2006

The Effects On Operator Performance And Workload When Gunnery And Robotic Control Tasks Are Performed Concurrently

Carla Joyner
University of Central Florida

THE EFFECTS ON OPERATOR PERFORMANCE AND WORKLOAD WHEN GUNNERY AND ROBOTIC CONTROL TASKS ARE PERFORMED CONCURRENTLY

by

CARLA THOMAS JOYNER
B.S. United States Military Academy, 1996
M.S. University of Phoenix, 2000

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Spring Term
2006

ABSTRACT

The purpose of this research was to examine operator workload and performance in a high risk, multi-task environment. Specifically, the research examined if a gunner of a Future Combat System, such as a Mounted Combat System, could effectively detect targets in the immediate environment while concurrently operating robotic assets in a remote environment. It also analyzed possible effects of individual difference factors, such as spatial ability and attentional control, on operator performance and workload. The experimental conditions included a gunner baseline and concurrent task conditions where participants simultaneously performed gunnery tasks and one of the following tasks: monitor an unmanned ground vehicle (UGV) via a video feed (Monitor), manage a semi-autonomous UGV, and teleoperate a UGV (Teleop). The analysis showed that the asset condition significantly impacted gunnery performance with the gunner baseline having the highest number of targets detected (M = 13.600 , SD = 2.353), and concurrent Teleop condition the lowest (M = 9.325 , SD = 2.424). The research also found that high spatial ability participants tended to detect more targets than low spatial ability participants. Robotic task performance was also affect by the asset condition. The results showed that the robotic target detection rate was lower for the concurrent task conditions. A significant difference was seen between the UGV-baseline (80.1%) when participants performed UGV tasks only and UGV-concurrent conditions (67.5%) when the participants performed UGV tasks concurrently with gunnery tasks. Overall, this study revealed that there were performance decrements for the gunnery tasks as well as the robotic tasks when the tasks were performed concurrently.

ACKNOWLEDGMENTS

I would like to thank each of my committee members. I thank Dr. Pamela McCauley-Bell, who served as the committee chair, for her guidance and direction in the conduct of this research. I would also like to thank Dr. Linda Malone for her worthwhile advice and words of encouragement. Thanks are also due to Dr. Jessie Chen for her expertise and for providing this research opportunity with Army Research Laboratory.

This research was funded by the Robotics Collaboration Army Technology Objective of the U.S. Army. I would like to thank the U.S. Army Research Laboratory, Human Research and Engineering Directorate for its support and guidance throughout the process of this research project. I also thank the RDECOM- Simulation and Training Technology Center (STTC) and the University of Central Florida- Institute for Simulation and Training, particularly Mr. Charles “Andy” Houchin and Mr. Dean Reed, for providing the resources, technical assistance and simulator that were used in this research.

I could not have completed this research without the support of my family. I thank my husband, Michael, for his continued support. I dedicate this paper to my daughter, Olivia, who was so patient and loving throughout this process. I hope that she will understand the importance of this process and continued education in the future. She is my little angel, and I love her dearly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS/ACRONYMS

ANOVA	Analysis of Variance
ATR	Automatic target recognition
ARV	Armed Reconnaissance Vehicle
BLOS	beyond-line-of-sight
CCT	Cube Comparison Test
FCS	Future Combat System
LOS	line-of-sight
MCS	mounted combat system
OCU	operator control unit
PAC	perceived attentional control
RCTA	Robotics Collaborative Technology Alliance
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SOT	Spatial Orientation Test
SSQ	Simulator Sickness Questionnaire
TCU	Tactical Control Unit
TS	total severity
TSS	Total Severity Score
UGV	unmanned ground vehicle
XUV	eXperimental unmanned vehicle

CHAPTER ONE: INTRODUCTION

The United States Army is undergoing transformation to a Future Force. The cornerstone of this force is the Future Combat System (FCS), a family of "networked air and ground-based maneuver, maneuver support, and sustainment systems that will include manned and unmanned platforms" (TRADOC, 2003, p. 1-4) linked together by extensive communication networks. Figure 1 provides a graphical depiction of the FCS core systems.

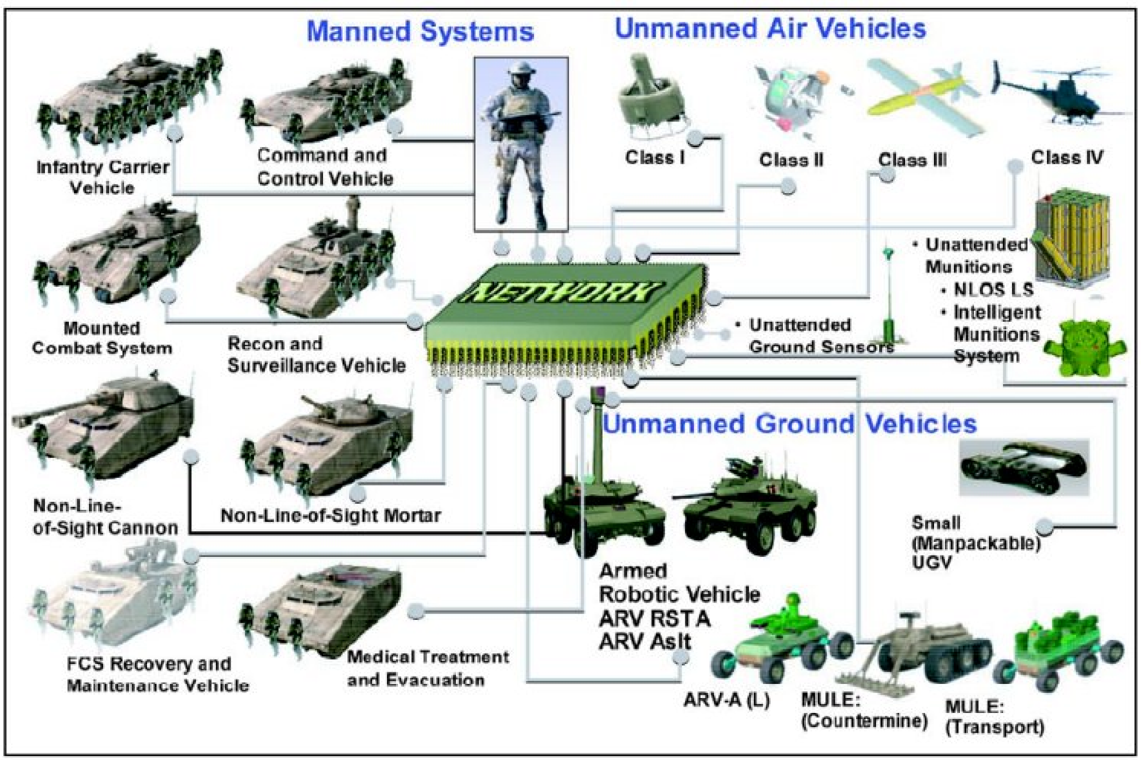

Figure 1. Future Combat System (FCS) network of systems (*Future Combat Systems (FCS*), 2005).

A key trend of the U.S. Army transformation and the FCS is that units be lighter and require minimal resources for deployment via military aircraft. A lighter and more agile force also includes fewer soldiers and crews to operate and maintain the FCSs. With the reduction of personnel, the concern arises as to who will control the unmanned assets that are an integral part of unit survivability and a combat multiplier on the battlefield. Soldiers will be called on to perform their primary task and take on the role as robotic operators in control of unmanned assets and their missions.

This multi-tasking is evident in the Mounted Combat System (MCS) Company, which has a combination of manned and unmanned assets. The MCS Company is equivalent to the current tank company but will have lighter and fewer vehicles as well as personnel than the current tank company (Gaylord, 2004). Figures 2 and 3 are examples of the U.S. Army’s principal combat tank currently in use and the lighter and smaller MCS future system, respectively.

Figure 2. M1A2 tank, the principal combat tank of the U.S. Army (Photo courtesy of U.S. Army)

Figure 3. Future Combat System Mounted Combat System (MCS) (Photo courtesy of the U.S. Army)

The MCS Company will have a headquarters section and three platoons. Each platoon has three MCS with nine soldiers, including a vehicle commander, gunner and crew chief/driver on each system (TRADOC, 2003). Each platoon also will have an Armed Reconnaissance Vehicle (ARV), which is a version of an Unmanned Ground Vehicle. However, there is no dedicated operator to control the platoon's ARV. Figure 4 is an organizational diagram of the MCS Company.

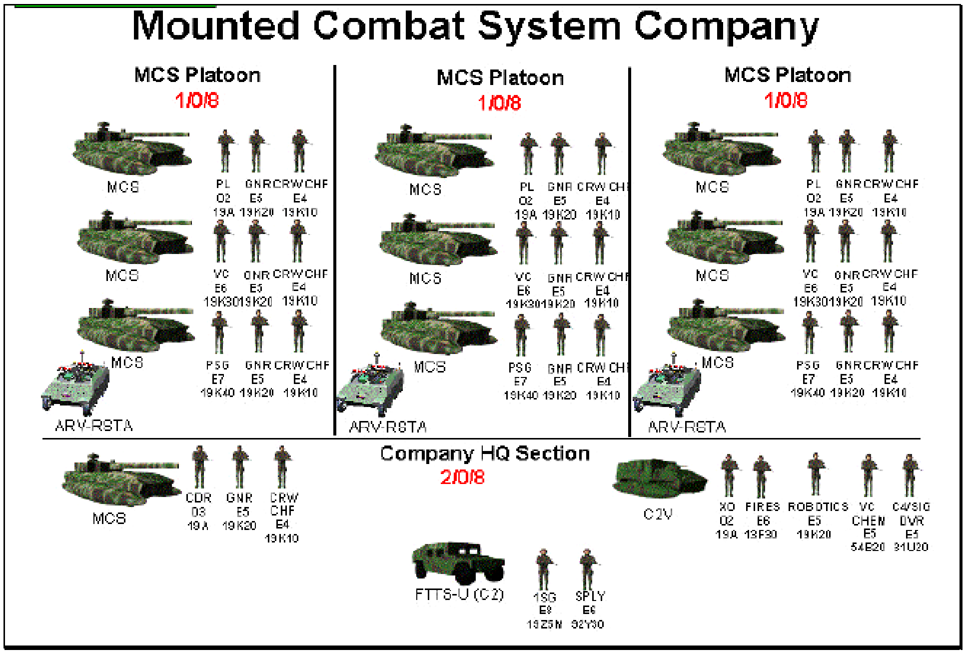

Figure 4. Organizational Diagram of MCS Company (TRADOC, 2003)

One of the three soldiers (i.e., vehicle commander, driver, or gunner) assigned to the MCS will be called on to perform his primary task and take on the role as robotic operator in control of an unmanned ARV and its missions. Mitchell (2005) conducted a workload analysis of the MCS platoon's use of unmanned assets. The Improved Performance Research Integration Tool (IMPRINT), a computer simulation tool, was used to model the performance of the crewmembers when the robotic control tasks were assigned to the MCS driver and gunner. She examined the workload of each crewmember during each scenario and found the gunner had the fewest instances of overload and could assume control of the ARV and its associated tasks.

Mitchell's (2005) study was the basis for this current research. Although results from the human performance model showed the gunner was the most viable option to control the

ARV, there were instances in the model when the gunner dropped his primary tasks of detecting and engaging targets to perform robotic control tasks. A decline in the performance of the gunner's task could threaten the survivability of the MCS crew and be catastrophic to the assigned mission. Due to the criticality of gunnery as well as the robotic operations, additional research with human participants actually performing gunnery and robotic tasks was necessary. The desired outcome of this research was empirical data that could be used to determine the feasibility of an operator, such as a gunner in this case, performing his primary duties and the duties of a robotic operator in control of unmanned vehicles.

Research Purpose

The primary purpose of this research was to conduct a simulator-based study to examine operator workload and performance in a high risk, multi-task environment. This research studied the effects of secondary robotic control tasks on the performance of critical primary tasks when the tasks were performed concurrently in a simulated environment. Specifically, the research examined if a gunner of a Future Combat System, such as a Mounted Combat System, could effectively detect targets in the immediate environment while concurrently operating robotic assets in a remote environment. It also analyzed possible effects of individual difference factors, such as spatial ability and attentional control, on operator performance and workload. The ultimate goal of this research was to provide useful input on concurrent operator performance to the FCS design teams, as well as other organizations in the Department of Defense and outside agencies that operate unmanned assets.

Research Questions

To achieve the goals of this study, several research questions were posed. They include the following:

- Does the addition of the robotic control tasks adversely impact the gunnery task performance?
- How does the secondary task complexity/density impact task performance?
- Which robotic control type produces better performance?

- Does spatial ability influence performance of concurrent tasks?
- Does attention control influence performance of concurrent tasks?
- How is perceived workload affected by the type of asset used?

In order to answer these research questions, a literature review was performed. Based on the findings from the literature and the objectives of this research, an empirical study was conducted. The subsequent chapters will provide detailed information on the literature and methodology used to answer these questions.

CHAPTER TWO: REVIEW OF LITERATURE

This review of literature begins with a brief discussion of past Human Factors studies of Future Combat Systems. This discussion will be followed by an explanation of the levels of robotic control, focusing on the levels that are applicable to this study. Models to predict operator performance of multiple tasks are discussed next and include accounts of how individual difference factors may affect multiple task performance. The subsequent section explains ways to assess mental workload. Finally, the review ends with research on visual search and concepts that may affect operator performance of dual tasks.

Human Factors in Future Combat Systems

Human Factors research is critical to the design and development of Future Combat Systems. Since the FCS are smaller and lighter than current U.S. Army systems, research is required to optimize human performance and to ensure users have safe, efficient and effective operational systems. Schipani (2003) conducted field studies to assess operator mental workload during the operation of the Army's Experimental Unmanned Ground Vehicle (XUV), a vehicle used to test FCS concepts and simulated in the current study. Figure 5 is a photo of the XUV used in the field studies.

Figure 5. The Experimental Unmanned Ground Vehicle (XUV) (Schipani, 2003).

Schipani (2003) manipulated the levels of autonomous mobility of the XUV to determine the impact of operator perceived workload. His research revealed that mental workload increased when human intervention was required and when the terrain became more difficult to traverse. His research findings provided baseline performance criteria for persons who will operate partially autonomous vehicles.

Other Human Factors research has included studies on the proper crew size for FCS. Because the vehicles are smaller and weight is a design issue, careful consideration must be given to the number of personnel assigned to a system. The minimal number of persons should be assigned to a system without sacrificing operational capability. Mitchell, Samms, Henthorn, and Wojciechowski (2003) conducted a study on the number of crew members that should be assigned to the Mounted Combat System and other FCS platforms. The study used a computer simulation tool, IMPRINT, to conduct a two- versus three-soldier crew analysis. The results showed that a two-soldier crew might be viable for non-combat vehicles. However, combat vehicles, including the MCS, require a three-soldier crew due to their high-risk environment. The results of the study influenced the operational and organizational requirement document, which changed the MCS requirement from two crew members to three (TRADOC, 2003).

The research mentioned above is just a few of the Human Factors studies that have contributed to the development of the FCS. They are highlighted because they are applicable to the current study. Other research has focused on comparative studies between operator performance with current U.S. Army systems and with FCS (Gaylord, 2004). It is hopeful that the findings from the current study will be added to the library of Human Factors research used by system developers and researchers.

Levels of Robotic Control

In the study of Human-Robot-Interaction, it is important to discuss the level of control with which human operators control unmanned vehicles. Endsley and Kaber (1999) proposed five possible levels of control from manual to fully automated. A task may be accomplished (a) by a human operator with no assistance from the system; (b) by the operator with recommendation from the system; (c) by the system with consent from the operator; (d) by the system automatically with the operator's ability to intervene when necessary; or (e) by the system fully automatic with no human interaction. Due to the uncertainty of the natural environment, the U.S. military has not adopted full autonomous control of unmanned vehicles. With this in mind, this research will focus on manual or teleoperated control and semiautonomous control.

Teleoperated robots have been used in various settings including military settings (e.g., route reconnaissance or investigating hazardous and dangerous environments), underwater marine explorations, NASA space missions (e.g., Mars Rovers), and search and rescue missions (e.g., rescue activities after the 2001 World Trade Center attack) (Chen, Haas, Pillalamarri, & Jacobson, under review). Regardless of the setting, the robots are manually controlled or teleoperated from a remote location by a human operator. This type of remote control introduces human performance issues. With teleoperated control, the operator performance is "limited by [his or her] motor skills and ability to maintain situational awareness. . . difficulty building mental models of remote environments. . .distance estimation and obstacle detection" (Fong, Thorpe, & Baur, 2003). Additionally, only a small portion of the environment is visible due to the video feed captured by the robot sensors, limiting the operator's field of view. These factors are challenges that affect operator performance, particularly in a multiple task environment.

Semi-autonomous control closely resembles the fourth level of control as described by (Endsley & Kaber, 1999). The system performs tasks automatically with human operator intervention at critical decision points. Some advantages of this type of control are the reduction of manual workload and fatigue, relief from routine operations or repetitive tasks, and more precise handling of routine operations (Wierner, 1985). With these benefits also come operator potential performance issues. Parasuraman, Sheridan, and Wickens (2000) discussed the effect of automation on human performance, including increased mental workload, decreased situation awareness, and degradation in skill. The use of automation increases the operator's monitoring and supervisory demands as he observes the system, which may increase mental workload. Operator situation awareness of the environment may decrease due to his over reliance on the system to perform tasks. The skills required to perform the task may also degrade with the introduction of automation. This degradation will be most obvious when automation fails or is not available and the operator must continue the task. As a remedy to these performance issues, researchers have explored advanced concepts such as adaptive automation, which dynamically allocates control functions between human operators and automated systems over time based on the state of the environment (Barnes, Cosenzo, Mitchell, & Chen, 2005; Kaber & Riley, 1999).

Predicting Multiple Task Performance

Performing two or more tasks at the same time can be difficult and sometimes impossible. When one has to accomplish more than one task at a time, performance of at least one of the tasks suffers. When this situation occurs, it is called time-sharing or divided attention. Psychologists have explored this phenomenon to gain insight into the way humans process information in multitask settings. It is generally accepted that humans have a "limited capacity to process information" and that capacity may be exceeded if several tasks are performed concurrently (Sanders & McCormick, 1993). Models and theories have been developed to study time-sharing and to predict how individuals will process inputs from multiple tasks. The recent theories are based on the concept of a limited pool of resources. Two that will be discussed for this research are the single resource theories and multiple resource theories.

Single Resource Theories

The basis of the single resource theories is that all mental processes share one pool of resources (Kahneman, 1973; Moray, 1967). These theories provide explanations of how task difficulty affects concurrent task performance. Generally, greater task difficulty demands more of the limited resources, leaving fewer resources to perform the remaining tasks (Sanders & McCormick, 1993). The theories also explains how resources can be allocated to different tasks as needed (Wickens, 2002). If one task is simple and requires little to no resources, the majority of the resources can be allocated to another concurrent task (Norman & Bobrow, 1975). One can make the assumption from the resource theory that easier tasks use fewer resources than more challenging tasks.

Some researchers have argued against the single resource theories because these theories do not explain (1) why tasks that use the same memory codes or processing modalities experience more task interference than tasks that shared different memory codes and processing modalities; (2) why in some cases an increase in task difficulty in one task does not effect the performance of the others; and (3) why time-sharing is perfect for some tasks (Sanders & McCormick, 1993; Wickens, 1984). To account for these issues, the multiple resource theories were developed.

Multiple Resource Theories

Multiple resource theories postulate several independent pools of resources, instead of the one source of resources as in the single resource theory (Kantowitz & Knight, 1976; Navon & Gopher, 1979; Wickens, 1980). These theories predict improved time-sharing and concurrent task performance due to tasks using different resources. Wickens (1984) provides four dimensions along which these resources may be allocated:

1. Stages: Perceptual and central processing versus response selection and execution. Research found that a tracking task, requiring response selection and allocation resources, interfered with another tracking task, but not with an arithmetic task that demanded central processing resources (Wickens & Kessel, 1980).

2. Perceptual modalities:

a. Auditory versus visual. Research has consistently showed that time-sharing is more efficient when concurrent tasks use different modalities (e.g., one presented visually and the other aurally). Dickson, Wickens, and Chang (2003) and Wickens, Sandry, and Vidulich (1983) found advantages of cross-modal displays in tracking experiments in the laboratory as well as in complex flight simulation. Other research showed that route guidance is better when presented with an auditory display rather than a visual display (Parkes & Coleman, 1990).

b. Visual channels. Another component of the input modalities are the two aspects of visual processing, known as focal and ambient vision. These visual channels define separate resources to support efficient time-sharing and use different types of information processing (Previc, 1998; Vidulich, 1988; Weinstein & Wickens, 1992). Focal vision requires high visual acuity necessary for fine details and usually includes the fovea of the field of view. Ambient vision involves spatial orientation and includes the peripheral vision. Weinstein and Wickens (1992) found that two peripherally located tasks were found to interfere more than one central and one peripheral task or two central tasks.

3. Processing codes: Spatial versus verbal. Spatial tasks involve moving, positioning or orienting objects in space (e.g., moving a joystick, mouse or steering wheel). Verbal tasks involve words, language or logical operations. Investigations have shown that time-sharing was better with one spatial and one verbal task than with two spatial tasks or two verbal tasks (Martin, 1989; Sarno & Wickens, 1995; Vidulich, 1988; Wickens, 1980; Wickens et al., 1983).

4. Responses: Vocal versus manual response. A vocal response such as calling out digits can be time-shared with a manual response such as a tracking task (Sanders & McCormick, 1993). However, entering digits on a keypad will not provide successful time-sharing with a tracking task (Sanders & McCormick, 1993).

Considering the time-sharing situation of the current study, acquiring targets while controlling a robot in a remote area, it is predicted that competition will exist for input modality, processing codes, and response resources since both tasks required spatial processing codes, visual input modality and manual responses. To the extent that these tasks require the same resources, performance is predicted to decline in this time-sharing situation.

Individual Difference Factors

The theories above provide generalizations about the capacity of humans. However, it is also important to realize that it is individual differences in people that make them perform differently under given situations. In a multiple task setting, some people perform better than others because they possess certain characteristics. Two characteristics that are explored in this research are individual spatial ability and attentional control. It is expected that these two traits will affect an operator's ability to perform multiple tasks. A brief summary of research for both of these concepts is provided below.

Spatial Ability

Spatial ability is part of the intellect that allows an individual to create, maintain, recover, and transform visual images. Ekstrom, French, and Harman (1976) provides a definition of spatial ability as "the ability to perceive spatial patterns or to maintain orientation with respect to objects in space" (p. 25). It follows that those who have good or high spatial ability are able to encode spatial information more easily, more accurately, and in more detail than those with poor or low spatial ability. Spatial abilities have been used to predict success in navigation performance in natural and virtual environments. In the context of this current study, research has shown that those with higher spatial ability performed better when operating unmanned vehicles (Chen, Durlach, Sloan, & Bowens, 2005) since this task requires one to transform one's view into another view of the environment in a remote location.

Attentional Control

Attentional control is a coping strategy to deal with stressful situations. Derryberry and Reed (2002) define attentional control as the "general capacity to control attention in relation to a positive as well as negative reaction." A scale of attentional control was derived from the attention focusing and shifting measures to determine one's ability to divert his attention to the appropriate task as necessary (Derryberry & Reed, 2002). Studies have shown that individuals with good attentional control coped with threats and other negative stimuli better that those with poor attentional control (Derryberry & Reed, 2002). Given this background information, it is expected that those with good attentional control will be able to efficiently manage concurrent tasks in a multitask setting because they have the ability to allocate resources based on task needs.

Assessing Mental Workload

The concept of mental workload has increasingly become an interest in academia and in industry. In fact, organizations have based their decision to downsize or eliminate positions on whether the remaining personnel could perform the remaining tasks without experiencing excessive workload. This was evident in the late 1970s when the flight engineer positions were eliminated to reduce the size of the medium-range jet aircraft (Lerner, 1983). The Army has also performed workload studies for crewmembers on newly designed systems. The general concern is how much work can be imposed on an operator without degradation in performance. The standard questions include (Wickens & Hollands, 1999):

How busy is the operator? How complex are the tasks? Can any additional tasks be handled above and beyond those that are already performed? Will the operator be able to respond to unexpected events? And how does the operator feel about the difficulty of the tasks being performed?

In order to answer these questions, one must first understand the definition of mental workload. Workload in its basic form is the “work” that is “loaded” on an operator (Huey & Wickens, 1993). Although a variety of interpretations and definitions of workload exists, this research uses the definition provided by Sanders and McCormick (1993): "a measurable quantity of information processing demands place on an individual by a task." Task performance depends on how many mental resources are allocated to the tasks and whether the mental resources can contribute to the task efficiently.

The concept of mental workload may provide theoretical insights into the above reports of performance degradation in a multitask environment. When the mental resource limit for one task has been met, the performance of the second task demanding the same resources will decrease (Meshkati, Hancock, Rahimi, & Dawes, 1995; Wickens, 1984; Wickens & Hollands, 1999). Task complexity also plays a role in workload and ultimately performance. As the complexity of a task or concurrent tasks increases, workload also increases. Findings showed that air traffic controllers experienced higher workload when the number of aircraft they had to control increased (Hurst & Rose, 1978). However, (Kantowitz & Casper, 1988) showed that cognitive complexity influenced workload more than the number of task elements. This was also evident in human-robot-interaction research that found that operator workload tends to increase when human intervention is required, as when the operator has to operate the robot in teleoperation mode or tend to the robot during a system failure (Schipani, 2003).

In addition to the limitation of human processing facilities and complexity of tasks, other factors may impact workload significantly. In a military setting of a combat system crew, as in this research, "fatigue, stress, training, crew coordination, and environmental stressors (e.g. heat, cold, vibration, noise, and danger)" influence operator workload (Huey & Wickens, 1993). Although best if all these factors were examined, it was not feasible or economically possible to study the effects of all these factors on operator workload in the multitask environment. However, crew coordination was integrated into a side task that will be discussed later.

The most typical ways to measure workload are classified into four broad categories: primary-task measures, secondary task techniques, physiological measures, and subjective rating measures (Wickens & Hollands, 1999). Physiological techniques are obtrusive since they usually require some type of device to be attached to the operators, which may interfere with task performance. With primary task measures, the two primary tasks may differ in how they are measured or what those measures mean, making a comparison difficult to interpret. Because of these reasons, only secondary task technique and subjective rating measures are used.

Secondary Task Technique

Using a secondary task technique to measure workload is a technique that has a long history (Ogden, Levine, & Eisner, 1979; Rolfe, 1973). The basic principle behind this technique is that the secondary task will use the residual capacity or resources that the primary task does not use. In fact, research has shown secondary task performance to be inversely proportional to the primary-task resource demands (Wickens & Hollands, 1999). A variety of secondary tasks have been proposed and used as far back as the 1960s. The rhythmic tapping task calls for the operator to tap his finger or foot at a constant rate (Michon, 1966; Michon & Van Doorne, 1967). The results show an increase in the variability of taps as the primary task workload increases. The random number generator calls for the operator to provide a series of random numbers (Baddeley, 1966; Wetherell, 1981). As workload increases, the operator's numbers are less random and become more repetitive. Another secondary task is the probe reaction time task. An assumption with this task is that increased primary task workload will result in a delayed reaction time to the secondary task stimulus (Kantowitz, Bortalussi, & Hart, 1987; Lansman & Hunt, 1982). These traditional techniques are dated and have been deemed obtrusive due to their tendency to disrupt performance of the primary task; however they are still referenced for workload measurements. A more recent technique is the use of embedded secondary task, which is "actually a legitimate component of the operator's total task responsibilities," but has lower priority than the primary task (Wickens & Hollands, 1999). Cummings and Guerlain (2004) also adds that the embedding task appears to be a part of the natural work environment.

An implication for this study is that secondary task should have lower priority than the primary task when using the secondary technique to measure workload. Additionally, the secondary task should use similar resources as the primary task. For example, a "secondary task of vocally responding to heard digits (auditory verbal speech) would mismatch the resource demands of driving (visual-spatial manual task)" (Wickens & Hollands, 1999). This in turn might underestimate primary driving task.

Subjective Measures

Subjective techniques are less obtrusive, easy to administer and provide reliable results. There are various techniques used to assess the subject's effort to perform a task. The oldest and most validated measure is the Cooper-Harper Scale (Cooper & Harper, 1969), which can be used for a wide variety of motor and psychomotor tasks with minimal rewording. The two most commonly used "multi-dimensional" assessments are the NASA Task Load Index (TLX) 7-point scale (Hart & Staveland, 1988) and the subjective workload assessment (SWAT) 3-point scale (Reid & Nygren, 1988). Both of these scales result in a single score for workload. Although they produce similar outcomes, the NASA-TLX scores are most consistent among people doing the same task (Vidulich & Tsang, 1985). Because of the consistency of scores, the NASA-TLX was adapted for this study to measure operator perceived workload.

Visual Search

Past research on visual performance demonstrated that as the size of the search set increased, performance degraded in terms of either speed or accuracy or both (Scanlan, 1977). Murray (1994) showed that as the number of the monitored display increased, operators' reaction time for their target search tasks also increased linearly. In fact, reaction time almost doubled when the number of displays increased from 1 to 2 and from 2 to 3 (a slope of 1.94 was obtained). According to Wickens, Dixon, and Chang (2003), visual angle separation larger than about 6.4 ~ 7.5 degrees may degrade event monitoring response time.

In the case of concurrent performance of gunner's and robotic operator's tasks in this study, it was expected that performance would be worse than when the operator only had to perform one task since concurrent tasks involved more displays to visually scan. In addition, research has shown that increased mental workload could reduce the size of operator's visual field (Rantanen & Goldberg, 1999). It was expected that the reduced visual field would have a significant impact on the operator's gunnery task performance (i.e., target detection in his immediate environment). Finally, signal-noise ratios were expected to impact operator's performance (Wickens, 1992). As visual noise increased in either the gunner's immediate environment or in the remote environment where the robots were located, the gunner's target detection performance was expected to degrade.

Summary

The primary objective of this research was to examine operator workload and performance when gunnery and robotic tasks were performed concurrently. Given the background information from the literature review, it was expected that performance would decline because robotic and gunnery tasks would compete for a limited pool of resources. Based on the individual difference literature, it was expected that those with good attentional control and spatial ability would perform better than those with low attentional control and spatial ability. Using the NASA-TLX subjective workload measure, it was expected that operator workload would be perceived higher when tasks were performed simultaneously than when tasks were performed alone. Table 1 highlights the literature that was used to make these predictions and the areas that are most significant to this study.

Table 1. Most Significant Areas of Literature Review

Reference	Predicting Multi-task Performance				Workload Assessment	Visual Search
	MRT	SRT	Individual Difference Factors			
			Spatial Ability	Attentional Focus		
Sanders & McCormick, 1993	X	X			X	
Norman & Bobrow, 1975		X				
Wickens, 2002	X	X			X	
Kahnemann, 1973		X				
Kantowitz & Knight, 1976	X					
Navon & Gopher, 1979	X					
Wickens, 1989	X	X				
Dickson, Wickens, & Chang, 2003	X	X				X
Martin, 1989	X					
Sarno & Wickens, 1995	X	X				
Vidulich, 1988	X					
Chen, et. al., 2005			X			
Ekstrom, French & Harman, 1976			X			
Derryberry & Reed				X		
Wickens & Holland, 1999					X	
Hart & Staveland, 1988					X	
Vidulich & Tsang, 1985					X	
Murray, 1994						X
Rantanen & Goldberg, 1999					X	X
Wickens, 1992						X

CHAPTER THREE: METHODOLOGY

To achieve the research objectives, an empirical study was performed using a MCS simulated environment. The participants' workload and performance of the combined position of gunner and robotic operator were examined. The experimental tasks included a primary gunnery task and a secondary robotic task using different robotic control assets. Participants also performed a tertiary communication task, which was not manipulated as a variable, but was used to simulate the gunner's communication with fellow crew members. Performance measures were obtained for each of these tasks. Additionally, the participants' spatial ability and attentional control were examined to determine if there were relationships between task performance and these individual difference factors. The following details characterized the experiment.

Participants

Twenty students (17 males and 3 females) attending the University of Central Florida were recruited to participate in this experiment. Each participant was required to have at least 20/20 normal or corrected vision. The age range was between 18 and 43. The age mean was 22.2 (6.4). The participants received $8 per hour of participation and/or extra class credit.

Apparatus

The simulator used for this study consisted of two systems with separate screens and controls: a simulated gunnery station and a tactical control unit to manage unmanned vehicles.

The gunnery component simulated the out-of-the-window view for line-of-sight (LOS) and beyond-line-of-sight (BLOS) fire capabilities of a Mounted Combat System (Figures 6 and 7). The interface consists of a 15” KOGI flat panel monitor and a FighterStick USB joystick. Participants used the joystick to rotate the sensors 360 degrees, zoom in and out, switch between firing modes, and engage targets.

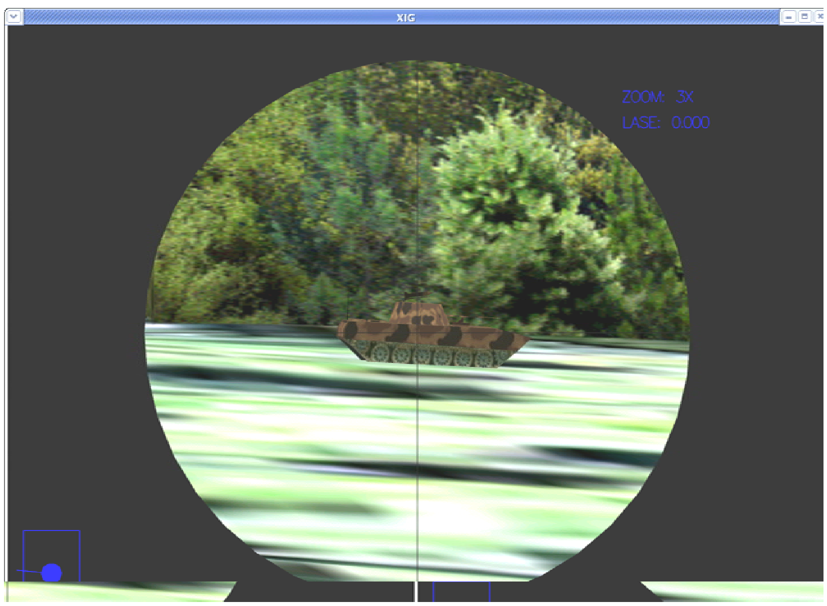

Figure 6. Gunnery component- Gunner’s out-of-window (LOS) view.

Figure 7. Gunnery component- BLOS view

The Tactical Control Unit (TCU) was developed by Army Research Laboratory's Robotics Collaborative Technology Alliance (RCTA) (Figure 8). The RCTA TCU is a one-person crew station from which the operator can control several simulated robotic assets, which can either perform their tasks semi-autonomously or be teleoperated. The Unmanned Ground Vehicle (UGV) simulated in this study is the eXperimental Unmanned Vehicle (XUV) developed by the Army Research Lab. The operator switched operation modes and display modes through the use of a 19" touch-screen display. A joystick was used to manipulate the direction in which the unmanned vehicles moved when in teleop mode.

Figure 8. User interface for Robotic Tactical Control Unit TCU

The two systems were placed directly in front of the participant (Figure 9). The systems were positioned side by side (approximately 6° separation). The RCTA TCU was to the participant's left with its joystick mounted directly in front of the system. The gunnery station was to the participant's right with its joystick position in front of the station.

Figure 9. Simulated Gunnery and Tactical Control Unit. The TCU and gunnery station is located on the left and right, respectively.

The simulation program used to generate the task scenarios was rSAF, the robotic version of the Semi-automated Forces (One SAF). The terrain for the scenarios was a model of Fort Indiantown Gap Military Reservation in Pennsylvania. The environment consisted of a combination of open rolling vegetated wooded terrain and open fields (Schipani, 2000).

Experimental Design

The experimental design was a two factor repeated measures design. The factors were Robotic Control (Monitor, Semi-autonomous, and Teleop) and Visual Density (High and Low). Participants were exposed to all conditions including the baseline gunner condition and robotic control baselines. The order in which the conditions were assigned was randomized. The following were the six conditions:

1. Gunnery baseline
2. Concurrent task conditions
    a. Gunnery + Monitoring one semiautonomous UGV (Monitor)
    b. Gunnery + Control of one semiautonomous UGV (UGV)
        1. Low visual density (UGV-low)
        2. High visual density (UGV-high)
    c. Gunnery + Teleoperation of one UGV (Teleop)
        1. Low visual density (Teleop- low)
        2. High visual density (Teleop - high)

Independent Variables

Concurrent task refers to the presence of robotic control tasks. No robotic control represents the gunner baseline. For the gunner baseline, the operator performed only gunnery tasks (i.e., target detection and engagement). In the remaining conditions, the operator had to monitor or manage an unmanned ground vehicle while performing gunnery tasks.

Robotic control refers to the level of control of the unmanned vehicle. There were three levels.

1. UGV monitor – The UGV traveled along a predetermined route without making any stops. No operator intervention or action was required. The operator's task was to monitor the video feed as the UGV traveled and report any target detected. There was no high or low density level.
2. UGV - Semiautonomous UGV was under supervisory control of the operator (Endsley, 1999). The UGV traveled along a predetermined route and stoped at designated points to conduct reconnaissance scans. The detection of a target required operator intervention/action. The operator's task was to monitor the video feed as the

UGV traveled, examine still images generated from the reconnaissance scans, and detect targets. More on the operator's task will be presented in the procedure section.

3. Teleop - Teleoperation required the operator to manually manipulate and drive the UGV along a predetermined route using the Tactical Control Unit. The detection of a target required operator action. More information will be presented in the procedure section.

Visual Density is visual noise or the level of complexity of the robotic control tasks (i.e., secondary tasks). Research has shown that the number of distractors or nontargets surrounding the target increases search times linearly (Drury & Clement, 1978). Other research showed that signal-noise ratios affect performance (Wickens & Hollands, 1999). The variable levels for this experiment represent the ratio of the number of targets to the number of distractors. Low refers to a 1:1 ratio and high a 1:3 ratio.

Dependent Variables

The dependent measures used to evaluate performance included mission performance, such as the number of targets detected, number of check points completed, communications task score, and perceived workload.

The target detection variable included gunnery and robotic performance. For the gunnery task there was a total of 20 possible targets (10 enemy and 10 neutral). For the robotic tasks, there were a total of five enemy targets and five to fifteen neutral targets depending on the visual density. The robotic target detection was measured by the percentage of targets detected based on the number of checkpoints completed. The check points completed variable was the number of check points the participant completed, out of six possible points, during the robotic tasks.

For all experiment conditions, participants had to answer simple military-related reasoning test and simple memory tests. They received a score for the number of correct answers, which was the communication task score. More on the communication task will be provided in the procedure section.

The dependent measure used to evaluate operator perceived workload was results from subjective questionnaires. Each participant completed a NASA-TLX Workload Assessment after each scenario (Hart & Staveland, 1988). Hart and Staveland developed and validated this workload scale, which is commonly used to assess perceived workload. This type of subjective measure was chosen because it has provided reliable and sensitive overall workload measurements in past empirical studies (Vidulich, 1989). Although it would be useful to gather subjective ratings during the scenarios, this technique would have disrupted performance. Studies have shown that retrospective subjective opinions data does not differ from data gathered while concurrently performing tasks (Ericsson & Simon, 1984).

Procedures

The research was conducted during two sessions, a training session, which took approximately two hours and a testing session, which took approximately 2.5 hours to complete. The two sessions were conducted on two separate days no more than seven days apart. During the first session, the participants were briefed on the purpose of the study and completed a consent form, demographic questionnaire, and an attentional control survey

(Derryberry & Reed, 2002). The attentional control survey consisted of 20 items and measured attentional focus and shifting. The survey required the participants to provide information about their ability to (a) focus attention (e.g. "My concentration is good even if there is music in the room around me"), (b) shift attention between tasks (e.g., "It is easy for me to read or write while I am also talking on the phone"), and (c) flexibility control thought (e.g., "I can become interested in a new topic very quickly when I need to"). The actual scale survey is in Appendix B.

Following the preliminaries, participants were administered the Cube Comparison Test (Educational Testing Service, 2005) and a Spatial Orientation Test (SOT) to assess the participants' spatial ability. The Cube Comparison Test (CCT) required the participants to compare, in three minutes, 21 pairs of six-sided cubes and determine if the rotated cubes were the same or different. The SOT, which was modeled after the cardinal direction test developed by Gugerty and his colleagues (Gugerty & Boorks, 2004), is a computerized test consisting of a brief training segment and 32 test questions. The program automatically captured both accuracy and response time.

After the spatial ability tests, participants received training and practice on tasks they needed to perform during testing. Training was a self-paced tutorial delivered by PowerPoint®. The tutorial included steps for completing various tasks, several mini-exercises for practicing the steps, and two exercises for performing the robotic control tasks (one for practicing the teleoperation task and one for practicing the semiautonomous UGV control tasks). The participants were then trained on the gunnery tasks and completed an exercise including both line-of-sight (LOS) and beyond-line-of-sight (BLOS) firing procedures. After participants became familiar with the gunnery tasks, they completed one final exercise in which they performed both the gunnery tasks and the robotic control tasks at the same time. The training session included one exercise that mirrored an actual test session. The only difference was that the participants could pause in case of mistakes or questions.

The testing session on the second day began with refresher training and an exercise similar to those during the training session. Once the participants successfully completed the exercise, testing began. Participants completed a total of six scenarios using the following conditions: gunner baseline, monitor, UGV-high density, UGV-low density, Teleop-high, and Teleop-low. All scenarios lasted approximately 15 minutes. The UGV and Teleop scenarios were divided into two segments, one high-density and one-low density. The order of robotic control scenarios and high versus low density was counter-balanced across participants. In addition to the six scenarios, half the participants completed a UGV only baseline condition and the other half a Teleop baseline condition, in order to examine the effects of concurrent gunnery and robotic tasks on robotic task performance.

The gunnery task for all scenarios, including the baseline and the concurrent conditions, was to monitor the screen, which simulated out-of-the-window view, and engage enemy targets as they were detected. The MCS, which carried the gunner, was simulated as traveling along a designated route. There were neutral vehicles and civilians in the simulated environment to increase visual noise for the target detection tasks (Wickens, 1992). Participants were instructed to avoid engaging neutral targets. Instead, they were to verbally report the presence of a neutral entity along the route. The total route was approximately 4.3

km and lasted approximately 15 minutes. The signal-noise ratio remained constant throughout the route. During the course, participants were also sent beyond line of sight (BLOS) targets to engage. The experimenter gave the command to prepare for BLOS target. After which, the participant switch to BLOS mode, aligned sights, and fired until the experimenter gave him a cease-fire. Once the BLOS was engage, the participant returned to the local firing mode.

For the robotic task, participants were asked to use their robotic asset to locate targets, a mixture of enemy tanks and dismounted soldiers, in the remote environment. There were also neutral vehicles and civilians in the simulated environment to increase the visual noise for the target detection tasks (Wickens, 1992). The ratios of target versus noise (i.e., neutral entities such as civilians and civilian vehicles) were manipulated. In high-density areas, the signal-noise ratio was 1:3; in low-density areas, the ratio was 1:1. Table 2 summarizes a list of tasks participants completed for each type of robotic control.

Table 2. Robotic Tasks for UGV and Teleop Conditions

Semiautonomous (UGV) (RSTA detected possible targets)	**Teleoperation (Teleop)** (Participant navigated area to detect targets)
Identify target or neutral	Identify target or neutral
Verbally report neutrals	Verbally report neutrals
Queue target (i.e., add to map)	Switch to Map Display
Switch to Map Display	Add target to the map
Label target	Label target
Submit Report	Submit Report

While participants performed their gunnery and/or robotic control tasks, they also completed cognitive communication tests. They heard questions delivered to them via a synthetic speech program, DECTALK®. The questions included simple military-related reasoning tests and simple memory tests that were pre-recorded by a male personnel. The questions were generated at a rate of one question approximately every 33 seconds. For the reasoning tests, there were questions such as "If the enemy is to our left, and our UGV is to our right, what direction is the enemy to the UGV?" For the memory tests, participants were assigned a number of call signs (e.g., Alpha 27). They had to report to the experimenter whether the call signs they heard was one of those they were assigned. The inclusion of these cognitive tasks was to simulate an environment where the gunner is communicating with fellow crewmembers in the vehicle (Huey & Wickens, 1993).

After each scenario, participants completed a NASA-TLX workload assessment and were given the opportunity to take a two-minute break. At the conclusion of all scenarios, a Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used to examine if the participants experience any simulator sickness. The questionnaire included a checklist of 16 symptoms with degrees of severity (none-0, slight-1, moderate-2, and severe-3).

CHAPTER FOUR: RESULTS

This chapter is divided into four major sections: (1) gunnery task performance, (2) robotic task performance, (3) communication task performance, and (4) mental workload. The dependent measures analyzed are addressed in each section.

Correlations were calculated for the performance of each of the tasks and the individual difference factors: spatial ability and attentional control. The Spatial Orientation Test (SOT) and Cube Test (Cube) measured spatial ability. The attentional control (Attention) score was derived from participants' answers to a survey. Participants were designated as high or low for each of these factors. To categorize scores as high or low, the median was determined. The values equal to or greater than the median were considered high and those below the median were low. The median for SOT, Cube and Attention were 26, 12, and 61, respectively. The results of correlation analyses will be used in subsequent sections.

Gunnery Task Performance

Neither the attentional control score nor the cube test score correlated with the gunnery task performance. Only the SOT scores correlated with the gunner performance. The correlation was significant for the gunner baseline (r = .407), Monitor (r = .489) and Teleop (r = .514) conditions. All p-values were less than .05. Based on the correlation analysis, the SOT score was the best predictor of gunnery performance.

Target Detection

An analysis of variance (ANOVA) was conducted with Asset condition as the within subject factor to examine the gunner baseline condition along with the concurrent gunnery and robotic control assets (Monitor, UGV, and Teleop). The analysis showed the Asset conditions differed significantly, $F(3, 16) = 5.519$, $p = .009$, with the gunner baseline (GB) resulting in the highest number of targets detected ($M = 13.600$, $SD = 2.353$), and concurrent Teleop condition the lowest ($M = 9.325$, $SD = 2.424$). See figure 10 for a summary of results.

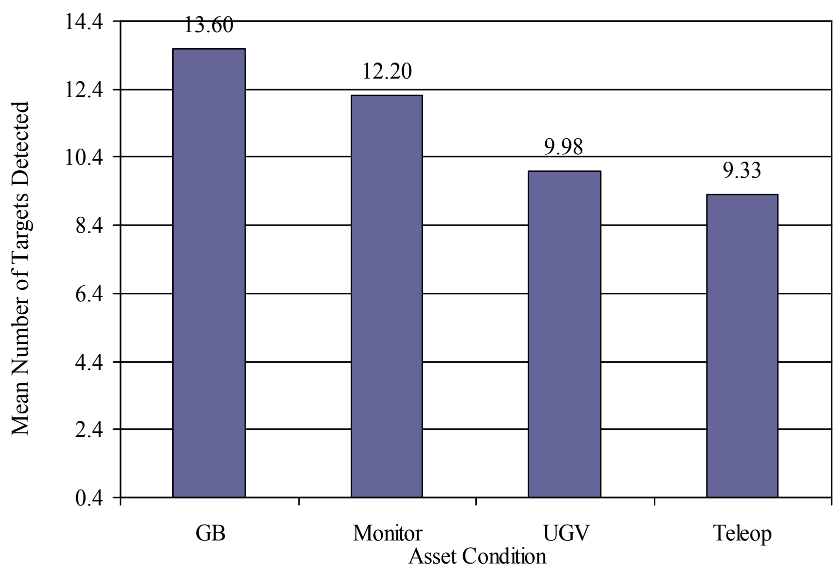

Figure 10. Gunnery target detection performance for each asset condition**.**

In order to locate the source of the effect, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the number of targets detected for the concurrent Monitor condition was slightly lower than the targets detected during the gunner baseline condition. There was marginal significance between the concurrent UGV and Teleop conditions. Finally, there was a highly significant difference between the gunner baseline and concurrent UGV and Teleop conditions as well as between the Monitor and UGV and Teleop conditions. Table 3 provides a summary of the pairwise comparisons.

Table 3. Pairwise Comparison for Gunner Target Detection

	Paired Difference				
Comparison	**Mean**	**Std. Dev.**	**Std. Error Mean**	***t***	**Sig.**
Gunner baseline / Monitor	1.4000	3.1018	.6936	2.019	.058
Gunner baseline / UGV	3.6250	2.3163	.5179	6.999	.000
Gunner baseline / TO	4.2750	1.9899	.4450	9.608	.000
Monitor / UGV	2.2250	2.542	.5683	3.915	.001
Monitor / TO	2.8750	2.7572	.6165	4.663	.000
UGV / TO	.6500	1.3774	.3080	2.110	.048

Since the correlation analysis found a relationship between gunnery performance and spatial orientation scores, an ANOVA was conducted with Asset condition as the within subject factor and spatial ability (SOT_LVL) as the between subject factor. The analysis showed the Asset conditions differed significantly $F(3, 16) = 26.504$, $p < .001$. With 20 targets available, the gunner baseline condition (GB) resulted in the highest number of targets detected ($M = 14.727$, $SD = 1.678$) over the concurrent conditions with the Teleop condition having the fewest number of targets detected ($M = 8.056$, $SD = 2.404$). Additionally, the spatial ability level (SOT_LVL) was significant $F(1, 18) = 8.760$, $p < .001$. The high spatial ability participants detected more targets than the low spatial ability participants. The analysis showed no significant interaction for asset condition and spatial ability, $F(3, 16) = 1.232$, $p = .307$. Figure 11 shows a graphical representation of these results.

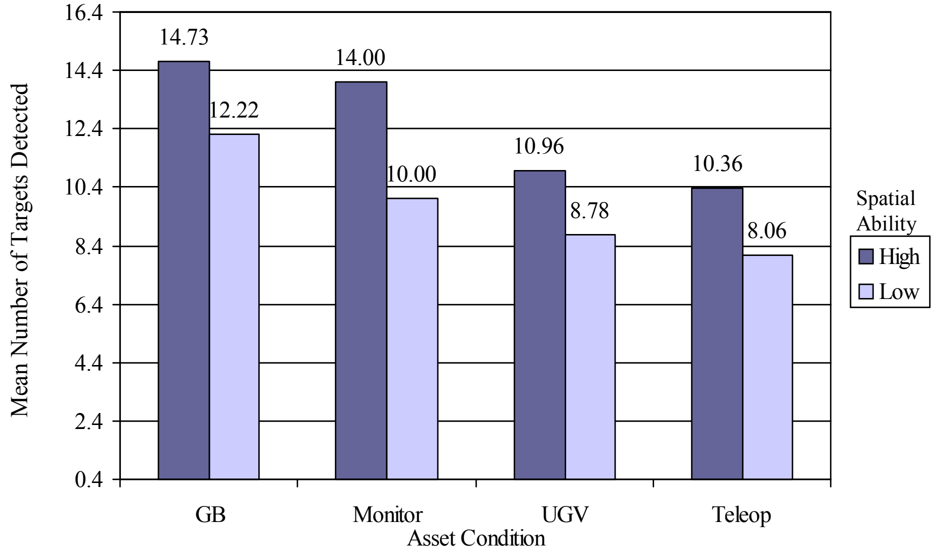

Figure 11. Gunnery target detection performance for each asset condition and spatial ability (high vs. low).

In order to determine the effects of the visual density of the robotic task on gunnery performance, a 2 x 2 within subject ANOVA was conducted. The two factors were Asset Condition (UGV and Teleop) and Density (high and low). The Monitor condition is excluded because it did not have two density levels. The results of the ANOVA found no significant effect for Density, $F(1, 38) = 1.314$, $p = .266$ and the Asset Condition x Density interaction, $F(1, 38) = .043$, $p = .839$. However, the Asset Condition was marginally significant, $F(1, 38) = 4.454$, $p = .048$ (see Figure 12).

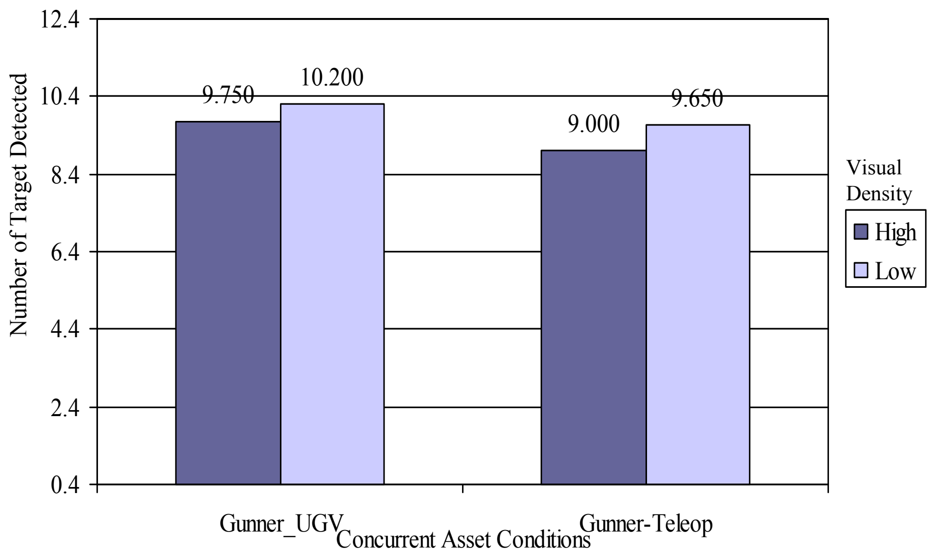

Figure 12. Effects of robotic task visual density on gunnery performance.

Robotic Task Performance

Although the robotic targets consisted of a combination of vehicle and human targets, participants detected only human targets in the Monitor condition. Because of this discrepancy, the vehicle target detection rate in the Monitor condition was excluded from the analyses. In some cases, human and vehicle target data were separated so that the Monitor condition could be analyzed with the other concurrent conditions.

Target Detection Rate

Half the participants completed a UGV only baseline condition and the other half a Teleop baseline condition to examine the effects of concurrent gunnery and robotic tasks on robotic task performance. The number of vehicle and human targets was combined for this analysis. The target detection rates for the UGV-baseline and Teleop-baseline conditions were compared to target detection rates for concurrent UGV and Teleop conditions, respectively. The results showed that the target detection rate was lower for the concurrent task conditions. The target detection performance difference was significant between the UGV-baseline and UGV-concurrent conditions, $F(1, 7) = 8.121$, $p = .026$, with 80.1% when the participants performed UGV tasks only and 67.5% when the participants performed UGV tasks concurrently with gunnery tasks. The target detection difference was not significant between the Teleop-baseline and Teleop-concurrent conditions $F(1, 7) = .295$, $p = .604$. Figure 13 depicts a summary of results.

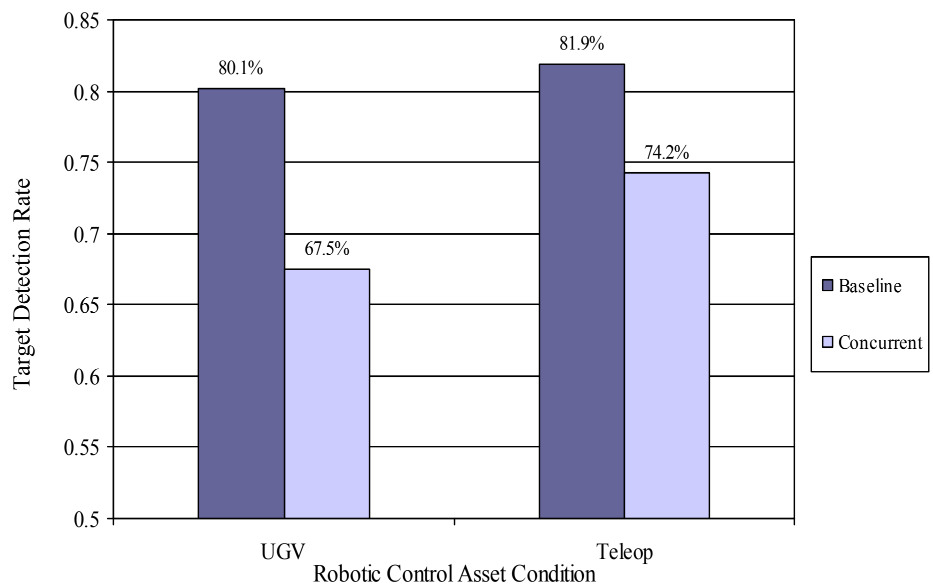

Figure 13. Robotic performance, baseline conditions vs. concurrent UGV and Teleop conditions

To understand the effects of the different levels of robotic control on target detection, two separate one-way, within subject ANOVAs were performed. One was for human target detection and the other was for vehicle target detection. The ANOVA for vehicle targets found no significant effect for Asset condition, $F(1, 18) = .829$, $p = .374$. For the human target detection, a significant main effect of Asset condition was found, $F(2, 17) = 3.795$, $p = .031$. There was significant difference among the Monitor, UGV, and Teleop conditions with UGV having the lowest target detection rate followed by the Teleop and Monitor conditions, as depicted in Figure 14.

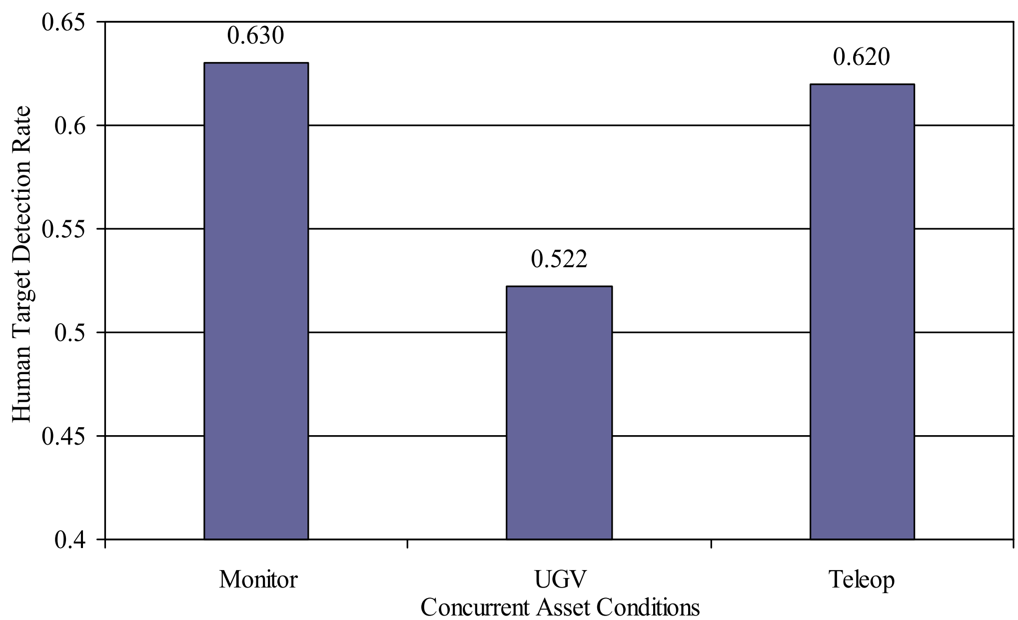

Figure 14. Human target detection performance for concurrent asset conditions.

In order to locate the source of the effect, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the largest difference was between the target detection rate for the UGV condition and the Monitor condition. The

UGV condition was significantly lower than the Monitor condition. Table 4 provides a summary of the pairwise comparisons.

Table 4. Pairwise Comparison for Human Target Detection Performance

Comparison	Paired Difference				
	Mean	**Std. Dev.**	**Std. Error Mean**	***t***	**Sig.**
Monitor / UGV	.1077	.1445	.0323	3.332	.004
Monitor / Teleop	.0102	.1858	.0416	.247	.808
UGV / Teleop	-.0974	.2371	.0530	-1.837	.082

The previous analysis indicated that the Teleop condition produced better target detection rates than the UGV condition, which was not expected. To examine the results further, an analysis was conducted to examine the targets detected along the route and within RSTA areas for the UGV and Teleop conditions. An ANOVA was conducted with two within subject factors, Asset Condition (UGV and Teleop) and Target Location (Route and RSTA). The analysis revealed that both effects were significant: Asset, $F(1, 34) = 5.75$, $p = .019$; Location $F(1, 34) = 18.01$, $p < .0001$ (Figure 15).

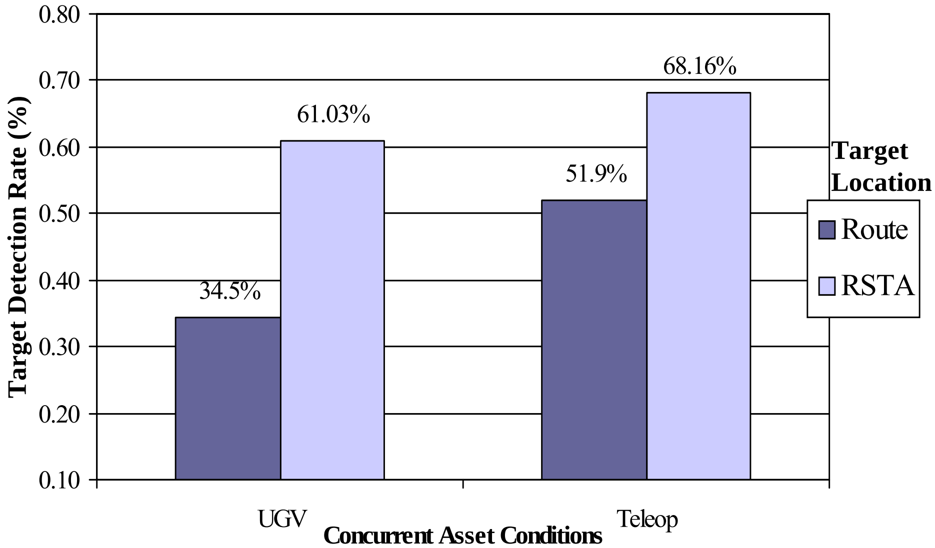

Figure 15. Targets Detected along Route and within RSTA for UGV and Teleop Conditions

In order to locate the source of the effects, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the most significant difference was between the UGV Route and RSTA target detection rates. The route target detection rate for both conditions was significant. However, the difference between the targets detected at the RSTA sites was not significant. Table 5 provides a summary of the pairwise comparisons.

Table 5. Pairwise Comparison of Route and RSTA targets for UGV and Teleop Conditions

	Paired Difference				
Comparison	**Mean**	**Std. Dev.**	**Std. Error Mean**	***t***	**Sig.**
UGV_Route / Teleop_Route	-1648	.3785	.0892	-2.83	.022
UGV_RSTA / Teleop_RSTA	-.0713	.2492	.0587	-1.21	.241
UGV_Route / UGV_RSTA	-.2557	.2749	.0648	-3.95	.001
Teleop_Route / Teleop_RSTA	-.1621	.2912	.0686	-2.36	.030

The visual density of the robotic tasks was manipulated to examine its effects on robotic task performance. An ANOVA was performed with two within subject factors as Visual Density (High and Low) and Asset Condition (UGV and Teleop). The visual density of robotic tasks significantly affected the target detection rate, $F(1, 38) = 8.781$, $p = .008$. The high density condition for both UGV and Teleop conditions resulted in lower target detection rates than the low density conditions (see Figure 16). There was no significant effect for the Asset condition, $F(1, 38) = 3.624$, $p = .072$ or the interaction between Asset and Density, $F(1, 38) = .010$, $p = .921$.

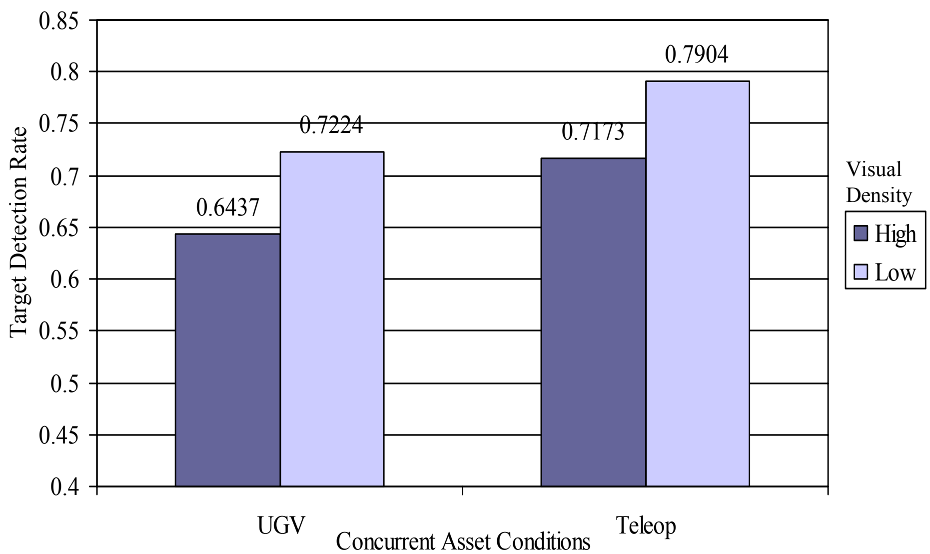

Figure 16. Robotic performance based on asset condition and visual density (High vs. Low).

Check Point Completion

A within subject ANOVA was conducted to compare the number of check points completed during the robotic baseline conditions to the number of check points completed during concurrent tasks. The check point completion difference was significant between the

UGV-baseline and UGV-concurrent conditions, $F(1, 7) = 18.103$, $p = .004$. Additionally, the check point completion difference was significant between the Teleop-baseline and Teleop-concurrent conditions, $F(1, 7) = 10.573$, $p = .014$. Figure 17 is a graphical depiction of the results.

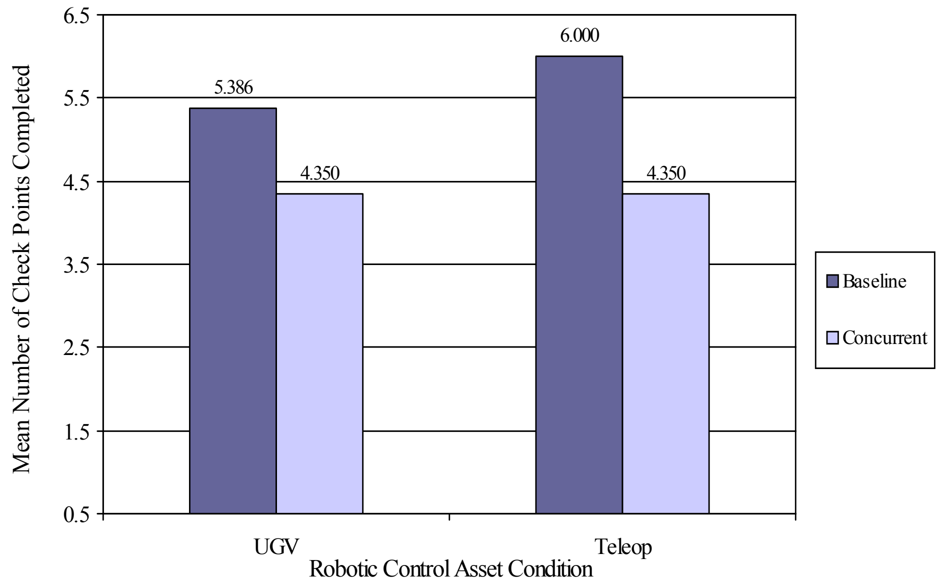

Figure 17. Number of check points completed for robotic baselines and concurrent tasks.

In order to locate the source of the effect, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the difference between the number of check points completed for the UGV-baseline and UGV concurrent condition and the difference between the number of check points completed for the Teleop-Base and Teleop concurrent condition were significant. Table 6 provides a summary of the pairwise comparisons.

Table 6. Pairwise Comparison of Check Point Completed for Robotic Baselines and Concurrent Tasks

Comparison	Paired Difference Mean	Paired Difference Std. Dev.	Paired Difference Std. Error Mean	*t*	Sig.
UGV_Base / UGV	.9375	.6332	.2203	4.255	.004
Teleop_Base / Teleop	1.1875	1.0329	.3652	3.252	.014
UGV / Teleop	-.1000	1.1425	.2555	-.391	.700

The effect of visual density on check point completion was examined using a within subject ANOVA with Asset (UGV and Telop) and Visual Density (High and Low) as the factors. None of the effects were significant: Asset, $F(1, 38) = .153$, $p = .700$; visual density $F(1, 38) = .000$, $p = 1.00$; and Asset x visual density, $F(1, 38) = .352$, $p = .560$. Table 7 contains a summary of results.

Table 7. Descriptive Statistics For the Effect of Visual Density on Check Points Completed

Asset Condition	Visual Density	Mean	Std. Dev.	N
UGV	High	4.200	1.152	20
	Low	4.300	.657	20
Teleop	High	4.400	1.187	20
	Low	4.300	1.380	20

Communication Tasks Performance

A within subject ANOVA was performed for the communication task scores for each of the asset conditions. The analysis found a significant effect for asset condition, $F(3, 15) = 6.754$, $p = .004$. The highest scores occurred with gunner baseline condition ($M = .9247$, $SD = .07553$), and the lowest scores when the communications task was performed concurrently with the gunner and UGV robotic tasks ($M = .8552$, $SD = .08756$). One participant had difficulty understanding the communication tasks, and his score was excluded from the analysis. A summary of results is depicted in Figure 18.

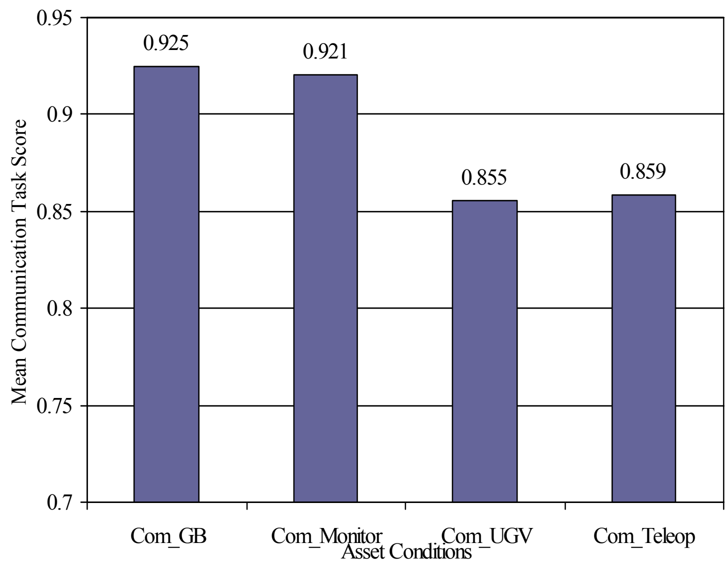

Figure 18. Communication task performance with gunner baseline and concurrent tasks

In order to locate the source of the effect, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the communication task scores were significant between the gunner baseline and UGV condition and the gunner baseline and the Teleop condition. Additionally, there was significance between the scores for the Monitor and UGV conditions and the Monitor and Teleop conditions. Table 8 provides a summary of the pairwise comparisons.

Table 8. Pairwise Comparison for Communication Task Performance

Comparison	Paired Difference Mean	Std. Dev.	Std. Error Mean	*t*	Sig.
Gunner Baseline / Monitor	.00421	.07214	.01655	.254	.802
Gunner Baseline / UGV	.06947	.06962	.01597	4.350	.000
Gunner Baseline / Teleop	.06605	.08877	.02036	3.244	.005
Monitor / UGV	.06526	.07617	.01747	3.735	.002
Monitor / Teleop	.06184	.09985	.02291	2.700	.015
UGV / Teleop	-.00342	.07487	.01718	-.199	.844

Correlation analyses were performed for communication task performance and the individual difference factors. The analysis found a relationship (r = .476, p = .023) with the attentional control scores in the Teleop condition. The correlation was marginally significant for the UGV condition (r = .385, p = .057). Participants were designated as high or low based on the attentional control score. Those who scored 61 or higher had high attentional control whereas those below 61 had low attentional control.

A mixed ANOVA was performed with Asset condition (Gunner baseline, Monitor, UGV, and Teleop) as the within subject factor and Attention_Level (High and Low) as the between subject factor. The Asset condition was significant, $F(3, 15) = 8.583$, $p < .001$. The Attention_Level effect and the Asset x Attention_Level interaction were not significant, $F(1, 17) = .180$, $p = .677$ and $F(3, 15) = 2.466$, $p = .073$, respectively (Figure 19).

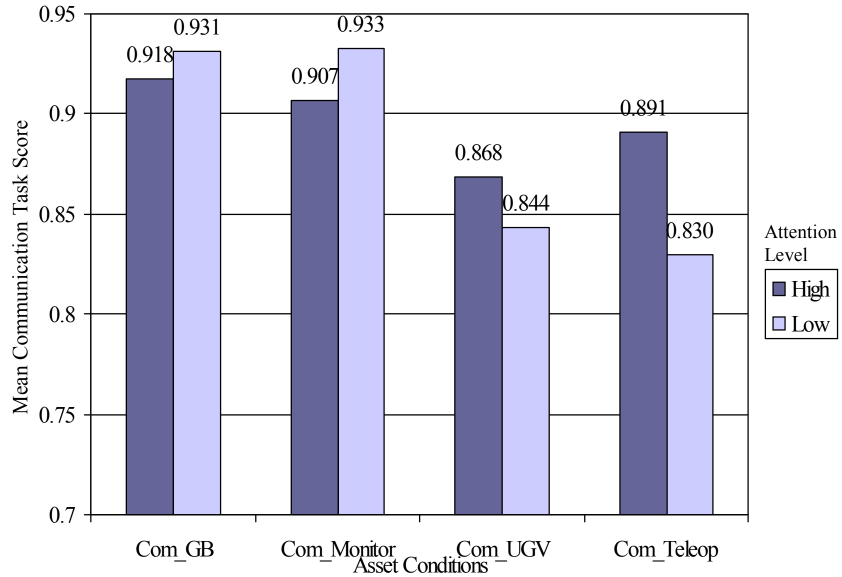

Figure 19. Communications task performance based on asset condition and attentional control level (High vs. Low)

Perceived Workload

A within ANOVA was performed with Asset condition (GB, Monitor, UGV, Teleop) as the within subject factor. The participant's self-assessment of workload was significantly affected by Asset condition, $F(3, 16) = 42.042$, $p < .001$. The perceived workload in the gunner baseline condition was lowest ($M = 22.35$, $SD = 7.89$), and the Teleop condition was the highest ($M = 43.03$, $SD = 6.56$). Figure 20 shows a summary of results.

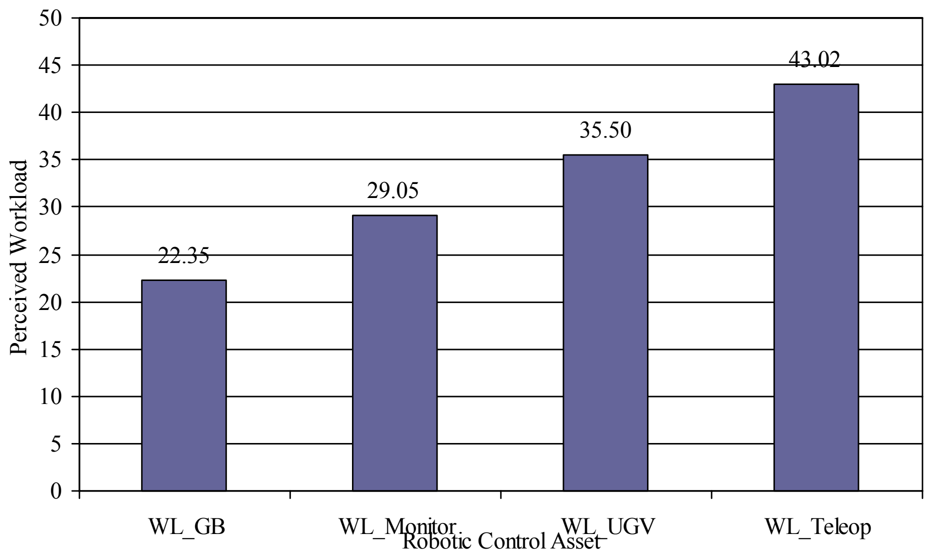

Figure 20. Participants' self-assessment of workload for each asset condition.

In order to locate the source of the effect, further investigation was conducted using the paired-sample *t*-test ($p < .05$). The results indicated that the perceived workload was significant lower for the gunner baseline than the Monitor, UGV, and Teleop conditions. There was also a significant difference between the Monitor and UGV conditions and the Monitor and Teleop conditions. Finally, the perceived workload for UGV was significantly lower than the perceived workload for Teleop conditions. Table 9 provides a summary of the pairwise comparisons.

Table 9. Pairwise Comparison for Perceived Workload for Asset Conditions

Comparison	Paired Difference Mean	Std. Dev.	Std. Error Mean	*t*	Sig.
Gunner Baseline / Monitor	-6.700	9.577	2.1415	-3.129	.006
Gunner Baseline / UGV	-13.150	9.063	2.027	-6.489	.000
Gunner Baseline / Teleop	-20.675	7.010	1.567	-13.190	.000
Monitor / UGV	-6.4500	10.489	2.345	-2.750	.013
Monitor / Teleop	-13.975	7.584	1.696	-8.241	.000
UGV / Teleop	-7.525	7.488	1.674	-4.494	.000

Correlation analyses were performed for perceived workload and the individual difference factors. The analysis found a relationship between workload and all three individual difference factors (Spatial ability: Spatial Orientation Test score and Cube Test score; and Attentional Control). Table 10 contains the correlation data.

Table 10. Correlation Data for Perceived Workload and Individual Difference Factors

Individual Difference Factor	Asset Condition	*r*	*p*
Spatial Orientation Test Score	UGV	.441	.026
Cube Test Score	UGV	.587	.003
	Teleop	.484	.015
Attentional Control	Teleop	-.516	.012

To determine the effects of asset condition and spatial ability, as measured by the Spatial Orientation Test, on perceived workload, a mixed ANOVA was performed with Asset condition (GB, Monitor, UAV, and Teleop) as the within subject factor and SOT_Level (High and Low) as the between subject factor. Neither the SOT_Level effect, $F(1, 18)$ =

.330, $p = .573$, nor the Asset x SOT_Level interaction, $F(3, 16) = 1.193$, $p = .321$, was significant. The Asset condition was significant, $F(3, 16) = 41.651$, $p < .001$ (see Figure 21).

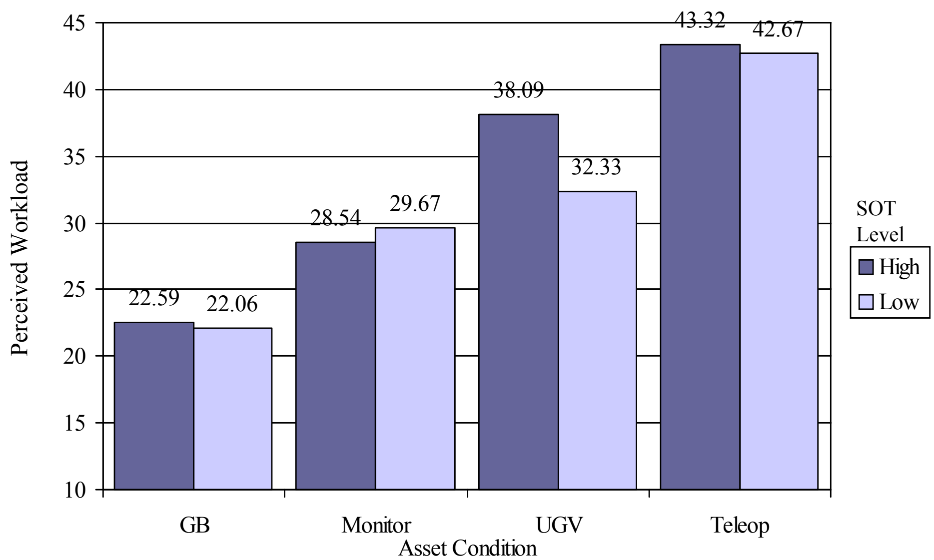

Figure 21. Perceived Workload Based on Asset Condition and Spatial Ability as determined by the SOT scores

To determine the effects of asset condition and spatial ability, as determine by the Cube Test, on perceived workload, a mixed ANOVA was performed with Asset condition (GB, Monitor, UAV, and Teleop) as the within subject factor and Cube_Level (High and Low) as the between subject factor. All effects were significant: Cube_Level effect, $F(1, 18) = 7.840$, $p < .001$, the Asset x Cube_Level interaction, $F(3, 16) = 3.471$, $p = .022$, and Asset condition, $F(3, 16) = 39.947$, $p < .001$. High spatial ability participants' perceived workload was slightly higher than those with low spatial ability in the gunner baseline, UGV, and Teleop conditions (see Figure 22).

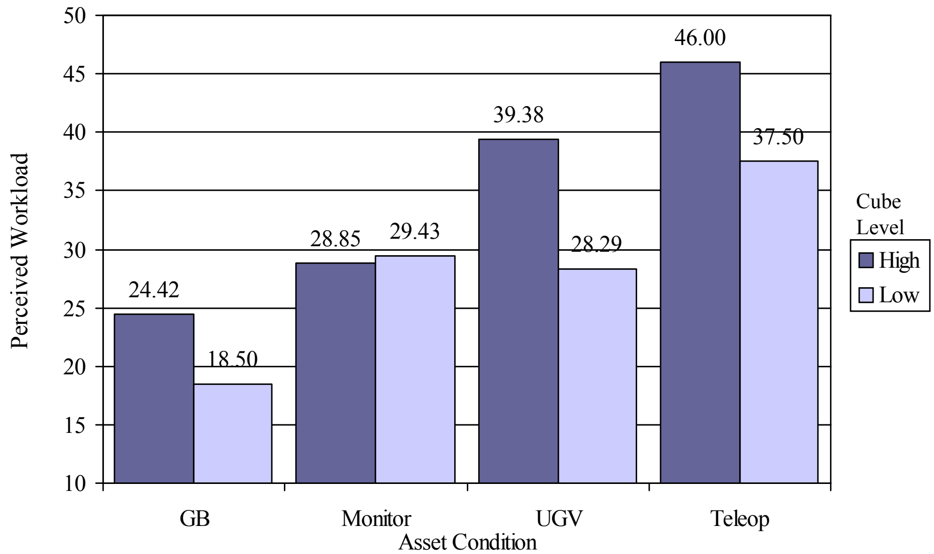

Figure 22. Perceived Workload Based on Asset Condition and Spatial Ability as determined by the Cube Test scores

To determine the effect of asset condition and attentional control on perceived workload, a mixed ANOVA was performed with Asset condition (GB, Monitor, UAV, and Teleop) as the within subject factor and Attention_Level (High and Low) as the between subject factor. Neither the Attention_Level effect, $F(1, 18) = .537$, $p = .473$, nor the Asset x Attention_Level interaction, $F(3, 16) = .596$, $p = .621$, was significant. The Asset condition was significant, $F(3, 16) = 41.147$, $p = .001$ (see Figure 23).

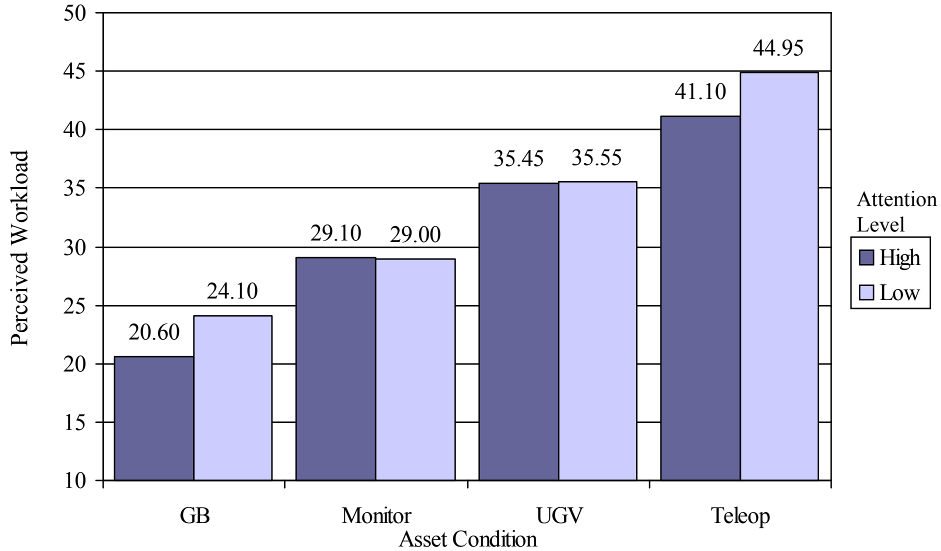

Figure 23. Perceived Workload Based on Asset Condition and Attentional Control

Simulator Sickness

At the end of testing, participants were administered a Simulator Sickness Questionnaire (SSQ). The purpose of the questionnaire was for participants to make a self-assessment of simulator sickness. Sixteen symptoms were listed, and the participants had to rate the level of severity of each symptom: None (0), Slight (1), Moderate (2), or Severe (3). The 16 symptoms were categorized into three subscales that represent the dimensions of simulation sickness: nausea, oculomotor disturbance, and disorientation (Kennedy et al., 1993; Kennedy, Stanney, & Dunlap, 2000). The total severity score (TSS) is a composite of the three dimension scores. All scores were calculated using formulas developed by Kennedy et. al., (1993).

The oculomotor dimension resulted in the highest average severity score contributing to an elevated TSS score. Table 11 provides a summary of the Simulation Sickness Questionnaire scores.

Table 11. Simulation Sickness Scores

Dimension	**Mean**	**S.D.**
Nausea Sub-scale	21.47	19.55
Oculomotor Sub-scale	32.22	23.57
Disorientation Sub-scale	31.35	28.52
Total Severity Score	29.36	24.06

This chapter analyzed performance measures for four major areas in this research: (1) gunnery tasks, (2) robotic tasks, (3) communication tasks, and (4) perceived workload. The results showed that baseline conditions (gunnery and robotic) produced better performance than concurrent conditions in each of these areas. A further explanation of these results is provided in the next chapter.

CHAPTER FIVE: DISCUSSION

An experimental study was developed to examine operator performance and workload in a multitask environment. The tasks included a primary gunnery task and a secondary robotic task. A tertiary communication tasks was also included, but it was not manipulated in this study. The performance measures included, the number of targets detected for gunner and robotic tasks, number of check point completed for the robotic tasks, perceived workload, and communications task score. All performance measures were significantly affected by type of asset used to perform each task. The performance measures will be discussed in the sections below.

Gunnery Task Performance

The type of asset used for each task significantly affected the gunner's performance. The average number of targets detected in the gunner baseline condition was higher than the number of targets detected while performing concurrent tasks. As expected, the monitor concurrent condition had more targets detected than the UGV and Teleop conditions. An explanation for this decline in performance may be attributed to the amount of operator intervention required at each level of robotic control. Operator intervention increased from the monitor condition (monitor video feed only), to the UGV condition (monitor video feed and respond to Automatic Target Recognition), and finally to the Teleop condition (manually maneuver XUV and detect targets). These findings suggest that as the participant focused more on the robotic tasks, the gunner task was neglected resulting in missed targets and decreased gunnery performance. No data was collected to compare response times or time spent on each task. Future research may include a time-based study to compare the amount of time spent on each task at critical points in a scenario to determine when the user switched attention from one task to another.

Spatial ability, as determined by the Spatial Orientation Test scores, highly correlated with the gunnery performance. Those with high spatial ability, on average, detected 12% more targets than those with low spatial ability. This is consistent with studies that found high spatial ability participants' target detection performance was better than low spatial ability target detection (Chen et al., 2005).

Visual density of the secondary robotic task did not significantly affect gunnery performance, which was unexpected. Research suggests that greater task difficulty of one task demands more of the shared resources, leaving fewer resources to perform the remaining tasks (Sanders & McCormick, 1993). It was expected that the gunner's task would suffer due to more resources being focused on the high density robotic task and the gunner's task being neglected.

Robotic Task Performance

The results showed that there was a decrement in robotic performance when one operator performed robotic tasks concurrently with gunnery tasks. The dual task conditions yielded substantially lower performance than the robotic baselines (Teleop and UGV) conditions. For the UGV asset, the target detection rate decreased from 80.1% in the baseline condition to 67.5% in the UGV concurrent task condition. The Multiple Resource

Theory (MRT) explains these results by suggesting that tasks that use the same resources (e.g. modalities and memory codes) experience more task interference than tasks that use separate resources (Dixon et al., 2003). The gunnery and robotic tasks relied heavily on the visual channel, thus performance of these tasks simultaneously resulted in degraded performance of the gunnery as well as the robotic tasks.

Robotic control level had a significant effect on performance. For human targets, the target detection rates for the asset conditions from lowest to highest were UGV, Teleop, and Monitor. These performance results contradict our initial expectations that the Teleop condition would have a worse performance score than the UGV condition. One explanation is that the semiautonomous control in the UGV condition resulted in out-of-the-loop performance decrements due to over reliance on the system (e.g., Automatic Target Recognition) and vigilance (Parasuraman, Molloy, & Singh, 1993; Wiener, 1988). Further analysis showed that there was little difference in the targets detected at the RSTA areas for both conditions. However, the larger difference was between the targets detected along the route. The UGV condition had significantly fewer targets detected along the route than the Teleop condition. This further supports the premise that the participants relied on the system to provide target information in the RSTA areas and did not focus much attention to the XUV as it traveled along the route, but waited for the auditory alert to inform them that targets had been detected.

There were significant performance differences in robotic task performance between the high and low density conditions, with the lower density producing better target detection rates. This is consistent with the Single Resource Theory, which predicts that in dual task environments, task interference and ultimately task performance are dependent on task difficulty (Kahneman, 1973). The more difficult the task, the more performance will suffer for one or more tasks. Other research also suggests that greater task difficulty demands more of the limited resources, leaving fewer resources to perform the remaining tasks (Sanders & McCormick, 1993). The complexity increased for the high density conditions due to the visual noise or distractors near the targets. This visual noise (e.g., the inclusion of non-targets) made it more difficult for participants to detect targets in the environment.

The type of robotic asset used significantly affected the number of check points completed. As expected, the participants completed more check points during the robotic baseline conditions than during the concurrent conditions. The average number of check points completed for the UGV and Teleop concurrent conditions were the same. The Teleop baseline resulted in the highest check point completion. Based on the review of literature for this study, one would expect the Teleop mode to have fewer check points completed because the operator would have to manually drive the XUV and detect targets. One explanation for the Teleop baseline results is that the participant's only task was to operate the XUV in teleoperation mode, where he had complete control over the XUV. The operator could go straight to the targets; he did not have to wait or rely on the Automatic Target Recognition system to detect targets, as in the UGV semiautonomous mode. Another reason may be due to the participants not detecting targets at the check points. In some cases during the experiment, participants failed to detect targets at some checkpoints because they did not check the area thoroughly. Although this may have affected the target detection rate, they processed the check points more quickly because they did not have to add the targets to the map or send reports.

Communications Task Performance

The assets used to perform each task significantly affected how the participants performed on the communication tasks. The average score for the communication task during the gunner baseline (92.5) was the highest of all other conditions. The monitor condition also resulted in a high average, only .004 points lower than the gunner baseline. These close scores may be due to the similarity of the two conditions. Other than watching the XUV video feed, the gunner baseline and concurrent monitor conditions were very similar. The largest difference in communication task performance was between the gunner baseline condition and the UGV and Teleop conditions and between the monitor condition and the UGV and Teleop conditions. During the concurrent UGV and Teleop conditions, the participant had to focus on detecting gunner targets, supervising and operating the XUV, and answering the communication task questions. Because these two conditions required more of the participant's attention, some of the participants could not concentrate on the questions. This resulted in questions being unanswered or answered incorrectly.

A correlation analysis found a significant relationship between the communication task performance and the attentional control scores. Further analysis revealed that high attentional control participants did not perform better than low attentional control for all conditions. It was expected that the high attentional control participants would perform better than the low attentional control participants. This was not the case for the gunner baseline and monitor conditions. Derryberry and Reed (2002) explained attentional focus as one's ability to focus and shift attention to the appropriate task as necessary under demanding situations. Since the gunnery baseline and monitoring tasks were not as demanding, Derryberry and Reed's explanation supports why the low attentional control group performed better during these conditions.

Perceived Workload

The perceived workload was lowest for the gunner baseline condition and highest for the teleoperation condition, as expected. These results are consistent with research that showed that the use of automation, or robots in this study, increases operator monitoring and supervisory demands, which may lead to increased mental workload (Parasuraman et al., 2000; Schipani, 2003). Additionally, research in human-robot-interaction found that operator workload tends to increase when human intervention is required (Chen et al., 2005; Schipani, 2003). The monitor condition required the least amount of operator intervention followed by the UGV and Teleop conditions.

Correlation analyses found significant relationships between workload and all individual difference factors. Analyses of variance was performed for all conditions with each of the individual factors as the between subject factor. Spatial ability was not significant when measured by the SOT test. However, spatial ability was significant when measured by the Cube Test. Those with high spatial ability, as measured by the Cube Test, perception of workload was greater for all conditions except the Monitor condition. Both the UGV and Teleop conditions were significant. Sanders and McCormick (1993) suggested that workload is a measure of information processing demands placed on an operator by tasks. Because the high spatial participant was able to successfully perform more tasks at one time, more information processing demands were placed on the participant, increasing his perception of workload.

The workload and attentional control analysis was not as conclusive. High and low attentional control participants' perceived workload was the same for the monitor and UGV conditions. Low attentional control participants' perception of workload was higher in the gunner baseline and Teleop conditions. This finding supports studies that suggest that those with good attentional control cope with threats and stressful situations better than those with poor attentional control (Derryberry & Reed, 2002). Additional research is needed to study the relationship between perceived workload and attentional control.

Simulator Sickness

Participants seem to experience an elevated severity of simulation sickness in the MCS environment that was simulated in this study. The oculomotor dimension resulted in the highest average severity score of the three sub scales. This study used a fixed-based simulator in which the operator stayed fixed in position while the vision system sensed motion. The high score may be attributed to the high visual demands that both tasks in this research required. These results are consistent with past simulation sickness research. Kennedy, Lilienthal, Berbaum, Baltzley, and McCauley (1989) found that between 12 to 60% of users experienced some form of simulator sickness when using a flight simulator. Stanney and Hash (1998) study of virtual environments suggested that simulator sickness would not be as severe when users have more control over their movement, as in the Teleop condition in this study. Because the SSQ was administered only once at the end of the study, no data was collected after each robotic control condition to substantiate Stanney and Hash findings. Further research is needed to determine the severity of simulation sickness associated with each robotic control type described in this study.

This chapter discussed the performance measures and key findings of the associated research.

Table 12 provides a summary of these findings.

Table 12. Summary of Key Findings

	Key Finding
Gunnery Task Performance	Operator performance was best when the gunnery task was performed only.
	Of the concurrent conditions, the Monitor condition produced the best performance followed by the UGV and Teleop conditions.
	Participants with high spatial ability detected 12% more targets than those with low spatial ability.
	Visual density of the secondary robotic task did not significantly affect gunnery performance.
Robotic Task Performance	Robotic performance (target detection and check point completion) was worse when the operator performed robotic tasks concurrently with gunnery tasks.
	Of the concurrent conditions, the Monitor condition produced the best target detection rates.
	The concurrent Teleop condition resulted in higher target detection rates than the concurrent UGV condition, which was not expected.
	The low visual density conditions produced better target detection performance than the high visual density conditions.
Communications Task Performance	The average scores for the Gunner baseline condition and Monitor condition were very similar; however, these scores were significantly higher than the Teleop and UGV conditions.
Perceived Workload	The perceived workload increased almost linearly in the order from gunner baseline, monitor, UGV and to the Teleop conditions.
	Participants with high spatial ability, as measured by the Cube Test, perception of workload was higher than those with low spatial ability.
Simulator Sickness	The severity of simulation sickness was significant in the simulated MCS environment that was examined in this study.
	The oculomotor dimension had the highest severity average of the three dimensions and contributed to the elevated total severity score.

CHAPTER SIX: CONCLUSION

The primary goal of this research was to examine the effects of secondary robotic tasks on primary gunnery task performance, robotic performance, and operator's perceived workload in a multiple task environment. To meet this goal, several research questions were posed.

(1) Does the addition of the robotic control tasks adversely impact the gunnery task performance?

(2) How does the secondary task complexity/density impact task performance?

(3) Which robotic control type produced better performance?

(4) Does spatial ability influence performance of concurrent tasks?

(5) Does attentional control influence performance of concurrent tasks?

(6) How is perceived workload affected by the type of asset used?

This study revealed that there were performance decrements for the gunnery tasks as well as the robotic tasks when the tasks were performed concurrently. The baseline conditions consistently resulted in better performance over the concurrent conditions. The secondary task complexity did not affect the gunnery task performance; however, participants' robotic task performance was significantly better in the low density conditions. The type of robotic control influenced gunnery performance. As the amount of operator intervention required for robotic tasks increased, the gunnery performance decreased. Of the robotic control types, the monitor condition produced the best gunnery performance during concurrent tasks. Spatial ability is the only individual difference factor that influenced performance of concurrent tasks. Those with high spatial ability tended to perform better. Finally the type of asset used affected the perceived workload. The perceived workload increased almost linearly in order from the gunner baseline, monitor, UGV and to the Teleop condition.

As shown in Figure 1, the FCS includes an array of unmanned vehicles, aerial and ground, that will be used within units across the Army (e.g., combat, logistics, engineering, etc.). Since the FCS concept to reduce required manpower applies to nearly all units, there will be more instances when soldiers will have to perform multiple tasks. An implication of this research is that in order for a user to perform a primary task concurrently with a robotic task effectively, the scope of the robotic task should be tailored to the primary task. In high risk, high consequence environments (e.g., combat and emergency rescue), the robotic task should be designed so that the user will only have to perform monitoring functions. If more user intervention is required (i.e., to handle system failures, to analyze a camera image, or to teleop a robot), the possibility of reduced primary task performance increases. In other environments with less significant threats, the level of robotic control may be increased.

An additional option to reduce task interference in high-risk conditions is to consider a team supervisory control protocol. Using the MCS as an example, there are three members of the crew. A protocol can be established so that when the gunner (or primary robotic operator) is fully engaged in a primary task, another crewmember can assume control of the robot. An extensive review of literature did not find any studies on the use of a team to control unmanned vehicles; therefore, further research is needed in this area.

Another implication of this study is that individual abilities should be carefully considered in the screening process of potential candidates who will work in multitask environments as described in this research. The military or those who use unmanned vehicles and robotic assets can target individuals who possess the skills, such as spatial ability and attentional control, to effectively control robotic assets while performing other tasks under pressure in high threat situations.

Shortcomings of Research

Although the research produced positive results, there are some issues that could limit the generalizability of the results as a whole. A potential limiting factor involves the subjects who participated in the study. It would have been more beneficial to use soldiers who would potentially be assigned to MCS units or soldiers with experience as a gunner in a tank or other major weapon systems. Due to the length of training and experimental sessions as well as the availability of soldiers, volunteer college students were used instead. The issue with subject selection is that individuals who are willing to participant in a simulator-based study at a university may not be representative of the target population as a whole.

A second issue, which could limit the generalizability of the results, is that of simulator fidelity. The interface for the simulator used in this study included two display monitors and associated joysticks. While the size of the gunnery component display closely resembled the size of the display that will be used in the MCS, the robotic Optical Control Unit (OCU) included a 19" display, which is larger than one would expect in a FCS. Since the OCU is a touch-screen interface, a smaller screen may have influenced the user's ability to operate the unmanned vehicles. The results of this research showed that robotic operator performance was negatively affected when tasks were performed concurrently with gunnery tasks. A smaller display may have impacted robotic performance to a greater degree. Subsequent studies should include a high fidelity environment with vehicles and equipment that more closely resemble the gunnery and robotic components not incorporated into the simulator used for this study. A high fidelity environment should also include the recruitment of soldiers from the target user group, as discussed earlier.

Future Research

Although the results of this research may prove helpful, further research is needed. In addition to the issues identified in the previous section, future studies should address performance improvement in high risk, multiple task environments. This study addressed conditions and factors that affect performance; however, it did not discuss ways to improve concurrent task performance in this environment. One way in particular is the use of different modalities as discussed in the Multiple Resource Theory (e.g., auditory, visual, tactile, etc.). Both tasks in this study relied heavily on the visual channel. If some functions were offloaded to another sensory modality, there may have been less competition for the limited visual resources allowing the user to manage multiple tasks more effectively.

Future studies should also consider the research setting. This evaluation was conducted in a laboratory type setting. Factors such as the environment, fatigue and noise may affect soldier performance. Future research should incorporate some of these factors into the research setting to produce a more realistic environment. Additionally, this study used stationary targets to measure robotic performance. Future studies should include a combination of stationary and moving targets as well as explore other functions of the Armed Reconnaissance Vehicle (e.g., obstacle detection/bypass, target engagement, and battlefield damage assessment). Finally, future researchers should investigate the effects of training on an individual's ability to perform tasks similar to those associated with the current study. More specifically, they should manipulate the time spent on training sessions and determine if performance will increase as the training time increases.

APPENDIX A: DEMOGRAPHIC QUESTIONNAIRE

DEMOGRAPHIC QUESTIONNAIRE

Participant # _______ Age ______ Major ________________ Date ___________ Gender ___

1. What is the highest level of education you have had?
Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School	Jr. High	High School
Technical School	College	Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other________ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:	
Use a mouse?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a joystick?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a touch screen?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use icon-based programs/software?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use programs/software with pull-down menus?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use graphics/drawing features in software packages?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use E-mail?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
_____ Novice
_____ Good with one type of software package (such as word processing or slides)
_____ Good with several software packages
_____ Can program in one language and use several software packages
_____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically? YES NO
If NO, please briefly explain:

8. How many hours of sleep did you get last night? ______ hours

9. Do you have normal color vision? YES NO

10. Do you have prior military service? YES NO If Yes, how long __________

APPENDIX B: ATTENTIONAL CONTROL SURVEY

ATTENTIONAL CONTROL SURVEY

For each of the following questions, circle the response that best describes you.

It is very hard for me to concentrate on a difficult task when there are noises around.
Almost never, Sometimes, Often, Always

When I need to concentrate and solve a problem, I have trouble focusing my attention.
Almost never, Sometimes, Often, Always

When I am working hard on something, I still get distracted by events around me.
Almost never, Sometimes, Often, Always

My concentration is good even if there is music in the room around me.
Almost never, Sometimes, Often, Always

When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me. Almost never, Sometimes, Often, Always

When I am reading or studying, I am easily distracted if there are people talking in the same room.
Almost never, Sometimes, Often, Always

When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.
Almost never, Sometimes, Often, Always

I have a hard time concentrating when I'm excited about something.
Almost never, Sometimes, Often, Always

When concentrating, I ignore feelings of hunger or thirst. Almost never, Sometimes, Often, Always

I can quickly switch from one task to another. Almost never, Sometimes, Often, Always

It takes me a while to get really involved in a new task. Almost never, Sometimes, Often, Always

It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures. Almost never, Sometimes, Often, Always

I can become interested in a new topic very quickly when I need to.
Almost never, Sometimes, Often, Always

It is easy for me to read or write while I'm also talking on the phone.
Almost never, Sometimes, Often, Always

I have trouble carrying on two conversations at once. Almost never, Sometimes, Often, Always

I have a hard time coming up with new ideas quickly. Almost never, Sometimes, Often, Always

After being interrupted or distracted, I can easily shift my attention back to what I was doing before.
Almost never, Sometimes, Often, Always

When a distracting thought comes to mind, it is easy for me to shift my attention away from it.
Almost never, Sometimes, Often, Always

It is easy for me to alternate between two different tasks.   Almost never, Sometimes, Often, Always

It is hard for me to break from one way of thinking about something and look at it from another point of view.   Almost never, Sometimes, Often, Always

APPENDIX C: NASA -TLX QUESTIONNAIRE

NASA -TLX QUESTIONNAIRE

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

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

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

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

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

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

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

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

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

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

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

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

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

7. Please mark the indicated loading that most closely matches the work performed by your visual, cognitive, and motor efforts on the task just completed.

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

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

Psychomotor (Relating to the physical activities associated with mental processes

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

APPENDIX D: SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)

SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)

ID________________ Time & Date

Instructions: Please indicate how you feel **right now** in the following areas, by **circling** the word that applies.

1.	General Discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye Strain	None	Slight	Moderate	Severe
5.	Difficulty Focusing	None	Slight	Moderate	Severe
6.	Increased Salivation	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty Concentrating	None	Slight	Moderate	Severe
10.	Fullness of Head	None	Slight	Moderate	Severe
11.	Blurred vision	None	Slight	Moderate	Severe
12.	Dizzy (Eyes Open)	None	Slight	Moderate	Severe
13.	Dizzy (Eyes Closed)	None	Slight	Moderate	Severe
14.	Vertigo*	None	Slight	Moderate	Severe
15.	Stomach Awareness**	None	Slight	Moderate	Severe
16.	Burping	None	Slight	Moderate	Severe

*Vertigo is a disordered state in which the person or his/her surroundings seem to whirl dizzily: giddiness.
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Are there any other symptoms you are experiencing right now? If so, please describe the symptom(s) and rate its/their severity below. Use the other side if necessary.

APPENDIX E: SCORING PROCEDURE FOR THE SSQ

SCORING PROCEDURE FOR THE SSQ

Symptoms scored 0 (None) - 3 (Severe)

Nausea (Raw) - Sum of General discomfort, increased salivation, sweating, nausea, diff concentrating, stomach awareness, burping

Nausea sub scale = Nausea (Raw) x 9.54

Oculomotor - Sum of general discomfort, fatigue, headache, eye strain, diff focusing, diff concentrating, blurred vision

Oculomotor sub scale = Oculomotor (Raw) x 7.58

Disorientation - Sum of diff focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), vertigo

Disorientation sub scale = Disorientation (Raw) x 13.92

TSS = [Nausea (Raw) + Oculomotor (Raw) + Disorientation (Raw)] x 3.74

APPENDIX F: IRB APPROVAL

University of Central Florida

Office of Research & Commercialization

August 22, 2005

Carla Joyner
3336 Waterlute Way
Lakeland, FL 33811

Dear Ms. Joyner:

With reference to your protocol #05-2785 entitled, **"Robotic Control in a Simulated Environment"** I am enclosing for your records the approved, expedited document of the UCFIRB Form you had submitted to our office. **This study was approved by the Chairman on 8/21/05. The expiration date for this study will be 8/20/06.** Should there be a need to extend this study, a Continuing Review form must be submitted to the IRB Office for review by the Chairman or full IRB at least one month prior to the expiration date. This is the responsibility of the investigator. **Please notify the IRB when you have completed this study.**

Please be advised that this approval is given for one year. Should there be any addendums or administrative changes to the already approved protocol, they must also be submitted to the Board through use of the Addendum/Modification Request form. Changes should not be initiated until written IRB approval is received. Adverse events should be reported to the IRB as they occur.

Should you have any questions, please do not hesitate to call me at 407-823-2901.

Please accept our best wishes for the success of your endeavors.

Cordially,

Barbara Ward

Barbara Ward, CIM
IRB Coordinator

Copy: IRB file
Pamela McCauley-Bell, Ph.D.

BW:jm

12443 Research Parkway • Suite 302 • Orlando, FL 32826-3252 • 407-823-3778 • Fax 407-823-3299

REFERENCES

Baddeley, A. (1966). The capacity for generating information by randomization. *Quarterly Journal of Experimental Psychology, 48*, 298-302.

Barnes, M. J., Cosenzo, K., Mitchell, D. K., & Chen, J. Y. C. (2005). *Soldier robot team as soldier augmentation in future battle spaces: An overview.* Paper presented at the Proceedings of the 11th Annual Human-Computer Interaction International Conference, Las Vegas, NV.

Chen, J. Y. C., Durlach, P. J., Sloan, J. A., & Bowens, L. D. (2005). *Robotic operator performance in simulated reconnaissance missions* (No. ARL Tech. Rep. ARL-TR-3628). Aberdeen Proving Ground, MD: Army Research Laboratory.

Chen, J. Y. C., Haas, E. C., Pillalamarri, K., & Jacobson, C. N. (under review). *Human robot interface: Issues in operator performance, interface design, and technologies*: Human Research and Engineering Directorate, Army Research Laboratory.

Cooper, G., & Harper, R. (1969). *The use of pilot ratings in the evaluation of aircraft handling qualities* (No. NASA TN-D-5153). Moffett Field, CA: NASA Ames Research Center.

Cummings, M. L., & Guerlain, S. (2004). *Using a chat interface as an embedded secondary tasking tool*. Retrieved August 28, 2005, from http://web.mit.edu/aeroastro/www/people/missyc/pdfs/CummingsHPSAA04.pdf.

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111*(2), 225-236.

Dixon, S. R., Wickens, C. D., & Chang, D. (2003). *Comparing quantitative models prediction to experimental data in multiple-UAV flight control.* Paper presented at the Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica.

Ekstrom, R. B., French, J. W., & Harman, H. H. (1976). *Manual for kit of factor referenced cognitive tests*. Princeton: Educational Testing Service.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics, 42*(3), 462-492.

Ericsson, K. A., & Simon, H. A. (1984). *Protocol analysis: verbal reports as data*. Cambridge, MA: MIT press.

Fong, T., Thorpe, C., & Baur, C. (2003). Multi-robot remote driving with collaborative control. *IEEE Transactions on Industrial Electronics, 50*(4), 699-704.

Gaylord, J. E. (2004). *The mounted combat system company: Not your current full spectrum armor force.* United States Army Command and General Staff College, Fort Leavenworth, KS.

Gugerty, L., & Boorks, J. (2004). Reference-frame misalignment and cardinal direction judgments: group differences and strategie. *Journal of Experimental Psychology: Applied, 10*(2), 75-88.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam: Elsevier Science/North-Holland.

Huey, B. M., & Wickens, C. D. (1993). *Workload transition: Implications for Individual and team performance*. Washington, DC: National Academy Press.

Hurst, M. W., & Rose, R. M. (1978). Objective job difficulty, behavior responses, and sector characteristics in air route traffic control centers. *Ergonomics, 21*(9), 697-708.

Kaber, D. B., & Riley, J. M. (1999). Adaptive automation of dynamic control task based on secondary task workload measurement. *International Journal of Cognitive Ergonomics, 3*(3), 169-187.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kantowitz, B. H., Bortalussi, M. R., & Hart, S. G. (1987). *Measuring pilot workload in a motion base simulator: Synchronous secondary task.* Paper presented at the Proceedings of the 31st annual meeting of the Human Factors Society, Santa Monica, CA.

Kantowitz, B. H., & Casper, P. A. (1988). Human workload in aviation. In E. Wiener & D. Nagel (Eds.), *Human Factors in Aviation* (pp. 157-187). San Diego, CA: Academic Press.

Kantowitz, B. H., & Knight, J. L. (1976). Testing tapping timesharing: Auditory secondary task. *Acta Psychologica, 40*, 343-362.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: an enhance method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*, 203-220.

Kennedy, R. S., Lilienthal, M. G., Berbaum, K. S., Baltzley, D. R., & McCauley, M. E. (1989). Simulator sickness in U.S. Navy flight simulators. *Aviation, Space and Environmental Medicine, 60*, 10-16.

Kennedy, R. S., Stanney, K. M., & Dunlap, W. P. (2000). Duration and exposure to virtual environments: Sickness curves during and across sessions. *Presence, 9*(5), 463-472.

Lansman, M., & Hunt, E. (1982). Individual difference in secondary task performance. *Memory & Cognition, 10*, 10-24.

Lerner, E. J. (1983). The automated cockpit. *IEEE Spectrum, 20*, 57-62.

Martin, G. (1989). The utility of speech input in user-computer interfaces. *international journal of Man-Machine System Study, 18*, 355-376.

Meshkati, N., Hancock, P. A., Rahimi, M., & Dawes, S. M. (1995). Techniques in mental workload assessment. In *Evaluation of Human Work* (2nd ed.). Bristol, PA: Taylor & Fancis Ltd.

Michon, J. A. (1966). Tapping regularity as a measure of perceptual motor load. *Ergonomics, 9*, 401-412.

Michon, J. A., & Van Doorne, H. (1967). A semi-portable apparatus for measuring perceptual motor load. *Ergonomics, 10*, 67-72.

Mitchell, D. K. (2005). *Soldier workload analysis of the mounted combat system (MCS) platoon's use of unmanned assets* (No. ARL-TR-3476). Aberdeen Proving Ground, MD: Army Research Laboratory.

Mitchell, D. K., Samms, C. L., Henthorn, T., & Wojciechowski, J. Q. (2003). *Trade study: a two- versus three-soldier crew for the mounted combat system (MCS) and other future combat system platforms* (No. ARL-TR-3026). Aberdeen Proving Ground, MD: Army Research Laboratory.

Moray, N. (1967). Where is capacity limited? A survey and a model. *Acta Psychologica, 27*, 84-92.

Navon, D., & Gopher, D. (1979). On the economy of human processing systems. *Psychological Review, 86*(254-255).

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource limited processes. *Cognitive Psychology, 7*, 44-64.

Ogden, G. D., Levine, J. M., & Eisner, E. J. (1979). Measurement of workload by secondary tasks. *Human Factors, 21*, 529-548.

Parasuraman, R., Molloy, R., & Singh, I. L. (1993). Performance consequences of automation-induced "complacency." *International Journal of Aviation Psychology, 3*(1), 1-23.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics, 30*, 286-297.

Parkes, A. M., & Coleman, N. (1990). Route guidance systems: a comparison of methods presenting directional information to the driver. In E. J. Lovesey (Ed.), *Contemporary Ergonomics* (pp. 480-485). London: Taylor & Francis.

Previc, F. H. (1998). The neuropsychology of 3-D space. *Psychological Bulletin, 124*(2), 123-164.

Reid, G. G., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedures for measuring mental workload. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 185-213). Amsterdam: North Holland.

Rolfe, J. M. (1973). The secondary task as a measure of mental load. In W. T. Singleton, J. G. Fox & D. Whitfield (Eds.), *Measurement of man at work* (pp. 135-148). London: Taylor & Francis.

Sanders, M. S., & McCormick, E. J. (1993). *Human factors in engineering and design*. New York: McGraw-Hill, Inc.

Sarno, K. J., & Wickens, C. D. (1995). Role of multiple resources in predicting time-sharing efficiency: Evaluation of three workload models in a multiple-task setting. *International Journal of Aviation Psychology, 5*(1), 107-130.

Schipani, S. P. (2003). *An evaluation of operator workload, during partially-autonomous vehicle operations.* Paper presented at the Proceedings of PerMIS 2003, Gaithersburg, MD.

Service, E. T. (2005). *Cube Comparison Test*. Princeton, NJ: ETS.

Stanney, K. M., & Hash, P. (1998). Locus of user-initiated control in virtual environments: Influences on cybersickness. *Presence, 7*(5), 447-459.

TRADOC. (2003). TRADOC Pamphlet 525-3-90 O&O: The United States Army Objective Force Operational and Organizational Plan Maneuver Unit of Action. Fort Knox, KY: Unit of Action Maneuver Battle Lab.

Vidulich, M. A. (1988). Speech responses and dual task performance: better time-sharing or asymmetric transfer. *Human Factors, 30*, 517-534.

Vidulich, M. A., & Tsang, P. (1985). *Assessing subjective workload assessment: A comparison of SWAT and the NASA-Bipolar methods.* Paper presented at the Proceedings of the Human Factors Society 29th Annual Meeting, Santa Monica, CA.

Weinstein, L. F., & Wickens, C. D. (1992). Use of nontraditional flight displays for the reduction of central visual overload in the cockpit. *International Journal of Aviation Psychology, 2*, 121-142.

Wetherell, A. (1981). The efficacy of some auditory-vocal subsidiary tasks as measures of the mental load on male and femaile drives. *Ergonomics, 24*(197-214).

Wickens, C. D. (1980). The structure of attentional resources. In R. S. Nickerson (Ed.), *Attention and performance VIII* (pp. 239-257). Hillsdale, NJ: Erlbaum.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention* (pp. 63-101). New York: Academic Press.

Wickens, C. D. (1992). *Engineering pyschology and human performance* (2nd ed.). New York: Harper Collins.

Wickens, C. D. (2002). Multiple resource and performance prediction. *Theoretical Issues in Ergonomic Science, 3*, 159-177.

Wickens, C. D., & Hollands, J. G. (1999). *Engineering pyschology and human performance* (3rd ed.). Upper Saddle River, New Jersey: Prentice Hall.

Wickens, C. D., & Kessel, C. (1980). The processing resource demands of failure detection in dynamic systems. *Journal of Experimental Psychology, 6*, 564-577.

Wickens, C. D., Sandry, D., & Vidulich, M. (1983). Compatibility and resource competition between modalities of input, output, and serial processing. *Human Factors, 25*, 227-248.

Wiener, E. (1988). Cockpit automation. In E. Wiener & D. Nagel (Eds.), *Human Factors in Aviation* (Vol. 433-459). San Diego, CA: Academic Press.

Wierner, E. L. (1985). *Cockpit automation: In the need of philosophy.* Paper presented at the Proceedings of the Behavioral Engineering Conference, Warrendale, PA.