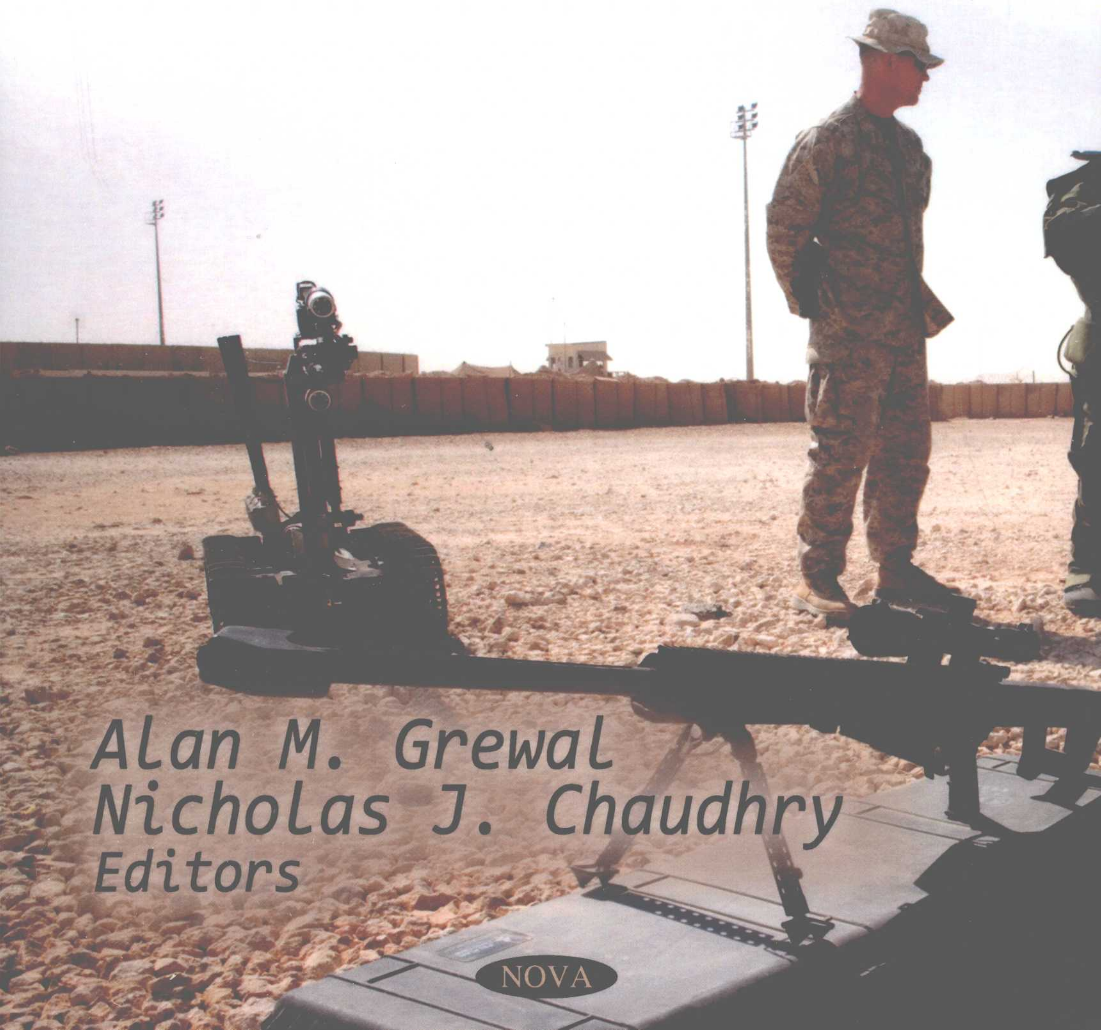
Robotics Research and Technology

SOLDIERS AND ROBOTS:
Interaction Studies



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ROBOTICS RESEARCH AND TECHNOLOGY

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INTERACTION STUDIES

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PREFACE

Warfighters working with robots are at the cutting edge of the Future Combat Systems (FCS) fighting forces. These individuals work with a diverse set of land, air, sea and undersea vehicles capable of a variety of missions. These missions vary and can include unattended sensors, reconnaissance, search and rescue, medical support and direct contact with enemy assets, with the systems ranging from single sensors to multirobot systems. Just as the missions and systems vary greatly, so do the operator control units and multioperator control unit interfaces employed to operate the robots. This variety of missions, robot types, and interfaces can be difficult to train for and manage. This book reviews the manipulations and outcomes of the workload in human-robot interaction.

Chapter 1- Warfighters working with robots are at the cutting edge of the Future Combat Systems (FCS) fighting forces. These individuals work with a diverse set of land, air, sea, and undersea vehicles capable of a variety of missions. The missions vary and can include unattended sensors, reconnaissance, search and rescue, medical support, and direct contact with enemy assets, with the systems ranging from single sensors to multirobot systems. Examples include FCS technologies network, TALON, iRobot, PackBot, the SPARTAN Advanced Concept Technology Demonstration, and the Family of Integrated Rapid Response Equipment sensors and vehicles (Powell et al., 2006). Just as the missions and systems vary greatly, so do the operator control units and multioperator control unit interfaces employed to operate the robots. This variety of missions, robot types, and interfaces can be difficult to train for and manage. It is therefore essential to identify the cognitive and task demands being placed on the warfighter to ensure successful mission outcomes.

Chapter 2- Unmanned vehicles (UVs) are being used more frequently in military operations, and the types of tasks they are being used for are evolving in complexity. In the future battlefield, Soldiers may be given multiple tasks to perform concurrently, such as navigating a UV while conducting surveillance, maintaining local security and situational awareness, and communicating with fellow team members. To maximize human resources, it would be ideal to designate a single operator to supervise multiple UVs simultaneously. However, research has shown that human operators are often unable to control multiple robots/agents simultaneously in an effective and efficient manner (Chen, Durlach, Sloan, and Bowens, 2008; Schurr, 2007). Additionally, as the size of the robot team increases, the human operators may fail to maintain adequate situational awareness when their attention has to constantly switch among the robots, and their cognitive resources may be overwhelmed by the intervention requests from the robots (Wang, Wang, and Lewis, 2008; Wang, Lewis, Velagapudi, Scerri, and Sycara, 2009). Wang et al. (2009) reviewed a number of studies on supervisory control of multiple ground robots for target detection tasks and concluded that "the Fan-out plateau lies somewhere between 4 and 9+ robots depending on the level of robot autonomy and environmental demands" (p. 143).

Chapter 3- In 2004, the U.S. Army Tank-Automotive Research Development and Engineering Center (TARDEC), in partnership with the U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED), pursued a 5-year program U.S. Army Technology Objective (ATO). The purpose of the ATO was to develop the tools, techniques, and autonomy to maximize mounted and dismounted control of ground and air unmanned systems and optimize Soldier-robot and robot-robot ground and air teams. Development included a scalable user interface for robotic control. The interface maximizes multi-function Soldier performance for primary tasks while minimizing unique training requirements, achieved by optimizing and standardizing the required interactions and managing the workload associated with the control of unmanned ground and air systems. This report highlights the Robotics Collaboration ATO Capstone Experiment on small robot control.

Chapter 4- Robotic swarms consist of a large number (potentially thousands) of small, relatively simple robots capable of autonomous travel and operation as a unit on land, sea, and air. Swarms can implement simplistic rules to accomplish a desired collective behavior that involves interaction between individual members as well as the behavior of the entire swarm [1]. These behaviors can be combined to enable swarm members to perform critical Army tasks such as accompanying convoys, mapping battlefields, and clearing minefields.

CONTENTS

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Chapter 1

DEVELOPMENT OF PRINCIPLES FOR MULTIMODAL DISPLAYS IN ARMY HUMAN-ROBOT OPERATIONS

Michael D. Coovert, Matthew S. Prewett, Kristin N. Saboe and Ryan C. Johnson

ABSTRACT

Work in the area of robots and human-robot interaction is exploding. This report reviews part of the literature and provides recommendations for future research. Three sections within the report outline topics of special interest: workload, autonomy, and visual displays.

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This work was supported by government contract number DAAD19-01-C-0065, task order 83. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

1. INTRODUCTION

Warfighters working with robots are at the cutting edge of the Future Combat Systems (FCS) fighting forces. These individuals work with a diverse set of land, air, sea, and undersea vehicles capable of a variety of missions. The missions vary and can include unattended sensors, reconnaissance, search and rescue, medical support, and direct contact with enemy assets, with the systems ranging from single sensors to multirobot systems. Examples include FCS technologies network, TALON, iRobot, PackBot, the SPARTAN Advanced Concept Technology Demonstration, and the Family of Integrated Rapid Response Equipment sensors and vehicles (Powell et al., 2006). Just as the missions and systems vary greatly, so do the operator control units and multioperator control unit interfaces employed to operate the robots. This variety of missions, robot types, and interfaces can be difficult to train for and manage. It is therefore essential to identify the cognitive and task demands being placed on the warfighter to ensure successful mission outcomes.

Several different approaches are necessary to cover the criterion space of these cognitive and task demands. The main strategy utilized here is an evaluation of the existing literature on human-robot interaction (HRI). Existing documents from the academic and the U.S. Army Research Laboratory literatures were examined and coded. The major dimensions of classifications uncovered included the number of platforms controlled, task difficulty comparisons, level of control by platforms, cuing/decision-making reliability, stereoscopic (SS) vs. monoscopic (MS) display, comparisons between modalities, comparisons within modalities, frame rate (FR), field of vision (FOV), latency/time delay, and camera perspective. A summary of these documents is available upon request.

This report contains several sections that support the taxonomy and provide recommendations for future multimodal displays and research. Sections 2–4 were originally three separate papers, each elaborating on specific aspects of the taxonomy. Each section covers a particular topic in HRI. Section 5 presents proposals for follow-on HRI research.

Due to size constraints, a separate, in-depth analysis of HRI cognitive task dimensions is not presented here but is available upon request from the authors. The in-depth analysis exists in two parts. The first portion is in this report and the second exists online. A database was created in RefWorks (2009) of articles eligible for meta-analysis. The coding sheet for the articles and instructions for using this database are also available from the authors. The database itself exists online and is available via the Web at http://www.refworks.com/.

Especially notable are any guiding principles culled from each article. Section 6 concludes with a references list of the articles in the meta-analysis folder of the REF WORKS database. These studies have been screened and coded as being eligible for meta-analysis.

2. Workload in Human-Robot Interaction: A Review of Manipulations and Outcomes

The current study reviews the relationship between manipulations of teleoperator workload and task outcomes, using multiple resource theory as the underlying framework. Results indicated that controlling more than two platforms is detrimental to many performance indices (reaction time [RT], error rate [ER]), but overall productivity improves. For studies that manipulated workload for a single robot task, visual demands were a limiting factor, and interventions that reduced visual demands improved performance. We conclude with guiding principles for managing workload and improving teleoperator performance.

2.1. Introduction

Autonomous agents have become an essential tool for a myriad of tasks. Through the use of unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs), service personnel can carry out tasks with a reduced risk to their safety. In recognition of these aforementioned advantages, there has been an increased interest in understanding and improving HRI (Chen et al., 2007). From a human factors perspective, understanding and mitigating the impact of workload should improve performance in HRI. This section addresses the issue of workload in HRI through a review of the experimental literature. Existing research has examined a multitude of manipulations and outcomes of workload demands, but a synthesis is needed to understand the state of the current research. The current review provides this need by integrating HRI studies according to manipulations, tasks, and outcomes in order to draw guiding principles.

2.1.1. Workload Manipulations in HRI

This section utilizes multiple resource theory (MRT) as the framework for workload in HRI, as described by Wickens (2002). The main tenets of MRT suggest that multiple cognitive resources allow for multitasking or time-sharing performance. Specifically, tasks requiring different cognitive resources can often be effectively performed together, but competition for the same resource(s) can produce interference. Much of the recent work on MRT has defined these resource channels while predicting the degree to which information from strained resource channels can be effectively offloaded to less-used channels. To summarize, tasks may strain cognitive resources through verbal, manual, or sensory demands (for a complete review, see Wickens [2002]).

Controlling a platform or interacting with an artificial agent imposes many demands, such as executing menu functions, navigating to waypoints, manipulating a foreign object, processing information from data uplinks, and communicating with team members. Most manipulations of HRI workload stem from changing the number of robots available or manipulating the demands of a single task or resource. Multirobot control affects workload by increasing the number of subtasks (monitoring, navigating, and executing). Although providing a user with more than one platform to control will certainly increase workload, will this additional strain outweigh the benefit of having multiple robots to execute task actions? Addressing this question may depend upon the tasks being performed and the criteria desired. Thus, we examine the issue of multirobot control by reviewing the HRI literature according to the tasks and criteria studied.

In contrast to manipulations of robot quantity, other manipulations of workload focus on a single task or cognitive resource. These interventions frequently include changing the performance standard (e.g., number of targets to process) or changing the environmental complexity (e.g., terrain detail). Whereas environmental complexity should impact primarily sensory (visual) demands, performance standards are more likely to affect responding demands. A review of these manipulations should reveal the practical limitations of various cognitive resource channels for HRI tasks.

2.1.2. Purpose

Now that MRT and the common workload manipulations in HRI have been outlined, the purpose of this section is to draw guiding principles for teleoperator* workload and performance. A qualitative review will allow us to compare the effects of distinct workload manipulations across a variety of tasks and study criteria. To analyze the literature, a systematic coding process was applied to the extant database, described next.

2.2. Method

2.2.1. Literature Search

The literature search included a query using several scientific and military electronic databases, including the Defense Technical Information Center (DTIC), the Association for Computing Machinery (ACM), and the Institute of Electrical and Electronics Engineers (IEEE). References from a recent HRI review (Chen et al., 2007), as well as obtained experimental studies, were also checked for eligibility. Finally, a hand search was conducted on the following journals and proceedings for the past 5 years: *Human Factors*, *Presence*, *Human Computer Interaction (HCI),* and *IEEE*.

2.2.2. Coding Procedure and Inclusion Criteria

Before coding, raters reviewed the variables of interest, constructed a coding sheet to reflect them, and accordingly screened articles for eligibility. Five studies were then selected and coded by all raters to examine validity and agreement. Based on acceptable agreement, one out of five raters coded the studies for this review based upon the definitions described in the following paragraph.

To be included in the present review, an article was required to report a study that experimentally compared operator performance between different workload conditions. Furthermore, tasks had to utilize artificial agents or involve teleoperation. Thus, studies that used equipment for non-HRI tasks (e.g., cockpit simulators) were excluded from this review. Criteria included

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* The word "teleoperator" is broadly defined here and refers to an individual operating a device from a remote location.

measures of (1) production (e.g., number of actions), (2) errors (e.g., incorrect actions), (3) RT, (4) efficiency (e.g., time to task completion), (5) perceived workload (e.g., the National Aeronautics and Space Administration Task Load Index [NASA-TLX] scores), and (6) situational awareness (SA). Finally, study characteristics such as the design (e.g., repeated measures), sample (e.g., student), task, and apparatus (e.g., UAV) were noted during coding.

2.3. Results

Table 1 lists the citations for the 18 studies assessing multirobot control, the number and type of platform used, the measured task outcomes, and key findings. In general, samples ranged from students to aviation and HRI professionals. Tasks predominantly included navigating platforms to targets or areas of interest, executing an action (e.g., inspection, manipulation), and monitoring and responding to system gauges and alerts.

When examining results by the task performance measures, we observe an emerging trade-off between production and other measures. In many studies, teleoperators could execute more total actions as they controlled more platforms (e.g., Crandall and Cummings, 2007; Lif et al., 2007; Squire et al., 2006). However, increasing the number of platforms also increased ERs in targeting and navigation (e.g., Dixon and Wickens, 2003; Galster et al., 2006), and it tended to increase RTs (e.g., Chadwick, 2006; Levinthal and Wickens, 2006). These results suggest that the control of multiple platforms allows the teleoperator to accomplish more tasks overall because of the increased resources. However, this added productivity comes at a cost of accuracy and efficiency. Although the control of one robot was optimal for task errors and RT across studies, the control of two robots did not inhibit performance to nearly the same degree as control of four or more robots (Adams, 2009; Chadwick, 2006; Ruff et al., 2002). Thus, control of two platforms might provide an optimal fit for maximizing both speeded performances and ER.

Finally, automation and multimodal feedback were examined as methods of improving the cognitive workload from additional platforms. In the case of automation, reliability made a much greater impact than the degree or type of automation (Levinthal and Wickens, 2006; Ruff et al., 2004). The addition of audio feedback, on the other hand, provided a consistently more positive effect (Wickens et al., 2003; Dixon and Wickens, 2003).

Table 2 presents the manipulation and the task affected as well as key findings for the 17 studies examining task demands. The types of devices used had more variability in this sample than in multirobot samples, including a robotic arm interface (Park and Woldstad, 2000), a decision- making simulation (Hendy et al., 1997), and virtual environments (VEs) from a variety of perspectives.

Table 1. Study Summaries on Multirobot Control

Study	Manipulation	Criteria (by Task Type)	Key Findings
Adams, 2009	One, two, or four UGVs	No. of actions, efficiency, and workload for search and transfer	• Slight differences between one and two UGVs, but efficiency and perceived workload were worse with four robots.
Chadwick, 2005	One or two UGVs	Targeting errors, navigation errors, and perceived workload	• No significant differences between groups.
Chadwick, 2006	One, two, or four UGVs	RT to hit target, RT to correct navigational error	• Response times degraded slightly from one to two UGVs. • Response times degraded markedly from two to four UGVs.
Chen et al., 2008	One or three UGV and/or UAVs	Errors, efficiency, SA, and workload in targeting (with navigation)	• Targeting errors were equal between three platforms and single UAV or UGV, but perceived workload and efficiency suffered.
Crandall and Cummings, 2007	Two, four, six, or eight UGVs	Errors and efficiency in navigation and target detection/transfer	• Four and two UGV conditions exhibited fewest lost robots. • Six and eight UGV conditions yielded highest no. of target successes.
Dixon and Wickens, 2003	One or two UAVs	Tracking error, target reporting accuracy, RT to system alerts	• One UAV user had slightly better performance indices than two UAVs. • Adding auditory feedback improved performance across conditions.
Galster et al., 2006	Four, six, or eight UAVs	Targeting accuracy, time processing key	• Four UAV users had better accuracy and RT, but equal processing times.

Table 1. (Continued)

Study	Manipulation	Criteria (by Task Type)	Key Findings
		targets, RT to probes, workload	• Workload differences between conditions emerged for difficulty.
Humphrey et al., 2007	Six or nine UGVs	Efficiency, workload, and SA in bomb disabling simulation	• No. of platforms also coincided with no. of bombs to diffuse (difficulty). • Performance and workload indices were similar between conditions.
Levinthal and Wickens, 2006	Two or four UAVs	Idle time during UAV navigation, RT to system alerts	• Users were less efficient when controlling four UAVs. • False alarms in automation hurt performance more than false misses.
Lif et al., 2007	One, two, or three UGVs	Number of waypoints reached within given time (production)	• Users visited more waypoints controlling two or three UGVs (equally) than controlling one.
Murray, 1995	One, two, or three sensors	Time to monitoring task completion	• Users were significantly slower completing the tracking task with three platforms than with one.
Parasur-aman et al., 2005	Four or eight UGVs	Completion time for game, no. of games won, workload	• Completion time and win rate deteriorated from four to eight UGVs. • As workload increased, automation features had a greater impact.
Ruff et al., 2002	One, two, or four UAVs	Targeting accuracy, correct rejection rate of automation errors, workload	• One UAV user had the fewest rejection errors, two UAV users had the best targeting accuracy, and four UAV users reported the most workload.
Ruff et al., 2004	Two or four UAVs	Targeting and navigation completion, RT to system alerts, workload	• All performance indices were better in two UAV conditions than four. • Reliability of automation, rather than level of automation, had greatest impact.