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14. ABSTRACT

As more focus is directed at technology for the future dismounted warfighter, new autonomous systems are being developed to enable bidirectional Soldier–robot dialogue. These autonomous systems implement multimodal communication methods to ensure communication robustness across operational environments. This research investigation had 2 major focuses: 1) investigate the use of exogenous orienting visual cues during unidirectional communication from a robot to a Soldier through a visual display and 2) investigate Soldier preferences for robot reporting of status information. Results under the first focus showed the longer it took to respond to a visual report, the higher the associated perceived workload and the lower the usability preference. Results under the second focus showed that the frequency with which participants expected status updates differed depending upon the difficulty of the primary task. In addition, most participants (75%) quickly and consistently identified a preferred report format (image or text). Recommendations for visual display designs are provided as well as suggestions for instantiating reporting capabilities within future robot teammates.

15. SUBJECT TERMS

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Contents

List of Figures

List of Tables

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1. Introduction

The advancement of robot capabilities and functionality has changed the way in which Soldiers perform many of their operational tasks. The various unmanned air (Valvanis 2008), ground (Zych et al. 2013), and submersible vehicles (Clegg and Rodgers 2015) currently deployed have significantly impacted present-day warfare. Although many of these systems have shown to be beneficial and effective for mission success, traditional control of these systems is through teleoperation (Chen et al. 2007; Lichiardopol 2007). While teleoperation may be necessary and appropriate for situations that may otherwise require soldiers to be exposed to hazardous or life-threatening situations, it is not recommended for dismounted operations (Chen et al. 2007). Hence, autonomous robots provide a solution that takes advantage of current robot sensing and intelligence while reducing the cognitive demands on the Soldier, allowing robots to maintain awareness of the operational environment (Kott et al. 2015). The implementation of autonomous robots within human teams carries with it concern regarding human–robot interaction (HRI) and, more specifically, human–robot communication.

Moving beyond teleoperation, military HRI has focused on integrating multimodal communication (MMC) methods that leverage the natural ways in which human–human interaction takes place and the commonly employed functionality for human–computer interaction (Abich et al. 2015). In a general sense, MMC is sending and/or receiving information through multiple sensory systems (e.g., seeing text information that is also presented auditorily). In terms of benefits for signal-communication processing, MMC systems are robust, flexible, efficient, intuitive, and redundant (Dumas et al. 2009; Partan and Marler 1999). While many robot systems are equipped with multimodal interaction capabilities (Barber et al. 2013; Harris and Barber 2014), the impact of each communication type on the Soldier's ability to perform task critical operations is not well known. Therefore, systematic evaluation of the components that comprise the transactions between humans and robots and the way in which information is conveyed is critical prior to the deployment of any system to the field.

There were 2 major goals of this experiment. The first was to investigate the effects on performance and operator perception of various exogenous orientation design cues associated with a visual display in a multimodal interface to facilitate squad-level communication within a dismounted Soldier–robot team. In particular, this goal focused on determining whether the elements of visually displayed robot reports provided adequate information about the situational context so the Soldier could quickly determine the best course of action the robot should take without being cognitively overloaded. The second goal was to investigate Soldiers' preferences when it came to status updates from a robot teammate (e.g., reporting frequency and format). Specifically, this aspect of the experiment focused on understanding the relationship between robot-reporting preferences, task performance, and situation awareness (SA) with a Soldier population.

1.1 Visual Displays for Dismounted Soldier–Robot Teams

The military has stated its interest in pursuing mobile technology for dismounted squads, such as smartphones or tablets, because of the high processing capabilities now available in smaller, lighter platforms. In 2014, the Federal Mobile Computing Summit held by the Department of Defense solicited *a US-based vendor that can supply an NSA-compliant device with a 12-24 hour battery life, compatibility with multiple commercial networks and the ability to integrate with a planned Defense Information Systems Agency application store…* (Mazmanian 2014). The Army's Communications-Electronics Research, Development and Engineering Center has been working on the Edge-Enabled System with the mission of developing a handheld interface for the future warfighter and is currently field testing command, control, communications, computers, intelligence, surveillance, and reconnaissance—commonly, C4ISR—technology (Jones-Bonbrest 2015; McCall 2010). Additionally, the Defense Advanced Research Projects Agency's (DARPA) Squad X Core Technologies program is geared toward developing new, lightweight, energy-efficient technology to support tactical advantages for dismounted infantry squads while avoiding negative repercussions such as cognitive or physical overloading (DARPA 2015).

Visual displays have the potential to provide a vast amount of information within a relatively small space. A single image can convey complex ideas. In a field study assessing the effects of different information-presentation types on task performance, Soldiers indicated visual displays were "easier to follow" and information was "easier to recall." They also exhibited better SA when using a visual display compared to an auditory display, potentially because graphical representations might facilitate chunking of information into manageable sizes (Glumm et al. 1999). Studies have shown that the decay of information in visual working memory can be gradual. Further, the capacity for storing visual images is larger compared to auditory working memory. Therefore, the larger working memory storage, in addition to the chunking of information, might explain the Soldiers' performance and preference when using visual displays (Card et al. 1983; Zhang and Luck 2009).

For visual displays to be effective, they must orient the attention of the user (Posner et al. 1980). Visual perception is driven by both internal (endogenous) and external (exogenous) orienting events. Endogenous orientation refers to "purposeful allocation of attentional resources" (e.g., scanning an arrival screen at an airport) while exogenous orientation refers to "reflexive, automatic responses" such as attention captured by a bright blinking light (Mayer et al. 2004). For the purposes here, we will be concentrating on exogenous orienting. To support exogenous orienting, non-content specific features should be implemented, meaning the cues used to attract attention should not be normally present in the environment or signal. These are referred to as feature singletons (Mulckhuyse and Theeuwes 2010). Highlighting would be considered an exogenous orientation event that provides visual cues to attract attention and support detection (Posner 1980). The highlighting of navigational routes and objects in an environment is an example of exogenous orienting because it elicits a reflexive and automatic response without having predetermined biases (Mayer et al. 2004). There are many factors that increase the chances of capturing visual attention, such as size, intensity, color, and transformation (Wickens and Hollands 2000), but the elements of highlighting should contain non-content features. In other words, the graphics (e.g., labels, shapes, colors) used should not be found within any of the images or environments to reduce any confusion and misunderstandings that could lead to errors (Salcedo et al. 2014; Wogalter et al. 2002). The colors used in this experiment contrast highly with the environment while not being accompanied by common associations, such as the colors red indicating a warning or stop, green indicating good or go, and yellow indicating caution or slow down (Wogalter et al. 2002). The application of such features becomes apparent when developing mobile applications that inherently have limited visual space.

Although mobile devices may be an HRI and communication solution for the future warfighter, it is imperative such technology not impair primary task performance; therefore, particular care must be taken when designing the interface. Chittaro (2006) states that simply scaling down visual information from a desktop computer or a larger display to fit a mobile device is not as straightforward as it may seem because of the many limitations that exist with the mobile device (e.g., limited space, display ratio reduction, reduced processing capabilities, and different interaction or input techniques). Further, mobile devices are more likely to be used in various physical environments (e.g., inside/outside, day/night) and must be robust enough to display information in all conditions. Even more of an issue is safety while performing other activities during interaction with a mobile device—a major concern because of the demand on the user's attention, which has limited allocation capacity (Kahneman 1973). These factors are crucial for a dismounted

Soldier as the increased attentional and cognitive demands related to operating the mobile device could lead to catastrophic and life-threatening events.

1.2 Information Sharing within Dismounted Soldier–Robot Teams

To operate effectively as a team, Soldiers should communicate with one another before, during, and after completion of a mission. Communication among team members can be facilitated through information sharing (e.g., information regarding the environment, task progress, or new directives); this is necessary for the development of an individual's SA while working within a team (Salas et al. 1995). In comparing the current state of the art in communicating within human–robot teams (i.e., continuous video feeds) to that of communicating within human–human teams (i.e., periodic communication of relevant information), it can be concluded that humans and robots have different mental models when it comes to engaging in information sharing. In other words, humans and robots each use different rules when deciding how often and what information should be shared among team members. This issue is less prevalent within human–human teams whereby team members draw from shared mental models that inform them of when information should be "pushed" to their team members (Johannesen et al. 1994; MacMillan et al. 2004). Thus, humans are often aware of their human teammates' informational needs.

In contrast, current robots are unaware of the informational needs of their Soldier team members. To combat this, current robots are designed to feed information to Soldiers in a continuous fashion via live video feeds (Scholtz 2003). This method of information sharing is not ideal for dismounted operations for 2 major reasons. First, it is taxing on the human visual and cognitive processing systems (Burke et al. 2004; Casper and Murphy 2003; Yanco and Drury 2007). Second, it requires the Soldier–operators to spend most of their time "heads down" (i.e., looking downward at a visual display) as they continuously control or monitor their robot teammate (RCTA 2014). Thus, this form of human–robot interaction makes it difficult for dismounted Soldiers to perform other tasking while managing the robot.

Unlike current Soldier–robot teams, whereby a Soldier is responsible for direct control of a robot team member, the vision for future Soldier–robot teams is one in which robots autonomously accomplish tasks and contribute to team performance (RCTA 2014). While this autonomy will allow Soldiers to perform other tasks, it will become even more important for robots to proactively push information (in the form of updates) to Soldiers in anticipation of their informational needs. What is unknown at this point is how often Soldiers expect to receive these updates and how they would like the shared information to be presented to them (e.g., via text, imagery, or auditorily).

1.3 Experiment Purpose

The first part of this study was robot assistance (RA) and focused on the unidirectional communication transaction from a robot to a dismounted Soldier teammate via a visual display during a surveillance task. Specifically, this explores the effects of various exogenous orienting visual display cues within robot-generated assistance request on participants' task performance, perceived mental workload, and usability preference. Primary task performance was assessed as the percentage of correctly detected targets during a signal-detection task; that is, the threat detection (TD) task described in Section 2.3.1. Task performance was also measured as the time it took participants to respond to reports (i.e., intervention response time) and the percentage of correct choices made (i.e., intervention accuracy) referring to the content of the RA requests. Two types of RA requests were investigated: navigational route and building selection. These requests were selected based on current robot capabilities and expected future-use cases in which a robot needs to address situations where both options have equal probability of being correct and the robot has not yet learned how to decide on its own (Barber et al. 2015). The mental workload of Soldiers was assessed using a subjective measure that captured demands imposed on the participants and on their interaction with the visual display. This assessment helped identify the sources of mental workload associated with the display designs. Usability preference was also captured using a subjective measure that provided a composite score across all items to indicate the participants' preference for display configuration. Five central research questions were of interest for the RA part of this study:

1) Is performance accuracy of the primary detection task affected by the type (navigation or building) or display version of the robot request?
2) Is there a difference in accuracy of correct responses to robot assistance requests for both navigational route and building selection depending on the type of exogenous visual cues displayed?
3) Is there a difference in response time to visual reports for both navigational route and building selection depending on the type of exogenous visual cues displayed?
4) How is workload affected by the type of exogenous visual cues displayed for both navigational route and building selection?

5) How is usability preference affected by the type of exogenous visual cues displayed for both navigational route and building selection?

The second part of this study was robot reporting (RR) and focused on investigating Soldier preferences in receiving status updates from a robot teammate. Given that there is little research indicating how often Soldiers expect to receive status updates from an autonomous robot teammate (i.e., how often they expect the robot to push information without being asked), this task attempted to address these questions by taking a slightly different approach to the problem. Participants were instructed to perform an individual task (i.e., the TD task), with the option of checking in on a robot teammate as often as they preferred (via the ability to request either text or image reports from the robot). This strategy allowed for an empirical examination of Soldier preferences for robot reporting (i.e., number and type of reports) and the factors that may affect their preferences (e.g., primary task difficulty). Four central research questions were of interest for the RR part of the study:

1) How often do Soldiers expect to receive status reports from a robot teammate, and is this preference influenced by the difficulty of a Soldier's primary task?

2) Is there a general preference among Soldiers for text-based or image-based reports when seeking updates from a robot teammate?

3) How is SA affected by the number and type of robot reports requested by the Soldier?

4) Is there a performance tradeoff associated with robot reports, whereby primary task performance decreases as more robot reports are received by the Soldier?

2. Method

2.1 Participants

Twenty-nine Soldiers from Fort Benning, Georgia's Officer Candidate School, 22 males and 7 females (mean age = 26.8, standard deviation [*SD*] = 3.3), volunteered for and completed the experiment. Participation was voluntary, and no compensation was awarded. Participants all had normal or corrected-to-normal (e.g., glasses, contact lenses) vision and were screened for color-vision deficiency (2 males were red/green color deficient but were still included in the analysis since they were not classified as data outliers). None of the participants had prior experience with the simulator or multimodal interface. Based on responses gathered from the demographics questionnaire, participants indicated they had little knowledge of basic robotics technology or experience interacting with robots.

Figure 1 illustrates the points during each scenario when the simulation was paused and measures were administered; in addition to situation-awareness probes, the NASA Task Load Index (NASA-TLX), System Usability Scale (SUS), and Situation Awareness Rating Technique (SART) were used. For the purposes of this study, we defined a route as the path traveled between 2 street corners. Figure 1 shows most of the measures were administered at the end of each route (i.e., once the Soldier and robot reached a corner). During the RR scenarios (i.e., RR1 and RR2), however, the simulation randomly paused twice during each route to administer SA probes.

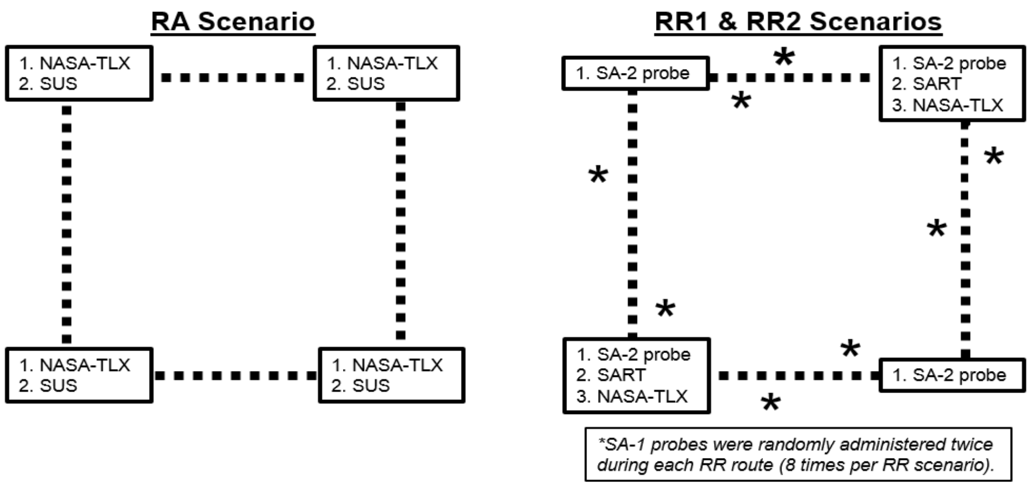

Fig. 1 Conceptual illustration depicting points at which the simulation was paused for each scenario and one or more measures administered

2.2 Questionnaires

2.2.1 Ishihara's Test for Color Deficiency

This color deficiency test assessed for red and green reduced sensitivity, which is the most common form of color-vision deficiency (Ishihara 2014). Participants viewed 11 colored plates requiring them to identify numbers or trace a path. If participants answered 5 or more incorrectly, they were considered color deficient. Participants were not removed if they were assessed to have a color-vision deficiency, but it was documented to account for any individual differences.

2.2.2. Demographics Questionnaire

This questionnaire (shown in Appendix A) was developed in-house and gathered background information on each participant's age, gender, visual acuity, and academic level of achievement (and type of degree, if applicable). Information on military experience—years in the service, rank, military occupational specialty, number of deployments, and mission-related experience—was collected. The questionnaire asked about computer use: length of time participants have been using a computer and how often as well as the ways they interact with the computer; further, video-game use, such as how often and what types, as well as any experience working with them was recorded. Finally, experience with and knowledge of robotics, both military and commercial, was recorded.

2.2.3 Cube Comparison Test

This spatial orientation test (shown in Appendix B) assesses the ability to mentally rotate and compare objects in space. The test comprises 2 parts and each part consists of 21 items, but only Part 1 was used. This test requires participants to compare 2 cubes and determine whether one cube can be rotated to match the other cube. Participants have 3 minutes to answer as many items as possible. A participant's score is the number of correct responses minus incorrect responses; therefore, guessing is not encouraged.

2.2.4 NASA-TLX

The NASA-TLX (Hart and Staveland 1988) is a perceived-workload assessment comprising 6 subscales: mental demand, physical demand, temporal demand, effort, frustration, and performance. A global perceived-workload measure is also calculated by averaging the 6 subscales. Each subscale was scored on a 100-point scale. For the RA scenario, the unweighted TLX (shown in Appendix C) was administered by computer at the end of each route (i.e., 4 times). For the RR scenarios, the unweighted TLX was administered after 2 routes had been completed (i.e., 2 times: halfway through each RR scenario and at the end of each RR scenario).

2.2.5 SUS

This 10-item questionnaire focused on perceived usability of the system; that is, hardware, software, and equipment (Brooke 1996). Ratings were indicated using 5-point Likert items (1 = strongly disagree; 5 = strongly agree). The composite score represents the overall usability of the system and ranges from 0 to 100 with higher scores indicating higher usability. Specifically, these questions focused on the participants' interaction with the device during the RA scenario. The questionnaire (shown in Appendix D) was administered at the end of each route of the RA scenario.

2.2.6 Free Response Questionnaire

This 6-item, open-ended questionnaire (shown in Appendix E) covered positive and negative aspects of the participants' interaction with the simulated multimodal interface device and their preference for display design, and asked them to suggest any improvements. Specifically, these questions were focused on the interaction with the device during the RA scenario. The questionnaire was presented to participants after completing the RA scenario.

2.2.7 Situation Awareness Global Assessment Technique (SAGAT) Probes

During RR scenarios RR1 and RR2 a modification of the SAGAT (Endsley 1988) was used to assess objectively the participants' SA at Levels 1 (Perception) and 2 (Comprehension) of Endsley's SA model (Endsley 1995). The SAGAT method pauses a simulation to ask participants questions about the simulation environment and task(s) being performed. For this experiment, SAGAT probes (shown in Appendix F) were presented to participants as they completed each RR scenario. Each time the simulation paused, participants received 2 questions: one about the safety of the Soldier's environment and one about the safety of the robot's environment. (Section 2.3.3.2 details the safety rules relevant to answering each question.) Specifically, there were 2 probes presented to participants: SA-1 and SA-2.

SA-1 probes appeared at random, as the Soldier moved along each route. These probes assessed Level-1 SA because correctly answering the questions only required the participant to have perceived elements within the environment (i.e., higher-level comprehension of said elements was not necessary). The same 2 questions were presented each time an SA-1 probe appeared. The first question assessed participant SA regarding the Soldier's environment and the second question assessed participant SA regarding the robot's environment.

In contrast, SA-2 probes appeared at the end of a route (i.e., once a corner was reached). These probes assessed Level-2 SA because correctly answering the questions required the participant to perceive and comprehend elements within the environment (i.e., a conclusion had to be formed based on information obtained while traversing the previous route). The same 2 questions were presented each time an SA-2 probe appeared. Similar to the SA-1 probes, the first question assessed participant SA regarding the Soldier's environment and the second question assessed participant SA regarding the robot's environment.

These probes served as an objective measure of SA because each question had only one correct answer. For each RR scenario, each participant answered 8 SA-1 probes

(2 per route) and 4 SA-2 probes (one at the end of each route). For the purposes of this experiment, scores on the SA-1 and SA-2 probes were calculated as the percentage of correctly answered probes.

2.2.8 Adapted SART

During the RR scenarios, a modification of the original Situation Awareness Rating Technique (Taylor 1990) was used to assess participants' subjective perceptions of their own SA during the RR scenarios. The original SART consists of 10 items that are divided into 3 subscales: demand on attentional resources, supply of attentional resources, and understanding of the situation. Participants responded to the SART by rating their level of agreement with each item using a 7-point Likert scale ranging from 1 (low) to 7 (high). The SART adapted for this experiment (shown in Appendix G) contained the original 10 items as well as 3 additional items specific to the participants' knowledge of their robot teammate. (These latter 3 items pertaining to the robot, however, are not included in the results of this report as they were for exploratory analytical use.) Scoring of the original 10 items followed the procedure used by Endsley et al. (2000). The mean of each subscale was calculated and then the mean of each subscale was used in the following formula:

> (Understanding of the situation) + (Demand on attentional resources) – (Supply of attentional resources) = Overall SART rating

Higher overall SART ratings (based on the original 10 items) correspond with higher subjective perceptions of one's own SA; lower ratings correspond with lower subjective perceptions of one's own SA.

2.3 Experimental Tasks

A general overview of the experimental tasks are provided first and then followed by a detailed description of each. The experimental scenarios were composed of 3 tasks—TD, RA, and RR—all performed within the Mixed Initiative eXperimental test bed (MIX) (Barber et al. 2008; Reinerman-Jones et al. 2010). Given that this experiment had 2 focuses, there were 2 types of scenarios: RA and RR. Both included a TD task. All scenarios simulated a reconnaissance and surveillance task where the Soldier and robot were traveling along separate, non-overlapping routes within the same portion of a city. Figure 2 is a conceptual illustration of these routes: the left box represents the Soldier's route and the right box represents the robot's route. Each "side" of the box (left, top, right, bottom) represents a different route through the city (i.e., there are 4 routes traveled during each scenario). In each scenario, the Soldier and robot both start at the same corner of their respective portion of the city (bottom left, top left, top right, or bottom right) and travel the same direction (clockwise or counterclockwise). Both the Soldier and robot travel at the same speed; thus, each reaches the beginning/end of each route at the same time. For example, if the robot and Soldier start at the bottom-left corner and are traveling clockwise, then they will reach the end of each route (i.e., corner) at the same time.

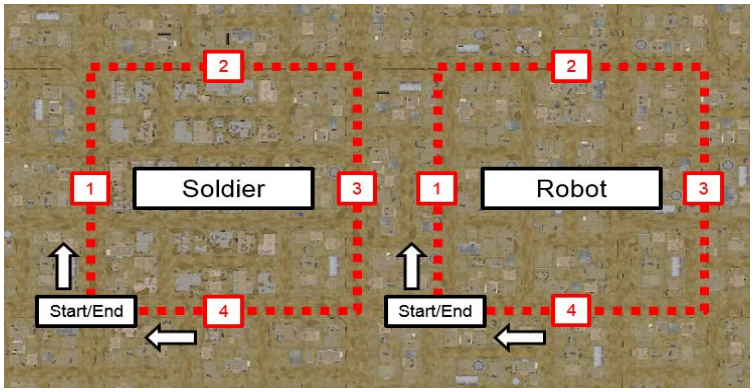

Fig. 2 Example overhead illustration of routes traveled by the Soldier and the robot during each scenario; initial starting location and travel direction were randomized for each participant but the Soldier and robot always started in the same relative location

In the RA scenario, the participant's role was to identify potential threats in their own environment and periodically respond to RA queries displayed on a visual prompt (Fig. 3) representing a virtual version of a multimodal interface (MMI). Figure 4 shows a conceptual mockup illustrating how the interaction between the Soldier and robot took place through the MMI during this scenario. As the robot travels through the environment and comes across an uncertain situation, it sends a report to a Soldier via the MMI. The Soldier responds to the report and that information gets transmitted back to the robot through the MMI.

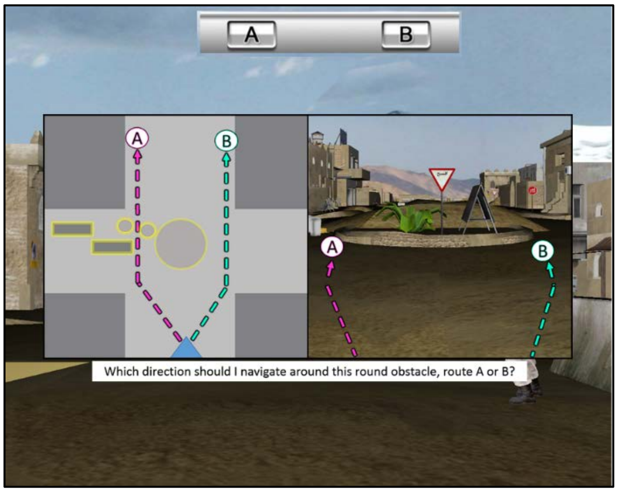

Fig. 3 Image represents the virtual MMI as a prompt on the screen within the MIX environment

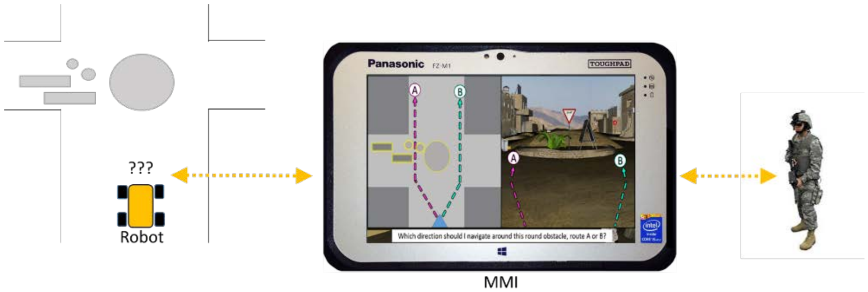

Fig. 4 Representation of the RA-scenario context; the MMI provided a visual interface for the robot to send RA queries and for the Soldier to respond, creating closed-loop communication

In the RR1 and RR2 scenarios, one of the participant's roles was to aid in the development of a robot's reporting capabilities by showing the robot how often (and in which presentation format) they preferred to receive information from the robot. In addition, participants were told they also were helping the robot learn which routes through a simulated urban area were safe for travel. For this scenario, status updates (i.e., robot reports) from the robot were displayed at the top left of the participants' display (Fig. 5). This scenario, thus, introduced a different use for the MMI (i.e., to request information from the robot).

Fig. 5 Image represents an alternative use of the virtual MMI, whereby status updates can be requested from the robot

2.3.1 TD Task

The MIX test bed was customized to represent the first-person perspective of a Soldier traveling through a generic Middle Eastern urban environment (Fig. 6). The Soldier's route was preplanned and did not require the participants to control the Soldier's movement. The participants' role was to identify potential threats in the environment (i.e., a signal-detection task) by capturing photos to help populate a robot teammate's database with examples so it could more effectively carry out mission tasks autonomously. There were 4 categories of characters (i.e., events) within the environment: friendly Soldiers, friendly civilians, enemy soldiers, and insurgents (Fig. 7). Each category included at least 5 different types of characters. Enemy Soldiers and insurgents were classified as threats (i.e., signals), and an equal number of each was presented. An equal number of each category of nonthreats was also present. All threats were identified by left-clicking with a mouse on the character within the environment. No feedback was provided regarding the accuracy of detection, but participants did hear the sound of a camera shutter to indicate they were capturing photos.

Fig. 6 Screenshot of the MIX test bed representing the first-person perspective of the Soldier traveling through a Middle Eastern urban environment

Fig. 7 Examples of characters used within the TD task are (l to r) friendly Soldier, friendly civilian, enemy soldier, and insurgent (armed civilian)

The event rate of the TD task—speed at which threats and nonthreats were presented within the Soldier's environment—differed among the RA and RR scenarios. In the RA scenario, the event rate was presented at 30/min with a signal probability of 13.33% based on previous research (Abich et al. 2013). In the RR1 and RR2 scenarios, the event rate of the TD task varied. Across the 2 RR scenarios, 3 event rates were encountered by each participant: low, moderate, and high. In all 3 event-rate conditions, signal probability (i.e., the ratio of threats to nonthreats among the characters) was consistent at 13.33%; however, the number of events encountered in each condition differed. The event rate was 15/min in the low event-rate condition, 30/min in the moderate condition, and 60/min in the high condition. Figure 8 depicts how the 3 event-rate conditions were distributed across the RA, RR1, and RR2 scenarios. The RA and RR1 scenarios both had a constant, moderate event rate while the event rate in the RR2 scenario switched from either low to high or high to low (depending upon the assigned counterbalancing condition).

Performance on the TD task was assessed as the overall percentage of correct responses. False-positive rates were very low; therefore, signal-detection theory indices were not calculated.

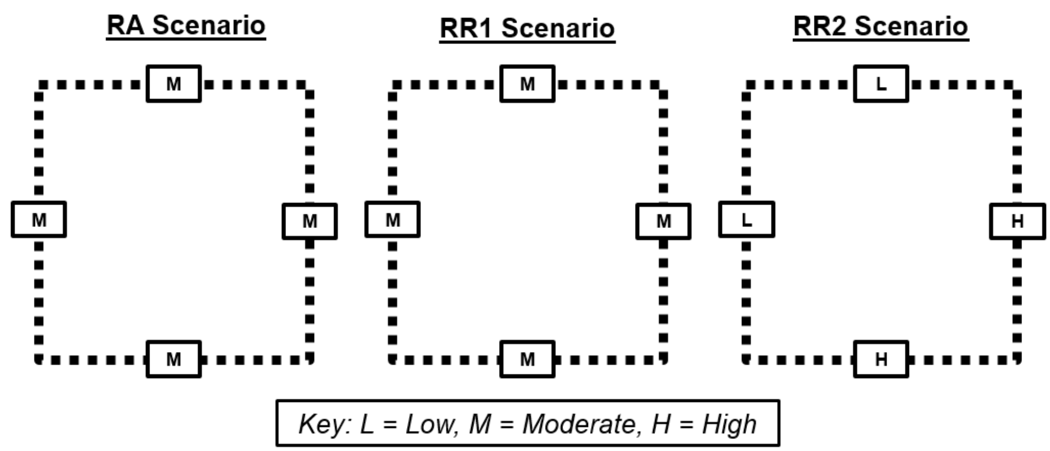

Fig. 8 Conceptual representation of how the event rates (low = 15/min, moderate = 30/min, high = 60/min) differed across the 3 scenarios

2.3.2 RA Task

While participants were performing the TD task (i.e., the primary task), visual prompts randomly appeared and required participants to respond to RA queries generated by a robot teammate (i.e., the secondary task). The visual prompts were a virtual representation of the MMI (shown in Fig. 2). The robot teammate was never viewed by participants, as the robot was traveling a separate route. At times, the robot required assistance because it could not deduce the best option based on its intelligence capabilities. The types of assistance the robot requested were for 1) navigational routes and 2) building identification (Figs. 9 and 10). The navigational-assistance requests asked participants to decide the best route for the robot to avoid obstacles. The building-identification assistance requests asked participants which building a robot should screen (i.e., monitor). The information the participants needed to make their decision was gathered from the MMI. Every

MMI prompt comprised 2 images: 1) the right image represented the point of view (POV) of the robot traveling through the environment and 2) the left image represented an aerial view of the operational area (Fig. 3). Both images represented the same scene but from different angles; therefore, the RA queries could be answered by gathering the pertinent information from either image. The research interest here lies in evaluating the workload impact and preference of visual display format by comparing the types of display formats for each query (i.e., Navigation A vs. B and Building A vs. B). Participants responded to the robot's query by left-clicking on one of the buttons located at the top of the screen to indicate their choice (shown in Fig. 3). No feedback was provided to the participants regarding the accuracy of their choices. The simulation paused—Soldier's movement through the environment stopped—when each RA query appeared and did not resume until a response to the robot's request was made.

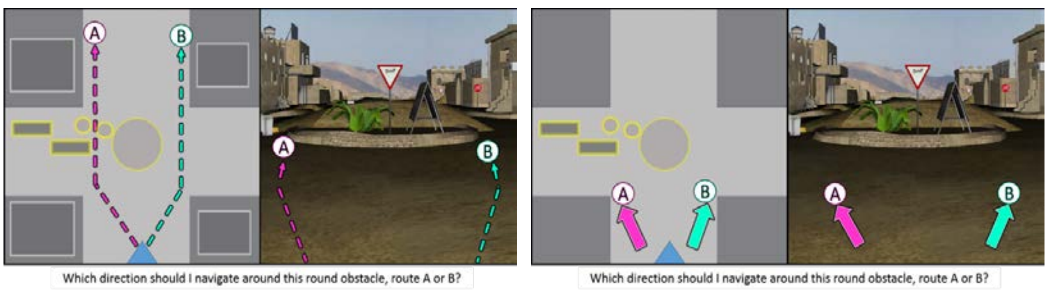

Fig. 9 Two images representing the robot's navigational-assistance-query display formats in the MMI; image on the left has extended directional arrows (Navigation A) while the image on the right has short, bold directional arrows (Navigation B)

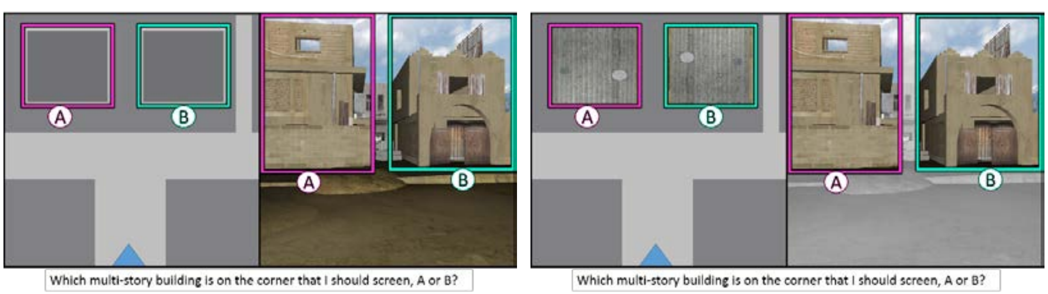

Fig. 10 Two images representing the robot's building-identification-query display formats in the MMI; image on the left has highlighted boxes around the buildings (Building A) while the image on the right has highlighted boxes around the buildings with modifications to the scene and aerial images (Building B)

The navigational-route RA queries displayed route options as either extended segmented arrows (i.e., Navigation A design) or short, bold directional arrows (i.e., Navigation B design). The building-identification RA queries displayed highlighted boxes around the buildings of interest (i.e., Building A design) or had highlighted boxes with enhanced modifications to the images such as grayed-out areas in the POV of the robot image and detailed aerial information (i.e., Building

B design). The queries for each type of display format (i.e., navigation and building) were the same; the only difference was the way in which the information was portrayed on the MMI. The elements comprising exogenous orientation highlighting were chosen based on their noncontent features. The labels, shapes, and colors had no relation or similarity to elements within the environment. The red (R), green (G), and blue (B) color values for the magenta were R: 255, G: 51, B: 204 and for the green were R: 0, G: 255, B: 204. The scenario lasted about 10 min, and there was a total of 32 RA reports (i.e., 8 of each type of display format): one presented (on average) every 15–20 s. Each route in the scenario was about 2.5 min and comprised one type of display format. The order in which the display formats were presented for each route was randomized using a random-number generator to determine the presentation order. At the end of each route, the workload and usability questionnaires were presented (depicted in Fig. 1). The order in which each participant navigated around the scenario was counterbalanced and randomized, meaning participants were randomly assigned starting locations at one of the 4 corners of the scenario and either traveled clockwise or counter-clockwise (shown in Fig. 2).

2.3.3 RR Task

Participants were informed their role in the RR scenarios (in addition to performing the TD task) was to aid in the development of a robot's reporting capabilities and to aid the robot in determining which navigational routes through a simulated city were safe for travel. Similar to the RA task, participants were informed the robot was traveling along a series of routes throughout a portion of the city separate from the one traveled by the Soldier. Participants were instructed they were responsible for helping the robot a) build a database of potential threats in the environment, b) decide how often it should send status reports and what type (image or text reports), and c) decide which routes through the city were safe for travel. Participants were informed that during the RR scenarios they were to identify threats from the first-person Soldier perspective (i.e., perform the TD task, the primary) while simultaneously performing the RR task (requesting robot reports and assessing the safety of the Soldier's and robot's routes, the secondary).

Thus, both the RA and RR scenarios required participants to perform the TD task, but differed in terms of the interactions taking place between the Soldier and robot. In the RA scenario, the robot pushed information to the Soldier (without prompting) and the Soldier could not request information (i.e., reports) from the robot. In contrast, in the RR scenarios, the robot only sent information to the Soldier if it was requested (via a text or image report).

2.3.3.1 Robot Reports

During each RR scenario, participants were told they could request reports from the robot that informed them of the robot's current environment. Participants were told that due to bandwidth limitations, the robot could only send new reports (i.e., containing updated information) every 10 s. Each report included a report number that appeared above the requested report to clearly identify it as unique (containing new information). These report numbers "reset" at the beginning of each route (i.e., whenever the Soldier and robot reached a corner). This made it clear to participants that a) each scenario consisted of 4 distinct routes and b) the SA-1 and SA-2 probes should be answered based on only the current route (not the previously traveled routes).

Participants had the option to receive these reports in text or image format by clicking on one of 2 buttons in the top-left portion of their screen (Fig. 11). When an image report was requested, participants were shown an image of what was being viewed from a forward-facing camera mounted on the robot (Fig. 12). The image showed bounding boxes around both threats and critical threats to assist the Soldier in assessing the number of threats present in the robot's immediate environment. Participants could also request text reports from the robot. These reports displayed the same information about the robot's immediate environment but in a text format. Specifically, the text reports provided the Soldier with the total number of threats, critical threats, and nonthreats present (Fig. 12). The TD task did not stop—simulation did not pause—when a robot report was requested. The decision to include a continuous TD task was made to assess more accurately the effect requesting and reviewing robot reports had on the primary task. In addition, participants could not view both an image and text report simultaneously (i.e., have both displayed at the same time); however, they could request one right after another and view the same information in both report formats if they wanted to.

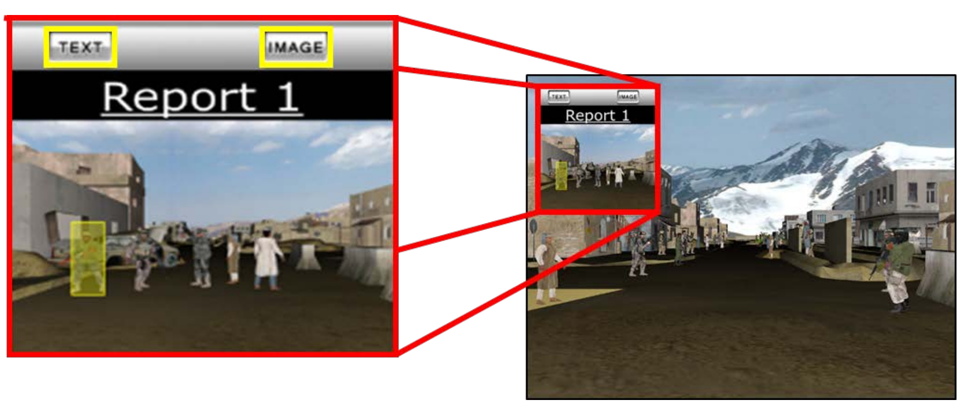

Fig. 11 Zoomed-in view of the portion of the screen dedicated to the RR task, with text-report button on the left and image-report button on the right

Fig. 12 (l to r) Example of an image report containing one threat and 4 nonthreats and the same report requested in text format

2.3.3.2 Safety Rules

In the RR scenarios, participants were also responsible for assessing the safety of their and the robot's environments. To accomplish this task, participants used a set of rules to determine the safety status of a particular environment. Participants needed to use these rules to correctly answer 3 of the 4 SA probes (i.e., one SA-1 probe and both SA-2 probes).

The only rule participants had to use to identify whether the Soldier's route was safe was as follows: "If three or more critical threats are seen along your route, then the route is unsafe." Critical threats differed from other threats in that they were armed with a rocket launcher. If 3 or more of these were present along the Soldier's route, the route was classified as "Unsafe". Participants used this rule to correctly answer the following SA-2 probe: "Was the Soldier's route safe?"

Participants were also responsible for classifying the safety of the robot's environment. There were 3 rules used to classify the robot's environment as "Safe" or "Unsafe". Two of these rules applied to the safety of the robot's immediate environment (i.e., what is displayed within the robot's report) while the third applied to the safety of the route the robot was traveling. The 2 safety rules relevant to the robot's immediate environment were as follows:

1) If the robot sends a report (either text or image) that includes 3 or more threats, the robot's immediate environment is unsafe.

2) If the robot detects a critical threat, the robot's immediate environment is unsafe.

Figures 13 and 14 illustrate these 2 safety rules in application.

Fig. 13 Robot's report shows its immediate environment is unsafe; (left) in image report 4 threats are bounded in yellow boxes while (right) text report counts the total number of threats

Fig. 14 Robot's report shows unsafe immediate environment; (left) in image report a critical threat is bounded in blue box while (right) the text report counts the number of critical threats

Thus, both of these rules were needed to correctly answer the following SA-1 probe: "Based on the currently available robot report, is the robot's immediate environment safe?"

The safety rule relevant to the robot's route was, "If the robot sends three consecutive unsafe reports while traveling a particular route, then that route is unsafe." For example, if a participant requested reports No. 5–7 and all 3 were unsafe, then the entire route the robot was traveling on was unsafe. This rule applied even when the 3 reports were a combination of text and image (e.g., Report 5 was image, Report 6 was text, and Report 7 was image). Participants used this rule to correctly answer the following SA-2 probe: "Was the robot's route safe?"

So participants' SA would not be influenced by the need to remember these 4 rules, they were given a "cheat sheet" to use during the RR scenarios. This cheat sheet depicted all 4 safety rules both graphically and in text (see Appendix H). In addition, participants were informed each scenario consisted of 4 distinct routes—each side of the boxes depicted in Figs. 1, 2, and 8 represent a distinct route—and they should keep that in mind when considering the safety of a particular route and answering the SA questionnaires (SA-1 probes, SA-2 probes, and SART).

2.4 Apparatus

The simulation was presented using a standard desktop computer or laptop with equal specifications (3.2-GHz, Intel Core i7 processor) connected to a 22-inch (16:10 aspect ratio) monitor. Responses to the tasks were collected using the left mouse button and keyboard. Participants wore headphones to reduce any interference between them while viewing the narrated training slides and listening to any sounds generated from the simulation.

2.5 Procedures

When participants arrived, they were instructed to first read the informed consent (see Appendix I). Upon consent, participants were assessed for color-vision deficiency; then, they completed the demographics form and the Cube Comparison test. Task training followed completion of the prestudy questionnaires.

2.5.1 Training

A 30-min, narrated PowerPoint presentation was used to support consistency of training for each participant. Training was accomplished in 3 phases. The first phase was 12 min, during which participants were instructed on the continuous task (TD) they were to perform and how to respond to the NASA-TLX. They were then given the chance to practice the task for about 1 min and respond to the NASA-TLX.

The next 2 phases of training continued in the same format. The second phase was 6 min and explained the purpose and elements of the 4 different RA-query display formats. Instructions were also provided on how to respond to the usability and free-response questionnaires. Participants then practiced responding to 2 display formats of RA queries; this illustrated the way queries would be presented and ensured the Soldiers understood how to respond to them. The third phase was 12 min and described the RR task and its associated SA questionnaires and probes. Participants practiced performing the task for about 1 min and responded to 3 SA probes.

2.5.2 Experiment's Design

Following the training, each participant completed 3 experimental scenarios: one RA and 2 RR. To reduce the level of confusion regarding the rules for the RA and RR tasks, the RR scenarios were always paired in consecutive order (e.g., scenario orders RA, RR1, RR2 or RR2, RR1, RA). This resulted in 4 total scenario-presentation orders:

- RA, RR1, RR2
- RA, RR2, RR1
- RR1, RR2, RA
- RR2, RR1, RA

Therefore, the order of presentation of the 3 experimental scenarios was randomized but only semicounterbalanced. In addition, the starting/ending location (i.e., starting/ending corner) within each scenario as well as the direction traveled, clockwise or counterclockwise, were fully counterbalanced to account for possible order effects.

During the study, up to 15 soldiers participated at the same time. Although grouped together in the facility (Fig. 15), participants worked independently of each other and wore headphones during tasks.

Fig. 15 The Fort Benning laboratory while 14 Soldiers participate in the experiment at the same time (no identifiable information can be gathered from photograph)

3. Results

3.1 RA Task

Paired sample *t*-tests were used to assess the impact of various RA-query designs on task performance, perceived workload, and display preference. Cohen's *d* effect sizes using the conventional scale of 0.2, 0.5, and 0.8 (small, medium, and large, respectively) are also reported for specific comparisons of RA-query designs. Bivariate correlations were run to find relationships among demographic characteristics, visual–spatial skills, performance, perceived workload, and usability preference. The sample size for all analyses was $n = 29$. The analyses were used to answer the 5 research questions related to the robot-assistance task, stated previously:

1) Is performance accuracy of the threat-detection task affected by the type (navigation or building) or display version of the robot's request?
2) Is there a difference in accuracy of correct responses to RA requests for both navigational route and building selection depending on the type of exogenous visual cues displayed?
3) Is there a difference in reaction time to respond to visual reports for both navigational route and building selection depending on the type of exogenous visual cues displayed?
4) How is workload affected by the type of exogenous visual cues displayed for both navigational route and building selection?
5) How is usability preference affected by the type of exogenous visual cues displayed for both navigational route and building selection?

3.1.1 TD Performance

Two paired sample *t*-tests were run to assess the effects on TD-task-performance accuracy of responding to the different building and navigation RA-report designs. Results in Table 1 show no significant differences were found ($p > 0.3$ and 0.6, respectively).

Table 1 Results of *t*-tests for TD task performance for both building and navigation display designs with mean (*M*), standard deviation (*SD*), and Cohen's d statistical value (*d*) reported

	M	*SD*	*M*	*SD*		
	Building A		Building B		*t*-test	*d*
Threat detection accuracy (% correct)	88.51	22.12	91.19	13.41	–0.96	0.05
	Navigation A		Navigation B			
	88.51	19.35	89.66	22.01	–0.46	0.15

Note: probability of rejection of the hypothesis (p) > 0.05

3.1.2 RA performance

Two paired sample *t*-tests were run to assess the effects of RA-report designs on RA-response accuracy. Statistically significant results were found for the difference in percentage of correct responses for building-identification and navigational-route selection (Table 2). Participants made significantly more correct choices when responding to the Building-A and Navigation-A design.

Table 2 Results of *t*-tests for robot assistance response accuracy for both building and navigation display designs

	M	*SD*	*M*	*SD*		
	Building A		Building B		*t*-test	*d*
Correct response accuracy (% correct)	57.33	18.15	45.26	16.84	2.27[a]	0.69
	Navigation A		Navigation B			
	71.98	15.54	55.17	22.79	3.28[b]	0.86

[a] $p < 0.05$
[b] $p < 0.01$

Two paired sample *t*-tests were run to assess the effects of RA report designs on response time for building identification and navigation route selection. Results show that no significant differences were found (Table 3).

Table 3 Results of *t*-tests for RA response time for both building and navigation display designs

	M	*SD*	*M*	*SD*		
	Building A		Building B		*t*-test	*d*
Average response time (s)	4.45	1.98	3.80	1.86	1.34	0.34
	Navigation A		Navigation B			
	5.10	2.72	4.23	1.85	1.73	0.36

Note: $p > 0.05$

3.1.3 Questionnaires

3.1.3.1 NASA-TLX

Two paired sample *t*-tests were run to assess the effects of RA report designs on perceived workload, and statistically significant differences were found between report designs for mental and global demand. The Navigation-A design elicited higher perceived demand on both nonweighted subscales. Results are reported in Table 4.

Table 4 Results of *t*-tests for NASA-TLX ratings for both building- and navigation-display designs

	M	***SD***	***M***	***SD***		
	Building A		**Building B**		***t*-test**	***d***
Mental	17.41	22.14	17.07	18.20	0.197	0.02
Physical	7.93	14.73	8.79	13.41	–0.623	0.06
Temporal	14.14	17.12	13.97	16.60	0.108	0.01
Effort	16.03	20.59	14.31	16.84	0.935	0.09
Frustration	11.90	20.59	10.00	16.09	0.938	0.10
Performance	18.97	27.40	13.28	20.58	1.516	0.23
Global	14.40	15.50	12.90	14.36	1.509	0.10
	Navigation A		**Navigation B**			
Mental	20.86	27.09	13.28	16.05	2.491[a]	0.34
Physical	9.14	17.06	6.72	13.11	1.545	0.16
Temporal	18.45	23.72	13.79	18.88	1.831	0.22
Effort	16.55	23.11	15.69	20.73	0.604	0.04
Frustration	17.59	25.45	13.28	20.50	1.314	0.19
Performance	15.86	23.19	16.72	22.88	–0.393	0.04
Global	16.41	19.17	13.25	15.29	2.320[a]	0.18

[a] $p < 0.05$

3.1.3.2 SUS

A series of *t*-tests was run to assess the effects of RA report design on perceived usability. Results show a significant difference between building-identification designs, but not for navigation design (Table 5). Participants rated the Building B higher in usability.

Table 5 Results of *t*-tests for usability for both building- and navigation-display designs

	M	***SD***	***M***	***SD***		
	Building A		**Building B**		***t*-test**	***d***
SUS rating	78.28	18.86	81.41	15.58	–2.051[a]	.18
	Navigation A		**Navigation B**			
	77.66	18.87	79.83	17.10	–1.167	.12

[a] $p < 0.05$

3.1.3.3 Free Response

Three independent raters conducted an evaluation of the data for common themes across participant responses to each item. Raters began by organizing the textual responses into common ideas and then comparing the frequency with which certain themes occurred in the text for each item. Common themes that were mentioned by at least 3 respondents for each item were retained. The 3 assessments were then compared for overlapping patterns identified by all 3 raters. Table 6 shows the results of the assessment. Within the table are the common themes, the number of participants who made that comment, and an example response.

Table 6 Common themes among participant responses to the Free Response Questionnaire for RA-display formats; numbers in parentheses next to each theme are total participants reporting each theme (an example of which is shown)

Item/question	Theme	Example responses
Positive aspects of the device	a) Ease of use (12) b) Multiple views (6) c) Benefit to Soldier (7)	a) The device was really simple and easy to use. b) The different perspectives provided for quick analysis and decision-making. c) It doesn't place any Soldiers in harm's way by allowing areas to be viewed without danger or risk involved.
Negative aspects of the device	Diversion (4)	I had to divert my attention away from the task to make decisions for the robot.
Navigational information	a) No preference for layout (9) b) Preferred aerial view (5) c) Clear and sufficient information (5)	a) The device did a very good job providing navigation. I did not have a preference. b) I looked at both but preferred the overhead view because I was able to distinguish the area better. c) The device provided clear and concise information to choose the best way for the robot to travel.
Building identification	a) No preference for layout (10) b) Preferred aerial view (5)	a) I liked having both views, both were beneficial. b) I think the aerial view was the easiest way to gauge how to give an answer to the presented question.

The 2 items that were not included in Table 6 probed for elaboration on the first 4 items and asked for suggested improvements. These items were not included because the responses did not provide any unique, additional information compared to the first 4 items. Few participants suggested any improvements, except one participant requested a zoom feature be added to provide a wider perspective of the environment.

3.1.4 Bivariate Correlations

Bivariate correlations were run to find relationships among demographic characteristics, spatial skills, task performance, perceived workload, and usability. To clarify, only the significant variables are listed in Table 7 and they refer to how often participants use a computer, how much experience they have playing video games, time when responding to the RA reports, global TLX associated with responding to RA reports, and RA report-design usability.

Table 7 Bivariate correlation matrix for statistically significant relationships among demographics, task performance, global workload, and usability

	1	2	3	4	5	6	7	8	9	10
1. How often use a computer	…	…	…	…	…	…	…	…	…	…
2. Working with video games	0.363	…	…	…	…	…	…	…	…	…
3. RA—response time—Navigation A	–0.151	0.194	…	…	…	…	…	…	…	…
4. RA—response time—Navigation B	–0.364	–0.013	…	…	…	…	…	…	…	…
5. RA—response time—Building A	–0.062	–0.106	…	…	…	…	…	…	…	…
6. RA—response time—Building B	–0.244	0.105	…	…	…	…	…	…	…	…
7. NASA-TLX—global—Navigation A	–0.399[a]	–0.286	0.429[a]	…	…	…	…	…	…	…
8. NASA-TLX—global—Navigation B	–0.430[a]	–0.318	…	0.425[a]	…	…	…	…	…	…
9. NASA-TLX—global—Building A	–0.513[b]	–0.270	…	…	0.493[b]	…	…	…	…	…
10. NASA-TLX—global—Building B	–0.465[a]	–0.324	…	…	…	0.180	…	…	…	…
11. SUS—Navigation A	0.451[a]	0.382[a]	–0.177	…	…	…	–0.715[b]	…	…	…
12. SUS—Navigation B	0.331	0.492[b]	…	–0.400[a]	…	…	…	–0.695[b]	…	…
13. SUS—Building A	0.468[a]	0.437[a]	…	…	–0.546[b]	…	…	…	–0.607[b]	…
14. SUS—Building B	0.456[a]	0.434[a]	…	…	…	–0.301	…	…	…	–0.696[b]

[a] $p < 0.05$
[b] $p < 0.01$

The correlation matrix shows that the more participants used a computer, the less perceived workload was elicited during the task; also, they reported a higher usability preference. Video-game experience was also shown to have a positive relationship with usability preference. For the most part, longer reaction times were associated with higher perceived workload, but only reaction time to RA reports of the Building-A and Navigation-B designs were negatively associated with usability preference at a statistically significant level. Overall, NASA-TLX and usability preferences were negatively correlated.

3.2 RR Task

One-way repeated-measures analyses of variance (ANOVAs), chi-square tests, and bivariate correlations were used to analyze the RR data and to address the 4 central research questions of the robot-reporting task. As stated previously, our research questions were

1) How often do Soldiers expect to receive status reports from a robot teammate and is this preference influenced by the difficulty of a Soldier's primary task?
2) Is there a general preference among Soldiers for text-based or image-based reports when seeking updates from a robot teammate?
3) How is SA affected by the number and type of robot reports requested by the Soldier?
4) Is there a performance tradeoff associated with robot reports, whereby primary task performance decreases as more robot reports are received by the Soldier?

To ensure the data used for the moderate event-rate condition (i.e., RR1 scenario) were comparable to data used for the low and high event-rate conditions (i.e., RR2 scenario), only the measures corresponding to the first half of the RR1 scenario (i.e., the first 2 sides of the box) were used for analyses involving rate comparisons. This decision was made because participants spent twice as much time performing RR tasks in moderate than they did in low or high (Fig. 8). Thus, it was decided only those measures corresponding to a participant's initial experience with the moderate condition would be used to ensure the data used for each event-rate condition were comparable (i.e., were based on a comparable amount of time spent within each condition).

The sample size for all analyses was n = 29. The effect sizes for the main effect of each repeated-measures ANOVA were calculated using partial eta-squared (η^2) and the effect sizes for each post hoc comparison (i.e., paired sample t-test) were calculated using Cohen's *d*.

3.2.1 Global Workload

A one-way repeated-measures ANOVA was conducted—with event rate (low, moderate, or high) as the independent variable and global workload as the dependent variable—to assess whether the different event-rate conditions resulted in differences in participants' perceived workload (i.e., global workload) while completing the RR scenarios. The goal of this analysis was to identify whether the event-rate manipulations resulted in the perception of a more (or less) difficult primary task. It was found there was not a significant main effect of event rate on global workload: Wilks' $\lambda = 0.88$, $F(2, 27) = 1.96$, $p = 0.161$, partial $\eta^2 = 0.126$.

To further investigate whether the event-rate manipulation resulted in a more difficult primary task, we ran a one-way repeated-measures ANOVA with the event rate (low, moderate, or high) as the independent variable and TD performance (% correct) as the dependent variable. It was found there was a significant main effect of event rate on TD performance: Wilks' $\lambda = 0.71$, $F(2, 27) = 5.44$, $p = 0.01$, *partial* $\eta^2 = 0.287$. To further investigate differences in TD performance among the 3 event-rate conditions, post hoc comparisons were conducted using paired-samples *t*-tests and a Bonferroni correction ($p < 0.0167$ was considered significantly different). The post hoc tests indicated participants had significantly worse TD performance when the event rate was high—$M = 87.93$, $SD = 15.53$—than when the event rate was moderate: $M = 96.55$, $SD = 5.64$; $t(28) = –3.11$, $p = 0.004$, Cohen's $d = –0.683$. There were, however, no significant differences in TD performance between the moderate and low—$M = 91.38$, $SD = 15.75$; $t(28) = 1.68$, $p = 0.103$, Cohen's $d = 0.348$—or the high and low conditions: $t(28) = –1.80$, $p = 0.083$, Cohen's $d = –0.333$. Figure 16 depicts these relationships.

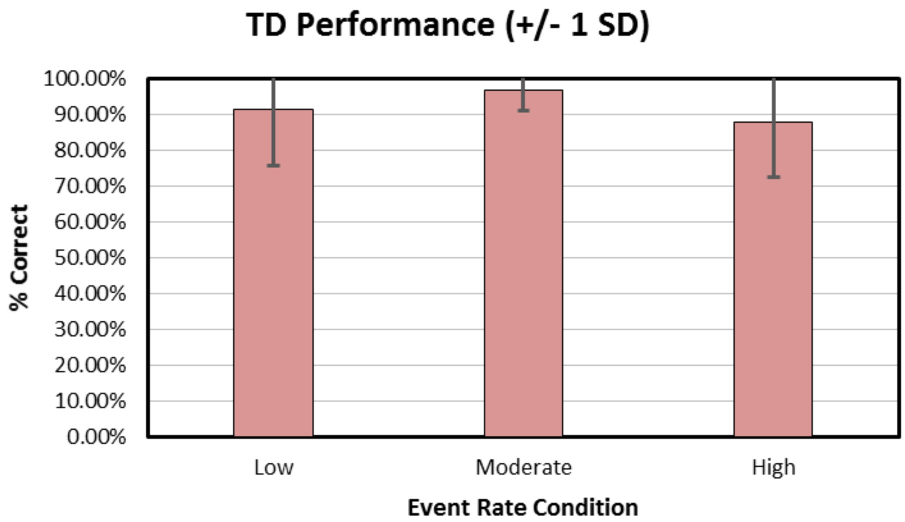

Fig. 16 Graph depicting TD performance across event-rate conditions for the RR scenarios

3.2.2 Number of Reports

The total number of reports requested by each participant during each route was calculated to identify the average number of robot reports requested during each RR route. It was found the Soldiers on average (averaging across all 8 RR routes regardless of event rate) requested a robot report 11.3 times during each route or once every 12.39 s.

The same procedure was used for each event-rate condition (i.e., averaging across both routes within each condition) to calculate the average number of robot reports requested during each RR route for a given event-rate condition. Then, a one-way repeated-measures ANOVA was conducted—with event rate (low, moderate, or high) as the independent variable and the number of reports as the dependent variable—to assess whether the number of reports requested in each condition was significantly different. It was found there was a significant main effect of event rate on the number of reports requested: Wilks' $\lambda = 0.55$, $F(2, 27) = 10.98$, $p < 0.001$, *partial* $\eta^2 = 0.448$. To further investigate differences in the number of reports between the 3 event-rate conditions, post hoc comparisons were made using paired-samples *t*-tests and a Bonferroni correction ($p < 0.0167$ was considered significantly different). The post hoc tests indicated participants requested significantly fewer robot reports when the event rate was high—$M = 9.19$, $SD = 6.74$—than when it was moderate: $M = 12.90$, $SD = 9.51$; $t(28) = –3.12$, $p = 0.004$, Cohen's $d = –0.633$. Participants also requested significantly fewer robot reports when the event rate was high than when the event rate was low: $M = 11.67$, $SD = 7.27$; $t(28) = –4.19$, $p < 0.001$, Cohen's $d = –0.789$. There was no significant difference in the number of requested reports between the moderate and low conditions: $t(28) = 1.01$, $p = 0.322$, Cohen's $d = 0.198$. Figure 17 depicts these relationships.

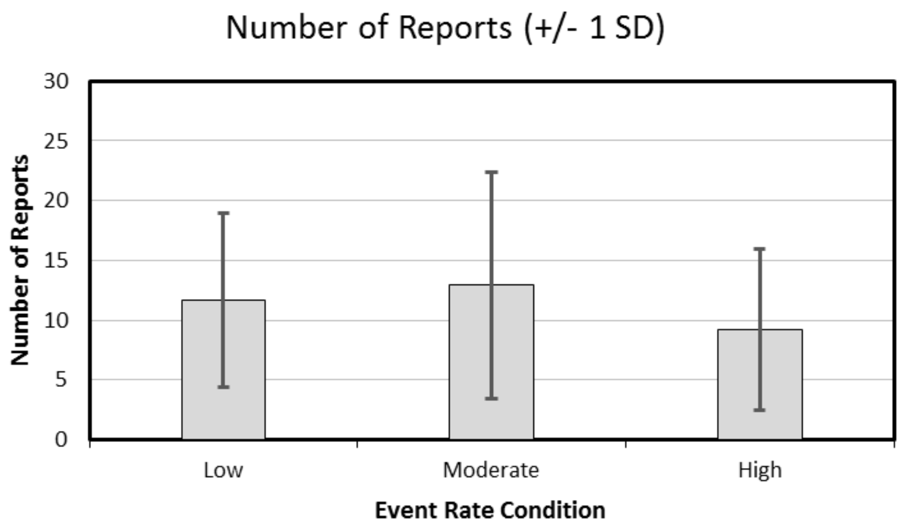

Fig. 17 Graph depicting number of reports across event-rate conditions for the RR scenarios

3.2.3 Report-Format Preference

To identify participants' preference when it came to report format, counts were used to identify the total number of text and image reports requested by each participant across the 2 RR scenarios (i.e., all event-rate conditions). Participants who requested more of one report format (> 50% of total reports requested) than the other were assumed to prefer the given format. For example, if a participant requested 80 text reports and 30 image reports, it was assumed the participant preferred text reports.

In total, 17 participants preferred the text reports while 12 preferred the image reports. A chi-square test was run to assess whether this distribution was greater than chance. It was found the distribution of preferences was not statistically greater than chance: $\chi^2(1) = 0.86$, $p > 0.05$. Furthermore, it was found that 2 of the participants exclusively used text reports (never requested an image report) and 2 of the participants exclusively used image reports (never requested a text report). Finally, it was found that 22 participants (75%) were consistent in their preference for either text or image reports, requesting more of their preferred format than the other format during 6 out of the 8 RR routes. An additional chi-square test was run to assess whether this finding was greater than chance. It was found the distribution was statistically greater than chance: $\chi^2(1) = 7.76$, $p = 0.005$. Close inspection of the data for these participants indicated report-format preference was independent of the event rate (i.e., participants stayed with their preferred format regardless of the event rate).

3.2.4 Bivariate Correlations

A series of bivariate correlations was run to examine 1) the relationship between 3 measures of SA relevant to the Soldier's environment: SA-1 probe, SA-2 probe, and overall SART rating; 2) participants' RR preferences via the number of reports requested and report-format preference (text preference was coded as 0; image preference was coded as 1); and 3) primary task performance (i.e., TD performance). These correlations were based upon the averages across all 8 RR routes, regardless of event-rate condition. Table 8 provides the correlations among these sets of variables. There was a significant positive correlation between the total number of reports requested and performance on the SA-2 probes (r = 0.559, p = 0.002). Most of the remaining variable pairs were positively correlated but none of these correlations reached statistical significance.

Table 8 Bivariate correlation matrix for situation-awareness measures, reporting preference, and primary task performance

	1	2	3	4	5	6
1. Number of reports	…	…	…	…	…	…
2. Report-format preference	0.293	…	…	…	…	…
3. SA-1 probes—% correct	0.222	0.059	…	…	…	…
4. SA-2 probes—% correct	0.559[a]	0.233	0.323	…	…	…
5. Overall SART rating	0.117	–0.101	0.221	0.220	…	…
6. TD performance—% correct	0.074	0.122	0.171	0.242	–0.030	…

[a] $p < 0.01$

4. Discussion

4.1 Robot Assistance

The first goal of this study was to explore the use and effects of various exogenous orientation visual cues within visual reports generated by a robot on a mobile platform to convey squad-level information to a Soldier teammate in a dismounted scenario. The findings support expectations that design differences have an impact on Solders' perceived mental workload, usability, and response performance to robot reports. Each cue design type (i.e., navigation and building) is discussed separately.

4.1.1 Navigational Routes

For TD-task performance, no effect was shown for either type of navigation report. This is likely due to the TD task being held at a constant rate. Additionally, when participants responded to the RA reports the simulation paused, which meant the cost of looking at the MMI on TD performance was not assessed during this experiment.

The performance for the RA reports shows that participants responded correctly more often when viewing the Navigation-A reports (d = 0.86). The exogenous orienting visual cues in the Navigation-A design displayed options that showed participants not only which way the robot could go, but also whether the robot would encounter any obstacles along each route and where the robot would end up. The additional information conveyed in the Navigation-A design, compared to the Navigation-B design, seemed to support decision making by visually displaying the consequences of each option. Further, responding to the Navigation-A reports elicited higher perceived mental-demand and global-workload ratings than Navigation-B reports, which could be partially explained by the difference in the amount of information visually displayed. Interestingly, mean ratings of the Navigation-B design were higher in terms of usability, but the effect was fairly low (d = 0.12) and not statistically significant; therefore, based on this sample, no preference was indicated, which corresponds to the open-ended responses. A key point is response accuracy to RA reports might be inherently linked with perceived workload, meaning display designs might need to elicit a certain level of perceived demand to facilitate decision making and engagement, potentially through more content-rich visualization. This is related to past research that found too little mental workload (Abich et al. 2013) or too much could lead to declines in task performance (Hancock and Warm 1989).

Taking into account the individual differences, it seems the more often a Soldier uses a computer, the lower the elicited workload response (as shown in Table 7), which makes sense considering the entire experiment was conducted on a computer and the MMI is designed on a computer-based platform. Overall, these findings show that even though task performance may be better supported by a specific visual-display design, if there is an increase in perceived cognitive demand the usability ratings of system will decline.

4.1.2 Building Identification

Similar to the navigation-display designs, no differences were found for TD-task performance. This could be explained by the same interpretation above. Additionally, and similar to the Navigation-A design, results indicate responses to Building-A reports had better accuracy (d = 0.69). The design for Building-A reports simply placed highlighted boxes around the areas of interest as opposed to desaturating the visual information outside the highlighted areas as in the Building-B design. Therefore, in terms of display-format design, all of the information displayed visually for object identification contributes to task accuracy and should be included because it provides contextual information that assists identification (De Graef et al. 1990).

When looking at the effects on perceived workload, although not statistically significant, reported mean scores show the Building-B design elicited lower ratings, which might have contributed to the significant effect on usability (d = 0.18); yet, the free-response questionnaires showed no stated preference. Further, response-accuracy performance was also lower. This could be explained thus: having too low of a mental load potentially leads to disengagement and poor decision making—as discussed previously (Abich et al. 2013). Further, correlations showed response times to either building design were positively associated with NASA-TLX ratings and negatively related to usability ratings (Table 7), suggesting both designs are related to task performance, cognitive demand, and display preference.

4.1.3 Limitations and Future Research

When the participants responded to the RA reports, the simulation paused. This was a known limitation implemented intentionally to first assess the quality of the RA report designs; but, to gain more ecological validity it would be best to have the primary task (e.g., TD task) continue as it would in the real world. Manipulation of this factor would support the quantified evaluation of the cost associated with MMI interaction in terms of task performance, cognitive impact, and SA. (A subsequent study is planned to assess this impact on Soldiers receiving robot reports from multiple robot teammates using nonvisual displays, such as auditory or visual–auditory combination, during a cordon-and-search task.)

Further, the extensive control of the laboratory settings allows for precise assessment, but limits the ecological validity of the findings as well. Ultimately, the results from this program of study will drive design of deployable products that will support Soldiers in a dismounted environment and, therefore, a balance of both field and lab studies is necessary to foster a transfer of findings from the lab to the field.

The intention of the free-response questions was to probe participants about their interactions with the MMI and to provide any suggestions for improvement. Although some participants did provide feedback regarding the MMI, it seems more responses were directed toward the capabilities of the robot—even though participants were told that evaluating the robot was not the focus of the study. In fact, the robot was never seen—just reports from the robot were displayed—yet participants were still evaluating the (notional) robot.

The next step will be to explore the effects of robot reports conveyed through other modalities, such as auditory or tactile, on dismounted Soldier performance and to use a more dynamic approach (i.e., higher-fidelity simulation).

4.2 Robot Reporting

The second goal of this study was to explore Soldier preferences when it came to receiving status updates (in the form of robot reports) from a robot teammate. Also of interest was the impact these reporting preferences had on participant SA and primary task performance.

4.2.1 Task Difficulty

The analysis of both global workload and TD performance served the purpose of assessing whether the event-rate manipulation resulted in a more or less difficult primary task for participants. We expected to find the low event-rate condition would be the least difficult (i.e., lowest global-workload scores and highest TD performance), high to be the most difficult (i.e., highest global-workload scores and lowest TD performance), and moderate to be between low and high in difficulty in terms of both global workload and TD performance. Instead, our results were inconclusive (as shown in Figs. 16 and 17). Participants did not perceive the event-rate manipulations as different, from a workload standpoint, and their performance was similar across most of the conditions. The only difference found was in TD performance between the moderate and high conditions.

Overall, it appears the TD task may have been a bit too easy for participants. Evidence of this comes from the fact that event-rate manipulation did not substantially impact participants (from either a workload or a performance perspective). Looking at the means for the 3 conditions for both global workload and TD performance, we see further evidence of this possible explanation. In all 3 conditions, the mean TD performance (i.e., accuracy) was more than 87%. In addition, mean global workload was below 30 (the scale is 0–100) for all 3 conditions. Taken together, this indicates participants tended to perform well at the TD task and perceive it to be minimally demanding across all 3 conditions.

4.2.2 Reporting Frequency

It was anticipated participants would request fewer reports from the robot as the event rate increased due to increased demands on the participant. In particular, we believed participants would spend more time focused on the TD task (due to the increased number of threats in the Soldier's environment) with less time spent requesting reports from the robot. We expected a linear relationship whereby most reports would be requested in the low event-rate condition, the second most in the moderate condition, and the least in the high condition. This hypothesis was only partially supported. The high condition did result in fewer reports being requested than in both the low and moderate conditions, but a similar number of reports were requested in both low and moderate (Fig. 17).

Overall, while the pattern of results did not match what we predicted, there were differences among the conditions. These findings highlight the importance of considering how "busy" one's team member may be when deciding how often to push information to them. Considering that Soldiers must perform a variety of tasks that are more or less time/resource intensive, this finding provides initial evidence that having a robot send reports to a Soldier teammate based on a strict rule (e.g., *Once every X seconds*) may not be ideal. Instead, it may be more appropriate to calibrate sending of reports based on nature of the task the Soldier will be performing.

4.2.3 Format Preference

When it came to Soldier preferences for a specific report format, more Soldiers preferred text reports than image reports, albeit this finding was not significant (i.e., this observed preference could be due to chance). While the Soldiers were not formally asked to describe why they chose/preferred one format over the other, several Soldiers informally shared their thoughts during (or after completing) the experiment. Soldiers who preferred the text reports mentioned the reports helped them process the information they needed quicker than image reports. This was because the text reports presented participants with the number of threats, critical threats, and nonthreats present, whereas the image reports required the participants to add up the number of threats and/or critical threats seen in the report. As for the image reports, Soldiers in favor of these reports may have found it easier to keep track of the reports due to each looking distinctly different from previous reports. Some Soldiers mentioned having difficulty quickly identifying the number of threats and critical threats with the text reports due to the font being similar for each category (i.e., same font style, size, and color).

Seventy-five percent of the participants were consistent in their preference throughout most of the RR scenarios; that is, they identified a preferred reporting format during the first or second RR route and stuck to that preference throughout the remainder of the RR routes, regardless of the event rate. The remaining participants may have switched back and forth to experiment with the 2 formats before deciding which they preferred. The fact most participants immediately decided upon a preferred report format is evidence it may be appropriate to allow Soldiers to inform their robot teammate of their preferred reporting format before beginning a mission. Only 4 Soldiers exclusively requested one format throughout all RR routes. Thus, 25 out of 29 (86%) of the Soldiers used both report formats in some capacity throughout the RR scenarios. This finding is initial evidence that despite having a general preference for a specific reporting format, Soldiers may still like to have another format available to them. It is possible the Soldiers may have wanted to use both report formats to double check the information in one report format against the other. Alternatively, at certain times during their tasking, having both formats may have helped them feel more comfortable in understanding the information that was currently available. However, because the Soldiers were not directly asked about their preference, we can only speculate on the reasons why both formats were used to such an extent.

4.2.4 Soldier SA

Despite the fact most linear relationships among the reporting variables (total number of reports and report format preference) and Soldier SA variables (SA-1, SA-2, and SART) were not strong enough to reach statistical significance, a discussion of the data trends is still relevant. In particular, it was expected there would be a negative correlation between the total number of reports and performance on both the Soldier SA-1 and SA-2 probes. In actuality, these 2 relationships were positive. This means participants who requested more reports from their robot teammate tended to perform better when asked about the Soldier's environment within the MIX simulation.

This finding is puzzling—it would seem participants who spent more time reviewing robot reports would be less able to keep track of the number of critical threats identified along the Soldier's route. One possible explanation for this finding may be that participants who requested more reports were more engaged in the tasks in general. In other words, participants who were requesting reports more frequently may have been more motivated to perform the experimental tasks in general and, therefore, kept better track of the total number of critical threats present along the Soldier's route.

The finding that TD performance was positively correlated to both Soldier SA probes (as opposed to negatively correlated) further supports this possible explanation. Another interesting finding is report-format preference was positively correlated with both the SA-1 and SA-2 probes but negatively correlated with the SART. This provides initial evidence that participants who preferred image reports tended to perform better on both the SA-1 and SA-2 probes (i.e., had higher SA) while simultaneously having lower perceived SA than participants who preferred text reports. Taken together, these relationships indicates that participants who preferred image reports may have believed they were less aware of the Soldier's environment than they actually were.

4.2.5 Limitations and Future Research

Three limitations related to the RR task should be considered.

First, despite the fact the event rate of the primary task was manipulated to achieve low, moderate, and high task difficulty (based on previous research with an undergraduate student population), participants did not necessarily perceive the different event-rate conditions as expected (nor did they perform as expected). Participants may not have felt the event-rate manipulations were substantial enough to change their perceptions of the primary task. Future research should pilot-test any difficulty/workload manipulations on the population of interest before full implementation with the final sample.

A second limitation related to the RR task is that participant preferences for robot-report format and frequency were completely derived from behavioral data (i.e., total number of reports and the number of each type of report requested). While the use of behavioral data resulted in interesting insights, the inclusion of surveys or questionnaires would have allowed participants to share their opinions and elaborate on why they preferred one format to another. Without these subjective data, it is difficult to know exactly why a given participant chose one format over another. Future research could address this by including a pre- and post-task survey that asks participants for their opinions of the 2 different reporting formats.

Finally, future research should also consider other factors that may influence a Soldier's preference for robot reporting such as reliability, trust, and the nature of the task.

5. Conclusions

In general, participants felt the MMI was fairly easy to use, was simple and straight forward, and could greatly benefit Soldiers in terms of mission safety by supporting remote interaction with a robot teammate. As expected, concerns the visual display could distract or allocate the attentional resources of the Soldiers away from their primary tasking were expressed in the free-response questionnaire. This is a primary reason the US Army is developing visual displays on mobile platforms (Young 2014); the intention is these displays will only be used for quick reference or response and should not require extensive viewing time. Additionally, part of the US Army's Robotics Collaborative Technology Alliance (RCTA 2014) research interests focuses on the use of other modalities that do not require a visual display for bidirectional communication between dismounted Soldier–robot teammates.

In addition, reporting frequency was impacted by primary task difficulty, which supports the idea of adaptive automation that manages the frequency of robot-to-human information sharing. While more participants showed a preference for reports that condensed and summarized information (i.e., reports displayed in a text format), participants still liked having both report formats available. For future MMI display designs this may mean redundancy in the presentation of information will likely be considered valuable to users.

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Appendix A. Demographics Questionnaire

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

Demographics Questionnaire

1. General Information

a. Age (yrs): ______ b. Gender: ___M ___F

c. Do you have corrected vision? ___None ___Glasses ___Contact Lenses

d. Do you have any type of color blindness/color vision deficiency? ___Yes ___ No

e. What is your native language? _________________

f. Do you speak more than one language? ___Yes ___No

g. If you answered **YES** to question **1.f**, how fluent would you rate your ability to speak a secondary language?

1	2	3	4	5	6
Very low fluency	Low fluency	Moderate fluency	Above moderate fluency	High fluency	Very high fluency

2. Military Experience

a. How many years have you been in the military? _________ b. Current rank _______

c. What is your MOS? _________________

d. Please list all combat deployments (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

Location Time

___________________________________ ________________________

___________________________________ ________________________

___________________________________ ________________________

___________________________________ ________________________

___________________________________ ________________________

___________________________________ ________________________

e. Do you have operational experience in complex urban terrain? ___Yes ___No

f. Do you have operational experience in reconnaissance situations? ___Yes ___No

3. Education

a. What is your highest level of education received? Select one.

____ GED
____ High School
____ Some College
____ Bachelor's Degree
____ M.S/M.A
____ Ph.D or other doctorate.
Other: ______________________

b. If applicable, what subject is your degree in (for example, Criminal justice)?
____

4. Computer Experience

a. How long have you been using a computer?

1	2	3	4	5	6
Never	Less than 1 year	1-3 years	4-6 years	7-10 years	10 years or more

b. How often do you use a computer?

1	2	3	4	5	6
Less than 1 hour a day	1-2 hours a day	Over 2 hours a day	Weekly	Monthly	A few times a year

c. For each of the following questions, circle the response that best describes **how often you:**

Use a mouse:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

Use a joystick:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

Use a touch screen:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

Use icon-based programs/software:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

Use programs/software with pull-down menus:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

Use a graphics/drawing features in software packages:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

5. Video Game Experience

a. Please indicate how often you **play video games**:

1	2	3	4	5	6
Never	Rarely	Once every few months	Monthly	Weekly	Daily

b. Please indicate how you would rate your experience in **working with** any type of video games:

1	2	3	4	5	6
Not at all familiar	Somewhat familiar	Moderately familiar	Above moderately familiar	Highly familiar	Very highly familiar

c. Which **type of video game** do you play most often?

_____Action-adventure
_____First person shooters
_____Military-based
_____Mobile/cellphone games
_____Multiplayer online gaming
_____Role playing
_____Serious games/Educational
_____Simulation
_____Strategy
_____Sports
_____Other, please indicate which one:
____

6. Robotics Experience

a. Have you any experience with **military robots**? ___Yes ___No

b. If you answered **YES** to question **6.a**, what type of robots and for what purpose?

Type Purpose

c. Please indicate how you would rate your level of experience with **any robots:**

1	2	3	4	5	6
Not at all familiar	Somewhat familiar	Moderately familiar	Above moderately familiar	Highly familiar	Very highly familiar

d. Please indicate how you would rate your level of knowledge regarding r**obotics technology (e.g., pack bot, big dog, talon, AIBO etc.):**

1	2	3	4	5	6
Not at all familiar	Somewhat familiar	Moderately familiar	Above moderately familiar	Highly familiar	Very highly familiar

INTENTIONALLY LEFT BLANK.

Appendix B. Cube Comparison Questionnaire

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

Cube Comparison Test

Name ____

CUBE COMPARISONS TEST -- S-2 (Rev.)

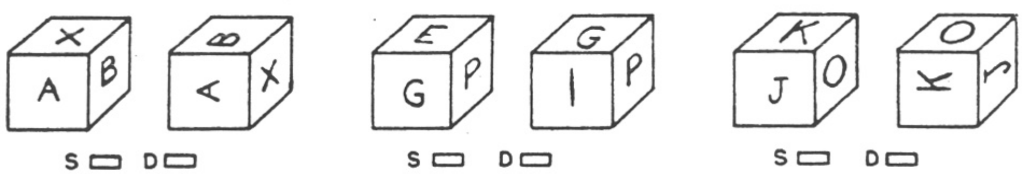
Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.

The first pair is marked D because they must be drawings of <u>different</u> cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

<u>Note</u>: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, <u>any</u> letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.



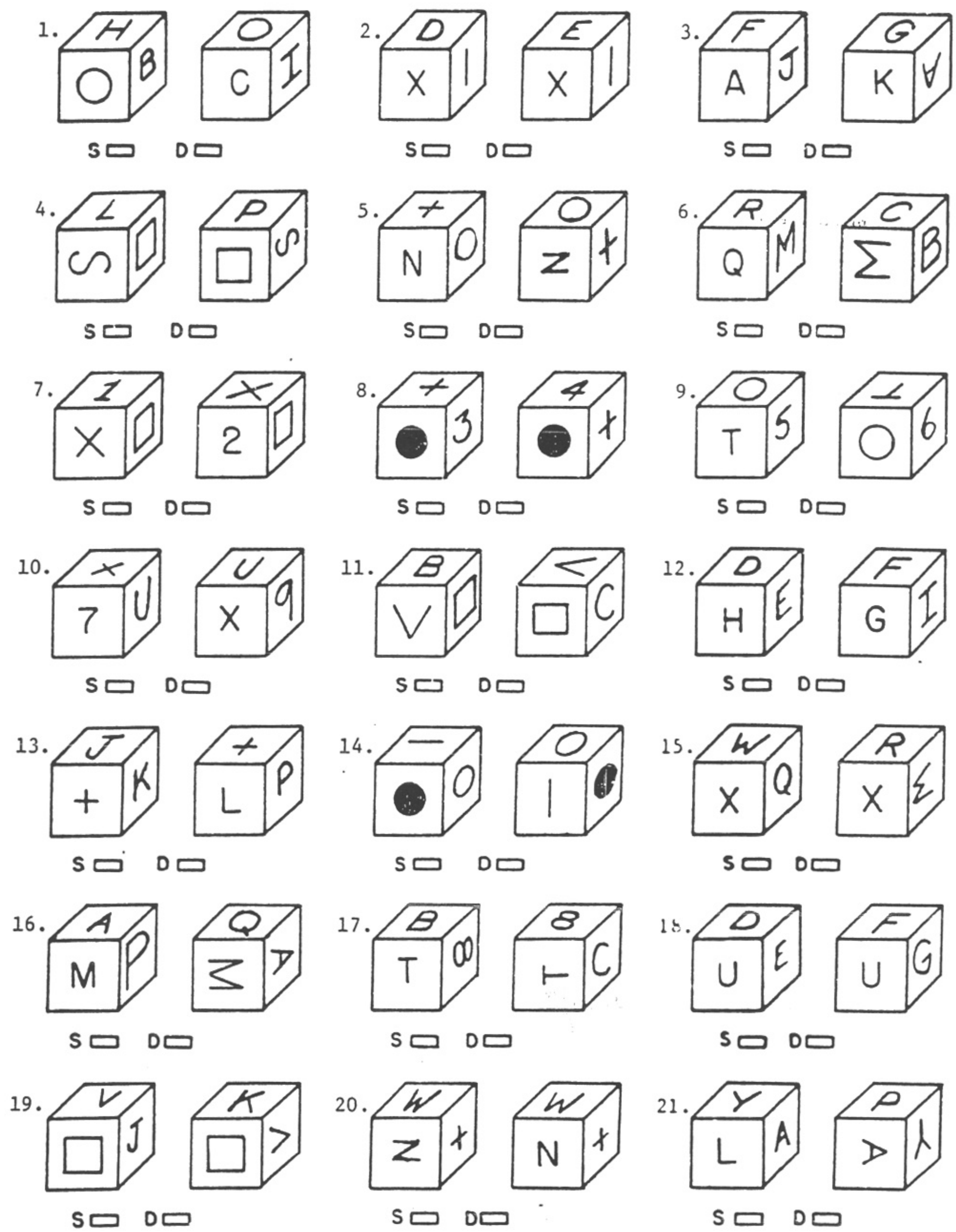
The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will <u>not</u> be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have <u>3 minutes</u> for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

Part 1 (3 minutes)



DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO. STOP.

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Appendix C. NASA-Task Load Index (NASA-TLX)

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

NASA-TLX Questionnaire

Please rate your overall impression of demands imposed on you during the exercise.

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

LOW |-----|----|----|----|----|----|----|----|----| HIGH
1 2 3 4 5 6 7 8 9 10

2. 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?

LOW |-----|----|----|----|----|----|----|----|----| HIGH
1 2 3 4 5 6 7 8 9 10

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

LOW |-----|----|----|----|----|----|----|----|----| HIGH
1 2 3 4 5 6 7 8 9 10

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

LOW |-----|----|----|----|----|----|----|----|----| HIGH
1 2 3 4 5 6 7 8 9 10

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

LOW |-----|----|----|----|----|----|----|----|----| HIGH
1 2 3 4 5 6 7 8 9 10

6. 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?

GOOD |-----|----|----|----|----|----|----|----|----| POOR
1 2 3 4 5 6 7 8 9 10

Appendix D. System Usability Scale

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

Comparison of System Usability Questionnaire

Please circle the response you feel is most accurate

1. I think that I would like to use the device frequently

Strongly disagree				Strongly agree
1	2	3	4	5

2. I found the device unnecessarily complex

Strongly disagree				Strongly agree
1	2	3	4	5

3. I thought the device was easy to use

Strongly disagree				Strongly agree
1	2	3	4	5

4. I think that I would need the support of a technical person to be able to use this device

Strongly disagree				Strongly agree
1	2	3	4	5

5. I found the various functions in this device were well integrated

Strongly disagree				Strongly agree
1	2	3	4	5

6. I thought there was too much inconsistency in this <u>device</u>

Strongly disagree				**Strongly agree**
1	**2**	**3**	**4**	**5**

7. I would imagine that the most people would learn to use this <u>device</u> very quickly

Strongly disagree				**Strongly agree**
1	**2**	**3**	**4**	**5**

8. I found the <u>device</u> very cumbersome to use

Strongly disagree				**Strongly agree**
1	**2**	**3**	**4**	**5**

9. I felt very confident using the <u>device</u>

Strongly disagree				**Strongly agree**
1	**2**	**3**	**4**	**5**

10. I needed to learn a lot of things before I could get going with this <u>device</u>

Strongly disagree				**Strongly agree**
1	**2**	**3**	**4**	**5**

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Appendix E. Free Response Questionnaire

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

Free Response Questionnaire

Instructions: Please answer the following questions about your experience with the device.

1. Please list the most positive aspect(s) of the <u>device</u>:

2. Please list the most negative aspect(s) of the <u>device</u>:

3. What do you think of the way in which the <u>device</u> provided building identification information? Did you have a preference?

4. What do you think of the way in which the <u>device</u> provided navigation information? Did you have a preference?

5. What else did you think was important, remarkable or surprising about your interaction with the robot using the <u>device</u>? Additional comments:

6. Please comment on any features of the <u>device</u> that you think had an impact on your interactions with the robot. You can comment on both positive and negative features, and suggest improvements.

Appendix F. Situation Awareness Global Assessment Technique (SAGAT) Probes

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

SAGAT Probes

SA-1 Probes

“1. Based on the currently available robot report, is the robot’s immediate environment safe?”

“2. Up to this point, how many critical threats have been seen on the Soldier’s route?”

SA-2 Probes

“1. Was the robot’s route safe?”

“2. Was the Soldier’s route safe?”

Appendix G. Situation Awareness Rating Technique (SART), Adapted

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

SART (Adapted)

Please rate your awareness of the situation by circling a number, according to the following dimensions.

Dimension 1: Demand on attentional resources

	Low						High
Instability: How likely did you feel that the demands of this mission and anything related to the situation would suddenly change?	1	2	3	4	5	6	7
Complexity: How complex did you feel this mission and anything related to the situation was?	1	2	3	4	5	6	7
Variability: How many elements of the mission did you feel were changing in this mission and anything related to the situation?	1	2	3	4	5	6	7

Dimension 2: Supply of attentional resources

	Low						High
Arousal: How ready did you feel you were in completing this mission and anything related to the situation?	1	2	3	4	5	6	7
Spare Mental capacity: How much attention did you feel you had left and could direct to other tasks?	1	2	3	4	5	6	7
Concentration: Did you feel you were able to concentrate on completing this mission and anything related to the situation?	1	2	3	4	5	6	7
Division of attention: How much attention did you direct towards this mission and anything related to the situation?	1	2	3	4	5	6	7

Dimension 3: Your understanding of the situation

	Low						High
Information quantity: How much information did you feel you understood while completing the mission?	1	2	3	4	5	6	7
Information quality: How good was the information you received while completing this mission?	1	2	3	4	5	6	7
Familiarity: How much knowledge did you feel you had about this mission and anything related to the situation?	1	2	3	4	5	6	7

Please rate your awareness of the robot's behaviors by circling a number, according to the following dimensions.

Dimension 4: Situation awareness of the robot

	Low						High
Perception: Please rate your knowledge of the robot's location, its surrounding environment, and its status during the course of the mission.	1	2	3	4	5	6	7
Comprehension: Please rate your ability to derive meaning from perception of the robot (e.g., its location, surroundings, and status) while completing the mission.	1	2	3	4	5	6	7
Projection: Please rate your ability to predict how the robot would behave in the near future, while completing the mission.	1	2	3	4	5	6	7

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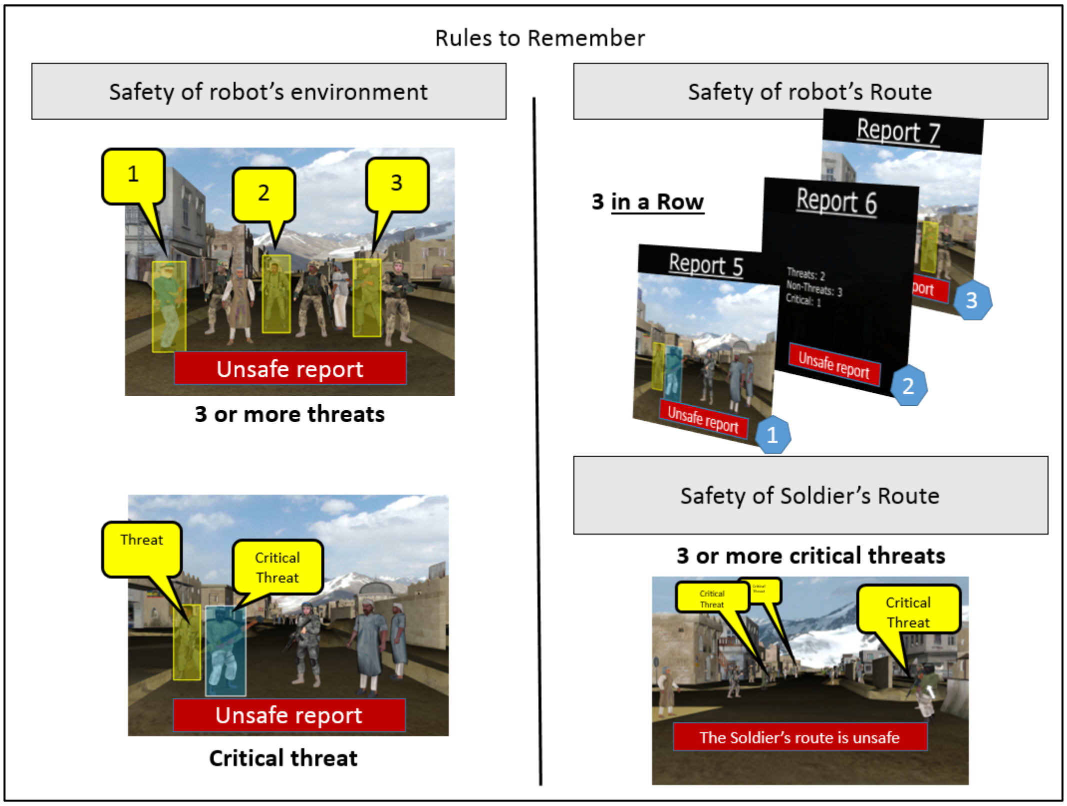
Appendix H. Cheat Sheet for Robot-Reporting Scenarios

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


Rules to Remember
Safety of robot's environment
1
2
3
Unsafe report
3 or more threats
Threat
Critical Threat
Unsafe report
Critical threat
Safety of robot's Route
3 in a Row
Report 7
Report 6
Report 5
Threats: 2
Non-Threats: 3
Critical: 1
Unsafe report
Unsafe report
3
2
1
Safety of Soldier's Route
3 or more critical threats
Critical Threat
The Soldier's route is unsafe

Appendix I. Informed Consent

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

Informed Consent to Participate in Research Form

Army Research Laboratory

Human Research & Engineering Directorate

Aberdeen Proving Ground, MD 21005

Project Title: Squad Level Soldier-Robot Communication Exchanges

Project Number: ARL-

Principal Investigators: Dr. Linda Elliott

Human Research and Engineering Directorate

Human Factors Integration Division

Weapons Branch, MCOE Field Element

(706) 545-5634, linda.r.elliott.civ@mail.mil

Dr. Daniel Barber

University of Central Florida

Institute for Simulation and Training

(407) 882-1128, dbarber@ist.ucf.edu

You are being asked to participate in a simulation-based assessment into differences in expectations of robot information sharing and information requesting. This investigation will focus on your requests for information from a robot in the form of status updates and preferences for how robots should request assistance. This consent form explains the evaluation 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 any questions at any time about anything you do not understand. You are a volunteer. At any moment, you may withdraw from the experiment without consequences.

Purpose of the Study

The purpose for this study is to collect information regarding how future robot teammates should communicate with Soldiers during reconnaissance and surveillance activities. Specifically, we are interested in when a robot should report information, what type of information is needed, how navigational assistance requests from a robot are presented, and how a robot should move when given specific commands. Your participation will provide additional understanding into how future robots should share and request information with Soldiers while they perform reconnaissance tasks. Results from this effort will drive requirements for future Soldier-Robot teaming concepts currently under development.

Test Procedures

You will be asked to complete a demographics questionnaire concerning your military background and experience. You will also be asked to complete a 3-minute spatial ability test. Next you will be trained how to perform the tasks within the simulation environment used for this study. First you will be trained on the different types of targets within the simulation, differentiating threats and non-threats. You will then perform a practice task where you will be required to classify targets (i.e. people, objects) considered threats based on the previous training. Upon completion of this practice task, you will then receive training on when and how to request information from the simulated robot. A practice task will be provided to familiarize you with the task and what information you must remember. Next, you will receive training and practice on what type of navigation assistance requests the robot will ask, and how to respond to them. After completing training on the individual tasks you will be given two additional practice scenarios: one with threat detection and robot information requests, and one with threat detection and robot assistance requests.

After completing training on how to perform the tasks, you will then execute three scenarios applying what was learned in the training. In two of the scenarios, you will perform a threat detection task while requesting information from a simulated robot performing a reconnaissance task. In the third scenario you will perform the same threat detection task while answering navigation assistance requests from a simulated robot performing reconnaissance. For all scenarios we will be recording when you communicate with the robot, the type of information requested, and models classified during the threat detection task. After completing each of the three scenarios you will be asked to complete the NASA-TLX and SART questionnaires to measure your workload and situation awareness respectively. Finally, after you have completed all scenarios, you will be asked to complete a "Robot Movement Questionnaire." This questionnaire will provide additional insight into your expectations of how a robot should move under different circumstances.

Discomforts and Risks

This study should offer minimal risks to your health and well-being. You can choose to withdraw from the experiment at any time, or to take a rest break at any time.

Benefits

You will receive no benefits from participating in the experiment, other than the personal satisfaction of supporting the Army's research in developing improvements in Soldier equipment.

Duration

Your participation in this experiment will take approximately 2 hours.

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. 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. However, complete confidentiality cannot be guaranteed because 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.

We would like your permission to take pictures/video during the experimental session. The pictures will be printed in technical reports and shown during presentations when we describe the results of the study. To protect your identity, we will ask you to remove your name badge and we will pixelate the image to obscure your face. You can still be in the study if you prefer not to be photographed/videotaped. Please indicate below if you will agree to allow us to take pictures of you.

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

Contact Information for Additional Questions

You have the right to obtain answers to any questions you might have about this research at anytime during this test. Please contact anyone listed at the top of the first page of this consent

University of Central Florida IRB
IRB NUMBER: SBE-14-10446
IRB APPROVAL DATE: 05/27/2015
IRB EXPIRATION DATE: 05/26/2016

form for more information about this study. You may also contact the Chairperson of the Army Research Lab Institutional Review Board, at (410) 278-5992 or (DSN) 298-5992 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 this number if you cannot reach the research team or wish to talk to someone else.

Voluntary Participation

Your decision to be in this evaluation 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 withdrawal 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 indicate the date below. You will be given a copy of this consent form for your records.

This consent form is approved from XXX to XXX.

__________________________________ ________________
Participant's Signature Date

__________________________________ ________________
Participant's Printed Name

__________________________________ ________________
Signature of Person Obtaining Consent Date

__________________________________ ________________
Printed Name of Person Obtaining Consent

UCF University of Central Florida IRB
IRB NUMBER: SBE-14-10446
IRB APPROVAL DATE: 05/27/2015
IRB EXPIRATION DATE: 05/26/2016

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List of Symbols, Abbreviations, and Acronyms

ANOVA	analysis of variance
B	blue
D	Cohen's d statistical value
DARPA	Defense Advanced Research Projects Agency
G	green
HRI	human–robot interface
M	mean
MIX	Mixed Initiative eXperimental
MMC	multimodal communication
MMI	multimodal interface
NASA	National Aeronautics and Space Administration
p	probability of rejection of the hypothesis
POV	point of view
R	red
RA	robot assistance
RR	robot reporting
SA	situation awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique
SD	standard deviation
SUS	System Usability Scale
TD	threat detection
TLX	Task Load Index
XUV	eXperimental unmanned vehicle

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C PAULILLO
RDRL HRF A
A DECOSTANZA
RDRL HRF B
A EVANS
RDRL HRF C
J GASTON
RDRL HRF D
A MARATHE