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Soldier Cognitive Processes: Supporting Teleoperated Ground Vehicle Operations

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14. ABSTRACT *(Maximum 200 words)*: Although small ground robotic vehicles provide great promise and benefit to units, there are challenges to overcome if the maximum benefit is to be gained from the introduction of these systems. The robots offer a host of capabilities. However, a person must know how to operate the system procedurally (e.g., use the hand controller buttons, know the menu options) and tactically (e.g., understand what the system can and cannot do). Learning how to operate and employ the ground robotic vehicle imposes a cognitive load on top of other military skills, perceptual decision-making skills, and communication skills that need to be utilized while operating the system. Therefore, trainers and leaders must understand what loads are placed on operators. The major issue is to understand how cognitive load impacts operators' performance. Finally, training materials and approaches for operators, especially when the operators have diverse backgrounds and skills, must be designed and developed so operators can effectively and efficiently take advantage of the capabilities offered by the small ground robotic vehicles.

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SOLDIER COGNITIVE PROCESSES: SUPPORTING TELEOPERATED GROUND VEHICLE OPERATIONS

EXECUTIVE SUMMARY

Research Requirement:

As small unmanned ground vehicles become more prevalent in supporting military operations, units must be prepared to take advantage of the capabilities these systems offer. A challenge in reaching this goal is to ensure robotic operators are properly trained; they not only have to know how to manipulate the system (e.g., hand controller button control, menu options), but also understand how to employ the system's capabilities. The challenge is exacerbated when robotic systems must be teleoperated out of sight from the operator, and while the operator is required to perform other tasks, such as providing verbal information to leaders who are not able to view the images being transmitted by the ground robot. This research report explores the cognitive demands placed on small unmanned ground robot operators. In brief, the research addresses the cognitive skills that system operators and trainers must consider when performing a series of common operating tasks.

Procedure:

While observing operator actions and inferring their thoughts, through direct visual observations, question probes, and post-task discussions, using the Task Analysis by Problem Solving approach, we captured the details of the tasks operators must perform. Analyzing the tasks helped identify multiple cognitive requirements on the operators of the ground robotic system.

Findings:

The findings highlight a range of perceptual, cognitive, and communication issues that surface in the course of teleoperating an unmanned ground robotic system, including compromised visual processing, impaired spatial cognition and reference frame orientation, and limited or ambiguous descriptions of visual scenes. Further, offered are training recommendations, such as ensuring ample practice time to approach automaticity of skills, and defining when certain skills are to be used. By training these and other skills, the learners will reduce their cognitive load and be better prepared for mission success.

Utilization and Dissemination of Findings:

The report can be used by robotic systems designers, instructional designers, trainers, leaders and operators to determine what and how to train teleoperated ground robotic vehicle operators, as well as a guide for understanding the complex nature of cognitive processing that occurs with operating robotic systems. A key value of this document is it makes clear the cognitive information that must be conveyed to learners; this is often information that has become internalized by experts and as a result is not explained clearly--or at all--to novices.

SOLDIER COGNITIVE PROCESSES: SUPPORTING TELEOPERATED GROUND VEHICLE OPERATIONS

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SOLDIER COGNITIVE PROCESSES: SUPPORTING TELEOPERATED GROUND VEHICLE OPERATIONS

Introduction

Ground-based robots have proven their importance in Iraq and Afghanistan across numerous mission areas. As the nation's 10 years of war winds down, the Department of Defense (DoD) inventories and funding of Unmanned Ground Systems (UGS) are expected to decrease, followed by an upward trend in 2016 and beyond (DoD, 2014). In response to Congressional concerns, the U.S. Army has developed a 30-year UGS campaign plan. The campaign plan was developed to coordinate and synchronize UGS research, development, and testing and evaluation efforts with Army force modernization requirements. The goals of the plan are to provide a modernized force of manned-unmanned teams with leader persistence, protection, and endurance. One concern for the trainer deals with the operator's increase in workload associated with small unmanned ground vehicle (SUGV) maneuvering, and research findings will identify ways to decreased physical and cognitive workloads on Soldiers, while increasing their combat capabilities. The outcome will be an affordable, modernized force as a manned-unmanned team with improved movement and maneuverability, protection, intelligence, and sustainment (DoD, 2014). In order for the Army to begin to achieve those goals, this report provides an overview[1] of the complex nature of the cognitive processes that developers, trainers, leaders and operators need to consider when rolling out any new teleoperated ground vehicle system.

Background

Promising technology evolution combined with modernization efforts have led to the development and fielding of new equipment items. Capitalizing on requirements and ideas of military units, deployed in combat and facing complex reconnaissance, security, and survivability tasks, the implementation of robotic equipment items (i.e., aviation, ground and marine vehicles) have seen an upsurge. One such item is the Army's XM1216 robotic SUGV. The vehicle is lightweight, remotely controlled, self-propelled, tracked, and can be used in multiple tactical situations to assist in minimizing risk and danger to personnel. The vehicle serves as a multirole mission platform capable of enhancing the small combat unit's ability to conduct military operations in urban terrain, confined access areas (e.g., tunnels, sewers, and caves), and over hazardous terrain. The SUGV increases unit options and supports the execution of manpower-intensive and high-risk functions, tasks, and missions (Wampler, Lipinski, Mabry, Blankenbeckler, & Dlubac, In Preparation).

The capabilities of the SUGV are designed to minimize direct exposure of Soldiers to hazards, direct fire, and observation. The system consists of a SUGV Operator Control Interface (see Figure 1), a SUGV chassis platform with video capability (see Figure 2), digital communications with audio relay modules (i.e., plug in/out—headset capabilities), and advanced

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[1] Although our introduction section is quite lengthy, our intent is to provide a fairly detailed description of various cognitive processes for the unfamiliar reader. We realize that some readers are well versed in these processes and we encourage all readers to review this section as deemed necessary.

sensor and mission modules. The modular, plug-and-play design allows rapid reconfiguration and integration of sensor payloads. Multiple payloads might be compatible with the system with additional payloads, sensors, and capabilities planned for the future.

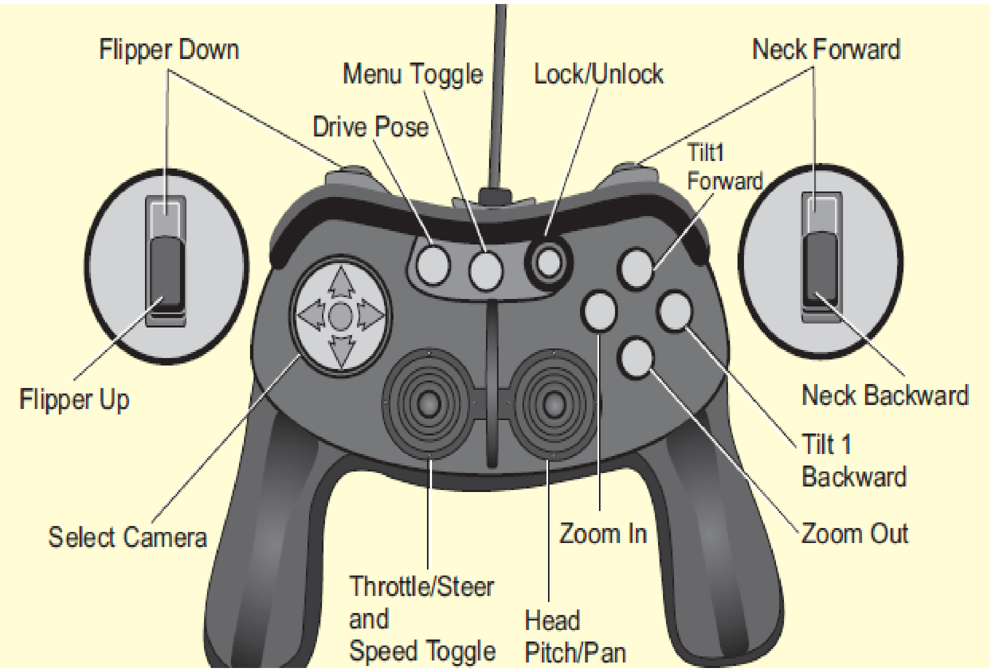


Figure 1. Display of a SUGV Operator Control Interface.

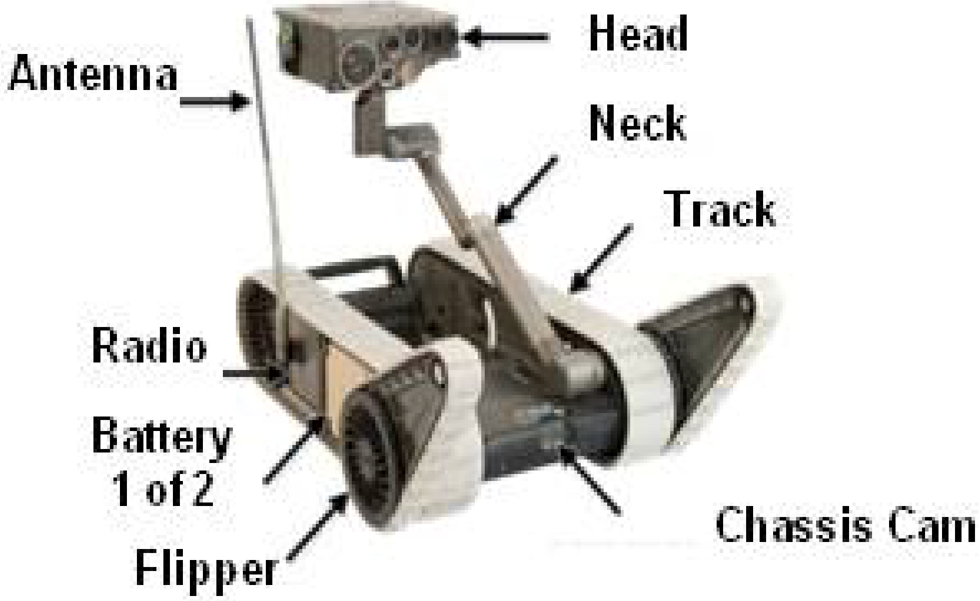


Figure 2. Example of the Army XM1216 SUGV chassis and its parts.

Communications and network interfaces on systems provide sensor data and imagery to the operator in real time and selective dissemination of information into the Mission Command network in real or near-real time. Current mobility features provide the SUGV with the ability to climb stairs, negotiate many obstacles, and maneuver in rough terrain. Deployments and testing of prototypes and specialized small robotic vehicles have produced positive mission results, saved lives and equipment, and provided valuable experience and lessons learned. The SUGV will be fielded to various Army units and will be employed to support a range of tactical missions and situations.

The SUGV is a complex device to learn to operate (Wampler et al., In Preparation); it is particularly challenging to operate under real-world conditions in which time, decision-making, and reporting requirements might be simultaneously critical. Nevertheless, there are no dedicated or specialized operators being planned for the SUGV; unit members will have an additional duty to operate the system. Nor is there additional staffing to support SUGV planning, mission management, or dissemination of reports or products. The current concept requires integration of the SUGV into existing organizations without added manpower or skill sets. Selected individuals, elements, and leaders in the unit are to be trained with the requisite skills to enable efficient and effective operation, maintenance, and employment of the SUGV. Units are to sustain operational skills and be able to employ the systems in support of their primary missions in full spectrum operations.

While the SUGV provides great promise and benefit to units, there are challenges to overcome if the maximum benefit is to be gained from the introduction of the systems. A Soldier must know how to operate the SUGV procedurally (e.g., use the hand controller buttons, know the menu options) and tactically (e.g., understand what the SUGV can and cannot do in certain situations). Learning how to operate and employ the SUGV imposes a cognitive load on top of other military skills, perceptual decision-making skills, and communication skills that need to be utilized while operating the SUGV. Therefore, trainers and leaders must understand what demands are placed on the operators. The major issue is to understand how cognitive load impacts operators' performance. Finally, training materials and approaches for operators, especially when the operators have diverse backgrounds and skills, must be designed and developed so operators can effectively and efficiently take advantage of the capabilities offered by the SUGV (Wampler et al., In Preparation).

Army initiatives are examining means to make dismounted Soldiers and small units more decisive on future battlefields. One aspect is to identify high-payoff areas of technology, such as robotic systems, that show promise to better prepare Soldiers for potential situations they could encounter. An Army Research Laboratory report (Hairston et al., 2012) discusses how a "whole system" design approach to technologies can improve their contribution to the operational success of Soldiers and small units. A key component to the design process should consider the system-Soldier interactions, which are driven by what the Soldier needs to accomplish to properly operate and employ the system.

Previous Observations of Cognitive Requirements

In a related research effort, Wampler et al. (In Preparation) identified challenges in training SUGV operators to perform their tasks. The project aimed to develop materials to train SUGV operators. Their team reviewed relevant literature on cognitive processes and loads, as well as available information discussing requirements to operate “robotic-type” systems or other related equipment. They also examined training materials available to train robotic operators. Materials came from a pilot SUGV Master Trainer Course as well as from the Future Combat System program. Researchers observed multiple iterations of SUGV Master Trainers instructing a group of students on how to operate a ground unmanned robotic system, plus interviewing trainers from the SUGV Master Trainer Course. Interviews were conducted at various points throughout the research effort. In addition, they identified tactical missions and situations where a robotic system could be used for support, and then analyzed how the robotic system might be employed and the requirements imposed on the robotic operator. Finally, they conducted structured exercises where SUGV Master Trainers performed two typical missions operating the robot. Researchers observed the exercises, audio was recorded of the dialog, the researchers asked clarifying questions and interacted with the robotic operators while the missions were being performed in order to gain detailed feedback from the operator. Recognizing the cognitive load placed on SUGV operators, the intent was to develop training materials to address those cognitive challenges.

The results from Wampler et al. (In Preparation) provided a starting point for the current research. They identified a number of tasks performed by both individuals and small units. The tasks included the skills needed to operate the SUGV system (psychomotor) as well as some information processing considerations (cognitive), such as interpreting images and verbally communicating what is being seen. Four typical missions were identified as the primary uses for the SUGV, including: conduct the reconnaissance, inspection, or search of a building; support a traffic control point by conducting a remote initial inspection of vehicles; investigate or search caves, tunnels, culverts or other subterranean environments; and support route clearance operations by remotely exploring for possible road hazards. Each of the missions has some unique skill requirements for operators. Four major areas for training were identified. The first is having the operator skilled enough to smoothly manipulate the SUGV to the desired location to support the mission demands. The second is developing the operators’ ability to accurately and quickly interpret the scenes observed through the SUGV optic devices. The third is being able to apply the skills rapidly enough within a time-pressure situation. The fourth is gaining the experience to effectively communicate (verbally) information seen through the robotic system cameras. Finally, a handbook was developed that contains an assortment of training materials to assist unit leaders in instructing SUGV operators. Some of the training materials were designed with the intent to address the cognitive loads placed upon the operators.

Cognitive Processes

While a SUGV system provides many advantages, the use of a teleoperated system presents some unique challenges. Foremost is the physical separation of the robotic sensor from the operator. Foundational approaches to cognition have emphasized the limited capacity of an individual to process abstract, symbolic information while using perceptual and motor processes as a means of operating in the world through input and output relations. Subsequent research across a host of domains has shifted the focus on a disembodied, computer-like operational system to one whose physical embodiment and sensorimotor processing is fundamental to cognition, action, and communication (Wilson, 2002). The relevant research literature to consider when analyzing the challenges of operating a SUGV under real world situations include divided attention, the allocation of scarce mental resources, the relationship between vision and spatial cognition, and performing tasks in a cognitively "noisy" environment.

Divided Attention. There is considerable evidence that when a person attempts multiple tasks simultaneously, there is a decrement in performance in one or more of the tasks. This occurs, for example, when a SUGV operator uses mental resources to communicate with a leader to report what they are seeing and doing, while also trying to make decisions about how to achieve some goal with the robot such as determining the distance of some object from the robot. This is related to the notion of “divided attention” in which a person attempts to monitor multiple “channels” or sources of information in order to perform a task. Given a constant amount of information, individuals tend to perform more accurately when monitoring a single source of information rather than multiple sources (e.g., getting readings from a single dial 24 times a minute rather than from 6 dials with 4 pieces of information each, per minute). This is commonly referred to as “load stress” (Conrad, 1951).

Load stress is readily observable in the SUGV operator's tasks. Load stress should be expected to cause operators to make errors in perceiving and interpreting information from the robot’s monitor while trying to move the robot appropriately and simultaneously providing a verbal report to a leader. Load stress is likely increased by perceived physical danger. Similar errors can be observed in other domains. For example, skill-based errors (inadvertent errors due to attention and memory failures) are the most common type of error seen in most aviation accident databases; these perceptual errors are more common than decision errors and intentional violations of rules (Pape, Wiegmann, & Shappell, 2001).

Allocation of Scarce Mental Resources. It is increasingly difficult to multitask if the similarity of the mental resources used in each task overlap, because individuals have only a limited set of mental resources available to execute cognitive tasks (“Multiple Resource Theory”; Wickens, 1984). If separate tasks are not competing as much for the same mental resources, multitasking can be accomplished more effectively. Further, when simultaneous tasks require the use of the same mental resources, it becomes more difficult to multitask without error. The problem becomes exacerbated when multiple tasks call on the same resources because now a mental “bookkeeping” function is added to the cognitive load. It is easier for an individual to perform two tasks where each task utilizes a distinct set of mental resources. An example is if an individual “shadows” (i.e., says aloud) a message which they are hearing (task one) while simultaneously typing out handwritten text (task two). In this case, multi-tasking is relatively easy because individual mental resources are devoted to each of the tasks. A joint auditory-verbal resource is devoted to task one (listening and shadowing); while a joint motoric-visual resource is devoted to task two (typing and reading). Neither task places a demand on the mental resource utilized by the other; listening and shadowing (task one) does not require the use of typing and reading mental resources. Similarly, typing and reading do not require the use of auditory-verbal mental resources. Hence, an individual is able to do both tasks at the same time without making many errors.

If, however, the tasks each involve the use of the same mental resources, it is far more difficult to multitask effectively. For example, suppose the individual types information which is spoken out loud (task one) while “shadowing” some written text (task two). Each task requires the use of the same mental resources. Task one requires the individual to type information (requiring the use of a visual resource) which is spoken out loud (requiring the use of an auditory-verbal resource). Task two requires the individual to shadow (requiring the use of an auditory-verbal resource) while reading written text (requiring the use of a visual resource). Each task competes for the same limited mental resources and is therefore more difficult to complete accurately because the two tasks now require a bookkeeping function to segregate mental resources devoted to each of the tasks, leading to more errors in the performance of both tasks.

The SUGV operator’s job more closely resembles the latter situation, requiring mental bookkeeping. The operator must perform activities using some combination of visual, verbal, auditory, or visual resources. The operator must communicate information to a leader (verbal resource) that requires the perception and analysis of information from a heads-up display or monitor (visual resource). Simultaneously, the operator must listen to the leader's instructions (auditory and verbal resource) and then translate the instructions into the subgoals and steps for achieving the subgoals with the robot. The simultaneous use of limited resources can lead to an array of cognitive and perceptual errors. To complicate things further, operators usually have nested tasks, such as scanning and communication while operating the robot; as well as a nested time-scale, to include a short-term time scale of immediate tasks (locomotion of robot), and the completion of “superordinate” tasks operating on a long-term time scale (mission objective).

Vision and Spatial Cognition. One of the most obvious perceptually complex tasks is related to dimensionality. To visually process information, we look for the environmental cues of height, width, and depth, called three-dimensional space (3D). When we try to process information from a two-dimension (2D--without depth) presentation (i.e., from a monitor) there are a number of additional processing steps needed to make sense of the image and translate it into our natural 3D interpretation (Haskell & Wickens, 1993). All of the additional processing steps require time. The additional time to process leads to asynchronous processing. For instance, because peripheral vision is limited, the SUGV operator must execute certain camera actions, such as rotation and multiple viewing angles, to better understand an image or object. To navigate in any environment, orienting and internal cues are needed. The cues are referred to as ideothetic. When observing the environment using just 2D, we eliminate or disrupt the essential navigation cues, thus adding more time to process our environs. Additionally, impaired reference frame coordination and orientation limits visual cognition and impairs pattern recognition to further extend the time requirements for the system. The camera functionality is also essential; if the screen is blurry, the degree of movement and time attending to an object to identify it is greater than it would otherwise be. This taxes one’s perceptual system and the inspection process, and places extended, if not always difficult, demands on the operator. Since 2D lacks depth, distance estimation also adds to the complexity of and the time to process an image. It takes mental energy to process and transform all of the information; energy not normally required if the images were 3D.

Our sense of the world is shaped by the sensory consequences of our motor commands. With remote vision on robotic systems we are disrupting many of the elements which then reciprocally alter the processing of the systems. Cognitive vision is dependent on the "richness of the action interface" (Gottesman & Gronlund, 2001). Motoric and perceptual systems are both dynamic systems that self-organize into meta-stable states (Vernon, 2006). Moreover, they are mutually informative and constrained particularly in the case of vision and action; vision informs action and action in turn informs vision. Placing constraints on one system (for example, vision when using an artificial system and motoric by limiting actions and feedback) alters the perceptual-motoric dynamics and potentially impairs cognitive processing and subsequent communication.

Performing Tasks in Cognitively "Noisy" Environments. "Noisy" is synonymous with complex. In general, at a given level of skill, when a person is performing a particular task, the number of errors that occurs increases as reaction time decreases. The challenge for the operator is, in part, a function of the speed at which they have to do their job. The shape of the function relating reaction time and accuracy is not linear; rather, for short reaction times, small time increases can lead to large increases in accuracy. As the reaction times get longer, further increases in reaction time lead to relatively little improvement in accuracy (Howell & Kreidler; 1963, 1964). Thus, it is in the "early middle" range of reaction times that we often find the best combination of speed and accuracy (Fitts, 1966). A trade-off exists; constraints or artificial demands to improve accuracy or speed can sometimes be followed by large costs to the other variable. Thus, extreme pressure to execute tasks quickly can lead a person to a correspondingly larger amount of inaccuracy. For instance, SUGV operators might unintentionally communicate incomplete or inaccurate reports because their attention is focused on some complex movement they are trying to make with the robot.

Adding more complication is the principle that under stressful situations with multiple tasks, people will often focus on easier tasks and accept higher error rates on more difficult tasks. This principle has been established in studies of air traffic controllers (Rantanen & Levinthal, 2005). The occurrence of the errors is not, however, necessarily linked to an awareness that errors are occurring. People are unaware their performance might be decreasing due to cognitive overload as suggested by studies examining drivers talking on cell phones (Lesch & Hancock, 2004), and it is consistent with observations that people might not be aware that their attempts to perform more rapidly will lead to a corresponding drop in accuracy.

The SUGV operator works in a complex environment with frequent interruptions. The effect on performance due to the deleterious factors is complex (Gawron, 1982). High levels of noise will have negative effects on general task performance. As previously discussed, verbal tasks exhibit performance decrements due to the additional processing time needed to make sense of the situation. The decreases in performance can be further traced to two other issues. The first is the environmental masking of verbal cues (due to constant shelling, a person might not hear spoken instructions clearly). Second is the disruption of the "inner ear" portion of the articulatory rehearsal loop. A "rehearsal loop" refers to the practice of mentally repeating verbally coded information and then mentally "hearing" what was just repeated. When disrupted by a noisy environment, individuals will have trouble processing commands because the rehearsal loop is disrupted; an operator will have difficulty rehearsing and then coding what needs to be remembered prior to carrying out a request because it was a challenge for the operator to internally "hear" the information.

The Effects of Cognitive Complexity on Performance Errors

Two domains in particular provide helpful context for evaluating the challenges, and subsequent errors, a SUGV operator may face: communications between pilots and air traffic controllers (ATCs); and the performance of emergency room (ER) physicians.

Errors in Pilot and ATC Communication. Pilots and ATCs exchange quickly changing information at a rapid pace concerning a number of variables critical to safe and efficient airspace. The variables include altitude, speed, heading, and weather, as well as a variety of others (Cardosi, 1993). Communications between pilots and ATCs are complex and take the form of a highly-coded and specialized vernacular, similar to SUGV operators. Both pilots and ATCs must devote limited mental resources to interpreting and communicating data so decisions can be accurately made—and revised—based on split-second changes in relevant information. Over time and with experience, the complete impact of each bit of data can be conveyed between pilots and ATCs. Likewise, Soldiers will interpret scenes differently and use the SUGV to explore different aspects of the scene as a result of their knowledge and experience. This is a function of embodiment because prior experience using the system determines the information used, the resulting actions of the SUGV, and what is communicated. In a very real way, intelligence is a dynamic construction rather than a static discovery and it does not mean all interpretations are valid or equal; it simply means operators are critical in the construction of their interpretation, not simply passive operators who cleanly pass information from SUGV to leadership. Further, expertise also influences cognitive load because the more seasoned and skilled operators will have more skills and automatic processing abilities, and thus will experience reduced cognitive workload and stress.

A variety of studies have examined the accuracy of the information exchanges between pilots and ATCs based on audio tapes made of the exchanges and have cataloged the frequency and type of errors. One study analyzed communications containing up to four different pieces of information which, when received, required readback by either the pilot or the ATC. They ultimately concluded that 1-3% of communications between pilots and ATCs contained errors (Cardosi, 1993). Other research studies have identified comparable error rates in other samples of pilot-to-ATC communications (Adam & Kelly, 1996; Cardosi, Falzarano, & Han, 1998). Similarly, one might expect communication errors to occur between SUGV operators and their leaders.

Errors Made by Emergency Room Physicians. Most ER physicians operate in a high-pressure environment in which speed of decision-making exacerbates the difficult task of assimilating large amounts of information from multiple sources requiring the use of diverse mental resources (i.e., both what the physician hears and observes from colleagues and the patient, as well as what the physician reads and sees). Like SUGV operators, ER physicians typically operate in a noisy and stressful environment in which each decision has immediate and important consequences.

A variety of studies have analyzed the frequency with which errors are made by doctors writing prescriptions in particularly high-stress environments, such as ERs and admissions, to neonatal and pediatric intensive care units (Selbst, Levine, Mull, Bradford, & Friedman, 2004). Those studies identify the environment as a major cause of prescription-writing errors because ER physicians frequently must perform multiple tasks that place competing demands upon cognitive and physical resources, "frequent interruptions are a contributing factor in committing errors" (p. 704). The work environment exacerbates the already difficult and diverse nature of the multiple tasks which must be performed in order to accurately write prescriptions. Overall, the time and stress factors that affect the performance of ATCs, pilots and ER physicians may also impact SUGV operators. Therefore, as with ATCs, pilots and ER physicians, it is important for SUGV operators to develop great skill (approaching automaticity) with various subtasks so they have more resources available to address the novel aspects of each situation they encounter.

Cognitive Load and Memory

Working memory is a limited resource (e.g., Baddeley, 2002) and working memory is used heavily during the learning process to construct new knowledge and to integrate new information with existing knowledge (Gyselinck, Ehrlich, Cornoldi, de Beni, & Dubois, 2000; Mayer & Moreno, 2003). Within cognitive load theory (DeLeeuw & Mayer, 2008; Sweller, Van Merriënboer, & Paas, 1998), three types of cognitive load are distinguished: *intrinsic*, *germane*, and *extraneous*. Intrinsic cognitive load refers to the number of elements integrated into a to-be-learned schema and therefore has to be processed in working memory simultaneously. Intrinsic cognitive load depends on the relational complexity of the to-be-learned content and the learner's degree of prior knowledge (i.e., schema availability). Germane cognitive load refers to the effort a learner invests "in processes that are directly relevant to learning, such as schema construction" (Sweller et al., 1998, p. 264). When intrinsic task demands leave sufficient cognitive resources available, learners can engage in schema formation, which increases germane cognitive load. Extraneous cognitive load refers to the result of implementing "instructional techniques that require students to engage in activities that are not directed at schema acquisition" (Sweller, 1994, p. 299). For instance, in computer-based learning, extraneous cognitive load might result from cognitive processes necessary to operate the computer or to interact with the learning environment. Extraneous cognitive load can impede learning as it requires cognitive resources exceeding the limits of working-memory capacity. Furthermore, cognitive resources required by extraneous cognitive load can no longer be devoted to cognitive processes associated with germane cognitive load.

Usually cognitive load theory assumes intrinsic cognitive load cannot be manipulated by instructional design because it depends directly on the number of elements to be integrated into a to-be-learned schema and have to be processed in working memory simultaneously. Interactivity in turn depends on the relational complexity of the to-be-learned content and on the learner's degree of prior knowledge (i.e., on schemas already developed and available). However, the assumption that intrinsic cognitive load cannot be manipulated is controversial (see Van Merriënboer, Kirschner, & Kester, 2003). For instance, when the content of learning pertains to solving complex tasks, it is an accepted instructional approach to break down the complex task in simpler subtasks that can be conveyed separately. When learners have acquired the subtasks, they usually will be instructed on how to solve the total complex task. The part-whole sequencing strategy is suitable for reducing intrinsic cognitive load because the load associated with the component task is less than the load imposed by the total complex task. It is also possible to provide a learner with a perspective on a domain that might have less intrinsic load relative to another perspective. For example, Catrambone and his colleagues (Catrambone, 1994; Gerjets, Scheiter, & Catrambone, 2004) developed a way of instructing probability problems dealing with permutations and combinations to reduce intrinsic load by helping learners understand a fundamental overlap in these types of problems, thereby eliminating the need to process two separate categories of problems with separate equations and solution procedures.

Cognitive load is an emergent cognitive state. Cognitive load itself can arise from a dynamic, interactive system in which the previous and current state of the system, the current and future goals, the time pressure, and in many cases the social consequences of success or failure, shape how an individual processes information, interacts with the environment, and communicates the information (DeLeeuw & Mayer, 2008). Once under the situation of high cognitive load, there are potential consequences: a decreased ability to offload cognition onto the environment because we are stripped of some of the key spatial reference frame data (e.g., no peripheral vision or ideothetic and inertial cues needed to coordinate reference frames); an increased need to internally represent the world; an increase on memory load because of internal spatial modeling needs; and, a decrease in the clarity of spatial communication. An additional consequence of high cognitive load relates to teleoperated functions.

With teleoperations, an individual cannot physically manipulate the environment and additional investigation of an object might require substantially more moves of the system. Further, it might be difficult to read or look into something due to camera constraints. If we are physically present, we literally act more quickly, interact physically with greater efficiency and categorize the space differently by having cleaner categories of concern (there are no concerns related to uncertainty of our processing versus the limits of the robot and the limits of 2D visual stimulus). The social relations through which information itself is processed function as a distributed cognitive network. There is information and structure in the processes themselves that shapes the processing of the information as it passes between physical agents. In a real sense, the intelligence is among the individuals and is created by an interactive process; it is neither here nor there, but rather everywhere, interactive and dynamic.

Instructional Design Considerations

So far, the emphasis has been on the complex nature of human cognition, perception and its effects upon performance and communications. The topic of training to teleoperate an unmanned ground robotic vehicle in light of these challenges is a critical consideration. If personnel are to be trained to operate SUGV systems, and take advantage of the capabilities they provide, training must be designed to accommodate the cognitive loads imposed on operators.

It is necessary to identify the factors that affect initial performance, learning, and the transfer of knowledge to determine how instructions can be developed to fulfill different educational goals. One such factor is related to the amount of effort users are willing to exert when following instructions to learn procedural tasks. Findings suggest people tend to minimize the effort needed to reach their goal. For example, Szlichcinski (1979) concluded that people complete tasks in a way that requires the least amount of effort. Redish and Touretzky (1997) suggested that people will turn to instructions only when they cannot figure out what to do; otherwise they will rely on expectations, interfaces, and prior knowledge. In addition, people do not necessarily engage in the required reasoning to determine how to apply system knowledge to system operations. Rather, they adopt passive or superficial strategies when learning from examples (Atkinson, Derry, Renkl, & Wortham, 2000; Atkinson & Renkl, 2007; Chi, DeLeeuw, Chiu, & LaVancher, 1994; Morris & Rouse, 1985). Because good learning and transfer requires learners to engage in effortful cognitive activities, instructions should be designed to encourage the use of strategies for the educational goal in question, especially for learning and transfer of knowledge. Providing learners with some abstraction or general description of what to do will increase the chance they will engage the necessary cognitive processes.

Instructional principles clarify how a system works by explaining the purpose of components and how they work together (Bibby & Payne, 1993; Duff & Barnard, 1990). The goal of providing users with principles is to enhance their understanding of why the system operates the way it does and as a consequence, better equip them to deal with unfamiliar or unexpected situations (Kieras & Bovair, 1984). There is evidence that people choose to study principles in instructions even if they do not provide exact information on the task they are trying to complete. On the other hand, research suggests principles are more helpful if they relate explicitly to the operations and actions used to execute tasks. Further, examples provide learners with a model of how a task is carried out, and can be useful to help people instantiate abstract concepts and provide them with an instance of how a rule governing the task applies to a particular situation (Pirolli & Recker, 1994; Reder, Charney, & Morgan, 1986). In addition, people seem to prefer examples over procedural instructions.

Instructions often contain diagrams and a learner must inspect a diagram to understand a text passage, and vice versa, and requires many shifts of attention between the two sources of information (Ayres & Paas, 2007; Bétrancourt, 2005; Hegarty & Just, 1993). Moreover, visual search is required to locate corresponding diagram components and text segments (Ginns, 2006). Attention shifts and visual searches are not thought to contribute to schema acquisition (Chandler & Sweller, 1991). Rather, the activities deplete the cognitive resources available for learning and add to extraneous cognitive load. Thus, instructional materials must be designed to minimize extraneous cognitive load so cognitive resources can be directed towards activities such as schema formation.

Using Cognitive Task Analysis to Guide Training

An expert in a domain--regardless of whether the domain is repairing carburetors, pitching baseballs, or designing houses--is, of course, very good at the tasks in their domain. However, a "cost" of expertise is that experts are often unable to describe *how* and *why* they do the various steps of a task. The cost is due to the fact, for an expert, many parts of tasks have become automated, many steps seem "obvious", and many cues for guiding the choice of steps (and even the choice of task) cannot be articulated easily. The aim of the task analysis approach developed by Catrambone (2011) is to uncover or rediscover the knowledge of an expert, through an evaluation of the responses made to problem-solving inquiries. The value of recovering such knowledge is it can form the basis for developing, and be integrated into, instructional materials for new learners as well as learners at various levels of expertise. A variety of task analysis techniques exist (for a review see Schraagen, Chipman, & Shalin, 2000). The merits and pitfalls of these techniques have been considered by multiple critics. Pitfalls include unnecessary complexity and overly narrow application (e.g., a given task analysis technique might not be useful for identifying procedures) (Schraagen et al., 2000). As a consequence of the criticisms, we selected the simplicity of using the Catrambone task analysis approach for this evaluation. Conducting a task analysis is not the same thing as developing "learning objectives". A teacher or trainer might have a learning objective for students to solve algebra word problems dealing with work. However, such learning objectives say little about the procedural content the student needs to know in order to solve problems.

To develop successful training systems (e.g., text instructions, images, animations, simulations, multimedia learning environments) it is crucial for the instructional designer to first identify what the learner needs to know, which is difficult to do because the subject matter experts (SMEs) who are involved in the development of training materials have often automated and chunked many aspects of their knowledge. As a result, they will fail to identify the many bits of knowledge that a novice needs to acquire. Thus, a task analysis can be crucial for identifying the needed information. The Task Analysis by Problem Solving (TAPS) approach to task analysis (Catrambone, 2011) will be described shortly. Once a task analysis such as TAPS has been carried out, the output can be used to guide the development of training materials. While TAPS can show *what* should be instructed, it is mostly agnostic about *how* to instruct it (although anecdotally, a great deal of the challenge is identifying the "right" information to teach; the way it is taught, while obviously relevant, might be secondary in importance).

Task Analysis by Problem Solving

The TAPS approach requires collaboration between a SME and a knowledge extraction expert (KEE) who is a novice to the domain. The TAPS approach typically proceeds as follows:

- The SME identifies a set of typical problems, tasks, or scenarios. The tasks are ones that someone who "understands" the domain (for example, the operation of the SUGV) should be able to execute.
- The SME solves and carries out the tasks with the KEE observing. The KEE's job, as a domain novice, is to require the SME to explain and defend the steps and decisions the SME makes as he carries out the task. The aim here is not just to identify the steps, but to create detailed notes to explain *why* each step is being carried out (and sometimes why a different step was not chosen) and, often, the subgoals being achieved by particular groups of steps.
- The KEE edits the notes which involve reorganizing the notes in order to extract procedures, decision rules, facts, etc. from the demonstrated tasks.

- The SME carries out the same tasks again. The intent is to allow the KEE to check and continue to edit the revised notes, to fill gaps, fix inconsistencies, etc.
- The KEE attempts to execute the tasks previously performed by the SME, as well as new tasks identified by the SME, allowing the KEE to verify the accuracy and completeness of the notes, often leading to elaboration of the notes. Inevitably the KEE will reach an impasse on a particular problem, the point in which the KEE's state of knowledge (represented by the notes) does not allow the KEE to determine what to do next. At that point the KEE consults with the SME. Typically such consultations lead the SME to recall some piece of information that had not been explicitly identified previously. The SME then supplies that bit of information. Sometimes a misunderstanding by the KEE is uncovered, which can be corrected through consultation with the SME.

The TAPS process can continue through more cycles as needed and as time permits until the KEE can successfully execute all the tasks provided by the SME. Keep in mind that the KEE is relying on the notes to execute the tasks; the intent is to develop complete notes and not to train the KEE per se. During the process, the procedural information in the notes becomes less tied to details of the specific tasks carried out by the SME and KEE. Again, depending on the intent of the task analysis process, the notes might be organized into subgoals, steps, facts, rules, definitions, implications, or conventions. Different domains might lend themselves to different characterizations of problem solving knowledge types. Subgoals have some psychological validity for predicting problem solving transfer (Catrambone, 1996, 1998), the other categories are more of an organizational tool.

After conducting the iterative knowledge elicitation process, the KEE can conclude that they have identified all of the needed information to solve problems or execute tasks in the domain. While it does not constitute a formal proof, the iterative approach has worked well. Further, the information is not derived--and probably cannot be derived--from a formal analysis of the domain. A formal analysis would not uncover the procedural knowledge.

Method

Participants

Three instructors from a SUGV Master Trainer Course at Fort Benning, GA participated as SUGV operators. The instructors were responsible for developing the SUGV training program and associated training materials. They were intimately familiar with how to operate the system to perform typical tasks. Each participant also had experience operating a SUGV in combat situations.

Procedure

The research team included one KEE facilitator and three retired military personnel with various operational mission and robotic system backgrounds. One researcher had supported the Future Combat System training program for nearly 10 years, analyzing and determining training needs based on shortcomings and training gaps, which included employment of the XM1216

SUGV. Members of the research team executed a single iteration of the TAPS process with the SUGV Master Trainers to identify the steps and requirements for operating the ground robot vehicle. The participants took turns executing typical SUGV tasks, which included:

- Putting the system into operation;
- Demonstrating basic driving and component functions to explain SUGV "buttonology";
- Ascending and descending stairs;
- Searching a room, both day and night; and
- Crossing varied terrain.

Generally, one participant completed a task, followed by a different participant executing the next task. Multiple participants were present during the execution of each task and each individual contributed to the dialogue by offering information and responding to KEE queries, and each individual's comments were separately noted.

Throughout task execution, participants identified the steps they were performing, explained why each step was being carried out, and sometimes explained if a different step was possible but not chosen. Based on their operational expertise, in addition to explaining the SUGV operating steps, participants offered personal insights on SUGV employment considerations and requirements. They offered details about what the SUGV operator would be required to do simultaneously while performing basic tasks (e.g., because only the operator can see the scene being viewed by the cameras on the SUGV, the operator must provide verbal information to leaders and respond to questions while they are operating the system).

Due to limited participant access, the KEE did not have time to iteratively edit and reorganize notes prior to executing the tasks. However, the KEE did attempt to perform the tasks, and expanded upon the notes based on that attempt. The process also facilitated further dialogue with the participants who demonstrated the cognitive requirements to not only operate the SUGV, but also to communicate verbally with others while controlling and employing the SUGV.

Materials

A single XM1216 SUGV system was used to execute the tasks and participants took turns operating the system. Most tasks were executed inside a facility with stairs and multiple rooms where the lighting conditions could be varied. The area immediately surrounding the facility provided different terrain conditions (e.g., paved parking lot, grass and dirt areas) where mobility and other employment considerations could be demonstrated and discussed.

Results

A specific focus was to identify the cognitive demands placed on teleoperated ground vehicle operators. The use of TAPS was an explicit attempt to learn in detail the operator tasks in employing the system. Some members of the current research team had previously observed SUGV operators performing typical tasks (see Wampler et al., In Preparation, for the results of a previous TAPS analysis of the XM1216). Information garnered from the earlier observations included the cognitive load being placed on operators while executing typical SUGV missions. The TAPS analysis confirmed and captured additional details concerning the cognitive loads placed on SUGV operators.

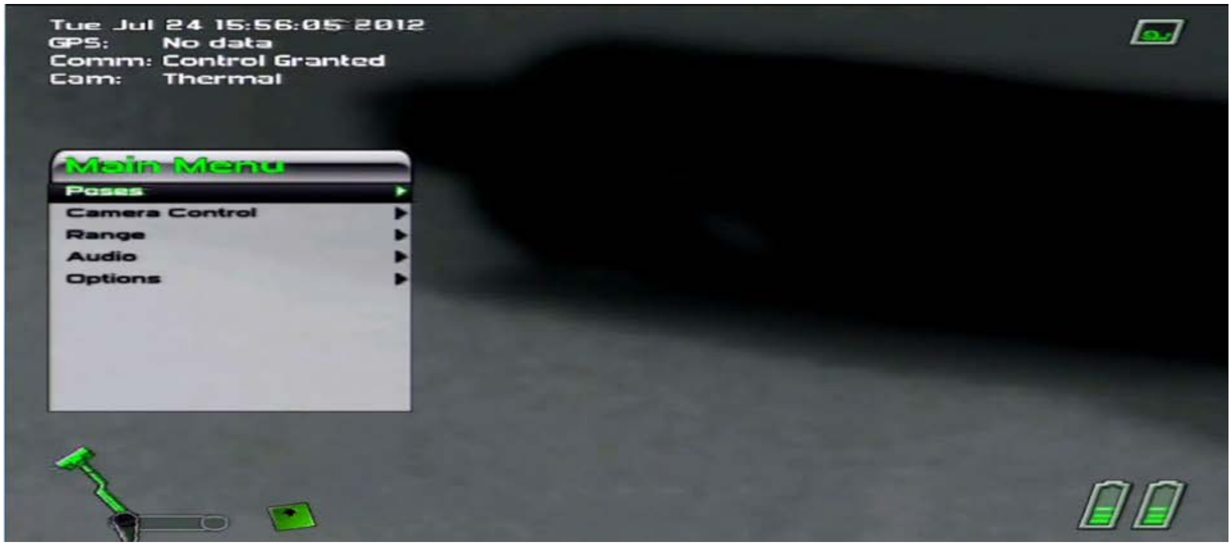
As a consequence of performing the TAPS, the KEE identified five categories of knowledge one needs to learn to operate and employ the SUGV. The first category addressed the “procedural skills”, or buttonology of the hand controller; knowing what each button, toggle switch, etc. controls and knowing the menu structure. This category involves robot movement, including knowledge about how to make the robot perform certain maneuvers such as descending or ascending stairs and "peeking" over an object. The next category addressed the knowledge of how to employ the SUGV to accomplish tasks, or “achieving task goals and subgoals”. This category includes knowledge such as the situations for which each of the multiple cameras on the SUGV are best suited and how to manipulate the SUGV so that it can accomplish the task. The third and fourth categories addressed the knowledge necessary to properly and effectively employ the system, and includes both specific “military knowledge” (e.g., recognizing and identifying weapons and explosives) and worldly “general knowledge” not unique to the military (e.g., typical components one would expect to see in and on different types of vehicles). The fifth category addressed knowledge required to communicate the appropriate information to leaders who are not able to view what the SUGV operator is seeing.

The five identified categories are not mutually exclusive and the knowledge in each category may heavily interact. For instance, while one might know the buttons to push to make the robot more forward, to operate the flippers, and to switch among cameras, there are strategies for how to approach an incline, how to make sure the robot is in a stable position, and how to be sure the robot has gone past a certain obstacle before attempting the next movement. The strategies require the correct buttons to be pressed and the correct menu selections to be made, but they also require the operator to have or form the correct goals and subgoals for executing a strategy irrespective of *how* to achieve goals and subgoals. Meanwhile, the strategies also depend on the operator's military knowledge as well as the ability to correctly interpret the information from the cameras.

As discussed, someone operating an unmanned ground robotic vehicle has multiple competitors for cognitive resources, including forming a plan for achieving some goal such as climbing stairs, dividing the goal into a set of subgoals (approaching the stairs, "squaring up", etc.), determining the appropriate buttons to press and menus to access to achieve each subgoal, making decisions based on feedback from the robot's cameras, and reporting the information as well as perhaps listening for directions from leaders who cannot see what the robot is doing or seeing. All the activities might have to be performed under high stress (e.g., time pressure or high risk) and physical danger. The following examples for the five categories of knowledge the operator has to recall were captured from the TAPS. Each of the examples demonstrates how an operator’s attention and mental resources must compete.

Procedural Skills

Operators must know the procedures of how to drive the robot, manipulate and choose cameras, access menus, etc. For instance, consider camera operation. In order to use the infrared (IR) camera, one must select the camera from a menu and recognize the "IR illuminator" is on. However, one must also know how to access the main menu and then how to get to the appropriate submenu for cameras and where to look for the IR illuminator. Figures 3 and 4 depict SUGV displays. The Menu options can be varied with multiple drop-down options, and the operator must know where to locate desired functions within the menus. Also shown, the heads-up display provides other information to assist in keeping the operator aware of the robot’s operating situation (e.g., the robot in the lower left of the image depicts the position of neck and head, as well as the flippers; the image to the right of the robot shows how the head is oriented with respect to the chassis of the robot; the image in the upper right corner indicates the speed of the robot movement [snail means slow]; the image in the lower right shows the remaining power on each of the two batteries).



Tue Jul 24 15:56:05 2012
GPS: No data
Comm: Control Granted
Cam: Thermal

Figure 3. SUGV heads-up display showing menu options and thermal image in background.

Tasks can be represented as goals and can be decomposed into smaller and smaller subgoals. Steps for achieving the subgoals essentially take the form of subroutines and can be applied in a variety of cases. The short subroutine for accessing the main menu using the Hand Controller is an instance of a subgoal and method that can be used in many different circumstances. Another example is the use of the Driver Pad, which is also part of the Hand Controller. An experienced operator will need for certain knowledge to become routine so the effort of recalling needed information is not competing with whatever task they are trying to accomplish such as looking for an improvised explosive device (IED) in a dark room.

Tue Jul 24 15:56:50 2012
GPS: 16S FA 9408 9628
Comm: Control Granted
Cam: Drive

Figure 4. SUGV heads-up display showing submenu options.

Achieving Task Goals and Subgoals

This category addressed knowledge about the judgments operators must make as they drive and manipulate the robot to perform various tasks. For instance, suppose the operator wants the robot to go down stairs. The operator needs to know how to drive the robot to the stairs and put it into the descend pose; this sort of knowledge should be well-learned and, therefore, trivial to recall. The operator needs to know they should use one of the cameras to look down the stairs to assess the slope, depth and width of each step, potential obstacles, etc., realizing the drive camera is probably located on the chassis and is most likely capable of looking only forward and not angling to see down the stairs until the robot actually begins the descent. Figure 5 shows a SUGV ascending stairs. To have the SUGV ascend stairs, the operator needs to consider how to: manipulate the SUGV to view the desired point and at the correct angle; adjust the flippers to extend their reach; rotate, tilt, and extend the neck and head; and determine where the SUGV is located in relationship to any obstacles. The key is to manipulate the components of the SUGV to negotiate various obstacles by properly positioning the head, neck, and flippers to maintain balance and avoid tipping.

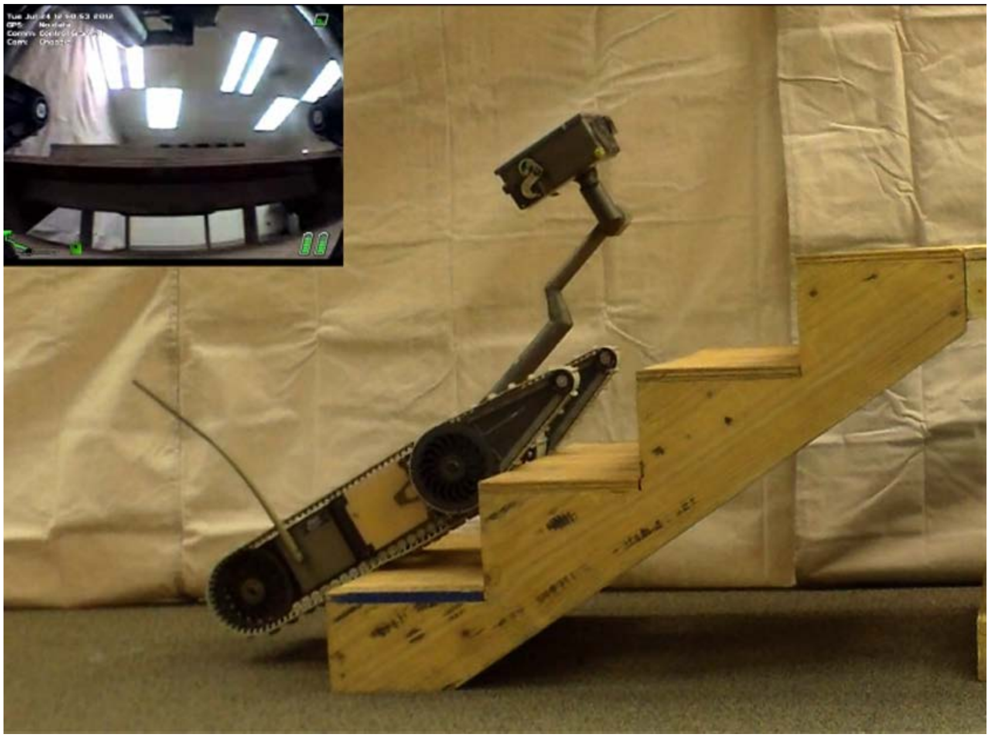


Figure 5. SUGV ascending stairs with camera image-upper left.

While “buttonology” knowledge is crucial for the operator to ascend stairs, there are more parts of the task. The operator also has to make judgments such as whether the robot is "squared up" to the stairs appropriately, how close to get to the stairs before lowering the flippers for stability, and when to move the neck forward to get a view in front of the robot. These sorts of judgments and decisions are not issues of *how* to make the robot do things, but rather forming and knowing the right subgoals for *when* to do things in a particular situation. If operators are fumbling with the procedural details of making the robot move, they will have fewer resources available to recall the strategy for approaching the stairs, fewer resources available for making judgments about the robot's position relative to the stairs, and fewer resources available for forming new subgoals to adapt to the situation if it changes.

Military Knowledge

The operator of the robot is a Soldier who has an array of knowledge pertaining to robots as well as Soldiering skills. As an example, regardless of whether it is a robot or a Soldier entering a potentially dangerous room, certain things need to occur such as, checking for booby traps across the doorway and once through the doorway, to scan left and right. This type of knowledge presumably is well-learned prior to a Soldier becoming a ground robot vehicle operator, but perhaps its application might need to be practiced by the Soldier-operator so they remember to apply it *to the robot*. Another example is recognizing an IED. A Soldier might already know about telltale signs of the presence of an IED as well as likely places they might be hidden (e.g., certain locations in cars, see Figure 6). Once again, the operator has to remember to apply their knowledge when using the robot.

Figure 6. SUGV investigating a vehicle for an IED.

General Knowledge

This is knowledge about the world that might affect how the robot is used or how to interpret information the robot is providing. For instance, suppose the operator is using the robot to check under vehicles and encounters a truck with two mufflers. If the operator knows a particular truck model comes with one muffler, or if the operator knows there should be a tailpipe for each muffler but sees only one tailpipe, then the operator could have reason to be suspicious about whether one of the mufflers might be an IED.

Communicating with Leaders

With the current SUGV system, the operator is the only person able to view what the SUGV is transmitting through its optics, and the SUGV operator must provide a verbal report to leaders. The effort to describe what is seen (and the operator’s interpretation of what is seen) requires mental resources and therefore provides another source of cognitive load that competes for resources with the other tasks outlined above. Ultimately, *all* the tasks (including the need to recall information) are competing for finite mental resources. The greater extent to which some of the tasks (such as robot movement) are automated, the less cognitive load they will generate and therefore the more cognitive resources will be available for the other tasks. For instance, someone who is an expert with buttonology will be able to devote more of the limited cognitive resources to making decisions about what is seen with the camera and describing it to a leader.

Discussion and Recommendations

Operating any type of robotic vehicle in a realistic situation requires a great deal of cognitive resources. An experienced ground robotic vehicle operator has probably automated some of the procedural knowledge such as the buttonology, many of the subgoals such as how to ascend stairs or determine which camera to use in a certain situation, and probably some of the military knowledge such as how to enter a potentially dangerous room. Nevertheless, the operational demands remain high. Further, the operator will also be interpreting information from the cameras as well as listening to directions from and providing reports to leaders. The additional tasks place more load on the operator, thereby making the overall task much more difficult. This section provides some general discussion and recommendations with regard to social cognition processes, training and automaticity implications when teleoperating an unmanned ground robotic vehicle. While the recommendations are derived from SUGV operators, they are applicable to other teleoperated robotic vehicles.

Situated Social Cognition

Social cognition is dependent upon how changing situations and contexts of operating a robot changes the cognitive context for the operator, which increases stress and cognitive load and could ultimately impact social cognitive processing. For example, visual processing and interpretation of a scene will depend on the perceived robotic functionality according to the operator. Further, the presence of a communication task shapes the outcome of the visual interpretation itself. Moreover, the expectations of what leaders want, plus the desire to not look inept and not miss anything obvious are also interacting. The social context influences visual perception and the interpretation of tasks.

Therefore, cognitive load and visual perception issues impact situated social cognition processes. There are key ways in which the use of an artificial system may impact cognitive processing. To overcome the impacts, one needs to consider the impacts upon visual processing and then provide a strategy to consider the impacts on cognitive processing more generally. Vision and the lack of natural movement impairs visual processing and spatial cognition, and occurs when the operator must rely on the system optics rather than his own visual cues, and it also impairs spatial processing which increases cognitive load. The follow-on is an increase in stress, fatigue, and also a reduction in effectiveness of communications.

Cognition of the situation is truly distributed and actively constructed by the operator and the leader with whom one is communicating with (Smith & Kosslyn, 2007). The social and perceptual dynamics here are completely intertwined. Included are stereotypes of what leadership is, who they are, what they know, and what they want. Stress and anger can aggravate the use of negative stereotypes (Smith, 2004).

In the case of a teleoperated vehicle, one's cognitive-visual interaction is severely constrained. This restriction not only impacts visual perception and perspective (i.e. natural 3D vision versus 2D vision from a screen), but also spatial reference frame processing, spatial memory, and communication. The task here is fundamentally spatial and yet the use of teleoperations in a key visual sense places great demands on human spatial cognition. The operator has no ideothetic cues and no natural visual flow. According to Glenberg (1997), such changes impact our memory for environments because memory is fundamental for acting in the world, and not simply for memories' sake (for related discussion see Wilson, 2002, p. 631).

The use of robotics places great demands on working memory because it makes it more difficult to off-load or reference elements in the immediate space. Instead, operators need to depend on the movement of the somewhat slower robot. In essence we are substituting the sensorimotor action of the Soldier for that of the robot. There are clear advantages to the situation, but there are also sensorimotor consequences for cognition and working memory that need to be understood and addressed in training (see Wilson, 2002, p. 633). The sampling of the visual space is much more labor intensive and time consuming with the robot. One cannot flick the eyes back and forth and must instead search the monitor. Obtaining the specific information available is more time consuming with a robot than with the human system. There is also the problem of coordinating reference frames, which can potentially create problems for memory of spatial location (Spencer, 2001) as well as descriptions of the spaces (Lipinski, Schneegans, Sandamirskaya, Spencer, & Schöner, 2012).

Spatial Cognition Issues for Training and Operation

One must consider the cognition of the Soldier as part of a transactional, dynamic system. The issues are readily obvious when looking at the challenges of orientation with the robot, such as going under vehicles. A Soldier physically inspecting a car is continually provided information about their orientation to the rest of the car, which is not the case with the robot, and therefore has major implications for training. Spatial cognition and sensorimotor processes also support off-line reasoning and problem-solving, so placing challenges on the systems by sensorimotor removal may also impact those abilities (see Wilson, 2002, p. 634). The cognitive problems tied to the Soldier are not solely internal to the Soldier but rather in the collective, interactive Soldier-robot system. The Soldier functions as an active interface between the leaders and the robot. The cognitive constraints of a Soldier impact the type and quality of the information available and provided to leaders.

One can manipulate space by moving objects into it or tag regions of space for later processing. When sensorimotor separation is introduce between the Soldier and the environment via the robot, reference frames are thrown off, they lose the ideothetic cues, and they risk disrupting their abilities to off-load information onto the environment via tagging. Rather than thinking “look over there again”, we may need to think “remember the yellow cone, the mound of towels, and the ambiguous object I cannot see clearly over there”. The reduced ability to off-load and tag increases the cognitive demands on the operator and impacts the thoroughness of the mission or task and communications (Robbins & Aydede, 2009). Once again, we see the advantage of having a good operator who can effortlessly manipulate the system—a reduced cognition demand. Teleoperations disrupts spatial cognition processes and makes it more difficult to use, view and manipulate the world (Brooks, 1991) and thus necessarily increases the representational demands on the operator. Instead, the operator must build their own internal representation and coordinate their reference frames. We know it is difficult (Brockmole, 2010; Wang, 2012). However, if the Soldier knows more about the goals and aims of leaders, they will be better able to meet leader needs. Everything requires effortful action: limited sensor capabilities, unknown places, spatial orientation and reference frames are off. Also, movement of the robot for climbing or inspection might add substantial load on the operator.

Recommendation #1

Due to limited cognitive capabilities and concentration, training needs to be enhanced and extended for the operator to focus on the things requiring additional attention. If everything is a struggle, including moving up and down stairs, or manipulating the robot chassis to get it into position, then the mission will take longer and will likely accomplish less because processing the situation will take longer and the whole experience will be demanding.

Recommendation #2

Due to the high cognitive demands and visual processing, alternating training and operations between pairs of operators may reduce overall stress. Most operators reported that after more than an hour operating a robot, they became fatigued and their eyes were strained. The robot has an extended battery life so it might be useful to have two operators who can switch off, communicate adequately and relieve each other.

Training Operators and Leaders to use Ground Robotic Assets

Effective trainers have the ability to impart knowledge and develop skills within a constrained period of time. Understanding the cognitive demands placed on the learner in the acquisition and execution of the relevant skill(s) is a critical component. The following recommendations outline the major concepts emerging from previous analysis of the SUGV simulated mission exercises that are most immediately relevant to training ground robotic system operators (Wampler et al., In Preparation), in addition to the present outcomes from the TAPS analysis. When operators are trained in these areas, the cognitive load diminishes and makes those resources available for other demands.

Recommendation #3

Due to the limits placed upon any situation, trainers should consider how to help the operator make the best use of available training and operating time. An operator must be able to know how long certain operations will take in order to ensure the highest priority actions are accomplished appropriately and within the allotted time. Just being able to conduct a thorough inspection is of little use if the inspection cannot be done to an acceptable standard within the established timeframe. The operator will need to know what “shortcuts” can be taken and when to speed task execution, what risks would be entailed with the shortcuts, and will need to ensure the leader understands the risks imposed with time constraints. An increased cognitive demand will generally slow task execution or at least hinder performance and therefore possible time-saving tradeoffs can be helpful. While constrained time is frequently an issue in accomplishing missions, the concept is NOT usually considered in operator training.

Recommendation #4

Due to the various capabilities of robotic systems, trainers need to train *when* it is appropriate to use those capabilities. There are a variety of cameras on the SUGV and other ground robots will likely have differing camera options. The operator must be trained as to which camera is appropriate to use under differing circumstances. A skilled photographer understands which camera and lens combination to use to obtain the desired picture. Likewise, as previously noted, much of the SUGV employment is situation dependent, and the situation (e.g., enemy threat, light conditions, intent of mission) should dictate which camera to use to accomplish the mission and not compromise the unit. As the mix and type of optics are changed, as well as the location and capabilities of the various cameras and optics are altered, operators will need to know the total system capabilities and under what circumstances to use each capability. Again, the trade-off between capability usages is NOT routinely covered in system operator training.

Recommendation #5

Due to the multiple functions, buttons, directional arrows, knobs, etc. on hand controllers, trainers need to train to a high level of understanding of the interface and buttonology. Some might simplistically equate this to operating a fork lift where multiple controls impact the speed and direction of the vehicle, as well as the elevation and angle of the forks, all of which affect the balance of the load being carried. The first core concept is that successful employment of a ground robot combines smooth physical control of the vehicle with accurate decision-making and interpretation of complex visual scenes. While operators will typically learn to physically operate the vehicle in a more automatic fashion with sufficient experience (as with driving a car), the early experiences will require substantial deliberate thought and effort. These mentally effortful operations may include remembering basic controller button functions, anticipating the consequences of a given movement and its impact on vehicle stability, and determining the best system configuration for a given maneuver (e.g., moving the head to balance the weight when descending stairs). Trainers should therefore give careful consideration to the operator's ability to physically manipulate the vehicle before attempting to train more mentally complex tasks such as those requiring complicated maneuvers, analysis of visual information, navigating through complex spaces, or the need to interact with the leader while operating the robot.

Recommendation #6

The visual scene interpretation and spatial orientation are more difficult when viewing a scene through the vehicle's cameras as opposed to direct eye view, and trainers must allow for the trainees to become adept in visually translating the observed 2D images into a 3D perception, which is similar to viewing objects at a distance through binoculars and attempting to estimate the range to the object or the size of the object. As previously discussed, when physically entering a room in person, Soldiers use visual and motor cues (e.g., peripheral vision, correspondence between physical movement and changes in the visual scene) to effortlessly interpret a scene and maintain spatial orientation. By contrast, such natural cues are largely eliminated when viewing the world through a camera.

Operators must therefore take deliberate steps to compensate for a decrease in information. For example, to better estimate the size and shape of a room, the operator must choose to rotate the vehicle or robot head to view the entire space. Such steps are unique to human-robot interaction and can substantially increase the mental demands placed on the operator. The need for such deliberate, compensating decisions must be understood and addressed through training to avoid compromised information gathering and to minimize cognitive loads.

Recommendation #7

With the current SUGV, the operator is the only person who can see the visual information coming from the sensors since the information is not shared through any network connection. Similarly, the same situation exists for many remote weapon stations that allow a person to shoot vehicle mounted weapon systems based on remote views through optics; there is no viewing by others since there is no network connection, and will likely to be the case for other ground robotic vehicles for the foreseeable future. Therefore, it is vital for the operator's experience and communication skills to meet the needs of the mission and leaders. There are at least three specific training and operational considerations. First, leaders may wish to take into consideration a Soldier's overall experience and ability to accurately assess a scene. More experienced Soldiers may be more likely to attend to relevant details and identify patterns of life relevant to leaders and decision makers. Second, leaders, trainers, and operators should work together to establish effective, efficient, and consistent methods of describing visual scenes in line with unit standing operating procedures. The absence of such methods may result in misleading or ambiguous scene descriptions and repeated clarifications which may slow operations. Even worse, without effective and accurate verbal communications, the leader might not gain the full appreciation of what the robotic operator is seeing and could make an ill-informed decision. Finally, communication with leaders during robotic operations places additional mental demands on the operator. Trainers should consider how communication with leaders impacts an operator's ability to operate the vehicle in the context of extremely challenging terrains, poor visibility, or increased time pressure.

Automaticity

Automaticity is valuable for two reasons. First, automaticity reduces the cognitive demands of a task, and increases the ability to attend, communicate, etc. Second, Wilson (2002) makes the point that automaticity allows for finer-grained control over a given action when additional control is required. For example, an experienced driver (highly automated skills) is more able to successfully navigate a tricky, new passage (p. 634). Limited skills in driving taxes a person's cognition, attention, and working memory. Additionally, disrupted reference frames and spatial cognition also impact cognition, attention, and working memory.

There is great value to experience. Experienced Soldiers will interpret scenes differently and use the vehicle to explore different aspects of the scene as a result of their knowledge. It is their prior experience with the system, as well as conducting missions in the situational environment that helps the operator determine what information is important to attend to, the resulting actions of the vehicle, and what is communicated. Information derived from experience is a dynamic construct rather than a static one. It does not mean all interpretations are valid or equal; it simply means operators are critical in the construction of information, not simply passive operators who cleanly pass information from the robot's optics to leaders. Experience also influences cognitive load because more experienced and skilled operators will have a higher degree of automaticity, thereby experiencing reduced load and stress. Simply put, repetition decreases cognitive load. People use what they know to shape what they do; all operators are not the same and not all are equal.

Recommendation #8

> Trainers need to ensure operators are well practiced. Operators need to have established routines for inspection and communications to insure they are thorough, they should not forget to investigate and reinvestigate areas, they should maintain an awareness of orientation and explicitly use reference points, and they should have established procedures of communicating to reduce any ambiguity resulting in an increased cognitive demand.

Conclusion

The operator will have the best chance of doing their job well if the lower level skills such as buttonology and subgoal formation are practiced enough to approach automaticity and therefore will free-up cognitive resources so the operator can perform other tasks (e.g., camera information interpretation, communication) with more cognitive resources available. In addition, training materials can be improved, and better training exercises developed, if a careful task analysis is conducted to identify what the operator needs to know (see Wampler, et al., In Preparation). The current robotic systems are going to mature and provide more capabilities, such as the addition of real-time auditory processing. The question remains, will the new capabilities add or reduce load upon the operator? Further, some of the recommendations herein may add light to the way in which operators are selected for these positions. Perhaps the operators of the robotic systems need to team up and distribute the high cognitive loads similar to the way ATCs team up. As our military components begin to reduce the number of forces in harm's way, it would be appropriate to take advantage of the opportunity to increase training efforts across all robotic platforms. In addition to using the information to determine training requirements and to influence the development of training programs, designers of robotic technologies to be operated by Soldiers would do well to consider the many cognitive impacts upon performance. If system functions and capabilities could be designed to accomplish some of the existing tasks, or provide aids to the operator in performing the tasks, the integration of these enhancements could lead to a more successful Soldier-robot system.

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