THE IMPACT OF MENTAL TRANSFORMATION TRAINING ACROSS LEVELS OF AUTOMATION ON SPATIAL AWARENESS IN HUMAN-ROBOT INTERACTION

by

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ABSTRACT

One of the problems affecting robot operators' spatial awareness involves their ability to infer a robot's location based on the views from on-board cameras and other electro-optic systems. To understand the vehicle's location, operators typically need to translate images from a vehicle's camera into some other coordinates, such as a location on a map. This translation requires operators to relate the view by mentally rotating it along a number of axes, a task that is both attention-demanding and workload-intensive, and one that is likely affected by individual differences in operator spatial abilities.

Because building and maintaining spatial awareness is attention-demanding and workload-intensive, any variable that changes operator workload and attention should be investigated for its effects on operator spatial awareness. One of these variables is the use of automation (i.e., assigning functions to the robot). According to Malleable Attentional Resource Theory (MART), variation in workload across levels of automation affects an operator's attentional capacity to process critical cues like those that enable an operator to understand the robot's past, current, and future location.

The study reported here focused on performance aspects of human-robot interaction involving ground robots (i.e., unmanned ground vehicles, or UGVs) during reconnaissance tasks. In particular, this study examined how differences in operator spatial ability and in operator workload and attention interacted to affect spatial awareness during human-robot interaction (HRI). Operator spatial abilities were systematically manipulated through the use of mental transformation training. Additionally, operator workload and attention were manipulated via the use of three different levels of automation (i.e., manual control, decision support, and full automation). Operator spatial awareness was measured by the size of errors made by the operators, when they were tasked to infer the robot's location from on-board camera views at three different points in a sequence of robot movements through a simulated military operation in urban terrain (MOUT) environment.

The results showed that mental transformation training increased two areas of spatial ability, namely mental rotation and spatial visualization. Further, spatial ability in these two areas predicted performance in vehicle localization during the reconnaissance task. Finally, assistive automation showed a benefit with respect to operator workload, situation awareness, and subsequently performance. Together, the results of the study have implications with respect to the design of robots, function allocation between robots and operators, and training for spatial ability. Future research should investigate the interactive effects on operator spatial awareness of spatial ability, spatial ability training, and other variables affecting operator workload and attention.

This is dedicated to pre-stroke Sherri Rehfeld. Prior to November 13, 2005, Sherri did an excellent job of working toward her Ph.D. She graduated college magna cum laude, completed her Master's Degree in Cognitive Psychology and discovered all that is Human Factors. She worked feverishly toward her goal of a Ph.D. and organized herself in a way that would not allow for the possibility of not achieving this goal. After proposing her dissertation in October of 2005, she created a pathway to success. Upon having a transient ischemic attack on the first day of data collection and a full-blown stroke two days later, post-stroke Sherri (me) found it easy to follow the path that was so organized and laid out with forethought and care. I owe her so much.

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CHAPTER 1: INTRODUCTION

Whether designed to entertain, increase productivity, or protect human health, the use of robots has significantly increased recently, and their use is projected to further increase within the next decade and beyond (National Defense Authorization Act, 2001; U.N. & I.F.R.R., 2002). A recent wave of research and development has focused on the design and implementation of robotic vehicles, particularly aerial and ground-borne remotely operated vehicles. Several types of robotic vehicles are currently being used to assist in search-and-rescue (SAR) operations (as with the aftermath of hurricane Katrina), in resolving hostage situations, and, within the military domain, in missions such as explosive ordnance disposal (EOD; i.e., bomb de-fusing), sentry duty, and reconnaissance (Gage, 1995). In the not-too-distant future, more autonomous forms of robotic missions are anticipated, in part, because of the 2001 Congressional mandate that 30% of the military be unmanned ground vehicles by the year 2015 (National Defense Authorization Act, 2001).

For the purposes of the current study, an unmanned ground vehicle (UGV) was defined as a ground-borne, robotic vehicle that can traverse ground terrain, at varying levels of autonomy (including teleoperation, supervisory control, or full autonomy, each of which will be discussed in detail below). In general, UGVs are not primarily used for human transportation; rather, they are designed to complete difficult or dangerous tasks in place of humans and for the security of humans (Burke & Murphy, 2004; Gage, 1995; Hinds, Roberts, & Jones, 2004; Young et al, 1999).

Specifically, UGVs can be used for purposes that vary from such stealthy procedures as battlefield reconnaissance or information collection during hostage situations, to determining from a remote location if unknown objects are explosive. For example, with respect to explosives, soldiers can maneuver a UGV to investigate a suspicious object from afar (Williams, 2005). Testing the weight by pushing an object can give clues as to the probability that an object is dangerous. If an object is light and moves easily, then it is most likely harmless. However, if an object is heavy (or explodes), then it may be (or was) dangerous. The use of UGVs in missions such as reconnaissance missions or hostage situations might require more attention of operators because travel distances might be longer, targets might be harder to detect, and the need to remain undetected might call for increased precision. Because of the increasing importance of UGVs for military and civilian missions, it is vital to investigate the possible human performance difficulties involved in operating UGVs and collecting reliable data from their deployment.

Problem Statement

Indeed, concurrent with the technical improvements and the increased uses of ground-based robots, scientists and engineers have begun to study a number of problems in the area of Human-Robot Interaction (HRI). One of the key problems in HRI, and specifically in the operation of UGVs, is an operator's ability to achieve and maintain spatial and situational awareness during a UGV mission. It was reported recently that operators have great difficulties in interpreting and translating the cues about a robot's environment into an accurate representation of the robot's location including where its sensors are pointing (Chadwick, 2005; Rehfeld, Jentsch, Curtis, & Fincannon, 2005). The research indicates that even when provided with rich visual and topographical cues, UGV robot operators frequently become lost, turn the wrong way, or report incorrect coordinates for their observations.

This problem is similar to problems in other environments where operators perform remote manipulations, such as in laparoscopic surgery, remote maintenance inspection, undersea mine clearing, etc. In all these environments, operators have to take limited, largely egocentrically generated cue sets and translate them into a correct representation of location and orientation in a different, frequently exocentric, reference frame. Consequently, research findings that might enhance a UGV operator's ability to achieve and maintain spatial and situational awareness, by facilitating mental transformations of images, would be useful across many domains.

Problem 1: Influence of Automation

Because building and maintaining spatial awareness is attention-demanding and workload-intensive, any variable that changes operator workload and attention should be investigated for its effects on operator spatial awareness. One of these variables is the use of automation (i.e., assigning functions to the robot). Prior research has shown that varying the types and levels of automation in systems not only affects an operator's workload, but also changes his/her attentional capacity to process critical cues for achieving and maintaining spatial and situational awareness. However, while changes in automation have been associated with changes in spatial and situation awareness, the direction and magnitude of these changes are currently unclear. According to one line of research, increased levels of automation and autonomy lead to “human-out-of-the-loop” (OOTL) problems wherein operators that were less involved in actual task performance had greater difficulty achieving and maintaining situation awareness (Endsley & Kiris, 1995). Conversely, another line of research seems to support the notion that reduced workload due to improvements in automation should, and actually does, improve spatial and situation awareness (L. Allender, personal communication, August 18, 2005). Clearly, these two lines of research support conflicting interpretations and implications, and further research is required in this area.

Problem 2: Translating Views

The key issue that affects an operator’s understanding of a remote robot’s location involves the operator’s ability to translate cue sets (such as an image from a vehicle’s camera) from one coordinate system and perspective (i.e., the machine’s egocentric view) into another coordinate system and perspective, such as a location on a map (i.e., an exocentric representation). Specifically, an operator needs to be able to relate the cue sets in an egocentric view by (a) capturing the perspectives of the cue sets, (b) mentally rotating them along a number of axes in order to translate them into a different coordinate system, and then (c) matching the coordinate systems’ reference points to translate the coordinates. For example, in the teleoperation of bomb disposal robots, the side view of a car or building from a vehicle-mounted camera needs to be mentally rotated to a top-down view of the car or building, as it would be depicted on a map. Clearly, conducting these mental transformations is a task that is both attention-demanding and workload-intensive, and one that is likely affected by individual differences in operator spatial abilities. Consequently, it is not surprising that research has repeatedly shown that determining and tracking a vehicle's current location remains difficult even in situations where plan view displays (such as map views and situation displays) are provided in addition to egocentric camera views (Chadwick, 2005; Yanco, Drury, & Scholtz, 2004).

Problem Summary

To address these issues, the study reported here focused on the performance aspects of human-robot interaction involving UGVs during reconnaissance tasks. In particular, Malleable Attentional Resource Theory (MART; Young & Stanton, 2002a) was used to demonstrate how changes in system automation and autonomy affect the attentional demands in operators during UGV operations. Further, this study investigated how changes in an operator's critical skill in mental transformation and rotation interacted with system automation and autonomy to influence attentional capacities, workload, and task performance. It was expected that the level of automation of the control task, as well as an operator's ability to mentally manipulate the available view, would have consequences for situation awareness and task accuracy.

In particular, this study examined how differences in operator spatial ability and in operator workload and attention interacted to affect spatial awareness during human-robot interaction (HRI). Operator spatial awareness was measured by the errors made by the operators, when they were tasked to infer the robot's location from on-board camera views at three different points in a sequence of robot movements through simulated military operations in urban terrain (MOUT) environment.

Operator spatial abilities were systematically manipulated through the use of mental transformation training. Mental transformation training was expected to decrease workload by increasing the automaticity of mental transformation (aspects of which include spatial orientation, spatial visualization, & mental rotation) and, therefore, to increase situation awareness and task accuracy as subjective and objective measures of human performance, respectively.

Additionally, operator workload and attention were manipulated via the use of three different levels of automation (i.e., manual control, decision support, and full automation). It was expected that by reducing mental workload, mental transformation training would have the greatest impact on spatial awareness during high workload conditions (i.e., under manual control). In contrast, it was expected that mental transformation training would not be as effective and efficacious under lower workload conditions, such as with moderate or full automation.

CHAPTER 2: MALLEABLE ATTENTIONAL RESOURCE THEORY (MART)

This section discusses Malleable Attentional Resource Theory (MART; Young & Stanton , 2002a), as it applies to the current research. This theory was considered important in facilitating the explanation and prediction of potential outcomes resulting from the interaction of UGV automation and operator spatial abilities.

Introduction of the Theory

Malleable Attentional Resource Theory (MART) is a relatively new perspective that posits a curvilinear relationship between attentional capacity and mental workload (Young & Stanton, 2002a). MART was created in response to the multitude of theories to explain existing performance problems associated with increased levels of automation. Young and Stanton depicted various current theories (such as trust and vigilance) as situation-specific but not generalizable across situations involving automation. Many of the theories include a common component of mental workload and the need to understand the effects of automation on mental workload. For example, when assessing mental workload with subjective (e.g., NASA-TLX, SWAT) and objective (e.g., task performance, ECG) measures, it seems logical to expect performance errors when mental workload is high. However, it has been found that significantly reducing mental workload by using full automation also produces errors and performance problems, such as the human out-of-the-loop performance problem (see for example, Brookhuis & Waard, 2001).

The Human Out-of-the-Loop (OOTL) Performance Problem

Research in the field of automation (Endsley & Kaber, 1999; Kaber & Endsley, 2004; Kaber, Onal, & Endsley, 2000; Kessel & Wickens, 1982) discovered that increases in the level of automation for complex cognitive tasks did not necessarily enhance performance or situation awareness, or indeed have any positive effects on workload (Endsley & Kiris, 1995). The OOTL performance problem is most obvious during an automation failure, when a human must assume manual control in order to complete a task. In responding to such situations, people tend to respond slower, take longer to understand how to fix a problem, and make more errors with increasingly higher levels of automation (Kaber & Endsley, 2004).

Introducing automation in order to reduce workload and, hence, increase performance, seems to work only to a certain extent. The surprising finding that relatively poor human performance occurs under conditions of both low workload and high workload leads one to wonder how this is possible and what mechanisms contribute to this paradox. The main features of MART address this seemingly illogical phenomenon across automation situations.

MART Features

Two defining characteristics of MART include (a) the flexibility of attentional capacity and (b) the moderation of attentional capacity by mental workload (Young & Stanton, 2002a). Young and Stanton acknowledged strengths and weaknesses of both single and multiple resource theories of attention as applied to single task (single resource) and dual task (multiple resource) differences. They noted, however, that both theories assume attentional capacity to be at a fixed and constant level. This leads to the first defining aspect of MART; namely, the flexibility or malleability of attentional capacity.

The focal premise of MART is that human attentional capacity is dynamic and malleable. In contrast to other theoretical conceptualizations, Young and Stanton (2002a) claimed that attentional capacity expands and contracts as a function of the level of mental workload. They argued that this contention was supported by existing human performance problems, such as the OOTL problem (Endsley & Kiris, 1995) and the vigilance decrement (Matthews, Davies, & Holley, 1993), as well as by their subsequent research findings (Young & Stanton, 2002b). The MART concept suggests that flexible attentional capacity can, and does, change in response to task requirements that produce different levels of mental workload. This leads to the second defining aspect of MART, the relationship between attentional capacity and mental workload.

Young and Stanton (2002a) compared the effect of mental workload on attentional capacity to the Yerkes-Dodson (1908) classic representation of the inverted-U relationship between arousal and performance. For instance, given a relatively easy or low workload task, attentional capacity is reduced to meet the needs of a task. This low attentional capacity can be a disadvantage if an unexpected change occurs in a system. Under reduced attentional capacity, an operator is not prepared to respond to operational changes or new situations, resulting in errors at low workload. Conversely, given a relatively difficult or high workload task, attentional capacity is expanded, but stretched thin across the relatively high task demands. Again, errors are likely to occur if an unanticipated change occurs in a system while attentional capacity is insufficient to provide attention to all task requirements. MART, therefore, suggests that an optimal level of mental workload is required in order for adequate attentional capacity to result in satisfactory performance.

MART provides a comparatively parsimonious explanation of performance and resulting performance problems, as mental workload varies across levels of automation. Thus, MART was used as the theoretical basis for human performance in the current study. The next two sections address the two key problems with HRI; namely, the influence of automation and the problems of translating views.

CHAPTER 3: LEVELS OF AUTOMATION

Among the questions raised regarding a framework for human-robot interaction, Thrun (2004) broached the issue of automation and the resulting effects of autonomy on the interaction of a robot with a human and vice versa. He noted that level of automation depends on the type of robot in use as well as the type of communication between the human and the robot. Given that the communication between an operator and an egocentrically operated UGV is via camera feed for remote operations, there are three general methods for robot control: teleoperation, autonomous operation, and supervisory control (Gage, 1995). *Teleoperation* of a UGV is accomplished by an operator navigating with a direct, dynamic, radio controlled system. Fully *autonomous* UGVs have a preprogrammed goal and control their own course via onboard sensory equipment without input from a human during operation. Finally, *supervisory control* can be any type of automation format, with levels of control varying between full teleoperation and full automation. These three methods for controlling a UGV as they relate to the current study are described subsequently using Endsley and Kaber's (1999) levels of automation taxonomy (refer to Table 1).

Table 1. *Relation between UGV Control and Level of Automation (Endsley & Kaber, 1999)*

Level of UGV Control	Level of Automation
Full teleoperation	Manual control
Supervisory control	Decision support
Fully autonomous	Full automation

Manual control is the lowest level of automation in which an operator is required to provide the highest level of full and direct control over a UGV, specifically through teleoperation. Under manual control, an operator is fully engaged in the cognitive and manual performance requirements that are necessary for operation of the robot. In this situation, an operator would monitor the status of a UGV (e.g., fuel, traction, machination, etc.), make decisions regarding a path and operational plan of a UGV, and execute those plans physically. Conversely, the robot only responds to the operator's input and provides feedback as required.

Decision support incorporates an intermediate level of automation in which a UGV provides assisted decision-making such as offering a selection of routes from which an operator may choose or give the operator the opportunity to create a different path. Once an operator has made all operational decisions, a UGV would then execute the choices with intervention or guidance from an operator as necessary. Thus, in this situation, an operator engages in supervisory control, performing as a teammate of the partially intelligent and autonomous robot.

Finally, *full automation* does not require operator involvement in any stage of the operation of the robot. All decision-making and task execution is under the fully autonomous control of the UGV. The role of the operator in this situation is simply to monitor the robot's operation and to intervene as necessary in emergency or other designated conditions.

Application of MART to Levels of Automation

When applied to human-robot interaction with MART as a guide, it is clear that the level of automation might have a large impact on task success. Under conditions of manual control, the operator must focus on the operation and performance of the UGV in addition to the accomplishment of the assigned mission of the robot. Thus, while planning and controlling the movement of a robot along a chosen path, an operator might also be required to monitor the terrain and the UGV's surroundings for signs of possible hostile action. These performance requirements place very high workload demands on the operator. This maximization of workload limits the operator's ability to deal with all aspects of task performance, because the available attentional capacity is insufficient to meet the demands of the task. Fortunately, advancements in technology, such as Global Positioning Systems (GPS) and automation, might soon make this unnecessary. The use of either decision support or full automation would allow an operator to concentrate on the overall mission task rather than focusing on the operation of the UGV, thereby reducing mental workload. However, as explained by MART and demonstrated by previous research (vigilance, OOTL, trust, etc.), a severe reduction of workload also reduces attentional capacity, resulting in impaired task performance. While increasing the level of automation (decision support or full automation) would also reduce the use of radio frequencies that may be detrimental (e.g., radio waves could be used by enemy forces to locate a UGV or base station), operator performance might suffer from the introduction of full robot automation. Accordingly, the following hypotheses are proposed:

Hypothesis 1a: When participants operate under conditions of manual control, performance should be relatively low. The manual control condition requires participants to focus on the navigation of a UGV as well as the main task (reporting UGV location), creating a situation with high mental workload and strained attentional capacity.

Hypothesis 1b: When participants operate with decision support, performance should be high, relative to the other automation conditions. Decision support allows an operator to be active in the operation of a UGV with the benefit of automation to complete the physical task of controlling the vehicle.

Hypothesis 1c: When participants operate with full automation, performance should be relatively low. The lack of vehicle control should directly affect awareness of the environment due to the low level of involvement and significant reduction in mental workload.

CHAPTER 4: MENTAL TRANSFORMATION

Background

Processes required to mentally transform a side view of an environment into the representation of a location on a map include, among others, mental rotation (MR). MR is a type of spatial ability that involves being able to picture an image in one's mind and rotate the image in order to establish how it would appear from a different perspective (Reisberg, 1997). For example, in a typical mental rotation task, a person might be presented with two images and asked to mentally rotate one of the images and compare it to the second image in order to determine if the two are similar, different, or mirror objects. Such a task might require the individual to mentally rotate one or both of the images along the X, Y, Z, or a combination of the three axes in order to achieve the desired perspectives necessary for task solution.

Three general factors have been shown to be related to performance in mental rotation tasks: (a) time available for rotation, (b) natural individual differences (e.g., gender, age, and lateralization of function), and (c) learned individual differences such as experience or training. Each of these factors is discussed in turn.

Time

The amount of available time is an important factor in mental rotations because when more rotation is necessary, more time is needed to accomplish a mental rotation task (Shepard & Metzler, 1971). Therefore, the greater difference in angle between two objects, the more time that is necessary to complete a mental rotation. Previous research has shown that mental rotation is involved with navigation and map reading to determine location on a map (Aretz & Wickens, 1992). Therefore, in order to translate a camera view into map coordinates, two mental rotations are required; a mental rotation of 90° from a camera view to a top-down view reflective of a map viewpoint, and rotation from that top-down view to match the perspective of an image presented in a map (see Figure 1). The first rotation is a constant 90° rotation, but a second rotation may change depending upon an angle of a view and the angle of a map. In the current study, the angles of rotation degree were controlled and kept constant across participants and conditions. In addition, the amount of time to complete a mission was not limited.

Figure 1. *Mental translation from a front view of a camera to a top view.*

Natural Individual Differences

One of the more important factors that might influence an interaction between a person and a UGV involves *individual differences*. Individual differences are natural/innate (e.g., age, gender) or learned (e.g., athletic ability, multilingual) differences of abilities between people. The subject of natural individual differences has produced much research in the field of spatial ability. It is generally accepted that young and middle aged adults show better performance with mental rotation tasks than children or older adults (Lin, Zhang, & Zhan, 2002) and that spatial ability tasks predominantly involve the right-hemisphere (Rilea, Roskos-Ewoldsen, & Boles, 2004). Gender differences in spatial ability, however, are a hotly debated topic. Until recently, researchers have found a robust effect showing that males tend to outperform females in most spatial ability tasks (Coluccia & Louse, 2004; McGee, 1978; Peters, 2005). To determine why a gender difference exists, research has delved into the possibility that strategies might differ (Bosco, Longoni, & Vecchi, 2004), the focus on speed or accuracy might differ (Scali, Brownlow, & Hicks, 2000), or performance differences might be mediated by the hormone testosterone (Bell & Saucier, 2004; Hooven, Chabris, Ellison, & Kosslyn, 2004).

These findings are relevant to the present study in that operating a UGV can be described as a type of spatial task. An operator is required to understand past, current, and future locations as well as the position of a UGV relative to other objects. Although determining the effects of natural individual differences is beyond the scope of the current research, biographical data acquired prior to the start of the study allowed for randomization of individual differences, such as gender and age, within and between conditions.

Learned Individual Differences

One example of a learned individual difference is someone who has experience with first-person video games and/or radio-controlled vehicles. Persons with this kind of experience would have more knowledge of vehicle controls and how a vehicle might respond to input and, therefore, might outperform people without this prior experience. In addition, research supports a link between video game playing and spatial ability, showing that playing video games improve performance on spatial ability tests (Cherney & Neff, 2004; Subrahmanyam & Greenfield, 1994). In the current study, biographical data were obtained prior to random assignment into conditions to control for learned individual differences, such as through experience with video games and remote controlled vehicles.

Mental Transformation Training

A program of mental transformation training developed for this study was used to manipulate spatial abilities in the area of mental transformation. Training can be, and has been, used to learn, maintain, and improve spatial abilities such as mental rotation (De Lisi & Wolford, 2002; Gluck, Machat, Jiraski, & Rollett, 2002; Kass, Ahlers, & Dugger, 1998). However, much of the research that has explored mental rotation performance has followed the original Shepard and Metzler (1971) study by using abstract, three-dimensional, connected blocks with at least three right angles for each of the three planes, constructed to be an unfamiliar object. It has been argued that the unfamiliar nature of abstract objects places greater demand on the ability to mentally picture an abstract object, rotate the object, and picture the object again in a different perspective (Kass, Ahlers, & Dugger, 1998; Willis & Schaie, 1988).

Accordingly, recent approaches to mental rotation training have attempted to remove either the unfamiliarity or abstract nature of the object that must be mentally rotated. For instance, success has been shown when training with a familiar or concrete object such as aircraft (Ashworth & Dror, 2000) or ships (Kass, Ahlers, & Dugger, 1998). Likewise, the unfamiliarity of objects might also be reduced through procedures such as training activities involving detailed explanations about mental rotation (Willis & Schaie, 1998), practicing the skill (De Lisi & Wolford, 2002), or possibly a combination of both techniques. Prior researchers (Kass, Ahlers, & Dugger, 1998; Willis & Schaie, 1988) have proposed that an abstract, pencil and paper mental rotation measure produces results that are different from real-world mental rotation situations. This research suggests that removing the abstract nature of the measure, whether via training or the measure itself, increases rotation accuracy of those with low mental rotation skills.

Research that uses concrete, recognizable objects and/or training techniques to increase mental rotation ability shows promise for UGV operation. Current robotic research has shown that operators of remote UGVs during Military Operations in Urban Terrain (MOUT; Chadwick, 2005; Rehfeld et al., 2005) scenarios and during a search and rescue competition (Yanco, Drury, & Scholtz, 2004) had difficulty translating a location viewed through a UGV's camera to the correct location on a map. It is highly improbable that all of these operators were unable to mentally rotate a front view from a camera to a top view of a map (i.e., Figure 1) exclusively due to poor mental rotation abilities. Rather, it is possible that their mental rotation ability was hampered by the operator's general lack of awareness of their surroundings. Recent research (Yanco, Drury, & Scholtz, 2004) recognizes the need to increase situation awareness by making operators more aware of the UGV's environment. This lack of awareness may be due to a high level of workload or to the narrowing of focus to the operation of a vehicle itself.

To address this two-factor possibility, one of the aims of the current project was to test the efficacy of mental transformation training with concrete, recognizable objects. By presenting a side view that moved to a top down view and then placing the top down view in a map where it was represented and shown as coordinates, a realistic conversion was created that related to mental transformation (Deutsch, Bourbon, Papanicolaou, & Eisenberg, 1988). This was especially important as Deutsch et al. (1988) showed that blood flow in the brain during mental rotation matched the pattern of flow that occurred during the actual motor manipulation of an object. Training mental transformation in a realistic setting, allows the participant to learn what a top-down perspective would look like given a side view, therefore translating a camera view to a map view. Therefore, the following hypothesis was proposed:

Hypothesis 2: Participants who received mental transformation training with concrete recognizable objects from a realistic environment would perform at a higher level than participants who did not receive mental transformation training.

Application of MART with Training and Automation

The main purpose of the specific training employed here was to manipulate operator spatial abilities. The training was intended to simplify the required mental transformation activity, to enhance skill acquisition, and to increase automaticity of the skill (Swezey & Llaneras, 1997). Thus, the training sought to increase the automaticity of mentally transforming the camera view to match the map view, thereby resulting in a reduction of workload for the operators. Considering that mental workload decreases with the addition of automation, it was expected that the reduction of workload would be greatest and have the most impact in the manual condition (with the highest level of workload). As explained by MART, the addition of automation to reduce workload does not necessarily enhance performance as attentional capacity is reduced with task demands. Therefore, the benefits of the mental transformation training would be lessened with the addition of automation. Consequently, the following hypothesis was proposed:

Hypothesis 3: The simple effect within the manual control condition (performance difference between the participants who receive training and who do not receive training) should be significant whereas the simple effect of training at the other levels of automation should not.

It is important to note that while mental transformation and level of automation are key problems, they are not the only factors influencing HRI. An array of factors that also affect HRI are discussed next.

CHAPTER 5: MITIGATING FACTORS AFFECTING HUMAN-ROBOT INTERACTION

A number of additional factors could also be expected to affect human-robot interactions. For example, the characteristics of the task, including the characteristics of the robot, and its human operator, likely influence the nature of the human-robot interaction. For the purposes of this study, the factors reviewed subsequently are particular to the task conditions involved in a search and rescue or military reconnaissance mission. This type of task requires an operator to operate a vehicle remotely with a camera feed. This task also necessitates that an operator understand the environment surrounding a UGV.

Table 2 displays a selection of the most relevant factors that might affect human-robot interaction, and the operation of UGVs, in particular. For the purposes of this study, these factors were controlled, randomized, or manipulated and measured, as displayed in the table. Each of the factors is discussed in turn with controlled or randomized factors discussed first, and manipulated and measured factors discussed next.

Table 2. *Factors Influencing Human-Robot Interaction*

Factor	Action of Current Study
Task Characteristics	
Vehicle characteristics	All controlled
Type (air, ground, water)	
Terrain	All controlled
Barriers	
Location in Terrain	
Military Operations in Urban Terrain	
Quality of ground terrain	
Simulated, realistic scale, real	
Map characteristics	All controlled
Type of map	
Accuracy of map	
Visual display	All controlled
Color	
Perspective	
Signal clarity	
Time of day	
Weather	
Human/Operator Characteristics	
Map Reading and Navigation	Randomized

Task Characteristics

The task characteristics discussed here were factors that needed to be considered, in general, for an operator of any type of remotely controlled vehicle and considered, in particular, with regard to the reconnaissance task with a UGV that was used in the current study. These factors included the type of vehicle to be used, state of the environment or terrain, type and accuracy of the map representing the terrain, and available technology to accomplish this task given an operator who was not located within a vehicle, or co-located with the vehicle.

Vehicle Characteristics

The type of vehicle and the vehicle's characteristics play a large part in the performance and success of UGV operation. The type of vehicle may affect task performance and awareness of the environment, depending on a vehicle's features. For instance, an unmanned underwater vehicle may not have a clear view of distant objects, whereas an unmanned ground vehicle will have a better view, and an unmanned air vehicle may have the best distance view. In addition, both underwater and air vehicles operate in three axes (forward-backward, side-to-side, up-down) while a ground vehicle only operates in two (forward-backward, side-to-side). This illustrates the problem at hand; when identifying coordinates of a vehicle's position, an operator of a flying vehicle views the ground from above and makes *at most* one mental transformation to match the top-down view to that of a map. Conversely, an operator of a ground or underwater vehicle, however, must make *at least* one mental transformation of a front view to a top-down view and then, if necessary, transform again to match the top-down view of a map. This need for further mental transformations for ground and underwater vehicles creates additional opportunities for confusion and errors.

Lastly, the actual operation of a particular unmanned vehicle may require specific and/or longer training than another, given each vehicle's complexities and level of automation. For instance, significantly more people have experience driving a ground vehicle (e.g., car, truck, etc.) than flying a plane or controlling a submarine. Therefore, learning to operate a remote ground vehicle would be much shorter and easier than learning about and controlling an underwater or air vehicle. Hence, a UGV is the most practical vehicle to use for the current study.

Terrain

As previously suggested when discussing vehicle types, terrain can also impact the successful interaction of a human and robot. Although research devoted to algorithms for automated robots to navigate through various landscapes exists (e.g., Rao, Nageswara, & Iyengar, 1990), research regarding the ability of a human operator to do the same with a radio-controlled vehicle is not as abundant (Yanco, Drury, & Scholtz; 2004). It is logical to assume that navigation with smooth terrain is easier than through rough or uneven terrain (as supported by the need for advanced algorithms with automated robots). Likewise, open terrain is easier to navigate than terrain with many obstacles such as trees, rocks, as well as buildings and other vehicles, which add complexity to the environment with additional visual obstructions. Use of a ground vehicle can be more problematic than an air or underwater vehicle. An air vehicle has few visual obstructions (e.g., clouds, foliage) and an underwater vehicle has the ability to float over or around most obstructions (e.g., coral, reefs). A ground vehicle, however, cannot traverse over obstructions in the environment and must attempt to maneuver around an obstacle. In addition, the complexity of the environment may either hinder the process of mental rotation such as visual cues not represented in a map (e.g., vehicles, temporary objects) or assist the process with unique visual cues (e.g., a fountain, obvious landmark). These limitations add unique terrain difficulty and complexity not only to the progress of a vehicle, but also the accomplishment of a mission task.

The actual driving task given to an operator, in itself, may also influence the successful operation of a robot. Task difficulty may include such features as number and difficulty level of barriers to overcome, distance that needs to be traveled from the base of operations, and location of target(s) in the terrain (e.g., beyond hills, behind buildings, etc.). Not only can an operation itself be objectively difficult, but perceived task difficulty (e.g., perceived mental workload) also increases depending upon task characteristics such as terrain difficulty and distance traveled (Schipani, 2003). Manipulation of task difficulty is beyond the focus of the current investigation; thus, task characteristics were kept constant across tasks, conditions, and participants, at a moderate level of difficulty. In addition, perceived mental workload levels were measured as a manipulation check to verify that the tasks are equivalent in all experimental conditions.

It is also important to consider that many military engagements, such as those in Mogadishu during *Operation Restore Hope* and the attack on the 507th Maintenance Company in An-Nasariyah during *Operation Iraqi Freedom*, occur within urbanized terrain. Therefore, the focus of operation for UGVs in the current study paralleled these engagement areas with paved streets, buildings, vehicles, in addition to some suburban areas and rural farmland. The chosen research setting included linear motion (via paved routes) and environmental complexities, with partial and full obstructions (e.g., buildings, vehicles, and foliage), that are typical of most urban terrain.

Operation of a UGV in this type of terrain can be studied in various ways including full simulation, the use of realistic scale models, or full-scale realism. However, the use of a synthetic environment via full simulation can be problematic in several ways. Such work is expensive and time consuming, especially if software needs to be created or commercial software altered to reflect a realistic scenario. In addition, participants in full simulations also tend to drive faster and collide with objects more often than in a realistic environment (Kamsickas, Foss, & De Mattia, 2003). It is essential to extend a level of realism in order to reflect accurate human performance and interaction with a UGV, hence, a level of caution included with realism is necessary. Consequently, this study used a practical, 1:35th scaled model layout equivalent to 250 m x 180 m that created a sense of realism when controlling an unmanned ground vehicle.

Map Characteristics

Other factors that were hypothesized to affect the success of human-robot interaction included the quality and quantity of equipment, such as maps, available to an operator. Maps need to be legible and relatively uncluttered, with position and orientation (if electronic) representations as key components of the map display (Wickens, Gordon, & Liu, 1997). Whereas an up-to-date, electronic, dynamic, north-up map would be most advantageous, the availability and technical or pragmatic limitations, such as availability of screen real estate and portability, may prevent or limit their use. A paper printed satellite mosaic map was used in the current study as they provide portability and do not require use of an additional monitor, screen, or other electronic equipment. Consequently, the same map was used in all conditions of the study.

Visual Display

The ability of an operator to navigate a vehicle may depend upon the perspective that a person has during operation, which may be either egocentric or exocentric. Whereas *egocentric* refers to an operator's viewpoint from inside an actual vehicle, *exocentric* refers to the view of a vehicle and terrain as seen from outside of a vehicle. The original use for operating a radio-controlled vehicle (i.e., recreation) was for people to operate while a vehicle was in full or partial view (exocentric view). Having full view of a vehicle and terrain allowed for easy decisions regarding the route that a vehicle would traverse. An operator could anticipate difficult terrain and adjust controls to negotiate the landscape successfully, requiring continual mental transformations from hand to vehicle movements. This is particularly important given that the environment for operating a UGV may be treacherous whether it may be the terrain or a mission environment in general.

The intuitive advantage of environmental awareness with an exocentric view was supported by research with aircraft navigation displays (Wickens & Prevett, 1995). Wickens and Prevett showed that exocentric viewpoints aids an operator's understanding of the general environment as well as the location of the vehicle in reference to other objects; whereas egocentric viewpoints assist in the task of navigating a route or path. Therefore, having only one viewpoint necessitates that an operator compensate for the lack of information that the other viewpoint would provide so that both the navigation is accurate and situation awareness is adequately maintained. Currently, teleoperation of a UGV involves an egocentric viewpoint, which is a limited view offered by a camera mounted on the vehicle and requires the operator to translate the camera view into a full understanding of the environment. Although this allows an operator to navigate a path easier than an exocentric viewpoint, it limits the ability of an operator to maintain full awareness of the environment, potentially negatively affecting an operator's situation awareness.

The type of visual display, via camera feed from a UGV to an operator, can influence navigation, and ultimately the success of a task. For instance, the use of color is important in a search or recognition task (tasks most often performed when operating a

UGV); therefore, a visual display would require color to differentiate objects in the environment. Similarly, time of day would affect the clarity of a display. Nighttime operations might require infrared technology, yet using infrared would change the color aspect of the surroundings in ways that would not reflect the true colors of the environment. The current study is such that use of this technology is a step or two beyond the area of focus. This also applies to the possibility of conducting a task during inclement weather and/or the occurrence of signal problems. Therefore, for the purposes of this study, all conditions employed full color during daytime, in fair weather, and with a full-strength signal. These conditions allowed for the clearest view so that a more accurate mental rotation was achieved from the camera view.

Summary

The type and characteristics of the task is one of the main factors that affect operation of a robot by an operator. Each of the major and minor factors of the task that can assist or impede in the operation of a robot needs to be considered for any study, and the specific impact on the variables in the current study. In the current study, all of these factors were controlled for, randomized, or held constant across conditions. The other main factor that needed to be considered in human-robot interaction related to the characteristics of the operator of a system, a topic that is discussed next.

Human/Operator Characteristics

A search or reconnaissance task with a UGV (such as the task to be employed in the current research) requires a human to understand how to operate a UGV and to interpret information provided through a display of a UGV. As previously discussed, the use of a ground vehicle allows for easier training considering the likelihood that an operator has experience driving a vehicle in general. The two most important operator characteristics of interest in the current investigation involve (a) an operator's ability to determine location by the top-down process of map reading, and (b) navigation or the aforementioned mental transformation ability, a bottom-up process that requires mentally rotating a display image in order to understand the current location in an environment.

Map Reading and Navigation

There are two ways to consider how an operator could determine a UGV's location: (a) a top-down method of reading a map to determine the location of a vehicle or (b) a bottom-up method of recognizing and processing visual cues from a camera view to determine location and relate the information to a map. The top-down method requires that an operator has pre-existing knowledge of a vehicle's start position and understands directionality of a vehicle. Research focused on map reading and navigation, such as wayfinding and route learning, concentrate on the use of this top-down processing (Farrell et al., 2003; Shelton & McNamara, 2004; Tkacz, 1998). The presupposition that an operator knows the location and direction of travel is not always the case, but this was not the focus of the current study.

Summary

It could be argued that many human/operator and system characteristics need to be considered as factors in human-robot interaction. Therefore, it is important to recognize that several textbooks and popular publications discuss these characteristics and their impact on human performance, HRI tasks, and system operation for other systems (Casey, 1998; Sanders & McCormick, 1993; Wickens & Hollands, 2000). The factors recognized here are limited to those that are most salient in the interaction between an operator and a UGV during a search or reconnaissance mission for control and randomization.

As discussed previously, the ability of a human to interpret the information provided via a camera feed is imperative in a task that requires an operator to understand where a UGV was, is, and will be located in the environment. This ability is the primary focus of the current study. The next section of this document introduces a military reconnaissance task that served as the domain for the study of this ability in the present research, highlighting the effect of level of automation and mental transformation training on situation awareness and task accuracy.

CHAPTER 6: RECONNAISSANCE TASK PERFORMANCE

The task chosen for the current study is a reconnaissance task embedded within a Military Operation in Urban Terrain (MOUT) scenario (see Chadwick, 2005; Rehfeld et al., 2005). In general, the purpose of a reconnaissance task is to acquire information about an opposing force's position, action, composition, size, barriers, and field fortification (McCarthy, 1995). The fundamental operations of a successful reconnaissance mission include: (a) placing maximum reconnaissance forward, (b) orienting on the reconnaissance objective, (c) rapid and accurate reporting, (d) freedom of maneuver, (e) gaining and maintaining contact, and (f) developing the situation (McCarthy, 1995; p. 41). Four methods can be employed to accomplish a reconnaissance task: (a) reconnaissance patrolling, (b) reconnaissance by fire, (c) reconnaissance in force, and (d) armed reconnaissance. The focus of the present study is on reconnaissance patrolling.

A reconnaissance-patrolling mission is not a fast, offensive mission with the intent of contacting opposing forces. Rather, the aim of a patrolling mission is to gather information to report to commanding officers using non-contact surveillance. With any reconnaissance mission, the basic method of communicating information is via radio (U.S. Marine Corps, 1999). Security of information conveyed is of utmost importance, and one problem with a radio frequency is the electronic signature of a transmitting radio. To reduce transmission length, the military has concocted brevity codes, ways to encrypt information, directional antennas, and communications-electronics operating instructions. The use of semi-automated or fully autonomous UGVs further help to reduce radio transmissions because an operator is located at a base position, rather than physically inside or with a vehicle during the reconnaissance mission, and it is no longer necessary to relay information verbally or textually (e.g., Morse code).

As noted, the use of radio-controlled UGVs increases security because no verbal communication is required during reconnaissance. Nevertheless, the radio transmissions involved in controlling a UGV continue to present a security hazard because the radio signals can be detected and traced to a location. In addition, it can be too demanding for an operator to maintain full situation awareness and complete a reconnaissance task successfully when also taxed with the requirement for directly controlling a vehicle. For these two reasons (potential risks to security and increased perceived mental workload) and given recent advancements in technology, it might be reasonable to transfer the task of directly driving a vehicle to either decision support or full automation to reduce workload of the task and improve task performance.

Task and Task Performance

The task in this study has two main functions; (a) understanding the location of the UGV with mental rotation and (b) navigation of the UGV with one of the three levels of automation. To accomplish these functions, the UGV traversed through a MOUT and stopped at specific locations for the operator to report updated coordinates of the UGV. This required that the operator employ mental transformation of the current camera view to a map view for the correct coordinates. Once the coordinates are reported, the navigation of the UGV (via manual control, decision support, or full automation) was then required to reach the final destination.

In an effort to make the two parts of the task less intertwined, the map was not consistently available to the UGV operator. The map was only available when the operator would need to report coordinates, therefore, preventing the operator from continually comparing the camera view to the map to update the location of the UGV throughout the task.

Task performance can be measured via subjective and/or objective means. Subjective measures involve a person reporting their perceived experience and the report can be given either throughout the task, or when the task has been completed. The use of a subjective measure itself depends upon the nature of the task. In the current study, situation awareness is a particularly critical aspect of the task performance and was reported via self-report.

Situation Awareness

Situation awareness (SA) is an understanding of one's current surroundings as well as the ability to understand and predict the state of one's environment in the near future (Endsley, 1995). Maintaining the SA necessary to operate a UGV successfully requires the operator of a robot to know and understand the current state of the robot and the robot's immediate environment. In order to predict actions and create a plan of action, the UGV operator also needs to have an understanding of possible future changes in the robot and its environment.

In UGV missions involving reconnaissance tasks, it is critically important to maintain SA, even when one is exercising little or no control over the UGV. Such missions require high levels of SA because of the sensitive nature of the task (reporting friendly and opposing forces) and the possible danger (both for the robot and for the operator) associated with the task, depending on an operator's location and detectability. One of the aims of the present study was to determine the extent to which the level of SA might be increased by increasing mental transformation ability through training. Increasing the operator's ability to translate the camera view into the map view provides information as to the current position of the UGV and gives cues as to the future direction as well.

A second impact on SA is the variability of mental workload, and therefore attentional capacity, that results from differing levels of automation. Previous research has shown an interaction of attention and mental workload on situation awareness (Adams, Tenney, & Pew, 1995; Endsley, 1995; Riley, Kaber, & Draper, 2004; Smith & Hancock, 1995) such that SA is directly affected by the level of perceived mental workload. In addition, this theoretical and experimental research supports the suggestion that attentional capacity is necessary in order for an operator to notice and attend to critical information in the environment. Therefore, as attentional capacity is sparse during tasks and situations with very high mental workload demands, SA should be improved with the reduction of mental workload. In addition, although attentional capacity is low during low mental workload situations, reducing workload further should not affect task performance.

While subjective measurement is necessary to determine the human's perspective on HRI, it is essential to measure the task performance outcome through objective means. Situation awareness is a mediating factor for resulting task performance; correctly identifying the location of a UGV. The objective measurement for the current study was the accuracy with which the task is completed.

Task Accuracy

The accuracy or success of a reconnaissance mission depends on an operator's attention to critical cues in the environment and ability to mentally translate the camera view to the map view. Therefore, for the purposes of the current study, task accuracy is defined as a person's ability to accurately report the location of a UGV on a map at several points during a reconnaissance mission.

Summary

The use of a reconnaissance task in a 1:35th scale test environment provides sufficient control to study situation awareness and task accuracy while allowing for generalizability regarding the interaction of humans and robots. It is hypothesized that the use of mental transformation training should improve the success of a reconnaissance mission across all levels of automation. Specifically, mental transformation training should produce a significantly larger improvement (increased SA and task accuracy) with the low level of automation (manual control) than the other levels of automation. The following section reiterates and clarifies the stated hypotheses for the current study.

CHAPTER 7: STATEMENT OF HYPOTHESES

In the interest of simplicity, the hypotheses for each of the variables and the interaction of the variables are presented subsequently.

Level of Automation

The theoretical application of MART provides a framework for predicting the performance effects of mental transformation training across low, moderate, and high levels of automation. In particular, it is predicted that the performance of participants without mental transformation training should produce the inverted-U curve in which there is low performance at the extreme automation conditions (manual control and full automation) and high performance at the moderate automation condition (decision support), leading to the first set of hypotheses:

Hypothesis 1a: When participants operate under conditions of manual control, performance should be relatively low. The manual control condition requires participants to focus on the navigation of a UGV as well as the main task (reporting UGV location), creating a situation with high mental workload and strained attentional capacity.

Hypothesis 1b: When participants operate with decision support, performance should be high, relative to the other automation conditions. Decision support allows an operator to be active in the operation of a UGV with the benefit of automation to complete the physical task of controlling the vehicle.

Hypothesis 1c: When participants operate with full automation, performance should be relatively low. The lack of vehicle control should directly affect awareness of the environment due to the low level of involvement and significant reduction in mental workload.

Mental Rotation

In general, the implementation of training should benefit task performance because of the skill acquisition and automaticity of mental transformation. This leads to the following hypothesized main effect:

Hypothesis 2: Participants who receive mental transformation training with concrete recognizable objects from a realistic environment should perform at a higher level than participants who do not receive mental transformation training.

Mental Transformation Training across Levels of Automation

The manual control condition should produce the highest workload of the three levels of automation because an operator is required to focus on the operation of the UGV as well as accomplish the reconnaissance task. Therefore, this condition should show the largest gain from the reduction of workload and automaticity of mental transformation from the training. In addition, the use of automation in itself is intended to reduce the amount of workload necessary to operate a UGV. Further reduction in workload should not affect the higher levels of automation to the same degree as the manual control condition. While still beneficial, mental transformation training should not show a similar benefit of the decision support or full automation conditions as the manual control condition, indicated by the final hypothesis:

Hypothesis 3: The simple effect within the manual control condition (performance difference between the participants who receive training and who do not receive training) should be significant whereas the simple effect of training at the other levels of automation should not.

Based on the preceding hypotheses, anticipated results are displayed as Figure 2:

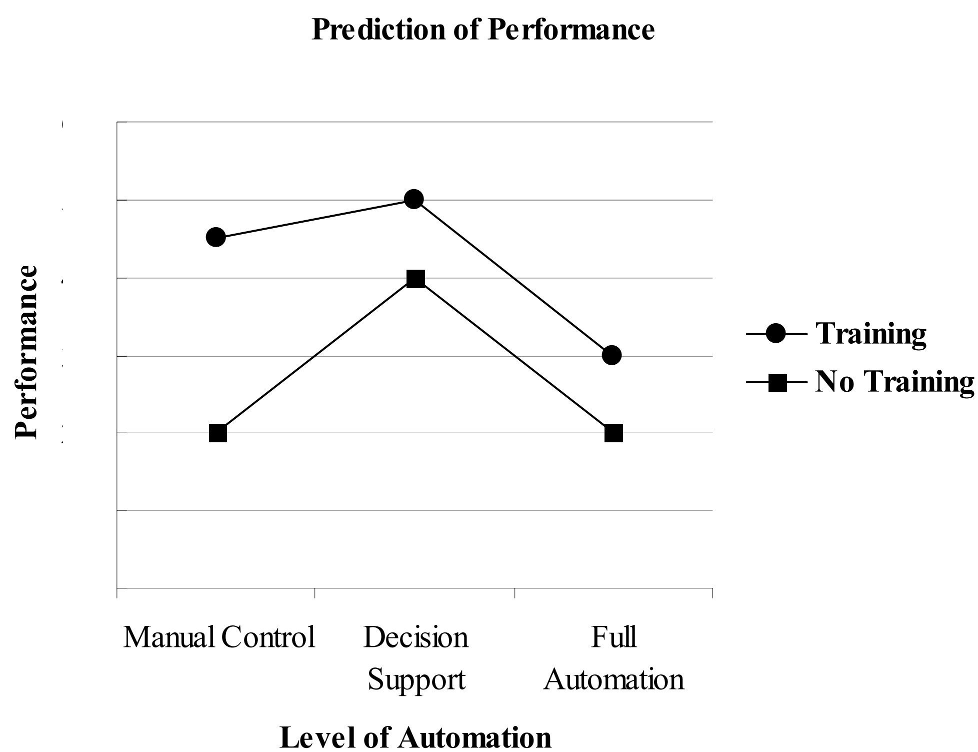


Figure 2. *Visual representation of hypotheses across levels of automation; with and without the implementation of mental transformation*

CHAPTER 8: METHOD

Participants

A power analysis (GPOWER; Faul & Erdfelder, 1992) showed that the current study required 72 (12 per cell) participants for a 0.25 effect size and power of 0.55. In order to complete representative assignment, the current study consisted of 90 participants. The participants were drawn from the University of Central Florida undergraduate pool in exchange for extra credit. Participation in the experiment was open to all undergraduate students, regardless of age, race, gender, or nation of origin. The present study met all requirements of ethical standards as put forth by the American Psychological Association (2003).

Design and Measures

A 2 x 3 x 2 mixed model design was used for this study (see Table 3). The between groups independent variables include Mental Transformation Training (Training video or No Training video) and Level of Automation (Manual Control, Decision Support, or Full Automation). The within groups variable was the Route (two routes deemed equal in length, counterbalanced). Dependent measures representing task performance include situation awareness assessed via the SART (Situation Awareness Rating Technique), the level of workload as measured by the NASA TLX, both administered after each route. In addition, the accuracy of reporting location during a mission was measured in two ways (a) whether the reported location was on the same street as the actual location and (b) the slant distance between the reported and actual locations.

Table 3. *Experimental Design with Independent Variables; Training, Level of Automation,, and Route*

Mental Transformation training	Level of Automation	Route
Training	**Manual Control**	**Route A then route B**
		Route B then route A
	Decision Support	**Route A then route B**
		Route B then route A
	Full Automation	**Route A then route B**
		Route B then route A
No Training	**Manual Control**	**Route A then route B**
		Route B then route A
	Decision Support	**Route A then route B**
		Route B then route A
	Full Automation	**Route A then route B**
		Route B then route A

Mental Transformation Training

The mental transformation training consisted of 10 camera views (previous research supports using anywhere from 3 to 10 images; Ashworth & Dror, 2000; Kass, Ahlers, & Dugger, 1998; Spetch & Friedman, 2003) that show a front view changing to a top-down view and matching the top-down view to a map that is consistently shown next to the video view. The full and explicit rotation from the front view to the map representation provides critical contextual cues for successful training. This level of detail provides training for the view at each angle rather than simply showing a static front view and then a static top view. Research suggests that encoding of the rotation itself can be transferred and generalized across similar stimuli (e.g., various building and foliage shape; Pavlik & Anderson, 2005; Spetch & Friedman, 2003) and that practice can assist in creating a memory image of the building angles (Heil, Rosler, Link, & Bajric, 1998).

Each view was presented twice, once in the order of a front view to top-down view to map view and once in the reverse order. Presentation of both sequences further encodes mental transformation so that the camera and map view could best be matched. The views were derived from a 1:43rd scale replica of a city in Bosnia. Each video contained a UGV-level camera view of a building with foliage and surrounding context. The camera view then moved via an arc from the front view of the scene to a top-down view. The top-down view of the scene then simultaneously shrunk and moved toward the map to show where the view is located on the map. The reverse sequence showed the map and moved a scene out of the map to an enlarged top-down view. The view then changed via an arc from the top-down view to a front view. Thus, this mental transformation training presents the view along the x-axis and translates the view along the y-axis to provide cues as to what the front view resembled as a top-down view and reverse. The video presented the importance of the building shape and context to assist in determining its location on a map.

This presentation is supported by research showing the similarity of cranial blood flow between manipulation of an object and mental rotation of the object (Deutsch et al..

1988). Further research using practice of mental rotation (Lizarraga & Ganuza, 2003) showed a gain in mental rotation ability across gender. Consequently, watching the rotation video trains the participant on the importance of the building and surrounding contextual cues during the process of mental rotation. The second rotation (from the top-down view to the map view) involved equal rotation to the left and to the right, at 0°, 90°, and 180°.

Participants in the No-Training condition viewed a video comprising 10 static pictures of the same 1:43th scale replica of Bosnia. The video matched the length of the Training condition video to equate the two groups with regard to time and the similarity of stimuli presented. Each participant completed two missions, in each mission, there were four pre-planned points at which the UGV stopped, a map of the city was presented, and the operator reported the vehicle's current coordinates. All participants completed the Guilford-Zimmerman Spatial Visualization survey, a test of mental rotation using a clock as a familiar object, the Guilford-Zimmerman Spatial Orientation survey (Guilford & Zimmerman, 1981) in addition to the Vandenburg mental rotation test (1971) and the Card Rotation test (ETS, 1975). This occurred two times, at the start of a session (prior to training) and after the training video, as a pretest and posttest measure. The first administration of the mental rotation test and spatial visualization survey measured the participant's level of mental rotation ability and determined the condition placement for the participant. The second administration was a manipulation check to assess the mental transformation training.

The software that was used throughout the video process include the 2004 edition of ATI All-In-Wonder X 600 Pro by ATI Technologies, Inc. to capture the video, 2002

Adobe Premiere 6.5 by Adobe Systems Inc. to edit the video, and 2003 Cleaner XL Discreet by Autodesk, Inc. to transfer from printing to video.

Levels of Automation

To differentiate the levels of workload during the navigation of the UGV, three conditions demonstrated the low (Manual Control), moderate (Decision Support) and high (Full Automation) levels of automation.

Manual Control. Manual Control of the UGV represents the lowest level of automation in which the operator is able to control vehicle movement via manual manipulation of a joystick. The view available to the operator in all conditions involved a live feed from a single wireless camera mounted on the front of the UGV, similar to the first view in Figure 1. In this condition, the vehicle only responded to the input of the joystick by the operator and did not employ any automation concerning navigation.

Decision Support. The use of Decision Support required that the UGV provide a suggestion for a direction in which to travel via computerized communication. The operator could then either approve or indicate a different direction for the UGV to travel. Therefore, the operator is not required to manually control the direction of the UGV throughout the task, yet is actively involved in the path that is traveled.

Full automation. When the UGV operated in Full Automation, the operator was unable to provide any input as to the direction of the vehicle. The UGV determined direction and path to the final destination.

Each participant completed two missions with the assigned level of automation; each mission had only one path to the final destination, ensured by the use of roadblocks.

The two missions were counterbalanced to account for order effects. The NASA-TLX (Hart & Staveland, 1988) was used as a manipulation check to demonstrate the differentiation between the levels of automation.

Materials and Apparatus in the Experimenter Room

Pencil and Paper Materials

Biographical data form. Information was garnered regarding participants' age, gender, military experience, visual acuity, experience with remote controlled vehicles (ground and air), experience with video games, and map reading ability (Appendix A) for use as covariates.

Informed consent and debriefing form. All participants completed an informed consent (Appendix B). This form notified participants of the nature and minimal hazard of participation. The debriefing form was read to each participant (Appendix C).

Mental rotation test. All participants completed a pencil and paper Guilford-Zimmerman Spatial Visualization and Spatial Orientation surveys (Guilford & Zimmerman, 1981) in addition to the Vandenburg mental rotation test (1971) and Card Rotation test (ETS, 1975).

NASA-TLX and SART. The NASA-TLX (Hart & Staveland, 1988; Appendix D) and SART (Appendix E) were administered after each completed mission. The NASA-TLX was used as a manipulation check to ensure that the different levels of automation elicited variations in perceived mental workload. The SART was used to measure situation awareness and was completed by the participants after each of the missions.

Apparatus

One 13-inch Advent monitor was used for the camera display. The monitor displayed a live feed from a single wireless camera mounted on the front of the vehicle and the camera was static and stationary. In order to control the vehicle, a USD Joystick (G60503A, by Gamers Factory) was placed in front of the monitor for use with manual control but was disabled during sessions with automation.

Apparatus in the Confederate Room

One Daewoo 13-inch monitor showed an aerial view of the facility to record the motions of the vehicle as a back-up in case the participant did not legibly write on the location report. An Exxis 15-inch color monitor was used by the confederate to operate the vehicle during the decision support scenarios. A USD Joystick (G60503A by Gamers Factory) controlled the movement of the vehicle. Two Magnavox DVD recorders recorded the camera feed from the vehicle. Lastly, an E Machine computer operated a C++ software program that allowed for control of the vehicle through a joystick.

Military Operation in Urban Terrain (MOUT) Room

A 1:35th scale urban replica of an exemplary Middle Eastern city was the setting for the missions. The vehicle consisted of a commercial off-the-shelf, remote controlled, 1:35th scale model tank (Radio Shack) powered by three 9-V batteries. A wireless mini-spy CCD pinhole camera was mounted on the turret of the tank to provide a live feed for both confederate and participant.

Procedure and Task

Experimenter

The experimenter remained in the same room as the participant for the full extent of each session. The experimenter requested that the participant read and sign an informed consent as well as complete a biographical data form. The experimenter also administered a Guilford-Zimmerman Spatial Visualization survey, Guilford-Zimmerman Spatial Orientation survey (Guilford & Zimmerman, 1981), Card Rotation test (ETS, 1975), and Vandenburg mental rotation test (1971) according to the printed instructions. Finally, the experimenter read from a pre-printed script (Appendix F) throughout each session to maintain control and consistency across participants.

Participants

After the participant completed the informed consent, biographical data form, and mental rotation tests, he or she completed the Spatial Orientation, Spatial Visualization, Mental Rotation, and Card Rotation surveys. The participant was then assigned to the Training or No Training condition based on the results of the Spatial Orientation test. That is, upon scoring the Spatial Orientation test, participants were assigned to the next available condition for that score such that each condition had an equal number of high, moderate, and low Spatial Orientation scores. This is to ensure that the conditions were representative regarding spatial ability. Assignment to the Level of Automation condition was randomized across participants once designated to the No/Training condition.

The session then continued with a 20-minute video. In the Training condition, participants viewed a video depicting 10 scenes from a 1:43rd scale prototypical city of

Bosnia in which each scene changed from a front view to a map view and the reverse. Each of the scenes showed portions of a building and foliage. Each scene was shown one time in which a front view changed to a top view to a map view and one time in reverse (a map view changed to a top view and to a front view). The forward and reverse scenes were randomized but the same forward/reverse scene was not shown in succession. Participants in the No Training condition viewed a video with static, front-only scenes from the same stimuli. This was to equate the exposure of stimuli and amount of time between the mental rotation tests and actual start of the mission. The participant completed the four spatial ability surveys directly after the 20-minute video as the posttest measure.

The participant then began the first of two missions, counterbalanced across sessions. The three Levels of Automation differed in that one allowed a participant to fully control a UGV (manual control), one required that a participant approve of initial direction supplied by the UGV (decision support), and one did not allow a participant to control the UGV (full automation). At the start of each mission, the participant was informed that the UGV has just recently regained signal after an hour of lost signal. Therefore, the UGV is within approximately 300-foot radius but the exact location is not known. When the monitor is turned on, the participant’s task was to study a view and determine the current position of the UGV via coordinates on a map. The participants wrote the coordinates on a sheet of paper (Appendix H) and indicated the location on the map with the number of the corresponding view (e.g., the number 1 was placed on the map where the participant believed the UGV to be located at the first preplanned view, the number 2 at the second, and so forth). This was to ensure that the participant’s indication via coordinates matched the location on the map. The following differentiated each subsequent task for each of the three levels of automation.

Manual control. The participant navigated the UGV via the joystick. There was only one route to reach the destination, in which roadblocks limited other direction choices.

Decision support. Through computer communication (electronic chat), the UGV requested approval for each direction that the UGV suggested. The participant gave approval or suggested a different direction and the UGV followed the approved direction.

Full automation. The UGV had the capability to return to base via a signal beacon. The participant did not have the option to operate the UGV.

To control for route variability, only one path led to the destination due to roadblocks that limited direction choices. After the initial location report (when the monitor was first turned on), there were three pre-planned points during each mission, in which the UGV stopped and requested a location report (the participant reported the coordinates of the UGV). This provided four data points for each mission for the measure of accuracy. While all four data points required a mental rotation from a camera view to a top down view, two of the data points required a 45° rotation and two required a 180° rotation. The associated physical map (Appendix H) for reporting location was presented only when the coordinates were requested.

After each mission, the participant completed the SART and NASA-TLX measures for situation awareness and perceived mental workload, respectively. After the last mission, the experimenter read a debriefing form and answered any questions that the participant had.

Confederate

A trained research assistant acted as a confederate and was responsible for operating the vehicle during the decision support and full automation conditions (Appendix I). The confederate was located in a room separate from the participant and from the MOUT facility. During operation of the vehicle throughout all conditions, the confederate stopped the vehicle at four predetermined points for the reporting of coordinates, as previously described.

CHAPTER 9: RESULTS

Overall Statistical Analyses

All analyses were computed using SPSS 11.5 for Windows. Based on theory and the stated hypotheses, the alpha level was set at .05 for all analyses, unless stated otherwise, and planned comparisons and directional tests were used where suitable.

Main Variables used in the Analysis

The independent variables involved were Mental Transformation Training (with, without), Level of Automation (manual control, decision support, full automation) and the Route (first Route A then B, first Route B then A). For the sake of simplification, the Routes will be referred to as Route A First, Route B Second, Route B First, and Route A Second to account for the different possibilities.

The subjective assessments of spatial awareness and workload via SART and NASA-TLX, respectively, were used to determine SA and workload for the manipulation checks. The performance data involved the participant's report of the vehicle's location as compared to the actual location of the vehicle. It consisted of two measures: (a) simple assessment of whether the reported location was the same street as the actual location (regardless of distance), and (b) slant distance of the reported and the actual location as measured by an overlaying grid (2/5ths of an inch for each cell in the grid, 19 rows and 25 columns).

Analytic Strategies

The analyses of the data for this study consisted of a one-way Analysis of Variance (ANOVA) to test for the validation of MART (Young & Stanton, 2002), an independent *t*-test to determine the effect of mental transformation training across all participants, and an ANOVA to determine the training by automation effect.

Data Screening

The performance data (slant distance from reported location and actual location) were positively skewed. A logarithmic transformation corrected the positive skew. The performance data included the four reports of location. The first report was given at the start of the trial when the monitor was turned on. The three remaining reports were provided after the vehicle has moved and the participant has garnered experience traversing the city. Hence, the last three location reports were aggregated into a single variable by averaging the respective performance measures across the three locations.

For all other variables, the assumptions of homogeneity of variance, linearity, and homogeneity of regression were satisfactory. No cases were removed because of outliers.

Check of Representative and Random Assignment

In order to assure that all groups contained an equal proportion of participants with low, moderate, and high spatial ability, the experimenter assigned the participant to the condition based on spatial ability and the next available condition (Appendix J & K). There were no significant differences between the pretest spatial measures across the automation and training conditions (Table 4; Table 5), which supported the instructions to assign participants based on spatial ability across conditions. Additionally, there were no significant differences on other biographical data (e.g., age, sex, or prior video game experience), suggesting that the random assignment effectively prevented differences among the groups on these critical variables.

Table 4. *Pretest percentage for spatial ability surveys across automation in the No Training condition.*

Automation	**CR**	**MR**	**SO**	**SV**
MC	**59.83**	**17.33**	**28.96**	**46.67**
DS	**67.42**	**22.33**	**24.88**	**44.33**
FA	**63.57**	**21.43**	**24.95**	**40.54**

Note: CR = Card Rotation, MR = Mental Rotation, SO = Spatial Orientation, SV = Spatial Visualization, MC = Manual Control, DS = Decision Support, FA = Full Automation

Table 5. *Pretest percentage for spatial ability surveys across automation in the Training condition.*

Automation	**CR**	**MR**	**SO**	**SV**
MC	**71.83**	**23.33**	**23.28**	**42.17**
DS	**67.08**	**22.33**	**24.58**	**38.83**
FA	**67.5**	**23.53**	**26.69**	**46.03**

Note: CR = Card Rotation, MR = Mental Rotation, SO = Spatial Orientation, SV = Spatial Visualization, MC = Manual Control, DS = Decision Support, FA = Full Automation

Manipulation Checks

Training Manipulation

Mental Transformation training was implemented in order to improve spatial abilities and performance on the task. The measurement of spatial ability was determined with the pre- and posttest results of the Spatial Visualization, Spatial Orientation, Mental Rotation, and Card Rotation tests. Although there were no significant improvements shown in the posttest results for Spatial Orientation and Card Rotation, there were significant improvements for Spatial Visualization ($F(1, 89) = 4.062$, $p = .047$, partial $Eta^2 = .044$) and Mental Rotation ($F(1, 89) = 5.101$, $p = .026$, partial $Eta^2 = .054$). On average, trained participants (Subscript *T*) scored 8.22 percentage points higher on the Spatial Visualization measure ($M_T = 58.6702$ vs. $M_{UT} = 50.4545$) than untrained participants (Subscript *UT*) and 8.75 percentage points higher on the measure of Mental Rotation ($M_T = 33.3$ vs. $M_{UT} = 24.55$). This showed that the manipulation was successful in that participants who received training scored higher than participants who did not receive training.

Automation Manipulation

The assumption behind the use of automation was to manipulate levels of workload and situation awareness. The veracity of this assumption was evaluated by first using the overall score for the NASA TLX and the SART.

NASA TLX combined score. In regard to the NASA TLX, although participants reported increased workload as automation increased from Manual Control ($M_C = 54.59$, $SD = 22.198$) to Decision Support ($M_{DS} = 56$, $SD = 18.994$) to Full Automation ($M_A =$

58.2, *SD* = 17.944), the differences were not statistically significant, $F(2, 88) = .260$, $p = .772$, partial $Eta^2 = .006$. As it can be argued that the NASA-TLX overall score is not necessarily an accurate representation of the sensitivity of a manipulation (Rubio, Diaz, Martin, & Puente, 2004), further investigation into the NASA TLX sub scores was warranted.

NASA-TLX sub scores. The NASA TLX sub scores consisted of the raw visual analogue scores. The ANOVA showed a statistically significant difference or approached statistical significance across automation conditions for the Physical Demand ($F(1, 87) = 8.610$, $p < .0005$, partial $Eta^2 = .165$; Figure), Temporal Demand ($F(1, 87) = 2.443$, $p = .093$, partial $Eta^2 = .005$; Figure 4), Performance ($F(1, 87) = 3.530$, $p = .034$, partial $Eta^2 = .075$; Figure 5), and Frustration ($F(1, 87) = 4.799$, $p = .011$, partial $Eta^2 = .099$; Figure 6) sub scales.

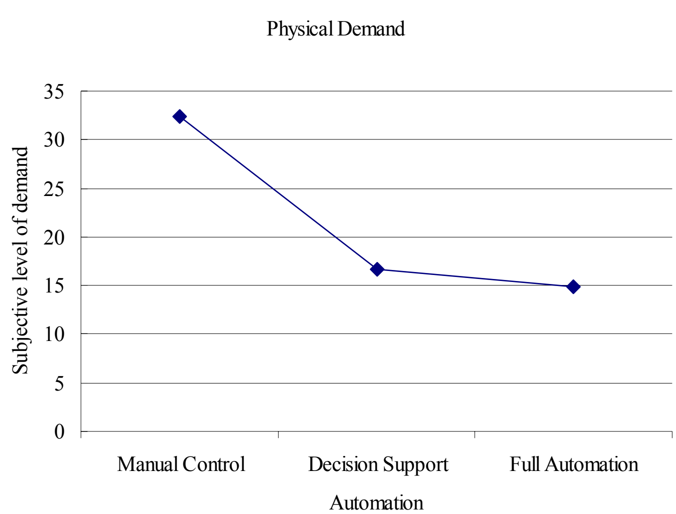


Figure 3. *The subjective report for the levels of automation from the NASA – TLX sub score Physical Demand.*

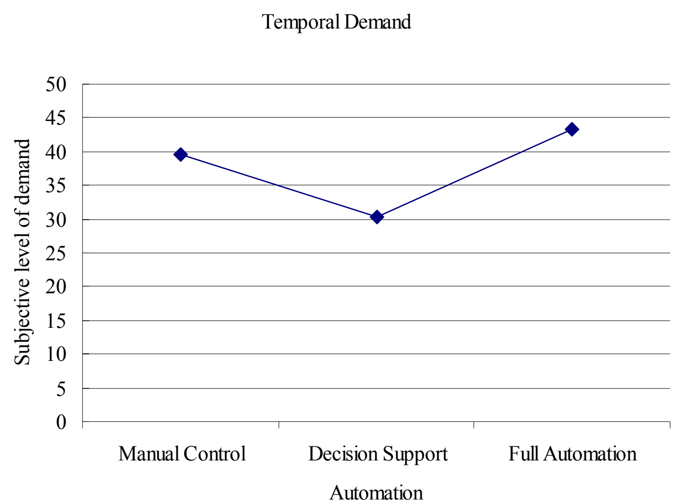


Figure 4. *The subjective report for the levels of automation from the NASA – TLX sub score Temporal Demand.*

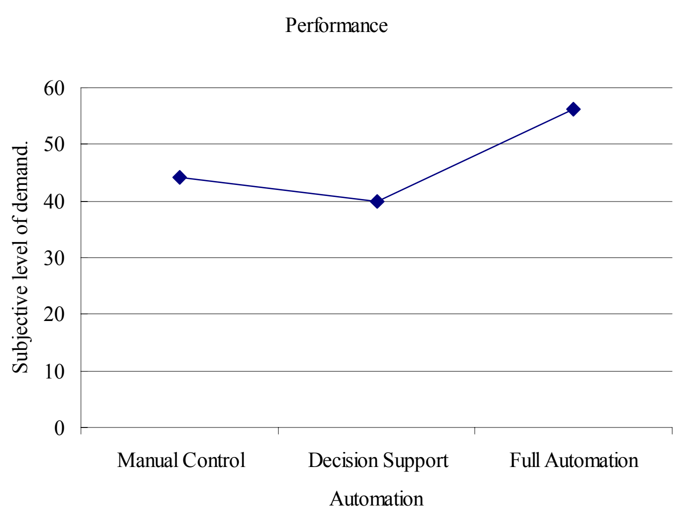


Figure 5. *The subjective report for the levels of automation from the NASA – TLX sub score Performance.*

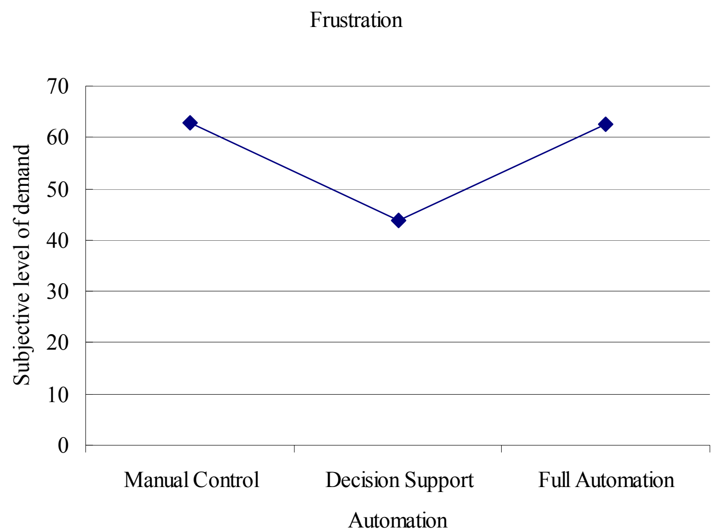


Figure 6. *The subjective report for the levels of automation from the NASA – TLX sub score Frustration.*

Score on the SART. Concerning SART, participants reported increased situation awareness as automation increased; Manual Control (M_{MC} = 14.97, *SD* = 7.618), Decision Support (M_{DS} = 18.87, *SD* = 7.776), Full Automation (M_{A} = 20, *SD* = 6.298) and the differences were significant, $F(2, 88) = 4.018$, $p = .021$, partial $Eta^2 = .084$. Since this result was in an unplanned direction, the sub scales also were analyzed.

SART sub scales. The Supply sub scale approached significance showing that the Manual Control and Full automation conditions showed lower supply demand than the Decision Support condition, p = .081, partial $Eta^2 = .040$, consistent with manipulation intention of automation levels (Figure 7).

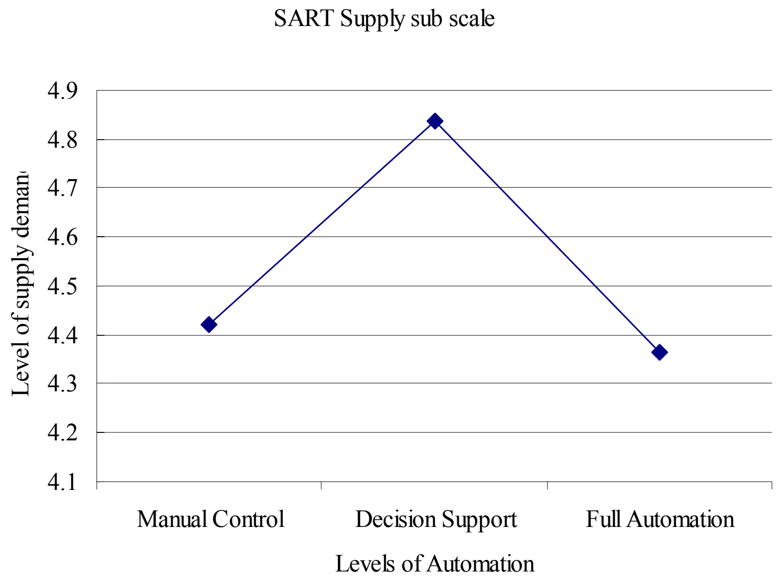


Figure 7. *The level of supply demand, a sub scale of SART, reported by participants across levels of automation.*

Route

As previously mentioned, two routes were created and used for the task. The distance of the routes were similar (Route A = 43 cm on the map and Route B = 45 cm). However, since the path was different, a test was conducted to determine if there was a workload or situation awareness difference between the routes as it was determined during data collection that Route B had the only curved road on the map, therefore, possibly making it an easier route. As suspected, the 2 x 2 Route (Route A, Route B) by Sequence (Route A First, Route B Second; Route B First, Route A Second) ANOVA showed a significant difference ($F = 4.021$, $p = .048$, partial $Eta^2 = .152$) when measuring workload (Figure 8).

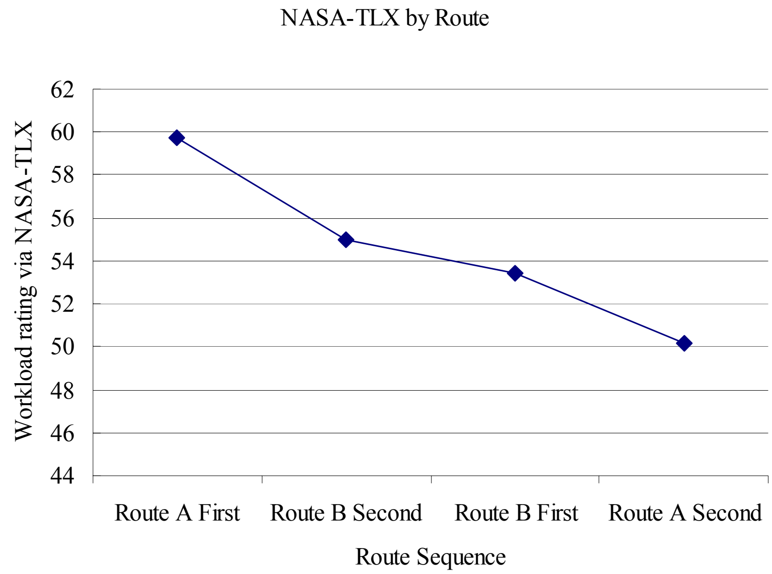


Figure 8. *The subjective report for the sequence of routes from the overall NASA - TLX score*.

This showed that participants who experienced Route A first reported higher levels of workload than participants who experienced Route B first, Route B second, or Route A second. The difference also approached significance when measuring situation awareness (SART) between the routes, $F = 3.175$, $p = .079$, partial $Eta^2 = .025$ (Figure 9), showing that Route A first produced lower situation awareness ratings than Route B second, Route B first, and Route A second.

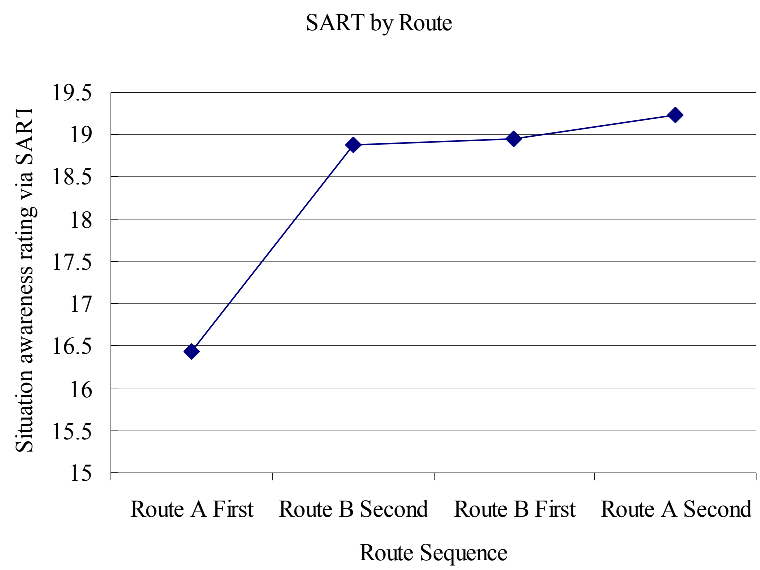


Figure 9. *The subjective report for the sequence of routes from the overall SART score.*

These differences showed that when Route A was experienced first, participants reported it as more difficult than in any of the other sequences. Since the focus of the current study was on the amelioration of errors in spatial and situational awareness under difficult conditions, all remaining analyses were conducted with data from only those participants who experienced Route A first, unless a different sample is clearly stated otherwise.

Hypothesis Testing

Restatement of the hypotheses

For Hypothesis 1, the following sub-hypotheses were tested:

Hypothesis 1a: When participants operate under conditions of manual control, performance should be relatively low. The manual control condition requires *participants to focus on the navigation of a UGV as well as the main task (reporting UGV location), creating a situation with high mental workload and strained attentional capacity.*

Hypothesis 1b: When participants operate with decision support, performance should be high, relative to the other automation conditions. Decision support allows an operator to be active in the operation of a UGV with the benefit of automation to complete the physical task of controlling the vehicle.

Hypothesis 1c: When participants operate with full automation, performance should be relatively low. The lack of vehicle control should directly affect awareness of the environment due to the low level of involvement and significant reduction in mental workload.

Planned comparison tests were conducted to test for performance (a) first if on the same street as actual location, then (b) the slant distance of reported and actual location. The first stop was tested separately from the remaining three stops as previously explained because of the potential differences in carry-over from the first (difficult) to subsequent (easier) stops. In addition, baseline performance was determined with performance in the No Training condition and the result of the Training condition separately.

Street measure. When participants' location report was based solely on whether the report was on the same street as the actual location, in the untrained condition, there was no significant difference when comparing the first stop reports (first sight of the surroundings). The average of the last three stops results showed a matching pattern predicted by MART (Figure 10) in that the Decision Support group reported locations that were on the same street as the actual vehicle more than the Full Automation (p = .025) and Manual Control (p = .042) conditions. The Full Automation and Manual Control Conditions did not show significant differences (p = .790). The Training condition showed no significant differences between the automation conditions regardless of the stops.

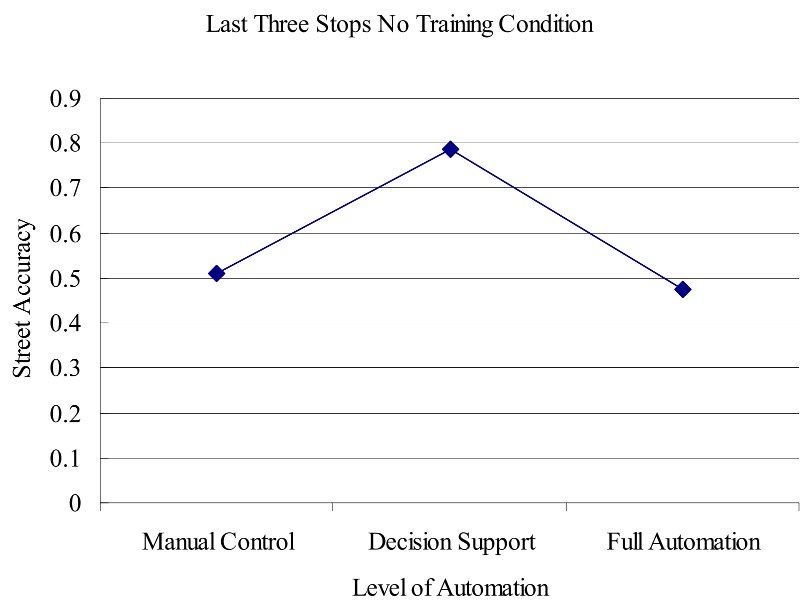


Figure 10. *Performance of untrained participants for the average of the last three stops. Street accuracy was measured in that 0 = not on same street, 1 = on same street.*

Distance measure. For the distance measure, participants' location report was based on the slant distance comparison from the participant report location and the vehicle's actual location. In the untrained condition, there was no significant difference when comparing the first stop reports (first sight of the surroundings). Similar to the slant measure, the average of the last three stops results showed a matching pattern predicted by MART in that the Decision Support (M_{UT} = .4136, SD = .2725) group reported locations that were closer to the actual vehicle than the Full Automation (M_{UT} = .7186, *SD* = .3285; *p* = .010) and Manual Control (M_{UT} = .6308, *SD* = .3122; *p* = .058) conditions. The Full Automation and Manual Control Conditions did not show significant differences (*p* = .443). In the Training condition, there was no significant difference when comparing the average of the last three stops. The first stop, in the Training condition approached significant results ($F(2, 46) = 2.32$, $p = .055$) in that the Manual Control condition (M_T = 1.061, SD_T = .1762) reported locations significantly closer to the actual location than the Full Automation (M_T = 1.114, SD_T = .2646) condition with no significant difference between Decision Support and the Manual Control and Full Automation conditions.

Hypothesis 2: Participants who receive mental transformation training with concrete recognizable objects from a realistic environment should perform at a higher level than participants who do not receive mental transformation training.

Planned comparisons for the street and slant distance measures showed no significant difference between the groups. To investigate further, the slant distance was reevaluated with the street measure as the covariate. The first location report showed no significant difference between participants who did and did not receive training, $F(1, 39) = .001$, $p = .975$. For the last three reported locations, participants who did not receive training reported locations that were closer to the actual location (M_{UT} = .4849, *SD* = .3199) than participants who received training (M_{UT} =.5815, *SD* = .274), $F(1, 39) = 7.813$, $p = .008$. This, in effect, falsely modified the results of the untrained participants by improving their distance error more than it should have due to the covariate.

Since the manipulation check of the training had shown significant improvements for Mental Rotation and Spatial Visualization, a multiple regression coefficient analysis was performed and showed that although Spatial Visualization did not predict the measure, Mental Rotation significantly predicted the street measure (p = .024, one-tailed, B = .755). This shows the significant effect of training on spatial ability as shown by the manipulation effect and the influence of spatial ability on the participant's ability to locate the correct street location of the vehicle. Concerning the distance measure, Mental Rotation did not significantly predict distance, however, Spatial Visualization approached significance in predicting the distance (p = .0695, one-tailed, B = -.046).

Hypothesis 3: The simple effect within the manual control condition (performance difference between the participants who receive training and who do not receive training) should be significant whereas the simple effect of training at the other levels of automation should not.

The simple effect of the Training (No Training, Training) variable at the level of Manual Control of the Automation variable showed no significant difference ($F(1, 43)$ = .208, p = .649) as tested by a computer program for the calculation of simple effects (Simple.exe; Silver, 1992). The Training variable at the other two levels of Automation, Decision Support $F(1, 43)$ = 9.444, p = .003 and Full Automation $F(1, 43)$ = 9.245, p = .0032, showed significant differences (see Figure 11). This showed that participants in the Training condition were closer to the actual location when reporting the vehicle location while in the Decision Support and Full Automation conditions but not in the Manual Control condition.

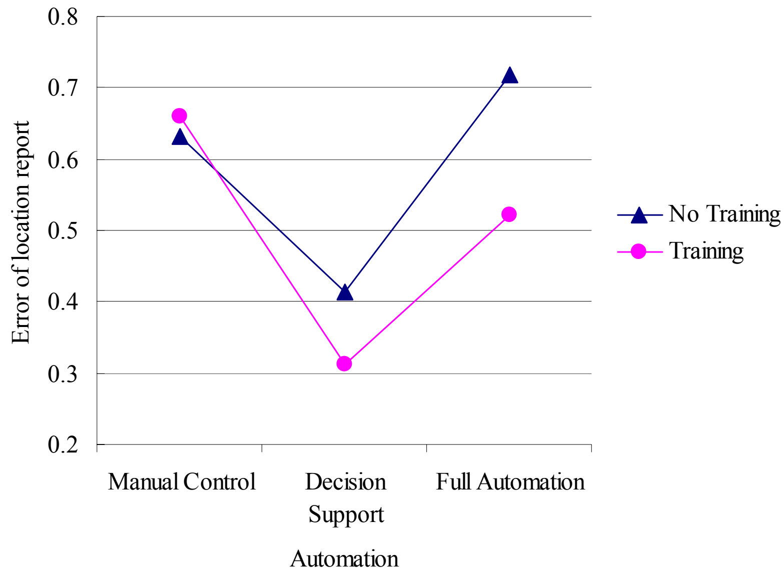


Figure 11. *Error of slant distance (reported location versus actual location).*

Summary

In summary, assignment checks showed that the groups were equivalent in terms of spatial abilities, age, gender, and gaming experience. Manipulation checks showed that the training improved two of the four spatial abilities and automation condition changed workload and SA perceptions as intended. Analyses of the performance measures showed significant effects of automation condition, but not of training; however, further analyses showed that the spatial abilities addressed by the training (in particular, Mental Rotation and Spatial Visualization), did predict performance in the simulation task.

CHAPTER 10: DISCUSSION

The current research had two main objectives: (a) to determine the influence of automation on achieving and maintaining spatial localization and situation awareness, and (b) to study and train the ability of an operator to translate an egocentric side view (from a camera) to an exocentric top-down view (i.e., a map). The experiment required participants to perform a military reconnaissance task that simulated the use of an unmanned ground vehicle (UGV) while it navigated through a prototypical Middle Eastern city. The participants identified and marked the location of the UGV on a physical map from horizontal camera views within the city.

From a review of the literature on spatial abilities and on automation, three hypotheses were developed for the relationships between levels of robot automation, spatial ability, workload, and performance, respectively. First, it was hypothesized that the two extreme automation situations (minimally automated [i.e., tele-operation] and fully automated) would produce extreme levels of workload (over- and underload) when compared to the mid-level automation condition, here simulated by the functions that a navigation decision-support system (DSS) would provide. Additionally, in accordance with Malleable Attention Resource Theory (MART), the two extreme workload situations (both extreme over- and underload) would result in comparatively lower performance (i.e., greater errors in the localization of the vehicle on a map) than the mid-level workload (i.e., decision-support system) condition. This first hypothesis was supported by the data.

Further, it was predicted that the use of supportive or assistive automation that is interactive should optimize workload and, thus, performance. Recent robotic studies have used different levels and/or types of automation (Rehfeld et al., 2005; Chadwick, 2005), but did not test the impact of the automation on workload, or the effect of the automation on the participant's ability to maintain location awareness. To address this gap, a second set of hypotheses predicted that spatial ability training should reduce workload and task demands by making mental transformation of views (here, from egocentric side views to exocentric, top down views) more routine. Making the task more routine, I argued, would assist participants in localization. Whereas some people with high spatial ability may find it easy to translate location in an unmanned vehicle, others with lower spatial abilities may have trouble with this task. Therefore, I expected that spatial ability (mental transformation) training would improve spatial abilities, and that higher levels of spatial ability would be associated with better (i.e., more precise) identification of the location/position of the UGV. This hypothesis was based on prior results for operators of unmanned vehicles, in which this training should help location awareness in UGVs. This hypothesis was partially supported.

The third and final set of hypotheses stated that gains in spatial ability from training should benefit participants experiencing the highest workload condition (minimal automation) more than for participants operating under either of the two conditions with automation (i.e., decision support and high automation). Manual control was expected to be the level with the most improvement possibility because the spatial ability training was intended to reduce workload by assisting in mental translation, and minimal automation should produce the highest level of workload.

Discussion of the Results

Influence of automation. As predicted, automation conditions differed with respect to workload, task demands, and, ultimately, performance. Specifically, performance was highest with assistive automation and lower for both extreme (minimal and maximum) automation situations. This shows ecological validity for the levels of automation that were used. The pattern of results also matched the workload estimates and SA pattern hypothesized on the basis of MART (Young & Stanton, 2002). MART predicted that a situation with minimal automation would be characterized by high workload, and perhaps even overload. Conversely, MART suggested that a situation with full task automation would be characterized by low workload, and in fact, may be associated with underload. Both situations result in poorer task performance. Finally, according to MART, a situation with a medium level of automation, such as in an assistive automation condition as simulated here in the decision support condition, would induce a moderate level of workload and moderate task demands. Although the automation manipulation changed the perception of workload and SA, it did not have a significant effect on performance measured in terms of the accuracy of locating the position of the vehicle.

The lack of statistical significance of the automation manipulation on performance could be related to the task or independent of the task itself. One possibility is that the task performance is independent of workload and/or SA. This is contrary to the majority of research on workload and performance. It is not logical that as the participant's workload increases the accuracy of the task would stay constant. An exception to this would be in the case of a minimal, insignificant increase in workload.

Regarding SA, logic would dictate that the better one's awareness of his or her surroundings the more accurately he or she would be able to locate his or her position. Therefore, SA would be necessary in task accuracy as well. A second, more probable prospect is that the differences in workload and SA as created by the automation manipulation were not strong enough to ultimately affect the performance on the task. That is, the levels of automation did not create strong enough differentiation in levels of workload and SA to affect task accuracy.

Together, these results show the benefits of MART as a theoretical framework for predicting workload, situation awareness, and – ultimately – performance. Although differences in workload and situation awareness did not directly translate into concomitant significant changes in performance in this study, the results do allow some conclusions about the link between automation and performance in a specific task. As indicated by the pattern of results, an operator may be overwhelmed at a task when it has to be completed manually. However, attempting to fully automate the task is not necessarily the answer in this case. The current results, as well as prior empirical results have shown that more errors and lower performance can result when high levels of automation are present; one mechanism explaining how high levels of automation may be associated with lower performance is the human out-of-the-loop problem as described in the Introduction.

The process of mentally transforming views. The current study used a comparatively short, simple, and technically unsophisticated observational exposure training video in which a front view of a building was shown and the camera moved in an arc from the front view to the top down view, and then rotated to align the top-down image with a cardinal direction (such as North-Up). Each practice exposure lasted approximately 40 seconds, and the training video showed 20 scenarios during the training session, once forward (front view to top down view) and once in reverse (top down to front view). The sequences were, however, shown without any special effects and without any further explanation.

Despite its simplicity and although no systematic practice opportunity was provided, the training session improved spatial ability as indicated by two standard tests of spatial ability. The two tests that showed improvement were the Shepard and Metzler (1971) Mental Rotation task and the Guilford-Zimmerman Spatial Visualization survey (1981). Both of these tasks show a 2-D representation of a 3-D object (i.e., for the Mental Rotation task, an abstract series of connected blocks is shown; in the Spatial Visualization survey, a small table clock is presented). Thus, both tests' items matched the training situation in this study by presenting realistic objects from different vantage (view) points. Consequently, scores on these tests may have been increased by the trainees' repeated exposure to representations of objects in the same dimensional relationships. That is, the monitor presenting the training video was essentially a 2-D depiction of realistic 3-D objects. This similarity may explain the positive effect of training on the two spatial ability tests, especially when one considers that the two tests whose scores were not significantly affected by training were the Card Rotation test (ETS, 1975) and the Guilford-Zimmerman Spatial Orientation survey (1981). The card rotation test consists of 2-D drawings that simply rotate along one axis. The spatial orientation survey involves the orientation of a boat in accordance with the shore. Neither of these tests resembles aspects of the training and the actual performance task in this study as closely as the Mental Rotation and Spatial Visualization tests.

Furthermore, regression analyses showed a linear relationship of spatial ability with task performance, as indicated by the accuracy with which participants identified the vehicle's location. Although the training itself did not show direct effects on performance, the effect of training on spatial ability, and the association of spatial ability with performance in this task, together formed a strong link suggesting that training indeed would influence performance. The current study used task-specific training that generalized to two areas of spatial ability: mental rotation and spatial visualization. As indicated above, general measures of these two abilities showed significant improvements after training. Furthermore, previous research had shown that exposure to a similar task or training environment as the one used here, namely the use of video games, provided similar benefits on spatial abilities (Sims & Mayer, 2002). Together, these results suggest that spatial ability can be improved through comparatively simple and inexpensive training. These results also suggest that training spatial ability in general can be improved and not just specific spatial ability training for a task. The issue then is why the training positively affected general spatial ability but not the task performance.

It is possible that the exposure training did not adequately reflect the actual mental process of translating the view to the map. Rather, it is possible that one tends to translate the map to one's view orientation instead of the training, which translated the view orientation to the map. The training video presented the side view transformed in an arc into a top down view and manipulated the top down view to match the map. It may be that while this exposure may assist in general spatial ability, it did not support the translation required by the task. Alternately, the actual mental transformation may be that one reorients the map to fit the view orientation (i.e. one rotates the map from north up to east up as the vehicle moves from north to east). Instead of changing the view to match the map, the map is manipulated to fit the viewpoint to understand vehicle positioning.

Can Other Task and Workload Theories Better Explain the Current Results?

Previous research by Dixon, Wickens, and Chang (2003) evaluated the performance of operators with unmanned aerial vehicles (UAV) under differing types and levels of automation. In addition to testing automation effects specific to UAV operation, Dixon et al.'s research had also tested three theories of workload, namely (a) single channel theory (SCT, which suggests that multi-tasking is not possible), (b) single resource theory (SRT, which posits that multi-tasking performance is dependent upon the task demand), and (c) multiple resource theory (MRT which contends that multi-tasking performance is dependent upon the modality resource). Dixon et al. had used single and dual tasks (performance with a single UAV vs. two UAVs) to test the theories.

When considering the findings by Dixon et al. (2003) while designing the current study, it was determined that the current UGV localization and navigation task would best be conceptualized as a single task, since the report of each location requires movement of the vehicle and the two cannot realistically be disentangled. In fact, the second, third, and fourth location reports depend on the vehicle moving to each of the locations throughout the mission, thus strengthening the case for seeing the task in this study as a single task, rather than the conglomerate or a group of several individual tasks.

Consequently, MART was chosen as the theoretical framework for making predictions about workload, situation awareness, and performance.

At the same time, it was acknowledged that conceptualizing the task as a single, integrated task, was just one way to look at it, and that other conceptualizations may be better explained by other theories. Therefore, post-hoc comparisons of the current results were made to predictions as suggested by the other task conceptualizations (i.e., dual task) and workload theories.

A dual task model with automation of one of the tasks would propose that overall workload should decrease, and hence that primary task performance should increase, as automation of a second task is applied. The results of the current study did not support these suggestions. Instead, the pattern of results reflected the predictions posited by the MART much better. In particular, rather than workload decreasing and performance increasing as automation was applied, workload was negatively affected at the extreme automation conditions resulting in poorer performance than the assistive automation condition. Therefore, it was reasonable to conceptualize the task in this case as a single task, and to use MART as the theory to base predictions about workload, situation awareness, and performance.

Implications for Human-Robot Interaction

A number of implications follow from the current findings. First, spatial ability appears to be quite malleable. Therefore, the benefits of spatial ability training can be used in many areas and fields that rely upon spatial ability in performance. In the medical field, for example, identifying and maintaining one's location and orientation will become even more important with an increased use of laparoscopic and robotic surgery. Similarly, police officers and dispatchers must quickly form and communicate information about spatial relationships, such as when trying to communicate the location of a suspect. Other domains include activities involving navigation (i.e., driving, flying, and diving). Furthermore, increasing the complexity and fidelity of the training might increase the strength of its effects and produce better localization performance. For instance, increasing the complexity would help in further generalizing spatial ability training. The fidelity, such as adding narration, would be used to explain the process in detail such as explaining the angles of the buildings at each of the views.

Second, the current findings have implications regarding trade-offs when designing UGVs and related procedures for improved spatial and situational awareness. As the current results showed, of all the things that may affect a UGV-operator's ability to build and maintain spatial awareness, the level of automation of the vehicle appears not to be the most important. Rather, the individual operator characteristics and possibly the type and number of displays seem to be more important in affecting spatial awareness in UGV operations. Likewise, SA might not be so much a function of attention or limits in attention, but limits in operator's ability to build a mental picture of the vehicle's location, even if that is the only task.

Limitations

Influence of automation. The lack of direct influence of the training on performance may be attributed to the demarcation of the levels of the automation independent variable. In effect, further defining the levels of automation might assist in the determination of workload affects. Additionally, the current data suggest that (a) this task might not be difficult enough, (b) the task was not long enough, or (c) the levels of automation were not representative of the levels of automation that were sought.

Translating views. First, the training component might not have been strong enough to impact performance directly. Second, there was no time limitation placed on the location report as the participant set the pace during the missions. Adding time limitation would increase workload and tax the speed of spatial transformation, resulting in an increase of the sensitivity of the measures. As discussed in the introduction, research has shown that no time limitation increases the accuracy of mental rotation (Peters, 2005). This indicates that some ceiling effects could possibly have occurred in the current study.

Finally, the parity of the routes proved to be problematic and should have been tested more thoroughly prior to the start of the data collection rather than simply equating the route length. In regard to statistical power, the level of overall effect sizes were moderate (the lowest at .005 and the highest at .165) suggesting that collecting additional data would not improve the results of the current study.

Conclusions

The rationale of this study was to provide research in the gap of literature spanning spatial ability and recent research on teleoperation of unmanned vehicles. Previous research (Chadwick, 2005; Murphy, 2005; Rehfeld et al., 2005) has repeatedly shown that operators of unmanned vehicles, and especially of UGVs, were not able to understand the vehicle's location even when additional external views were provided, such as overhead camera views, multiple viewpoint cameras, etc. Factors that determine whether observers can build and maintain spatial awareness is, therefore, an important research question whose answer will greatly facilitate achievement of one of the enabling objectives necessary for successful human-robot interaction; that is, building and maintaining spatial and situational awareness. More specifically, the aims of the current study were to study whether changes in spatial ability would assist the operator with this understanding as well as decrease workload, and whether these changes would interact with the type of automation and autonomy given to an unmanned vehicle.

The current study showed that minimal automation and full automation might produce differing negative workloads (under and overload) but with similar consequences (decrease in performance). The idea of assisted automation was supported, albeit contingent upon whether automation is intended for a primary task or a secondary function, as discussed previously.

In summary, by improving spatial ability with training, the operation of a remote vehicle can be improved significantly since the operator would have the ability and understanding of the vehicle's location and environment. This linkage shows that spatial ability training can be used to improve performance regardless of the operator's innate spatial ability. Therefore, assistive automation can optimize workload and attentional resources for a most favorable level of performance with a primary task.

Future Research

The next step of research in this area requires stronger definitions for the levels of automation. In particular, it could be argued that the 'manual control' condition in the current study did not have a lack of automation; the use of a joystick could be considered automation. In addition, a longer or more intensive task could be used to better characterize the workload levels experienced with manual control and the use of automation. The current study's missions lasted between 10 to 20 minutes. A longer and more intensive or complex task could more accurately differentiate the workload levels between the automation conditions. Furthermore, increasing workload with inclement weather and nighttime tasks (producing limited visual display) would also aid in increasing the sensitivity of the subjective and objective measures by adding higher levels of workload. Given the brief training (20 minutes) session, further improvements including the use of multi-media (such as narration to explain the mental transformation) in the training could produce increased spatial ability for a position dependent upon them showing an increase in ability, and subsequently performance, in a relatively short time frame.

APPENDIX A: BIOGRAPHICAL DATA FORM

Identification Number ______

Biographical Data Form

Please complete the following questions. Any information you provide is voluntary and will be kept strictly confidential. A participant number will be assigned and in no way will your name be associated with the data. The information you provide will be used only for the purposes of this study. If you have any questions, please ask.

1. Age: ____ Gender: ____ M ____ F
2. Military experience (including ROTC), area and length of time:__________________
3. Map reading experience (class, hobby, etc.): ______________________________
4. Native language (if not English): _________________
5. Do you wear prescription glasses or corrective contact lenses? ___ Yes ___ No

   If yes, are you wearing them now? ___ Yes ___ No
6. Please rate your experience with *seeing* or *using* any type of ***radio or remote controlled ground vehicles*** (cars, trucks, toys, etc.):

1	2	3	4	5	6	7
Not at all familiar			Somewhat familiar			Very familiar

7. Please rate your experience with *seeing* or *using* any type of ***radio or remote controlled air vehicles*** (airplanes, helicopters, blimps, etc.):

1	2	3	4	5	6	7
Not at all familiar			Somewhat familiar			Very familiar

8. Please rate your experience with *seeing* or *using* any type of ***video games***:

1	2	3	4	5	6	7
Not at all familiar			Somewhat familiar			Very familiar

9. Please rate your experience with *seeing* or *using* a ***video game*** as a ***first person shooter***:

1	2	3	4	5	6	7
Not at all familiar			Somewhat familiar			Very familiar

APPENDIX B: INFORMED CONSENT

Student Informed Consent Form

Name: ______________________________ **Identification No.:** ____________

I agree to participate in the study "Working with Robots," conducted by principal investigator; Sherri Rehfeld, and research assistants Bill Evans, Mike Curtis, Moshe Feldman, Raegan Hoeft, and Jessica Ottlinger.

In this research, I will participate in a study targeted at measuring workload, awareness, spatial ability, and accuracy. The experiment will consist of one session with two parts. The first part will consist of paperwork including biographical data and a spatial ability survey. The second part will focus on training and three trials of operating a remote controlled vehicle for about 20 minutes each with a workload and awareness assessment survey following each trial, which should take approximately 5 minutes. Performance on these tasks will remain completely confidential (see below). Including training, performance during the sessions, paperwork, and debriefing, this experiment will last approximately 2 hours. Upon completion of the study, credit for participation in an experiment will be given in accordance with the procedures established within the Department of Psychology.

Risks and Benefits

Participation in the current study does not involve any risks other than those commonly associated with the use of computer display terminals. All performance and personal data will be kept confidential.

If you believe you have been injured during participation in this research project, you may file a claim with UCF Environmental Health & Safety, Risk and Insurance Office, P.O. Box 163500, Orlando, FL 32816-3500 (407) 823-6300. The University of Central Florida is an agency of the State of Florida for purposes of sovereign immunity and the university's and the state's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the university's and the state's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.
Information regarding your rights as a research volunteer may be obtained from:

UCFIRB Office
University of Central Florida (UCF) Office of Research
Orlando Tech Center
12443 Research Parkway, Suite 207
Orlando, Florida 32826
Telephone: (407) 823-2901

Confidentiality of Personal Data:

All data I will contribute to this study will be held in strict confidentiality by the researchers. That is, my individual data will not be revealed to anyone other than the researchers and their immediate assistants.

To insure confidentiality, the following steps will be taken: (a) only researchers will have access to the data in paper or electronic form. Data will be stored in locked facilities; (b) the actual forms will not contain names or other personal information. Instead, a number assigned by and only known to the experimenters will match the forms to each participant; (c) only group means scores and standard deviations, but not individual scores, will be published or reported.

MY PARTICIPATION IN THIS RESEARCH IS VOLUNTARY. I CAN WITHDRAW MY PARTICIPATION AT ANY TIME WITHOUT PENALTY - THIS INCLUDES REMOVAL/DELETION OF ANY DATA I MAY HAVE CONTRIBUTED. SHOULD I DECIDE NOT TO COMPLETE THE STUDY, HOWEVER, I WILL BE ELIGIBLE ONLY FOR THE COURSE CREDIT FOR THAT PART OF THE STUDY WHICH I HAVE COMPLETED.

This research is conducted by Florian Jentsch, the principal investigator. I have been given the opportunity to ask the research assistants any questions I may have. For further questions regarding this research, contact Sherri Rehfeld:

Sherri Rehfeld
Team Performance Lab
University of Central Florida
Orlando, FL 32816-1390

Phone: (407) 921-3555

Signature:____ Date: _______

APPENDIX C: DEBRIEFING FORM

Debriefing Form

As explained earlier, this experiment was designed to examine performance and time on task for reconnaissance missions with unmanned ground vehicles. More specifically, some participants received a training session for mental rotation to assist in the mission and some participants saw pictures of Iraq. In addition, all participants experienced different levels of control over the vehicle, none, some, or all. We are trying to determine the best combination of variables for performance in the field.

We want you to know that we could not do our work without your help, so your participation is greatly appreciated. Please feel free to ask any questions at this time about the procedure or the experiment in general. Should you desire to learn more about the study or receive the results of the experiment when they become available, please contact the principle investigator; Sherri Rehfeld at 407-921-3555 or srehfeld@yahoo.com.

Thank you for your participation.

APPENDIX D: NASA-TLX (NATIONAL AERONAUTICS AND SPACE ADMINISTRATION TASK LOAD INDEX)

NASA-TLX Instructions

Part I

Rating Scales. We are not only interested in assessing your performance but also the experiences you had during the experiment. In the most general sense, we are examining the "workload" you experienced. Workload is a difficult concept to define precisely but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put into it, or the stress and frustration you felt. In addition, the workload contributed by different task elements may change as you become more familiar with the task. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to assess.

Since workload is something that is experienced individually by each person, there are no set "rulers" that can be used to estimate the workload associated with different activities. One way to find out about workload is to ask people to describe the feelings they experienced while performing a task. Because workload may be caused by different factors, we would like you to evaluate several of them individually rather than by lumping them into a single, global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during this task. Please read the descriptions of the scales carefully. If you have any questions about any of the scales in the table, please ask me about them. It is extremely important that they be clear to you. You may keep the descriptions with you for reference while completing the scales.

For each of the six scales, you will evaluate the task by typing in a multiple of 5 that can range from 0 to 100 to reflect the point that matches your experience. Pay close attention to each scale's endpoint description when making your assessments. Note that when the rating scale for PERFORMANCE appears, the scale will go from "good" on the *left* to "bad" on the *right*. This means that a *low* number will represent good performance, while a *high* number will signify poor performance. This order has been confusing for some people. Upon completing each scale, press the "return" key to go on to the next one. Read the description for each scale again before making your rating.

NASA-TLX Instructions

Part II

Pairwise Comparisons. Rating scales of this sort are extremely useful, but their utility is diminished by the tendency people have to interpret them in different ways. For example, some people feel that mental or temporal demands are the greatest contributors to workload regardless of the effort they expended in performing a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low; and if they performed poorly, then it must have been high. Still others believe that effort or feelings of frustration are the most important determinants of their experiences of workload. Previous studies using this scale have found several different patterns of results. In addition, the factors that determine workload differ depending on the task. For instance, some tasks might be difficult because they must be completed very quickly. Other tasks may seem easy or hard because the degree of mental or physical effort required. Some task may seem difficult because they cannot be performed well no matter how much effort is expended.

The next step in your evaluation is to assess the relative importance of the six factors in determining how much workload you experienced. You will be presented with pairs of rating scale titles (e.g. EFFORT vs. MENTAL DEMAND) and asked to choose which of the two items was more important to your experience of workload in the task that you just performed. Each pair of scale titles will appear separately on the video screen. Type in “1” if the uppermost scale title in the pair represents the more important contributor to the workload of the task. Type in “2” if the lower scale title in a pair represents the more important contributor to workload. After indicating your response to a pair of scale titles, press the “return” key to go on to the next pair.

Please consider your choices carefully and try to make them consistent with your scale ratings. Refer back to the rating scale definitions if you need to as you proceed. There is no correct pattern of responses. We are only interested in your opinions.

Do you have any questions?

RATING SCALE DEFINITIONS

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	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?
PERFORMANCE	GOOD/POOR	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?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

NASA-TLX Scoring Form

Identification number: ________

Mission number: ____________

Mission name: ______________

Scoring Form 1

1. Mental Demand - Individual

Low High

2. Physical Demand - Individual

Low High

3. Temporal Demand - Individual

Low High

4. Performance - Individual

Good Bad

5. Effort - Individual

Low High

6. Frustration - Individual

Low High

Scoring Form 2

For each of the pairs (e.g., mental demand vs. effort) choose which one of the two items was more important to *your experience of workload* (Circle).

Circle one of each pair:

Sources of Workload Comparisons

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

APPENDIX E: SART (SITUATION AWARENESS RATING TECHNIQUE)

Definitions of SART Rating Scales

Demand on Attentional Resources

Instability: Likelihood of situation changing suddenly.
Complexity: Degree of complication of situation.
Variability: Number of variables changing in situation.

Supply of Attentional Resources

Arousal: Degree of readiness for activity.
Concentration: Degree of readiness for activity.
Division: Amount of attention in situation.
Space Capacity: Amount of attentional left to spare for new variables.

Understanding of the Situation

Information Quantity: Amount of information received and understood.
Information Quality: Degree of goodness of information gained.

		LOW						HIGH
		1	2	3	4	5	6	7
Demand	**Instability of Situation**							
	Variability of Situation							
Supply	**Complexity of Situation**							
	Arousal							
	Spare Mental Capacity							
Under	**Concentration**							
	Division of Attention							
	Information Quantity							
	Information Quality							
	Familiarity							

APPENDIX F: EXPERIMENTER INSTRUCTIONS AND SCRIPT

Experimenter Instructions:

Participants can sign on up to an hour prior to the study. Go to www.ucf.experimentrak.net, choose Status –Researcher and email address – srehfeld@yahoo.com with password robots to check to see if someone is signed up for your session.

Setting up before the session:

- Be sure to arrive at least 15 minutes prior to the start of the session, make sure the experiment is ready for the participant so that they are not kept waiting.
- Check that the binders are ready for the session (**Spatial Abilities** and **TXL/SART** binders for participant and **Experimenter** binder for you!). Two sharpened pencils and a marker should be on the participant desk. The keyboard should be on the desk by the door, far from the participant. The participant computer should be started and in logged into the Operator mode. On the laptop, bring up the IM between the confederate and experimenter for communication.
- Prepare the remaining materials & label scantrons with the corresponding test. Make sure you have a **consent** form, **biographical data** form, **SO** scantrons, **SV** scantrons, **MR** scantrons, **CR** answer sheets, **NASA-TLX** response sheets, and **SART** response sheets as well as the **debriefing form**. Tape two **transparencies** to the participant desk so that the top one is easy to remove. Cover the maps with the cardboard.
- Have the RA phone with you until the participant arrives as that is the contact number in case they are lost or need to reschedule. Make sure your cell phone is turned off after participant is in room.
- If the scheduled time arrives and the participant has not arrived, wait 15 minutes. If the participant does not show, enter a negative credit (-1) in Experimentrak. (0 points if call BEFORE study & try to reschedule)
- At the start of the session, hand the participant the **consent form** and **biographical data form**. Ask them to have a seat to complete the forms. While they are completing the forms, put the "Do Not Enter. Experiment in Progress" sign on the outside of the door, close the experimenter's door and write their information in the **participant log**.
- If anyone knocks on the door, ignore it and tell the participant to do the same. If any startling noise such as a knock on the door or loud conversation in the next office occurs, or if you feel something is wrong with the study (computer crashes, power outage, participant doesn't understand English well) then flag the participants in the **participant log** with a small explanation and let Sherri know about it.
- *During the study, DO NOT disturb the participant – no talking, eating, drinking, candy, or gum and DO NOT enter or exit the room once the session has begun.*

- *Score all of the tests while the participant is taking them (score the SO while they are taking the SV, and so on). If the participant scores above a 14 on the SO, mark them as **high** and if they score below, mark them as **low**. If they score a 14, then wait until they take the SV before marking them – if they get above a 13 on the SV mark them as **high** and if they are below, mark them as **low**. Follow the instructions on the Stratified Assignment sheet.*

Running the experiment:

"Hello. My name is ___________ and I'm running the experiment today. First, I need to ask that you turn off your cell phone or pager *(wait for them to turn it off),* thank you."

"There will be four sections for this session today. First, you will be asked to complete four timed spatial tests. Second, you will see a video that is approximately 20 minutes long. Third, you will be asked to complete the same set of timed spatial tests again. Last, you will complete two missions with an unmanned ground vehicle. If you have any questions along the way, please feel free to ask me."

- **Spatial orientation** survey, provide the participant with the test binder "*This is the first test. Please read through the instructions, please do not turn past page 3, and let me know if you have any questions.*" Allow the participant to read the first 3 pages at their own pace and answer any questions that they may have. Once they have finished reading the instructions, hand them the scantron and say "*You will be using a scantron for this test. Work as quickly as you can without sacrificing accuracy. Your score on this will reflect both the correct and incorrect responses. Therefore, it doesn't help you to guess unless you have an idea which ones are correct. You will have 10 minutes. Do you have any questions?*" Answer any questions and when finished, queue the timer for 10 minutes, press start, and say *"You may begin.*" When the time is up, say "*Please stop.*" and gather the scantron.

- **Spatial visualization** survey, turn the binder to the right page "*This is the second test with 3 pages of instructions; let me know if you have any questions.*" Allow the participant to read the first 3 pages at their own pace and answer any questions that they may have. Once they have finished reading the instructions, hand them the scantron and say "*Just like the last one, you will have 10 minutes so try to work fast with accuracy without guessing at the answer. Do you have any questions?*" Answer any questions, queue the timer for 10 minutes, press start, and say *"You may begin.*" During this time, score the **SO** and follow the directions on the **Stratified Assignment** sheet. When the time is up, say "*Please stop.*" & take the scantron.

- **Mental rotation** test, turn the binder to the right page, "*You are more than half-way done in this section, these 2 pages are the instructions for the third test, let me know if you have any questions.*" Allow the participant to read the first 2 pages. Once they have finished reading the instructions, say "*Here is the scantron. Please remember that there are **always 2 and only 2 correct** answers for each item. Again, please try to work quickly and accurately without guessing. You will have 3 minutes for this test.*" Give them the scantron, queue the timer for 3 minutes, press start and say "*You may begin.*" When the time is up, say "*Please stop.*" and collect the scantron.

- **Card rotations** test, turn the binder to the right page "*This is the last test. Let me know if you have any questions about the instructions.*" Allow the participant to read the first page of instructions at their own pace. Once they are finished, hand them the answer sheet and say "*For each row, be sure to mark for each of the 8 cards whether it is the same or different than the image to the left of the line. As with the other tests, please do not guess and answer as quickly and accurately as possible. Do you have any questions?*" Answer any questions, queue the timer for 3 minutes, and say "*You will have 3 minutes and you may begin.*" and start the timer. When the time is up, say "*Please stop.*" and gather the answer sheet and binder.

- "*That finishes the first portion. You have the option to take a 5-minute break as it will take me a minute to set up the rest of the study.*" Ready the appropriate video for the condition. When you are ready and the participant has returned, *"You will now see a video that will last about 20 minutes."* and start the video. During the video - write the participant's identification number on all materials (including maps) <u>before</u> the session begins and IM the confederate what the condition will be for this session. After the video, "*Now that the video is done, you are more than halfway finished with today's session, and it is important to complete the spatial abilities tests once again."*

- **SO** survey – *"This is the first test that you took before. Please review the instructions and let me know when you are ready to begin."* Queue the timer for 10 minutes and when the participant indicates that they are ready, say *"Just as before, both speed and accuracy are important so work quickly without guessing. You have 10 minutes and you may begin."* Start the timer. When the time is up, say *"Please stop"* and gather the scantron.

- **SV** survey – *"This is the second test. Please look over the instructions and let me know when you are ready to begin.*" Queue the timer for 10 minutes and when the participant indicates that they are ready, say "*You have 10 minutes and you may begin.*" Start the timer. When the time is up, say *"Please stop"* and gather the scantron.

- **MR** test – *"This is the third test and the one that requires 2 answers for each image. Please review the instructions and let me know when you are ready.*" Queue the timer for 3 minutes and when they are ready, *"You have 3 minutes and may begin.*" Start the timer. When the time is up, say *"Please stop"* and gather the scantron.

- **CR** test – *"This is the last test and the one that requires you to determine if each of the 8 images are different than the first one to the left of the line. Here are the instructions, let me know when you are ready.*" Queue the timer for 3 minutes and when they are ready, *"You have 3 minutes and may begin.*" Start the timer. When the time is up, say *"Please stop"* and gather the scantron.

- After the tests, take the **Spatial Abilities** binder and hand the participant the **NASA-TLX** and **SART** instruction binder, *"While I set up the missions, I ask that you please sit here* (indicate the empty chair to the side) *and read through these instructions. This is just to familiarize yourself with them and these same instructions will be* *provided after each mission."* Collect all forms and binders from the participant prior to starting the mission.

- While the participant is reading the instructions, ready the computer for the appropriate condition:

    - Manual Control – double click on the **TV** program, click on the minimize icon, and let the confederate know that you are ready to start. **Turn off the monitor.**

    - Decision Support – bring the keyboard to the participant desk. Double click on the **TV** program and the **Network Chat** program, click on the minimize icon in the TV program, and let the confederate know that you are ready to start. **Turn off the monitor.**

    - Full Automation – double click on the correct Full Auto condition (AB or BA), unobtrusively and quickly, move to the keyboard by the door and press Ctrl+P to pause the video. **Turn off the monitor.**

Make sure that you are reading and following the correct section of automation for that session's condition.

MANUAL CONTROL

- *Place the UGV Location Report in front of the participant and ask the participant to read the directions. When they are finished reading:*
- "You are in charge of a UGV – an unmanned ground vehicle. There are often signal problems and the vehicle signal has just been regained. It will be your job to figure out where the UGV is located at the start of the mission, and several times throughout the mission, and to navigate the UGV back to the base that has the American flag. You will be able to see the map of the area at each of the stops. When the vehicle stops, use the marker to show on the map where you believe the vehicle is located for each stop. Then determine the coordinates and write the coordinates on the UGV Location Report sheet in front of you. For example, write the number 1 and circle it where you believe the vehicle is located when the monitors are first turned on, write a number 2 and circle it when the vehicle stops the next time, and so on *(show the example template over the map)* you will only be able to see the map when the vehicle stops. The vehicle will not be able to go around or over roadblocks. If you encounter a roadblock, redirect the vehicle and follow a clear path. Be sure to stay on the road and don't run over any people or buildings. Do you have any questions?"
- *After answering any questions that the participant may have,* "Okay, now again, when the monitor comes on, mark on the map and write the coordinates where you believe the vehicle is located then use the joystick to navigate the vehicle back to the American base. I will try to answer any questions that you may have but I will not be able to help you in locating or navigating the vehicle."
- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. Be sure that the cardboard is covering the map between UGV location report points. If the participant seems confused at any point, try to address the issue without showing the participant where the vehicle may be located or helping with navigating the vehicle. Throughout the mission, make sure that the participant puts four numbers (1-4) on the map and writes down the corresponding coordinates.*
- *After the mission is complete and the participant has returned to base,* ***turn off the TV monitor***. "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions."
- *Provide the participant with the binder turned to the NASA-TLX page and* ***scoring forms****. At this time, communicate with the confederate that the monitor is off and to change the route and move the vehicle to the second mission. Remove the top map & write the route name / condition on the top of the transparency.*
- *Once the TLX & SART have been completed, remove the binder. "*Again, you are in charge of a UGV and it is your responsibility to determine where the UGV is located and navigate the UGV back to base. Just like the first mission, you will note on the map and write the coordinates for where the UGV is located at the start and throughout the mission. Do you have any questions before you begin?"

- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. Be sure that the cardboard is covering the map between UGV location report points. Throughout the mission, make sure that the participant puts four numbers (1-4) on the map and writes down the corresponding coordinates.*

- *After the mission is complete and the participant has returned to base,* ***turn off the TV monitor***. "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions." *Flip to the End of Session page of the experimenter instructions.*

Make sure that you are reading and following the correct section of automation for that session's condition.

DECISION SUPPORT

- *Place the UGV Location Report in front of the participant and allow the participant to read the directions. When they are finished reading:*
- "You are in charge of a UGV – an unmanned ground vehicle. There are often signal problems and the vehicle signal has just been regained. It will be your job to figure out where the UGV is located at the start of the mission, and several times throughout the mission, and to approve the UGV's route back to the base that has the American flag. You will be able to see the map of the area at each of the stops. When the vehicle stops for location coordinates, use the marker to show on the map where you believe the vehicle is located for each stop. Then determine the coordinates and write the coordinates on the UGV Location Report sheet in front of you. For example, write the number 1 and circle it where you believe the vehicle is located when the monitors are first turned on, write a number 2 and circle it when the vehicle stops the next time, and so on *(show the example template over the map)* you will only be able to see the map when the vehicle stops. The vehicle will not be able to go around or over roadblocks. You have the option to approve or suggest a different direction than the one that the UGV offers using the dialog box. The vehicle will follow directions that are specifically forward, reverse, left, or right. Do you have any questions?"
- *After answering any questions that the participant may have,* "Okay, now again, when the monitor comes on, mark on the map and write the coordinates where you believe the vehicle is located then use the dialog box to approve or suggest direction for the vehicle to return to the American base. I will try to answer any questions that you may have but I will not be able to help you in locating or navigating the vehicle."
- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. Be sure that the cardboard is covering the map between UGV location report points. If the participant seems confused at any point, try to address the issue without showing the participant where the vehicle may be located or helping with navigating the vehicle. Throughout the mission, make sure that the participant puts four numbers (1-4) on the map and writes down the corresponding coordinates.*
- *After the mission is complete and the participant has returned to base,* ***turn off the TV monitor***. "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions."
- *Provide the participant with the binder turned to the NASA-TLX page and* ***scoring forms****. At this time, communicate with the confederate that the monitor is off and to change the route and move the vehicle to the second mission. Remove the top map & write the route name / condition on the top of the transparency.*
- *Once the TLX has been completed, remove the binder. "*Again, you are in charge of a UGV and it is your responsibility to determine where the UGV is located and navigate the UGV back to base. Just like the first mission, you will note on the map and write the coordinates

for where the UGV is located at the start and throughout the mission. Do you have any questions before you begin?"

- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. Be sure that the cardboard is covering the map between UGV location report points. Throughout the mission, make sure that the participant puts four numbers on the map and writes down the coordinates.*
- *After the mission is complete and the participant has returned to base,* ***turn off the TV monitor****.* "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions." *Flip to the End of Session page of the experimenter instructions.*

Make sure that you are reading and following the correct section of automation for that session's condition.

FULL AUTOMATION

- *(Signal to the confederate that you are about to begin the mission portion of the session) Place the UGV Location Report in front of the participant and allow the participant to read the directions. When they are finished reading:*
- "You are in charge of a UGV – an unmanned ground vehicle. There are often signal problems and the vehicle signal has just been regained. It will be your job to figure out where the UGV is located at the start of the mission, and several times throughout the mission while the UGV returns to base that has the American flag. You will be able to see the map of the area at each of the stops. When the vehicle stops, use the marker to show on the map where you believe the vehicle is located for each stop. Then determine the coordinates and write the coordinates on the UGV Location Report sheet in front of you. For example, write the number 1 and circle it where you believe the vehicle is located when the monitors are first turned on, write a number 2 and circle it when the vehicle stops the next time, and so on *(show the example template over the map)* you will only be able to see the map when the vehicle stops. To activate the vehicle again, press the left key on the box in front of you. The vehicle receives signal from the base and is able to return on its own. Do you have any questions?"
- *After answering any questions that the participant may have,* "Okay, now again, when the monitor comes on, mark on the map and write the coordinates where you believe the vehicle is located. The vehicle will return to the American base. I will try to answer any questions that you may have but I will not be able to help you in locating the vehicle on the map."
- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. Be sure that the cardboard is covering the map between UGV location report points. If the participant seems confused at any point, try to address the issue without showing the participant where the vehicle may be located or helping with navigating the vehicle. Throughout the mission, make sure that the participant puts four numbers (1-4) on the map and writes down the corresponding coordinates. When the vehicle stops,* ***quietly*** *press Ctrl+P to pause the vehicle and again to start the vehicle when the participant presses the button.*
- *After the mission is complete and the participant has returned to base,* ***turn off the TV monitor***. "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions."
- *Provide the participant with the binder turned to the NASA-TLX page and* ***scoring forms****. At this time, communicate with the confederate that the monitor is off and to change the route and move the vehicle to the second mission. Remove the top map and write the route & condition on the top of the transparency.*
- *Once the TLX has been completed, remove the binder. "*Again, it is your responsibility to determine where the UGV is located while the UGV returns to base. Just like the first mission, you will note on the map and write the coordinates for where the UGV is located at the start and throughout the mission. Do you have any questions before you begin?"

- *Flip the cardboard covering the map back so that the participant can view the map and turn on the monitor. <u>Be sure that the cardboard is covering the map between UGV location report points</u>. Throughout the mission, make sure that the participant puts four numbers on the map and writes down the coordinates.*

- *After the mission is complete and the participant has returned to base, **turn off the TV monitor**.* "We are interested in the level of workload and awareness of the environment that you experienced during that mission. These are the assessment forms that you read earlier. Please complete the forms and let me know if you have any questions." *Flip to the End of Session page of the experimenter instructions.*

End of Session:

- *Hand the End of Session Survey, "*Please answer these six questions about your experience. If the question does not apply to what you experienced, please circle False."

- *Once the participant has finished with the survey, read the debriefing form, explain the purpose of the study, and answer any questions. Provide the participant with the Research Experience Evaluation Form (**be sure to complete the top of the form**) and ask that they turn it in at the Psychology Department.*

- ***Urge participants to avoid discussing anything about this experiment with other students.*** Thank them for participating.

- *Be sure to keep each participant's materials together and write their participant number and condition on each form.*

Once participants have left (after the session is over):

- Paperclip all of the forms together in the following order:

    1. Spatial orientation scantron
    2. Spatial visualization scantron
    3. Mental rotation scantron
    4. Card rotation scantron
    5. NASA-TLX for mission 1 & 2 (in that order)
    6. SART for mission 1 & 2 (in that order)
    7. UGV location report & map for mission 1 & 2 (collated & in that order)
    8. End of session survey
    9. Biographical data form
    10. Informed consent

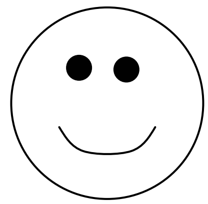
- Place in the data folder.

- Make sure that all of the supplies are stocked and ready for the next session/experimenter. Make sure there are plenty of forms and scantrons. Leave the sharpened pencils for the next session and clean the experimental room. Log onto the

Experimentrak website and update credits for participants who participated (1 point for every 30 minutes) and for those who did not show (-1 credit for no-shows).

- Turn off the monitor and shut down the computer.
- Prepare the room for the next experimenter (computers should be turned off overnight).

You're done!



APPENDIX G: UGV LOCATION REPORT

UGV LOCATION REPORT

There are **two** (2) things that need to be completed at each stop.

First, mark the position of the vehicle on the map exactly where you believe the vehicle is located. Do this by writing the stop number with a circle around it. Second, write the coordinates of the vehicle from the map on this Location Report. Write the letter and the numeral for the section that you believe the vehicle to be located.

For example, when the monitor is first turned on, place a number **1** with a circle around it on the map exactly where you believe the vehicle is located, a number **2** for the second time you will mark the location, and so on. Then, for example, write T28 for a vehicle located in the **T** row at the **28**th column.

If you have any questions, please ask the experimenter.

Stop number:	Location coordinates:
(1)	___________________
(2)	___________________
(3)	___________________
(4)	___________________
(5)	___________________
(6)	___________________
(7)	___________________
(8)	___________________
(9)	___________________
(10)	___________________

APPENDIX H: EXPERIMENTAL MAP

APPENDIX I: CONFEDERATE INSTRUCTIONS

Confederate Instructions:

Setting up before the session:

- Be sure to arrive at the start of the session, to make sure the experiment is ready for the participant.
- Make sure your cell phone or pager and the office phone are turned off.
- *During the study, DO NOT disturb the participant – no loud talking in the confederate room (sounds carry easily into the next room) and DO NOT enter or exit the* experimental *room once the study has begun. If you want to see into the experimental room – be sure to turn off the lights prior to moving the curtain.*

MOUT Room:

- *Turn on all lights for the room*
- *When going into/out of the Iraqi city – be very careful with the cloth "sky" and Velcro as it tends to rip away from the cloth and the wall (hold down the Velcro itself and only hold onto the Velcro, not the cloth when you tear it apart from the wall)*
- *Locate the correct vehicle (#2 – the red one) and make sure the other vehicle is out of the Iraqi city*
- *Batteries:*
    - *When the green light on the charger is steady – the battery is fully charged. Be sure to press the battery firmly onto the tank.*
    - *When replacing an old battery on the charger, be sure that the green light is blinking before you replace the old battery on the charger, otherwise it won't charge.*
- *Put the vehicle in the correct location for that mission (depending on if Route A or Route B is first) and make sure that the proper roadblocks are in place – check the maps on the back of the MOUT room door.*
- *Turn on the vehicle controllers that are attached to the computer and set them up for the proper route to avoid dead spots -* ***Test drive vehicle – watch for dead spots etc****.*

Recording the data:

- Check with the experimenter as to the condition and order of the missions after the spatial tests are scored.
- Label the DVD with the correct identification number of the participant, the mission order, and the condition. For example: 1 Training Decision Support AB represents participant number 1 in the Training condition with Decision Support automation and the mission order is Route A first then Route B.

- Start recording when you receive indication that the participant's monitor will be turned on.
  Using the Magnavox
  - Use only DVD+R and DVD+RW CD's
  - Insert disc
  - Change channel to EXT 2
  - Press RECORD
  - (If no signal appears press STOP, then MONITOR, then RECORD)

- If anything happened during the missions, or if you feel something is wrong with the study (computer crashes, power outage) then, after the session, flag the participants in the participant log with a small notation and let Sherri know about it. Stop recording at the end of the second mission.

Confederate Room:

- Put the "Experiment in Progress." sign on the outside of the door of both MOUT and confederate room. Bring up the IM between the experimenter and confederate for communication. Also activate the Network Chat between the participant and confederate just in case the Decision Support condition will be used.

- Open the "User Manual.doc" file on the desktop and follow the instructions except for the "tracker" part – we will not be using that software.

- **Between missions (move fast!):**

  - If anything was moved in the MOUT city during a mission, return the object to its place of origin, after the monitor is turned off.

  - Change the roadblocks from the first mission to the arranged places for the second mission; see maps on the back of the MOUT door.

  - Communicate with the experimenter through IM that the city is ready.

Running the experiment for the *Manual Control* condition:

- Follow along as the participant drives the vehicle throughout the city and stop the vehicle by clicking the joystick trigger at the preplanned points (refer to map with indications). Once the participant realizes that the UGV will not move and that they need to write the coordinates, click the trigger again so that the participant has control over the vehicle again.

- Follow the "**Between missions**" section mentioned above.

Running the experiment for the *Decision Support* condition:

- Double click on the Network Chat program. When the monitor has been turned on and the participant is ready, follow the dialogues for each mission. You are a robot – type and drive like a robot.

Chat dialogue Route A:

- Type: ***Vehicle to activate right turn. Please "approve" or suggest "right, forward, or reverse"*** (don't move until participant types "approve" or a different direction – if anything else is typed, repeat above line)
- At each intersection, look at each direction & suggest the direction that is a clear path and type ***Vehicle to activate (direction). Please "approve" or suggest "left, right, forward, or reverse"*** (leave out the direction in the typed part that you suggested).
- If participant suggests different direction, type ***(direction) confirmed*** and attempt to drive that direction. When the roadblock is apparent, type ***Obstacle noted. Vehicle to reverse, please "approve".*** Do not move until they approve then suggest clear/correct direction.
- At each location report point (refer to map indications), type, ***Location report requested. Please type "ready" when location is recorded.*** Suggest direction. When UGV is at base, ***Mission accomplished***.

Chat dialogue Route B:

- Type: ***Vehicle to activate forward direction. Please "approve" or suggest "right, left, or reverse"*** (don't move until participant types "approve" or a different direction – if anything else is typed, repeat above line)
- At each intersection, look at each direction & suggest the direction that is a clear path and type ***Please "approve" or suggest "left, right, forward, or reverse"*** (leave out the direction in the typed part that you suggested).
- If participant suggests different direction, type ***(direction) confirmed*** and attempt to drive that direction. When the roadblock is apparent, type ***Obstacle noted. Vehicle to reverse, please "approve".*** Do not move until they approve then suggest clear/correct direction.
- At each location report point (refer to map indications), type, ***Location report requested. Please type "ready" when location is recorded***. Suggest direction. When UGV is at base, ***Mission accomplished***.

APPENDIX J: STRATIFIED ASSIGNMENT

Stratified Assignment

Level of Automation Condition:

Training Condition:		***Manual Control***		***Decision Support***		***Full Automation***	
***Training*:**		**High**	**Low**	**High**	**Low**	**High**	**Low**
	High						
	Low						
***No Training*:**							
	High						
	Low						

1) Score the scantrons for SO (above 14 is high, below is low – if they get a 14, score the SV) & SV (above 13 is high, below is low).

2) On this sheet, below the *Training* or *No Training* condition in the left-most column; write the participant number in the cell to the left of High or Low based on their score (we want the cells to be equal).
3) Go to Order of Conditions folder & determine the next condition based on the training condition that the participant will be in.
4) Fill out the Order of Conditions for that participant in the Order of Conditions folder.
5) On this sheet, write the participant number in the cell below Level of Automation condition for the conditions that they are in.

The aim is to have an equal number of high and low spatial ability participants in all levels of both IVs.

APPENDIX K: ORDER OF CONDITIONS

ORDER OF CONDITIONS:

	Training/ Control/ Route Order	Date/Time of session	Initials	Total N MC AB	Total T MC AB	Total T DS BA	Total N DS BA	Total T FA AB	Total N FA AB	Total N DS AB	Total T DS AB	Total N MC BA	Total T MC BA	Total N FA BA	Total T FA BA
1	**N/ MC/ AB**														
2	**T/ MC/ AB**														
3	**T/ DS/ BA**														
4	**N/ DS/ BA**														
5	**T/ FA/ AB**														
6	**N/ FA/ AB**														
7	**N/ DS/ AB**														
8	**T/ DS/ AB**														
9	**N/ MC/ BA**														
10	**T/ MC/ BA**														
11	**N/ FA/ BA**														
12	**T/ FA/ BA**														
13	**N/ MC/ AB**														
14	**T/ MC/ AB**														
15	**T/ DS/ BA**														
16	**N/ DS/ BA**														
17	**T/ FA/ AB**														
18	**N/ FA/ AB**														
19	**N/ DS/ AB**														
20	**T/ DS/ AB**														

N/ MC/ AB	= No Training Video	Manual Vehicle Control	Route A then Route B
E/ MC/ AB	= Training Video	Manual Vehicle Control	Route A then Route B
E/ DS/ BA	= Training Video	Decision Support Vehicle Control	Route B then Route A
N/ DS/ BA	= No Training Video	Decision Support Control	Route B then Route A
E/ FA/ AB	= Training Video	Full Automation Vehicle Control	Route A then Route B
N/ FA/ AB	= No Training Video	Full Automation Vehicle Control	Route A then Route B
N/ DS/ AB	= No Training Video	Decision Support Vehicle Control	Route A then Route B
E/ DS/ AB	= Training Video	Decision Support Vehicle Control	Route A then Route B
N/ MC/ BA	= No Training Video	Manual Vehicle Control	Route B then Route A
E/ MC/ BA	= Training Video	Manual Vehicle Control	Route B then Route A
N/ FA/ BA	= No Training Video	Full Automation Vehicle Control	Route B then Route A
E/ FA/ BA	= Training Video	Full Automation Vehicle Control	Route B then Route A

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