robot to turn its head, I want to see the picture moving, not sudden stops and starts so have to guess how long to hold the button down. Function to “lock” camera to a target no matter where I maneuver.	1
For navigation, it was very difficult to tell which way the robot was travelling. The only way I could follow the waypoint map was to watch the green line and red “history” line on the overhead map while travelling down the route. I want to scan my “eyes” for items of interest. Its’ easy to get separated which direction you’re looking around compared to which direction you are driving. Those two horizontal lines that represent the width of the robot just don’t cut it because as you turn your robot head farther, they are out of sight. It would	1

Comments	**No. of Responses**
help a lot if there was some kind of gradient for the entire field of vision. This way, as I swivel my head, it's easy to keep driving because I know where my body is I relation to my head. Also, the camera – there needs to be a sound effect or some kind of indication or flashing light or something to confirm I took a picture. Sometimes a small image of the photo I took would appear, and when there were several pictures to take at once it was unclear if I got the picture or if the button didn't push or what.	1
The picture (video feed) from robot was a tiny corner of the screen and satellite map was most of the screen. I was straining and sitting close to see the video, but the map was so big. Why not swap them so have a large video to see the IEDs more clearly and I can navigate with a smaller route map. Or the route map may disappear completely and only appear when I call it up with a button on the controller. Think of it like a video game: I should get options to customize how I want the display to look, how the buttons work (steering, zoom in/out). The more options I have, the better I can customize the robot's performance to what fits me.	1
Display in the Laptop was too small.	1
Hard to keep track of the meanings of each button, and the display on the computer is confusing.	1

TELEPRESENCE: BUILDING							
	N	**Mean**	**Std. Deviation**	**Skewness**		**Kurtosis**	
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**
Move the robot in the correct direction	16	5.1875	1.32759	-1.171	.564	.922	1.091
Avoid obstacles	15	4.8667	1.18723	-.299	.580	-.304	1.121
Avoid potholes	4	4.5000	1.00000	-2.000	1.014	4.000	2.619
Assess down slopes for navigability	2	4.0000	1.41421	.	.	.	.
Assess side slopes for navigability	2	4.0000	1.41421	.	.	.	.
Identify any other terrain features that makes it difficult to maneuver through the terrain	10	5.4000	.84327	.389	.687	.370	1.334
Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	6	5.5000	1.04881	.000	.845	-.248	1.741
Anticipate whether the turn radius of the vehicle will allow a turn	16	4.0000	1.63299	.000	.564	-.458	1.091
Identify if the robot is on the correct path	12	5.4167	.90034	-.152	.637	-.427	1.232

TELEPRESENCE: BUILDING							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Navigate far enough ahead to plan route in advance	15	5.4667	1.12546	-.425	.580	.261	1.121
Navigate well enough to drive at slowest speeds	15	6.0000	.75593	.000	.580	-1.077	1.121
Navigate well enough to drive at medium speeds	15	5.9333	1.09978	-1.339	.580	2.449	1.121
Navigate well enough to drive at fastest speeds	14	5.5000	1.28602	-.380	.597	-.715	1.154
Finish the course quickly	16	5.4375	1.15289	-.423	.564	-.189	1.091
Find IEDs and other objects of interest	16	5.9375	1.06262	-1.386	.564	2.789	1.091
Navigate to the next waypoint	10	5.6000	1.07497	-.322	.687	-.882	1.334
Ability to map the bldg (after recon)	15	5.8000	1.08233	-.328	.580	-1.126	1.121
Ability to take pictures	16	5.9375	1.28938	-1.149	.564	.341	1.091
Being aware of the direction the camera is pointed when it is not centered on the front of the robot	4	4.7500	1.25831	-1.129	1.014	2.227	2.619
Make robot understand you	10	5.8000	1.03280	-.272	.687	-.896	1.334
Ability to control the camera (viewing direction)	16	5.5000	1.59164	-1.077	.564	.234	1.091
Maintain situation awareness	16	5.2500	1.43759	-.654	.564	-.121	1.091
Overall ability to perform this reconnaissance	16	5.5625	1.03078	-.191	.564	-.945	1.091
Move the robot and camera angle at the same time	12	4.8333	1.85047	-.949	.637	.415	1.232
Maintain direction to way-point while searching for items	9	4.7778	1.85592	-1.094	.717	.963	1.400

Laptop: BUILDING							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Move the robot in the correct direction	16	5.6250	1.08781	-.899	.564	.982	1.091
Avoid obstacles	16	5.2500	1.23828	-1.023	.564	2.089	1.091
Avoid potholes	5	5.4000	1.14018	.405	.913	-.178	2.000
Assess down slopes for navigability	3	4.0000	1.00000	.000	1.225	.	.
Assess side slopes for navigability	3	4.0000	1.00000	.000	1.225	.	.

Laptop: BUILDING							
	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Identify any other terrain features that makes it difficult to maneuver through the terrain	12	5.8333	1.19342	-.392	.637	-1.446	1.232
Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	8	4.6250	1.30247	-1.140	.752	1.652	1.481
Anticipate whether the turn radius of the vehicle will allow a turn	16	4.4375	1.36473	-.210	.564	-1.337	1.091
Identify if the robot is on the correct path	14	5.2143	1.31140	-.458	.597	-.751	1.154
Navigate far enough ahead to plan route in advance	15	5.3333	1.11270	.306	.580	-1.157	1.121
Navigate well enough to drive at slowest speeds	15	6.0000	.92582	-.623	.580	-.179	1.121
Navigate well enough to drive at medium speeds	15	5.8000	1.01419	-.493	.580	-.598	1.121
Navigate well enough to drive at fastest speeds	14	5.3571	1.00821	-.858	.597	1.211	1.154
Finish the course quickly	16	5.2500	1.23828	-1.505	.564	2.597	1.091
Find IEDs and other objects of interest	16	6.3125	.70415	-.537	.564	-.643	1.091
Navigate to the next waypoint	8	6.1250	.83452	-.277	.752	-1.392	1.481
Ability to map the bldg (after recon)	16	5.8750	1.20416	-1.039	.564	.653	1.091
Ability to take pictures	16	6.3125	.79320	-1.578	.564	3.902	1.091
Being aware of the direction the camera is pointed when it is not centered on the front of the robot	4	4.7500	1.89297	-1.659	1.014	2.615	2.619
Make robot understand you	10	6.1000	.99443	-1.085	.687	.914	1.334
Ability to control the camera (viewing direction)	16	5.4375	1.50416	-.602	.564	-.974	1.091
Maintain situation awareness	16	5.1250	1.14746	-.274	.564	.249	1.091
Overall ability to perform this reconnaissance	14	5.6429	.49725	-.670	.597	-1.838	1.154
Move the robot and camera angle at the same time	11	4.9091	1.86840	-.965	.661	.385	1.279
Maintain direction to way-point while searching for items	10	5.0000	1.76383	-1.215	.687	2.245	1.334

Comments	**No. of Responses**
TELEPRESENCE: BUILDING	
Great for field.	1
This was the easiest and less frustrating mission out of all of them.	1
Easier than outside.	1
Inside was easier to navigate and find IEDs because of the closeness.	1

Comments	No. of Responses
Vision better indoors; robot maneuvered better too.	1
Much easier to move and understand information, both inside and out.	1
Easier to find objects because they didn't blend in with the surroundings.	1
Sometimes the visual quality was bad; hard to identify items. I had trouble seeing the guide posts on occasion.	1
Good resolution of photographs/camera; got thru course well enough.	1
Responsive controls made for smoother negotiation of course.	1
The controls were not difficult to use and felt very straightforward.	1
My poor skills with remote controls likely contributed the most to slow times or missed items.	1
The controller occasionally would not register the map on the map functions (zoom/item scrolling). My one complaint is the head piece is bulky and, because of the cords in the rear, sometimes harder to turn than it should be.	1
Given smaller size of buildings, slightly more difficult to maneuver.	1
Very unsettling because of feeling room was smaller than it was. Recommend using the same room with objects being moved. Glitches could be part of the nauseating feeling.	1
The cameras of robot were much more functional with Telepresence; much faster and easier to use, but very difficult to distinguish anything. Why not just put the head tilt sensor on a headband (no Telepresence goggles) and let me move the robot's eyes by moving my head still; but I would much rather see all the video come over the Laptop screen.	1
Telepresence goggles have other imitations: hard to see when looking down at my feet or something close by me. And the power cords of Telepresence goggles are heavy and make it hard to move my head around. The cord should be hanging from the ceiling or something.	1
Taking pictures was even harder because I kept having to switch screens and select the category from a list. I DON'T WANT TO BE BLIND while I'm selecting from a list or watching a map. Make the map or list come to my video screen when I push the button, so I can still operate and function while I am navigating and taking pictures.	1
Having a large back end makes turning through doorways difficult and you need to look down to see where antennae are located.	1
Bumpy terrain of road contributed to slight motion sickness, but easily resolved by "mono."	1
Overall, no need for "stereo" camera function because mono provides enough clarity and resolution to do the job well.	1
Camera quality still made it hard to determine what an object was.	1
Not for urban operations.	1
I do not like controlling the camera with the headset. I have always used a controller to maneuver in video games and with other robots.	1
Laptop: BUILDING	
Camera was crisp and controlling vehicle was quite easy.	1

Comments	**No. of Responses**
Overall this system was easier to use and felt more natural than the headset. The one other recommendation I would make is to make the control that moves the cameras not so sensitive.	1
Much easier to see and feel where the robot is and how to maneuver it.	1
It is possible to move the robot and the camera at the same time. (I wasn't aware that t was possible, so I did not use that feature.)	1
The "1" button function to re-center the "eyes" to the body was very useful. I used it constantly to get my bearing as I traveled. Inside it let me look around as I pleased and quickly return focus to the front without having to wander my eyes back. More options like that would be nice. Like, tapping the "eyes left" stick twice would make the robot look 90 degrees left or tapping "move right" twice executes "right face" turn of robot's body. Do a brainstorm of all the operations that would be beneficial for the functionality of this unit and think how best to implement them in the form of user friendly controls.	1
It was not too easy to make this robot go through doorways (and look for objects at same time). I was always worried about banging it up against a wall or getting stuck. And took extra time.	2
Camera freezing was the only problem.	1
The stereo optic view presents a much better indoor navigation, and makes it easier to scan for items compared to the Laptop system. That said, in my opinion the Laptop is superior for outdoors navigation because it retains a map to orient off of.	1
Found it easier to not move the robot and camera at the same time. It was too disorienting to drive and adjust the camera.	1
Darkness of rooms led to misidentification. Otherwise, would like a bigger picture.	1
The controller and display did not feel like one unit.	1

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

	NO. OF RESPONSES	
	Telepresence	**Laptop**
a. Eyestrain	9	3
b. Tunnel vision	2	0
c. Headaches	0	0
d. Motion sickness	3	1
e. Nausea	1	0
f. Disorientation	4	2
g. Dizziness	0	0
h. Competition between eyes for vision of different scenes at which they are looking	4	0
i. Any other problems?	2	0

Comments	No. of Responses
TELEPRESENCE	
Dry eyes.	1
Eyestrain caused by poor image quality.	1
Eyestrain due to objects looking even smaller.	1
Tunnel vision: Unable to see some areas because of the device.	1
Motion sickness was very slight, in "stereo vision."	1
h. Cameras not aligned.	1
Image quality is a NO GO!	1
A little blurry for first 5 seconds.	1
Laptop	
No comments.	

3. What are your comments on this iteration?

Comments	No. of Responses
TELEPRESENCE	
The interface I think will be very useful but it takes a little time to get used to. However, it is a more natural way to view things and moving your head allows you to point the camera exactly where you need to.	1
A zoom function would be helpful with identifying objects.	1
Made it sometimes harder to look down and see the antennas, which made it harder to navigate turns.	1
I was unable to complete this iteration while using the stereo vision.	1
Laptop	
More user-friendly. Worked better in this mode and it was also much easier to stay oriented to where you are. Whereas, with the headset you could become disoriented much more easily. While the headset seems cooler, this system is the easier to use which is what matters in a combat environment.	1
Camera system works really well overall. It seemed to be more inside the building than outside. The coupling of the map and red and green lines make it easier to orient yourself to the camera. The re-center button is a huge help for quick correction.	1
After rebooting the system, I photographed and labeled three soda can IEDs as cell phones/PDAs.	1

A-4 - Experiment 1: End of Experiment Questionnaire Results

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

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

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
TELEPRESENCE							
Completeness of introductory training	16	6.31	.873	-1.397	.564	2.016	1.091
Comprehension of overall concept of the robot	16	6.31	1.014	-2.478	.564	7.791	1.091
Outdoors: How to drive	16	6.19	1.047	-1.219	.564	.546	1.091
Outdoors: Time provided to practice	16	6.13	1.025	-1.129	.564	.492	1.091
Outdoors: How to perform reconnaissance	16	5.81	1.167	-1.025	.564	.833	1.091
Building: How to drive	16	6.19	.834	-.391	.564	-1.443	1.091
Building: Time provided to practice	16	6.06	1.181	-1.521	.564	2.057	1.091
Building: How to perform reconnaissance	16	6.13	.957	-.798	.564	-.235	1.091
Overall training evaluation	16	6.13	.957	-.798	.564	-.235	1.091
Laptop							
Completeness of introductory training	16	6.31	.873	-1.397	.564	2.016	1.091
Comprehension of overall concept of the robot	16	6.44	.629	-.653	.564	-.321	1.091
Outdoors: How to drive	16	6.25	.775	-.492	.564	-1.062	1.091
Outdoors: Time provided to practice	16	6.06	1.181	-1.521	.564	2.057	1.091
Outdoors: How to perform reconnaissance	16	6.13	.957	-.798	.564	-.235	1.091
Building: How to drive	16	6.19	.834	-.391	.564	-1.443	1.091
Building: Time provided to practice	16	6.00	1.317	-1.603	.564	1.929	1.091
Building: How to perform reconnaissance	16	6.25	.931	-1.133	.564	.677	1.091
Overall training evaluation	16	6.38	.806	-.845	.564	-.838	1.091

Comments	**No. of Responses**
Excellent.	1
Very comprehensive.	2
Training was very specific and well-explained.	1

Overall, very good.	2
Ease of use was good.	1
Training was very logical and easy to comprehend.	1
Instructions were clear.	1
The robot is very easy to operate.	1
Controls were easy to use.	1
Conditions and standards were well explained and understood.	1
I felt I had received the proper training to perform all the duties.	1
I really like the second trial with the Telepresence; much easier. My eyes were less strained to see what I was looking at.	1
The Laptop offers a format most people are used to using, so it is easier to take the new technology. Whereas, the HMD is foreign and not as familiar to new user.	1
I prefer the Laptop by far.	1
I found it more difficult to control the camera using Telepresence than using the Laptop.	1
A little more instruction on how to turn and maneuver the robot and use of the lines would have been helpful.	1
Very much the same.	1
Some variables make it more inclined for others to get motion sickness while using the Telepresence.	1
Laptop screen was hard to use due to the small picture and camera controller.	1
Would like a larger viewing screen and a smaller GPS map. Would make targets easier to identify.	1
Zoom function would have been nice.	1

2. What were the easiest and hardest training tasks to learn?

Comments	**No. of Responses**
Easiest	
To swivel the camera to view items of interest.	1
How to use the camera to conduct recon.	1
Taking a photo.	1
How to move the robot and look for items listed.	2
Moving the robot with the Laptop.	1
Driving.	1
Driving with the Laptop.	1
Driving indoors.	1
Using the controls.	2
Finding waypoints and your sense of direction was easiest.	1
Hardest	
Moving your head in sync with the robot, or just looking around in general while driving the robot in a specific direction.	1

Comments	No. of Responses
To learn to maneuver the robot, especially around or near obstacles to doorways.	1
Driving the robot.	2
Driving with Laptop.	1
Trying to move the camera.	1
Moving the camera with the Laptop system.	1
Centering the camera with the Telepresence.	1
Using the headset and getting oriented with it.	1
Using the virtual headset to move camera.	1
Controlling the camera and the robot at the same time using Telepresence.	1
Multifunction tasks: selecting which object from list before taking picture, simultaneous camera move/robot move.	1
Identifying the objects.	1
Controls took awhile to get used to.	1
Remembering the button functions and to make sure to call the waypoints.	1
Getting used to the HMD.	1
Backward up and down was difficult with the controller.	1

3. What are your overall comments on the training?

Excellent training.	2
Good.	3
It was interesting and fun to participate in the research study.	1
Very simple; perfectly adequate.	1
Easy to understand and operate.	1
Visual guide for the controller was excellent.	1
Adequate to orient the operator to how to use the controls and what tasks needed to be accomplished.	1
Will help the military to save lives.	1
It was adequate, but helpful to learn and familiarize myself with the controls.	1
Laptop unit was simple and easy to quickly identify targets.	1

4. Using the scale below, please rate the following characteristics of each control system.

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

CHARACTERISTICS	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
TELEPRESENCE							
Resolution (Clarity)	16	5.25	1.390	-.850	.564	.798	1.091
Size of objects appearing in the display	16	5.25	1.483	-.630	.564	.008	1.091
Ability to adjust display	15	4.60	1.502	-.659	.580	1.060	1.121
Comfort of viewing	16	4.75	1.183	-.276	.564	.971	1.091
Display brightness	16	5.25	1.342	-1.088	.564	1.221	1.091
Display glare	16	5.63	1.310	-.210	.564	-1.793	1.091
Contrast between objects on the driving display	15	5.53	1.302	-.532	.580	-.837	1.121
Display color	15	5.47	.990	-.149	.580	-.844	1.121
Comfort of using display	16	5.31	1.352	-.838	.564	.900	1.091
Number of controls	16	5.88	1.025	-.571	.564	-.592	1.091
Control locations	16	6.25	.856	-1.274	.564	1.907	1.091
Size of individual controls	16	6.25	.683	-.358	.564	-.592	1.091
Complexity of controls	16	6.25	.775	-.492	.564	-1.062	1.091
Ability to use controls without activating other controls	16	5.94	1.181	-1.251	.564	1.289	1.091
Size of entire control unit	16	6.56	.629	-1.183	.564	.633	1.091
Adequacy of this control unit for teleoperation	16	6.00	.966	-2.028	.564	6.127	1.091
Ease of controlling camera (viewing direction)	16	5.38	1.784	-.893	.564	.551	1.091
Overall assessment of this control unit	16	5.75	1.065	-.189	.564	-1.183	1.091
Laptop							
Resolution (Clarity)	16	5.81	.544	-.189	.564	.555	1.091
Size of objects appearing in the display	16	5.38	.806	.027	.564	-.130	1.091
Ability to adjust display	15	4.87	1.187	-.004	.580	-.791	1.121
Comfort of viewing	16	5.81	.911	-.797	.564	.412	1.091
Display brightness	16	5.81	1.047	-.375	.564	-.948	1.091
Display glare	16	5.13	1.455	.051	.564	-1.485	1.091
Contrast between objects on the driving display	15	5.47	.640	-.802	.580	-.127	1.121
Display color	15	5.67	.724	-.676	.580	.948	1.121
Comfort of using display	16	5.69	1.195	-1.445	.564	1.841	1.091
Number of controls	16	5.50	1.155	-.297	.564	-1.411	1.091
Control locations	16	5.94	1.181	-1.251	.564	1.289	1.091
Size of individual controls	16	6.13	.719	-.192	.564	-.821	1.091
Complexity of controls	16	5.88	1.147	-.936	.564	.939	1.091

CHARACTERISTICS	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Ability to use controls without activating other controls	16	6.12	1.025	-1.129	.564	.492	1.091
Size of entire control unit	16	6.56	.629	-1.183	.564	.633	1.091
Adequacy of this control unit for teleoperation	15	6.20	.561	.112	.580	.378	1.121
Ease of controlling camera (viewing direction)	16	5.31	1.352	-.838	.564	-.529	1.091
Overall assessment of this control unit	16	5.81	.750	.334	.564	-1.004	1.091

Comments	**No. of Responses**
TELEPRESENCE	
Telepresence is better for controlling the robot, but mainly only for indoor situations.	1
Felt more comfortable and I was less pressured for time because of that.	1
Better for indoors.	1
Better for observation, but sometimes disorienting.	1
Felt like I was in the robot's head, looking for IEDs.	1
Not very much better until the image quality from the Telepresence glasses is addressed.	1
Cords of Telepresence are heavy.	1
I would never want to use in the field if I had access to a control and display system like the Laptop.	1
Laptop	
Easier to use and felt more natural.	1
More user-friendly.	1
Good for outdoors.	1
Laptop did not make me feel nauseated.	1
Too small.	1
Resolution problems and clarity issues (none of which were present with Telepresence).	1
General Comments:	
Great. May be its too simple.	1
Make video screen larger.	1
Needs more adjustment options.	1
Both comfortable for viewing.	1
Needs to be mounted from ceiling.	1
"Change map button" is close to "vibrate button."	1
Depends on the situation as to which system is better.	1

5. Using the scale below, please rate each control system for the following tasks.

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

TASKS	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
TELEPRESENCE							
Avoiding obstacles	16	5.31	.946	-.187	.564	1.950	1.091
Assessing terrain for navigability	16	5.81	1.109	-.588	.564	-.860	1.091
Driving straight route	16	5.25	1.238	-.060	.564	-.962	1.091
Driving multiple waypoints	16	5.44	1.263	-.293	.564	-.872	1.091
Looking for objects of interest	16	5.50	1.461	-.734	.564	-.578	1.091
Identifying objects	16	5.44	1.632	-1.557	.564	2.642	1.091
Scanning surroundings	16	5.75	1.342	-.615	.564	-.809	1.091
Maneuvering corners	16	5.50	1.265	-.226	.564	-.790	1.091
Maintaining situation awareness	16	5.31	1.621	-1.331	.564	2.213	1.091
Overall Building reconnaissance	16	5.81	1.424	-1.365	.564	2.044	1.091
Overall Outdoor reconnaissance	16	5.06	1.389	-.126	.564	-.993	1.091
Laptop							
Avoiding obstacles	16	6.13	.719	-.192	.564	-.821	1.091
Assessing terrain for navigability	16	6.06	.772	-.113	.564	-1.194	1.091
Driving straight route	16	6.13	.957	-.798	.564	-.235	1.091
Driving multiple waypoints	16	6.06	.680	-.074	.564	-.489	1.091
Looking for objects of interest	16	5.69	.946	-1.430	.564	3.626	1.091
Identifying objects	16	5.75	.577	.000	.564	-.066	1.091
Scanning surroundings	16	5.56	1.094	-.356	.564	.549	1.091
Maneuvering corners	16	5.88	.806	.245	.564	-1.368	1.091
Maintaining situation awareness	16	5.87	1.088	-1.143	.564	1.889	1.091
Overall Building reconnaissance	16	5.63	1.025	-.810	.564	1.645	1.091
Overall Outdoor reconnaissance	16	6.00	.816	.000	.564	-1.467	1.091

Comments	**No. of Responses**
TELEPRESENCE	
Great for outside.	1
Much easier to tell what the objects were and where they were.	1
Not bad.	1
Telepresence seems better, but the system needs some refinement before it is the clear winner.	1
If it had a map integrated, would be perfect.	1
Waypoint identification difficult due to the need to go back and forth between two maps.	1
Harder to use indoors.	1
Laptop	
Superior outdoors, primarily because you can use the map to orient the robot's direction.	1

Comments	**No. of Responses**
TELEPRESENCE	
Easier to use and control.	1
More familiar and a better interface for the given task.	1
Would have been nice and easier to use the Laptop if the map was the smaller, inset image and the camera image was the main image.	1
Laptop was too small and unclear for fast and accurate identification.	1
General comments:	
Stereoscopic vision was not useful to me at all on this system.	1
Very hard to identify objects on inner rooms.	1

6. Which control system do you prefer (why, and under what conditions)?

Number of Responses	
Telepresence (HMD)	**Laptop (Laptop)**
9	6

*one no response

Comments	**No. of Responses**
TELEPRESENCE	
Superior for indoor navigation, especially with the depth perception.	1
Stereo display was helpful.	1
I prefer the Telepresence in the building environment. Control of vision and navigation were superior to Laptop, but the video image was much easier to identify items of interest than the Telepresence goggles. Higher quality goggle image is definitely needed.	1
Had a much easier time doing surveillance and scanning.	1
Easy during outdoor, and especially the indoor was easier to see and tell what the objects were and where they were on the screen.	1
Easier on outside because you can move while scanning for explosives.	1
A more natural way to search, leaving the mind able to focus on the search and not the controls.	1
Ability to control the view so easily.	1
Not good on inside.	1
Had to be re-calibrated during the exercise.	1
Laptop	
The Laptop was more user-friendly and seemed to have a somewhat clearer display.	1
Familiarity.	1
Easier to use because of the access to the menu without switching back and forth.	1
Joystick control of the camera offers steadier picture.	1
Crisper picture.	1
Easier not to become disoriented than the Telepresence.	1

Comments	**No. of Responses**
Better for outside.	1
Display picture was too small and hard to see.	1
Laptop inside because the objects are more clear.	1

7. What suggestions do you have for ways to increase the effectiveness of the following?

Comments	**No. of Responses**
TELEPRESENCE	
Very good.	1
Work out glitches with software to hardware to prevent video freezing. Commands not being received and fix the drift of what is "facing straight ahead" on the headset with the cameras. Forward should always be forward.	1
Put the list of objects to identify on both views (the map and the real time view).	1
Both cameras should be adjusted to show a better display with close objects.	1
Have the map inset into screen instead of having to switch between the two.	1
Integrate a map in the upper left corner or right corner, toggled by the map button, to aid in navigation.	1
More contrast between colors.	1
An in/out zoom for the cameras.	3
A wider peripheral vision would help.	1
A light headpiece would influence more head turning.	1
Better resolution of the picture.	5
Make the view not so jumpy when the head is moved.	1
More stabilization of headset so that it does not require re-calibration.	1
Controls feel touchy.	1
Could be enhanced by not making it as sensitive to the motion so it is easier to keep straight.	1
"Stereo" is unnecessary because "mono" is more than adequate for accomplishing the mission.	1
May need a small camera on back to see reverse.	1
Attach the cord so that it does not slip or become caught, jerking the controller's head.	1
Laptop (Laptop)	
Hard to improve because it does not offer what the Telepresence does.	1
Have the camera higher off the ground to see farther/more clearly.	1
Using keyboard controls rather than the joystick (or combination of both).	1
Make the controls more sensitive to slight movements on the controller.	1
Reprogram the control unit.	1
Increase the size of the camera display image.	5
Make the video large and the waypoint map smaller.	2
Make pre-defined functions (combos) that can be entered on the controller, such as "right face," "left face," etc.	1

Comments	No. of Responses
TELEPRESENCE	
Very good.	1
Work out glitches with software to hardware to prevent video freezing. Commands not being received and fix the drift of what is "facing straight ahead" on the headset with the cameras. Forward should always be forward.	1
Put the list of objects to identify on both views (the map and the real time view).	1
Both cameras should be adjusted to show a better display with close objects.	1
Have the map inset into screen instead of having to switch between the two.	1
Integrate a map in the upper left corner or right corner, toggled by the map button, to aid in navigation.	1
More contrast between colors.	1
An in/out zoom for the cameras.	3
A wider peripheral vision would help.	1
A light headpiece would influence more head turning.	1
Better resolution of the picture.	5
Make the view not so jumpy when the head is moved.	1
More stabilization of headset so that it does not require re-calibration.	1
Controls feel touchy.	1
Could be enhanced by not making it as sensitive to the motion so it is easier to keep straight.	1
"Stereo" is unnecessary because "mono" is more than adequate for accomplishing the mission.	1
May need a small camera on back to see reverse.	1
Attach the cord so that it does not slip or become caught, jerking the controller's head.	1
Laptop (Laptop)	
Hard to improve because it does not offer what the Telepresence does.	1
different options for up and down.	
Make the controls not as sensitive, invert the y-axis.	
Could be approved by allowing for a broader range of camera angles; perhaps 360^{o} view.	
Better resolution; clearer.	
Ability to zoom the camera.	

A-5 - Experiment 2: Demographic Results (N = 22)

MOS		**RANK**	**AGE**	**DUTY POSITION**
09S –	17	E-4 – 4	26 years (mean)	OCS – 22
15Q –	1	E-5 – 15		
92A –	1	NR – 3		

1. How long have you served in the military? _12_ months (mean)

2. How long have you had an infantry-related job? _5.5_ months (mean) (N = 2)

3. How long have you been deployed overseas? _15_ months (mean) (N = 3)

4. How long have you been deployed in a combat area? _12_ months (mean) (N = 1)

5. With which hand do you most often write? _21_ Right _1_ Left

6. With which hand do you most often fire a weapon? _20_ Right _2_ Left

7.a. Do you wear prescription lenses? _9_ No _13_ Yes

b. If so, which do you most often wear? _8_ Glasses _4_ Contacts _1_ NR

c. Which is your dominant eye? _18_ Right _3_ Left _1_ NR

d. Do you have any vision-related problems? _16_ No _3_ Yes _3_ NR
If so, what? 20/40 in right eye, near-sightedness (2),

8. Do you have any hearing-related problems? _17_ No _1_ Yes _4_ NR
If so, what? Slight hearing loss in right ear.

9. Have you ever experienced motions sickness? _14_ No _5_ Yes _3_ NR
If so, under what conditions? Riding in a car, roller coaster (2), boats (2)

10.a. Have you ever used a robotic system? _20_ No _0_ Yes _2_ NR

b. If so, what type?

c. Please describe the conditions under which you used the robotic system.

11. Please rate your skill level for each of the following activities?

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

ACTIVITY	MEAN RESPONSE
Operating ground unmanned vehicles	1.14
Operating aerial vehicles	1.18
Target detection and identification	1.73
Playing commercial video games	2.82
Training with Army video simulations	1.86

12. How many years of experience do you have operating a robot
_21_ None _1_ Less than 1 year _0_ 1-2 years _0_ 2-5 years _0_ More than 5 years

13. How many hours of robot simulator experience do you have? _14_ None
_22_ Less than 2 hours _0_ 2-5 hours _0_ 5-10 hours _0_ More than 10 hours

14. How many times have you been deployed and used an unmanned vehicle for EOD missions?
_22_ None _0_ 1-2 times _0_ 3-4 times _0_ 5-6 times _0_ 7 times or more

15. How often do you play video games?
_1_ Never _5_ 5-11 times per year _6_ 1-3 times/month _9_ 1-6 times/week _1_ Daily

16. Which gaming system do you plan most often? XBox (6), Sony PSP, Playstation (8), iPhone, PC/Laptop (4), Wii (4), Nintendo DS (3)

A-6 - Experment 2: Performance Results

Audio Task: Time to find target

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Std. Error**
Target B							
BT_sec1	16	29.00	196.00	64.6250	41.08183	2.453	.564
BMJ_sec1	16	55.00	562.00	141.6875	126.78418	2.759	.564
BMH_sec1	16	33.00	196.00	85.8750	43.19394	.969	.564
Target D							
DT_sec1	16	28.00	153.00	75.1875	36.11319	1.208	.564
DMJ_sec1	16	56.00	272.00	134.8125	64.76132	1.225	.564
DMH_sec1	16	46.00	248.00	107.3750	53.02185	1.599	.564
Target H							
HT_sec1	16	28.00	83.00	46.8125	16.16671	.817	.564
HMJ_sec1	16	37.00	469.00	95.6250	104.10307	3.467	.564
HMH_sec1	16	23.00	165.00	68.3750	34.80397	1.302	.564
Target J							
JT_sec1	16	37.00	197.00	98.2500	44.35689	1.019	.564
JMJ_sec1	16	64.00	258.00	139.2500	63.49541	.459	.564
JMH_sec1	16	44.00	231.00	103.5000	48.32805	1.534	.564
Target G							
GT_sec1	16	24.00	120.00	47.5625	23.11412	2.180	.564
GMJ_sec1	16	25.00	355.00	83.2500	77.05626	3.241	.564
GMH_sec1	16	30.00	259.00	70.5625	56.60385	2.719	.564
Target E							
ET_sec1	16	26.00	92.00	57.3125	19.72382	.129	.564
EMJ_sec1	16	39.00	234.00	89.1875	55.94428	1.730	.564
EMH_sec1	16	29.00	254.00	93.3125	57.44414	1.642	.564
Valid N (listwise)	16						

Descriptive Statistics

	Mean	Std. Deviation	N
Btime	97.3958	60.39502	16
Dtime	105.7917	41.39921	16
Htime	70.2708	44.22170	16
Jtime	113.6667	48.13376	16
Gtime	67.1250	37.27871	16
Etime	79.9375	38.16770	16

Audio Search times by target

Time to Approach by Display and Target

	Mean	Std. Deviation	N
BT_sec2	89.6250	39.34950	16
BMJ_sec2	164.6250	130.33591	16
BMH_sec2	112.5625	54.42545	16
DT_sec2	112.1875	93.39252	16
DMJ_sec2	154.3750	66.80906	16
DMH_sec2	128.1250	56.34640	16
HT_sec2	69.0000	23.44355	16
HMJ_sec2	124.6250	120.17591	16
HMH_sec2	90.1250	44.86703	16
JT_sec2	122.7500	44.32682	16
JMJ_sec2	172.5625	80.43463	16
JMH_sec2	130.5625	61.54886	16
GT_sec2	65.9375	27.24817	16
GMJ_sec2	101.8750	80.23538	16
GMH_sec2	81.8125	53.83954	16
ET_sec2	75.8125	22.31358	16
EMJ_sec2	111.3125	55.38438	16
EMH_sec2	108.5000	59.98555	16

Mean Percentage correctly Identified by display and target

	Mean	Std. Deviation	N
BT_ID	.9375	.25000	16
BMJ_ID	.2500	.44721	16
BMH_ID	.3125	.47871	16
DT_ID	.6250	.50000	16
DMJ_ID	.6250	.50000	16
DMH_ID	.5625	.51235	16
HT_ID	.9375	.25000	16
HMJ_ID	.8750	.34157	16
HMH_ID	.8125	.40311	16
JT_ID	.9375	.25000	16
JMJ_ID	.6875	.47871	16
JMH_ID	.6875	.47871	16
GT_ID	.8750	.34157	16
GMJ_ID	.6875	.47871	16
GMH_ID	.8125	.40311	16
ET_ID	.8750	.34157	16
EMJ_ID	.5000	.51640	16
EMH_ID	.7500	.44721	16

Mean Distance to Target by Display and Target

	Mean	Std. Deviation	N
BT_dist	32.2167	9.50323	15
BMJ_dist	28.0833	5.64632	15
BMH_dist	31.2333	10.32528	15
DT_dist	47.5833	20.65072	15
DMJ_dist	44.1167	20.54457	15
DMH_dist	41.1333	21.55286	15
HT_dist	9.5833	4.13788	15
HMJ_dist	13.6167	6.30042	15
HMH_dist	15.0833	6.81167	15

JT_dist	49.5000	11.66803	15
JMJ_dist	45.2000	14.82102	15
JMH_dist	46.7167	13.80860	15
GT_dist	22.3000	4.09943	15
GMJ_dist	20.7633	4.58579	15
GMH_dist	22.6833	5.02624	15
ET_dist	26.3667	1.90363	15
EMJ_dist	27.9667	8.36333	15
EMH_dist	27.5833	7.52654	15

Mean driving errors by Display and Target

	Mean	Std. Deviation	N
BT_drive	.0000	.00000	15
BMJ_drive	.8000	1.47358	15
BMH_drive	.2000	.56061	15
DT_drive	.0667	.25820	15
DMJ_drive	.6667	1.17514	15
DMH_drive	.4000	.73679	15
HT_drive	.2000	.41404	15
HMJ_drive	.5333	.74322	15
HMH_drive	.5333	.74322	15
JT_drive	.8000	.86189	15
JMJ_drive	.8000	.94112	15
JMH_drive	.4000	.63246	15
GT_drive	.3333	.48795	15
GMJ_drive	.6667	1.29099	15
GMH_drive	.2667	.59362	15
ET_drive	.2667	.45774	15
EMJ_drive	.2000	.56061	15
EMH_drive	.3333	.48795	15

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
T_TLX_mental	17	1.00	15.00	6.7647	3.89759	.646	.550
T_TLX_physical	16	1.00	11.00	3.4375	2.78014	1.608	.564
T_TLX_temporal	16	1.00	19.00	6.7500	5.36035	1.553	.564
T_TLX_performance	16	11.00	20.00	15.8750	2.52653	-.577	.564
T_TLX_effort	16	2.00	17.00	7.6250	4.77319	.728	.564
T_TLX_frustration	16	1.00	13.00	4.3125	3.82481	1.483	.564
MH_TLX_mental	16	2.00	20.00	9.9375	4.94596	.137	.564
MH_TLX_physical	16	1.00	16.00	4.4375	4.04918	1.881	.564
MH_TLX_temporal	16	1.00	19.00	7.5625	5.54940	1.025	.564
MH_TLX_performance	16	8.00	19.00	14.1250	3.38378	-.229	.564
MH_TLX_effort	16	3.00	17.00	8.9375	4.50879	.426	.564
MH_TLX_frustration	16	2.00	15.00	7.3125	4.48284	.658	.564
MJ_TLX_mental	16	2.00	20.00	12.6875	4.71478	-.788	.564
MJ_TLX_physical	16	1.00	18.00	5.8125	4.81966	1.311	.564
MJ_TLX_temporal	16	1.00	19.00	8.9375	5.91573	.292	.564
MJ_TLX_performance	16	3.00	19.00	11.2500	4.75395	.150	.564
MJ_TLX_effort	16	3.00	18.00	11.6875	4.23822	-.743	.564
MJ_TLX_frustration	16	2.00	18.00	10.6875	5.54640	-.122	.564
Valid N (listwise)	16						

A-7 - Experiment 2: Robot Control Questionnaire (N = 19)

1. Using the scale below, please the training you received:

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

	MEAN RESPONSE
Verbal explanations	6.28
Practice	6.17

Comments	**No. of Responses**
Verbal helped with initial understanding of tasks.	1
Practice allowed me to understand how to use equipment.	1

2. What were the easiest and hardest training tasks to learn?

Comments	**No. of Responses**
Easiest	
How to move forward.	1
Using head motion control.	1
Headset.	2
Head tracking the video.	1
Moving my head with the mono headset.	1
Controlling the movement of the robot.	4
How to maneuver camera both with head motion, as well as manual (joystick).	1
Using the remote to control the robot.	1
Moving the robot as an entire unit.	1
Concept behind controls.	1
Using head motion to adjust point of focus was extremely intuitive. It was easy to determine direction of sound in stereo mode.	1
Controlling with joystick (similar to play station joystick and controlling much like a modern first person shooter with left sick being motion and right being camera). Using head tracking.	1
Utilizing the antennas on the robot to avoid hitting walls or objects.	1
Working the joystick and headset in unison was much easier than I expected and it makes controlling the robot a breeze.	1
Visual capabilities were the best part about the training task.	1
The verbal explanations given by the staff members. They broke it down step by step which was really easy to understand.	1
Hardest	
None.	1
Spatial awareness forced me to always look down at the antenna on either side or the	1

<u>Comments</u>	**<u>No. of Responses</u>**
red pointer, but got easier as time went on.	
Pinpointing the exact place the noise is coming from.	3
Being asked <u>not</u> to move your head; to keep head still.	3
Not moving my head when controlling the head movements via the joystick took a few sessions to get down completely.	1
Looking around the joystick without moving head.	1
Moving the camera by joystick and trying to move the robot at the same time.	1
Joystick with two controllers.	1
Movement was difficult at times.	1
Took a few minutes to become acclimated to the robot's turning radius, particularly the clearance required on the back side of the robot. Adjusting to point of focus with a joystick was also a challenge.	1
Making tight turns.	2
Control of the robot was a little difficult.	1
Rotating the head of the robot.	1
Controlling robot from 3rd person perspective.	1
Learning the robot's physical dimensions intuitively, especially the clearance in the back.	1
<u>General Comments</u>	
Awesome training; enjoyed using the technology.	1
Very thorough instruction was given.	1
I learn best by doing, so getting my hands on the controls was the best way to learn how to maneuver the robot.	1
Very easy to pick up if the soldier is familiar with modern FPS videogames because controls are similar for both muscle memory on joystick and the way the camera is controlled.	1
Solid platform that would work well with the right chassis and extension arms for control.	1
Need more rear vision for maneuverability.	1
It's nearly impossible to discern if a noise is coming from above or below.	1
Difficult to look and maneuver robot in a fluid motion, the time to process the visual obstacles (walls, charts, etc.(to the maneuver of the robot.	1

Control Conditions

A – Telepresence (Stereo vision 3D audio & Head tracking)
B – Mono/Head Tracking
C – Mono/Joystick

1. Using the scale below, please rate how easy or difficult it was to perform each of the following tasks with each robot control condition above.

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

	MEAN RESPONSE		
	A	**B**	**C**
Move the robot in the desired direction	6.11	5.74	4.63
Avoid obstacles	5.42	5.00	3.95
Turn around	5.32	4.95	4.53
Maneuver around corners	5.42	5.11	4.47
Back up	5.11	4.74	4.58
Hear the target sound (sound volume)	5.47	4.58	4.11
Locate target objects by sound (sound location)	5.47	3.89	3.26
Locate target objects by sight	6.00	5.79	4.89
Find targets quickly	5.42	4.79	3.89
Know your location in the room	5.95	5.89	5.53
Remember target locations	5.63	5.47	5.21
Move quickly	5.47	4.84	4.26
Maneuver probe close to the IED object (when requested)	5.63	5.32	4.74

2. What difficulties did you experience in performing the target locating task?

Comments	**No. of Responses**
A – Telepresence	
Easiest for me because I could hear where the sound was coming from.	1
In the stereo vision mode, it was difficult to look around.	1
C – Mono/Joystick	
The joystick made it a lot harder to maneuver the robot, as well as see to turn corners.	
Using the joystick to control sight and movement.	1
General Comments	
Head tracking was easy to control, but required more physical exertion than joystick control, which was both easy and effortless.	1
After practicing, it was quite easy apart from maintaining special awareness of the robot.	1
Finding/locating the task.	1
Since some items are close to each other, I find it a little hard to identify the exact object that is making the noise.	3

Comments	No. of Responses
The volume was very low, it seemed. Sometimes I would have to guess which direction the sound was coming from and then adjust depending on whether the volume was getting louder or quieter to decide if I'm going in the right direction.	1
Hearing where the target sound was coming from with objects that were close together. For example, in the room with the landmines, the objects were close together so it was difficult to identify which particular object was projecting sound.	1
In mono-sound modes, it was difficult to tell which direction the sound was coming from.	5
I had the most difficulty with the mono-sound and the joystick movement as opposed to the head tracking.	1
When using the mono/joystick, I sometimes forgot that where I was looking wasn't necessarily where the robot was facing.	1
I could not tell which target was making an audio indicator.	1
Moving the head with the joystick slowed my down somewhat.	1
Joystick was much more difficult than using the head sensor.	1
I forgot about the mortar, soda cans, and some other IEDs so I kept choosing the more obvious ones.	1
Hard to determine where IED is without Telepresence, up/down Joystick would be easier if inverted (like flight control).	1
Turning around was somewhat difficult without bumping the rear of the robot.	1

3. Please use the following scale to rate the robot control system features.

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

DISPLAY/CONTROL CHARACTERISTICS	MEAN RESPONSE		
	A	B	C
Resolution (clarity) of the display	5.33	5.28	5.11
Precision of camera movement control	5.44	5.22	5.11
Sensitivity of camera movement control	5.17	4.94	4.67
Time lag of camera movement control	4.83	5.06	4.88
Controlling camera and movement at the same time	5.72	5.67	4.53
Capability to hear sound (volume)	5.50	5.17	4.83
Capability to locate sound (direction)	5.33	4.00	3.33
Overall ease of use	5.94	5.50	4.72
Adequacy of this control unit for tele-operating a robot	5.67	4.94	4.61
Overall assessment of this control unit	5.78	5.00	4.39

4. Please indicate how much each of the following features would contribute to a recon mission.

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

	MEAN RESPONSE		
	A	**B**	**C**
3-D audio	6.56	NA	NA
Stereo vision	6.22	NA	NA
Head-tracked camera	6.06	NA	NA
Mono audio	3.67	NA	NA
Mono vision	4.11	NA	NA
Joystick camera	4.56	NA	NA

Comments	No. of Responses
A – Telepresence	
The easier it is to control the robot, the more success it will have in the field.	1
Definitely more effective with this one.	1
Control was very intuitive, but I found myself turning my head in joystick mode and vice versa.	1
I found that while the stereo sound was indispensible to "hearing" the target, stereo video tended to lag when I was trying to go quickly or move my head or the robot. Almost made me crash a few times.	
Head tracking has a very short learning curve; with an hour's practice, it becomes second nature.	1
General Comments	
Everything works great except for two things: the top of the head gear puts pressure on my head and movement of the camera gives me slight motion sickness.	1
Joystick camera is better. No lag. It offers more precision.	1
Joystick control has a much longer learning curve for a non-gamer.	1
Head tracking is not a useful work tool unless it is integrated with a Kevlar helmet.	1
I think, for me at least, stereo sound and mono video would be the best combination, if possible.	1
A zooming feature for the camera would have been nice, especially useful on the second test with the randomly placed items. 4 minutes in locating items from a distance instead of wasting time maneuvering towards it to identify it.	1
I'd like to try the robot using stereo vision and audio, but control the camera movements via remote control. I was finding it easier to maneuver the robot using directional pad camera control, especially around corners.	1

5. Using the scale below, please rate how easy or difficult it was to perform the following:

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

	MEAN RESPONSE		
	A	**B**	**C**
Maneuver probe close to the IED object (when requested)	5.79	5.00	4.53

Comments	No. of Responses
A – Telepresence	
It seemed easier to get closer to an IED using the stereo visual display based on depth perception. What helped was the pointing device located in the center of the robot.	1
C – Mono/Joystick	
Joystick took longer to adjust than vision of the robot.	1
Joystick was difficult to maneuver.	1
General Comments	
Pretty straightforward; simple.	1
When the probe was over top an object (box), I couldn't tell if the body/wheels would hit that box before the probe reached the target.	1
It was hard to maneuver the robot close to probe the IED, but it does take time to do so.	1
Unable to see or know exactly what the rear of the robot was doing.	1
The antenna and red probe would have been much more useful if they were in the centered/zeroed sight because, especially with the joystick, it slowed me down to always be looking down at them and also made me lose perception of the centered sight. It got easier only because I had the room removed with the layout and IED placement but if it was switched or random, it would have really messed me up.	

6. Which control condition did you prefer? Why?

Number of Responses			
Telepresence	**Mono/Head Tracking**	**Mono/Joystick**	**No Response**
13	2	3	1

Comments	No. of Responses
A – Telepresence	
Just seemed easier to use.	2
Easier for sight.	1
Easier to locate target.	1
Firing arm is free for use.	1
Natural.	1
The most impressive, allowing a quicker assessment of the situation and greater ease of maneuver.	1
Easier to locate and identify objects while being able to move your head (as part of the camera/stereo vision). I felt the 3D audio was very precise and so was the head tracking feature.	1
3D audio helped a lot for target identification when multiple units were in the same area.	2
3D audio helped to locate the direction of the sound a lot faster.	1
Because I naturally was inclined to move my head with the 3D view. With video games, I was used to the joystick, but the television for that is further away and less impressive, which this system it was much easier to use the head tracking.	1

Comments	**No. of Responses**
I didn't notice an appreciable difference in terms of the stereo vision increasing my depth perception. This may have been mainly attributable to the poor quality of the display.	1
Felt the most precise. I could move quickly and fluidly through the course.	1
Easiest overall control of box and easiest ability to listen to where the sound was coming from.	2
The head tracking was extremely helpful in the overall maneuvering of the robot. It combined the head movement along with the stereo audio. That was a huge plus.	1
B - Mono/Head Tracking	
Felt like I was in control of the robot more while in mono/head tracking. Could focus more on the task at hand.	1
Felt I could find the target quicker.	1
C - Mono/Joystick	
I preferred maneuvering the robot using the joystick camera.	1
Easier to use joystick to move.	1
A lot easier after being on the machine for over 30 minutes.	1
It gives me almost a 360° view of the environment and it wouldn't have to turn my head often which decreases my motion sickness that I was feeling during the test.	1
General Comments	
I want stereo sound and joystick controls.	1
The mono stereo was more near or far not left or right. Confusing (mono) when more than one target was in same location.	1

7. What are some suggestions for improving the robot control system?

Comments	**No. of Responses**
Outstanding equipment!	1
More practice to make sure it would work in combat.	1
Increase resolution of the camera and improve response time in vision and movement. Movements were also somewhat jerky.	1
Try to make a clearer picture and, if possible, a smaller robot would be more effective as well.	1
Make robot movement speed change/respond to how far forward joystick is pressed.	1
For objects that are close together, maybe some way to really make that particular object stand out through sound.	1
Increase the sound/hearing capability. I had the hardest time pinpointing the exact location to move in because I sometimes could not tell where the sound was coming from.	1
Have a rear facing camera that you can switch to for better maneuverability.	1
Use the stereo vision and 3D audio with head tracking.	1
For 3D and head tracking, maybe we could be able to switch off one ear or the other in order to better identify where the target is coming from or have volume sensitivity between the robot ears and the wearer's ears, i.e., if the sound is coming from the left have it reflected from the left ear piece and vice versa.	1

Comments	**No. of Responses**
Make the head tracking system less bulky.	1
The robot is fine; however, decrease the size of the robot to make it easier to maneuver in tight areas. Make headset for robot lighter because after awhile, it puts pressure on the top of the head which in turn gives me a headache, plus the motion sickness.	1
Utilize the clip on the Kevlar helmet to place the VR goggles where NVGs typically go.	1
The head tracking pinches the brain and gave me a headache.	1
Find a display system which does not induce headaches/motion sickness. Display should also do a better job of utilizing stereo vision capabilities.	1
A more comfortable helmet would be nice, but it would also be helpful to possibly include more peripheral vision; though this would require some ingenuity.	1
For those wearing glasses, the headset moves the glasses and makes vision or focusing a small problem.	1
Maybe not a 360°, but more of a turning radius for vision.	1
Mono/Joystick should have up/down inverted like flight stick.	1
A less bulky body would help with maneuvering.	1
More range on the axis of the camera.	1
Ability to see down/left/right more.	1
With the joystick, an XBOX 360 controller set-up would be easier for both control of the robot and the camera than a play station style controller.	1
A more comfortable headset would place less stress on the crown and make it easier to use the head tracking effectively and for longer periods of time.	1
Crash/collision sensors.	1
A heads-up display.	1

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

	No. of Responses
Eyestrain	8
Tunnel vision	0
Headaches	8
Motion sickness	5
Nausea	5
Disorientation	0
Dizziness	4
Competition between eyes for vision of the different scenes at which they are looking	4
Other	7

Comments	**No. of Responses**
Same discomfort from weight.	1
The headset hurt my head (too heavy/hard/tight) and created discomfort.	4
Fatigue.	1
Hands started to tingle with the increase of above symptoms (headaches, motion	1

Comments	No. of Responses
sickness, nausea, dizziness).	
I was only able to do tasks in groups of 3 before nausea had set in. After each break, I was able to resume, but the nausea came back at a faster rate each time.	1
Headaches may be due to seeing double during the breaks. Also, there was some lag at one point.	1

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Appendix B. National Aeronautics and Space Administration Task Load Index (NASA-TLX) Mental Workload

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

The NASA-TLX was administered using a computer-based version. First, Soldiers were asked to rate their experience with the controller, for the following task demand factors. Afterward, Soldiers completed paired comparisons, choosing from each pair the aspect which contributed more to their workload experience.

NASA-TLX Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the robot controller you just used.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Definition of Task Demand Factor

Mental demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

NASA-TLX Mental Workload Rating

Soldiers performed the following paired comparisons within a computer-administered version of the NASA-TLX.

For each of the pairs listed below, circle the scale title that represents the more important contributor related to operating the robot controller.

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

Appendix C. Informed Consent Form

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

Informed Consent Form

Army Research Laboratory, Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005

Title of Project: Robotic Telepresence User Interfaces: Situation Awareness and Perceptual Motor Tasks

Project Number: 9MC254

Sponsor: Army Research Laboratory

Principal Investigator: Linda R. Elliott
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Informed Consent Form
Army Research Laboratory, Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005

You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask the research staff any questions at any time about anything you do not understand. You are a volunteer. If you join the study, you can change your mind later. You can decide not to take part now or you can quit at any time later on.

Purpose of the Study

The purpose of this evaluation is to determine the effects of two different robot control interfaces on Soldier performance while conducting robotic search tasks.

Procedures to be Followed

The study will be conducted using two robot control devices: regular teleoperation and enhanced Telepresence teleoperation. After training on the operation of the controllers, you will be asked to conduct two building and route reconnaissance missions using an unmanned ground vehicle. Effectiveness of robot operation will be evaluated based on objective performance data, data collector observations, and self-report questionnaires.

You will be asked to complete a demographics questionnaire regarding your military training and experience.

Trainers from the Army Research Lab and TNO Netherlands will provide a course on the use of the robot control systems. The training course will include hands-on exercises. You will be asked to complete a questionnaire on the adequacy of the training.

Discomforts and Risks

The risks that will be encountered during this investigation are typical of the risks encountered performing training and duties pertaining to your military occupational specialty. These risks include physical fatigue and work-related injury. There is also a potential risk of motion sickness. You should inform your unit leadership or the experiment personnel if you experience any discomfort or if you have any problems during the evaluation. You may be told to stop activities until problems or conditions are resolved.

You will be controlling the robots from inside a building. Activities will be suspended during any weather conditions that are inherently dangerous or will cause evaluation trials to be dangerous. Water will be available and you will be instructed to drink often. Water breaks will occur at least every 30 minutes for all trials that exceed 30 minutes in duration.

In a site emergency from any source, personnel will have the capability for radio and telephone contact with the Fort Benning Ground Fire Department and Emergency Medical Service (EMS). EMS ambulance service is approximately 20 minutes away at Martin Army Hospital and is available 24 hours a day.

Benefits

You will receive no benefits from participating in the evaluation, other than the personal satisfaction of supporting the Army's research in robotics for Soldiers.

Duration

Your participation will last approximately 8 hours, from 0800 to 1700.

Confidentiality

Your participation in this research is confidential. The data will be stored and secured in the offices of the principal investigator in a locked file cabinet. The data, without any identifying information, will be transferred to a password-protected computer for data analysis. After the data is put in the computer file, the paper copies of the data will be shredded. This consent form will be retained by the principal investigator for a minimum of three years.

If the results of the experiment are published or presented to anyone, no personally identifiable information will be shared. Publication of the results of this study in a journal or technical report, or presentation at a meeting, will not reveal personally identifiable information. The research staff will protect your data from disclosure to people not connected with the study. Officials of the U. S. Army Human Research Protections Office and the Army Research Laboratory's Institutional Review Board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects. Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities.

We would like your permission to take pictures or video of the experimental session. The pictures will be used to document problems encountered during the study. Photographic or video images of you taken by HRED personnel will not be identified with any of your personal information (name, rank, or status), although the photos which include your face may be included in the evaluation report. Please indicate below if you will agree to allow us to record you. You can still be in the study if you prefer not to be recorded.

I give consent to be photographed during this study: ____Yes ____No please initial:____

I give consent to be videotaped during this study: ____Yes ____No please initial:____

If you choose not to participate in this evaluation, you can convey that choice privately to the evaluation manager, who will then inform, without elaboration, to your unit leadership that you did not meet the criteria for participation in the evaluation.

Contact Information for Additional Questions

You have the right to obtain answers to any questions you might have about this research both while you take part in the study and after you leave the research site. Please contact anyone listed at the top of the first page of this consent form for more information about this study. You may also contact the Chairperson of the Human Research & Engineering Directorate, Institution Review Board, at (410) 278-5992 with questions, complaints, or concerns about this research, or if you feel this study has harmed you. The chairperson can also answer questions about your rights as a research participant. You may also call the chairperson's number if you cannot reach the research team or wish to talk to someone else.

Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform Code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate.

Civilian employees or contractors cannot receive administrative sanctions for choosing not to participate in or withdrawing from this study.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study based on the information outlined above, please sign your name and the date below.

You will be given a copy of this consent form for your records.

Informed Consent Form
Army Research Laboratory, Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005

This consent form is approved from 19 October 2009 to 18 August 2010.

Do not sign after the expiration date of 18 August 2010

____ ____________________

Participant's Signature Date

____

Participant's Printed Name

____ ____________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

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