Simulation to Assess an Unmanned System's Effect on Team Performance

Eric Ortiz, Daniel Barber
Institute for Simulation & Training at the University of Central Florida
Orlando, FL
eortiz@ist.ucf.edu, dbarber@ist.ucf.edu

MAJ Jonathan Stevens, Dr. Neal Finkelstein,
U.S. Army's Research, Development and Engineering Command SFC Paul Ray Technology Center
Orlando, FL
jonathan.stevens@us.army.mil, neal.finkelstein@us.army.mil

ABSTRACT

In the contemporary operational environment, U.S. Soldiers routinely conduct military operations with unmanned systems. Typically, these systems are used to conduct Improvised Explosive Device (IED) interrogation, and Unmanned Aerial System (UAS) surveillance, and reconnaissance. Current unmanned systems operate non-autonomously and in a physically separate location from their human teammates. Although the physical augmentation of human Fire Teams by unmanned systems during combat offers a logical extension of this use the U.S. Army does not currently integrate unmanned systems into mixed-initiative team operations or training. The impact of integrating an unmanned system with a human Fire Team represents a critical issue for the U.S. Army.

To investigate the effect on team performance when a non-autonomous unmanned system is integrated into a human team during training, the U.S. Army's Research, Development and Engineering Command (RDECOM) SFC Paul Ray Smith Simulation & Training Technology Center (STTC), in partnership with the Institute for Simulation and Training at the University of Central Florida, has begun studies in which a human team member is replaced with an unmanned Remote Weapon System (RWS) prototype. At two U.S. Army installations, trials were conducted with trained Fire Teams using the Engagement Skills Trainer 2000 (EST 2000), a virtual training simulation supporting realistic collective training. The EST 2000 was utilized to investigate performance differences between Fire Teams who were either fully manned by humans or when one team member was replaced by a RWS prototype. This paper describes the motivation for the investigation, the experimental plan and methodology, some preliminary findings, and the impact on Human-Robot Interactions (HRI). Research results supplied by this study will serve as a foundation for the development of operational and training strategies to enhance the integration of unmanned systems into human teams.

ABOUT THE AUTHORS

Mr. Eric C. Ortiz *is a Virtual Learning Environment Developer* for the Applied Cognition and Training in Immersive Virtual Environments (ACTIVE) Lab at the Institute for Simulation and Training (IST) at the University of Central Florida. Eric became a member of the ACTIVE Lab following eight years of service with General Dynamics Information Technology. He has over thirteen years experience in the creation of virtual environments, and has managed experiments utilizing Human Robot-Interactions in military simulations.

MAJ Jonathan Stevens is the Military Deputy of the Simulation and Training Technology Center (STTC), a subordinate element of the U.S. Army's Research, Development and Engineering Command (RDECOM). He is a Major in the U.S. Army, providing oversight to numerous research and development programs and efforts. He earned his Master's degree in Modeling and Simulation from the University of Central Florida.

Mr. Daniel Barber is a Research Associate for the Applied Cognition and Training in Immersive Virtual Environments (ACTIVE) Lab at the Institute for Simulation and Training (IST) at the University of Central Florida, leading the Robotics and Intelligent Systems team. He has over five years of experience in the field of robotics, with research in intelligent systems, machine learning, control systems, and environment modeling. He has designed

multiple autonomous systems and is a mentor and faculty advisor for the Robotics Club at the University of Central Florida.

Dr. Neal M. Finkelstein is the Division Chief at the Simulation and Training Technology Center located in the Florida Simulation Center in Orlando, Florida, Dr. Finkelstein serves as a principle senior technical advisor on technical, programmatic, and organizational issues that cut across the organization.

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INTRODUCTION

Unmanned systems conduct many vital missions in the modern battle space, and since the beginning of Operations Enduring Freedom and Iraqi Freedom, employment of unmanned systems has escalated exponentially. As of October 2006, coalition Unmanned Aircraft Systems (UASs) had flown almost 400,000 hours; Unmanned Ground Vehicles (UGVs) had responded to over 11,000 Improvised Explosive Device (IED) situations, and Unmanned Maritime Systems (UMSs) had secured numerous ports (Office of the Secretary of Defense (OSD), 2007).

Despite the widespread application of unmanned systems, many critical mission areas remain under-supported. The *Unmanned Systems Roadmap* (OSD, 2007) outlines an aggressive plan to address these capability gaps over the next 25 years. The report also lists important areas of research necessary to support its vision, including the careful weaponization of unmanned systems, ensuring Warfighter confidence in these weaponized robots, and developing a better understanding of Human–Robot Interaction (HRI). The present study was undertaken to explore such fundamental HRI issues.

Sponsored by the U.S. Army's Research, Development and Engineering Command (RDECOM) SFC Paul Ray Smith Simulation & Training Technology Center (STTC), in collaboration with the Institute for Simulation and Training at the University of Central Florida, this study investigates the impact of a co-located Remote Weapon System (RWS) on Soldiers. The performance of Army Fire Teams was evaluated within the Engagement Skills Trainer 2000 (EST 2000) immersive battlefield simulator. In the control condition, all four members of the Fire Team executed collective scenarios. Then in the experimental condition, one member of the Fire Team was replaced by a RWS, which the replaced Soldier operated from another location. The RWS possessed video input, but it lacked audio input or output capacity, or other communication modalities.

Given the interdependent nature of Fire Teams, this research hypothesized that physically separating one team member, thus greatly reducing his/her ability to communicate with the rest of the team, would negatively impact team performance. This research further posited that the physical presence of a moving, firing, weaponized unmanned system may negatively impact the team performance of Soldiers co-located with the RWS.

Results suggest that no significant differences in team marksmanship performance existed between conditions; however, Soldiers appeared to engage in compensatory behaviors in the experimental conditions. These findings, and their implications for the future of fielded Soldier-robot teams, are discussed in this article.

Remote Weapons Systems

A RWS is a non-autonomous, remotely-operated unmanned weapon system. RWSs are designed for light and medium caliber weapons and can be equipped with standard weapons already used in the Department of Defense's inventory. RWSs can be installed on a variety of military vehicles, platforms, or robots. However, they are most often mounted to vehicles, enabling military Gunners to operate the weapons from within the relative protection of the vehicle (Amant, 2005; Gourley, 2003; Associated Press & FOX News, 2005).

Examples of Ground-Based RWSs

CROWS – The Common Remotely Operated Weapon Station (CROWS) mounts on various vehicle platforms and supports a range of weapons, including the MK19 grenade launcher, the .50-caliber M2, the M240B, and the M249 squad automatic weapon. The first CROWS systems were fielded in Iraq in 2004, with a deployment of over two hundred units (Amant, 2005).

Stryker XM151 – Similar to the CROWS, the Stryker XM151 RWS can support a .50-caliber M2 machine gun, 40 mm automatic grenade launcher, and other weaponry. The XM151 is employed within the Stryker Brigade Combat Team (SBCT) and is currently carried on infantry, mortar, command, and engineer squad vehicles (Cline, 2005). At the beginning of 2003, more than three hundred units were already delivered to the U.S. Army's Stryker Brigade, with production planned to continually increase (Gourley, 2003).

SWORDS – The Special Weapons Observation Reconnaissance Detection System (SWORDS) is the armed version of the TALON robot. In contrast to the CROWS and Stryker XM151, which are mounted to vehicles, SWORDS is a standalone robot. It supports small arms combat and can carry a variety of weapons, such as the M16 rifle, M249, M240B machine gun, and M202A1 FLASH incendiary weapon. Three SWORDS units, each equipped with a M249 machine gun were deployed to Iraq in 2007, marking the first time that armed robots have been put in place for battle (Shachtman, 2007). Recently, the Army unveiled the successor to the SWORDS, called the Modular Advanced Armed Robotic System (MAARS). MAARS improves the control, mobility, and safety of the SWORDS platform (QinetiQ, 2009).

Human–Robot Teams

While increasing amounts of research have focused on the operation and maintenance of unmanned systems, fewer investigations have examined how the presence of a robot impacts the performance of wider operational teams (e.g., Cooke, Pringle, Pedersen, Conner, & Salas, 2006). Yet, as the Army moves towards its vision of fielding human–robot teams, researchers must develop a clearer understanding of how humans and unmanned systems will collaborate. As outlined in the *Unmanned Systems Roadmap* (OSD, 2007):

> Human–robot teams provide a unique challenge, that is, how to develop unmanned systems technologies to enable the human to predict, collaborate, and develop trust with the unmanned system (51).

The collaboration between humans and RWSs presents additional issues, given the high potential for injury if a malfunction occurs. Already, the military has demonstrated its distrust of robotic RWSs: The three SWORDS units deployed to Iraq in 2007 were shelved almost immediately upon arrival, before firing a single shot. The Soldiers noticed the guns moving when no commands had been given, and they became nervous. Although no shots were fired and no injuries occurred, the SWORDS were immediately pulled from the battlefield (Sofge, 2008). As this incident demonstrates, the trust between humans and robots is fragile; yet, for future RWSs to be effectively employed, it is essential that Warfighters are comfortable working near and relying upon their unmanned teammates. Thus, researchers must begin to explore humans' social expectations and behaviors when operating with weaponized unmanned systems.

DEVELOPMENT OF A PROTOTYPE RWS

To support experimentation, a medium-fidelity RWS was constructed. The RWS prototype consisted of an M240B machine gun, modified to function within an immersive simulation, and mounted on a pan-and-tilt framework on a stationary platform (see Figure 1). The M240B represented the largest caliber (7.62mm) weapon that could be placed on a RWS and still fit comfortably within the spatial constraints of the selected simulation testbed, the EST 2000.

Figure 1. M240B RWS Prototype

The prototype RWS was modeled after the M151 Protector, the commercial version of the Stryker RWS described above (Cline, 2005). The prototype RWS was controlled via a remote operator station located in a separate room. The RWS operator viewed the EST 2000 through a camera mounted on the device, which was calibrated to function in the low-light conditions of the EST 2000. The operator controlled the movement and speed of the pan-and-tilt device, which allowed two-degrees of freedom and enabled the operator to visually traverse the full simulated scene.

RWS Mechanics

Due to the weight of the weapon, 12.5 kg (27.6 lbs), and the recoil that it generated, a durable pan-and-tilt unit was needed. The PTU-D300 Heavy-Duty Pan-Tilt by Directed Perception which has a payload capacity of almost 40 kg (70 lbs) and provides pan/tilt speeds up to 100° per second with a resolution of 0.00625° was chosen. In addition to its high payload capacity and speeds, the Pan-Tilt Unit (PTU) provided a serial interface for computer control, facilitating easy integration with other software applications. The M240B was shock-mounted to the PTU using a custom bracket that attached to existing mounting points on the weapon. In addition to the PTU, a high torque actuator was attached to the side of the M240B bracket in order to push and engage the weapon's trigger mechanism.

RWS Camera

Because of the low-light conditions within the EST 2000 the Sony DCR-HC62 MiniDV Camcorder was selected, which provided clear, focused views of the simulators projections. In addition to its low light capabilities, the MiniDV Camcorder supports IEEE1394 connections, making it easy to integrate with the PTU software. The center of the cameras picture was aligned with the weapons' barrel position and calibrated before each trial. The operator control software superimposed an artificial reticle on the video stream, to help the RWS operator aim at targets.

RWS Software Messaging Protocols

A Mini-ITX based PC controlled the PTU, camera, and trigger mechanism of the RWS. All RWS components were integrated into a single Joint Architecture for Unmanned Systems (JAUS) subsystem and controlled over a standard Ethernet connection. JAUS is an international messaging standard designed to ensure interoperability across the range of unmanned systems, irrespective of specific hardware or technology configurations. A custom implementation of JAUS, called JAUS++, was used to allow the RWS to be rapidly integrated with a previously-developed Operator Control Unit (OCU) (Barber, 2008). JAUS++ is publically available at http://sourceforge.net/projects/active-ist.

RWS Operator Control Unit

The RWS operator station was placed in a remote location, from which operators could not directly see or hear the EST 2000 or their teammates within it. The OCU included a 24" LCD monitor that displayed the video feed from the RWS camera. As described earlier, the OCU software superimposed a reticle at the center of the video image, which corresponded to the weapon's firing position. The OCU used a standard Logitech Joystick to control the movement and firing of the RWS, and from the operator station, participants were able to fully traverse the EST screen, acquire targets, and engage them using the joystick (see Figure 2).

Figure 2. View from RWS Operator Station

RWS Verification and Validation

Prior to beginning the experimentation, a pilot study was conducted at STTC to ensure operability of the EST 2000 scenarios and the RWS prototype. Then at the beginning of each day of the experiment, the research team re-verified the functionality of the RWS reticle alignment, video clarity and vibration, weapon recoil absorption, joystick controls and speed. A Subject Matter Expert (SME) from the U.S. Army also validated that the RWS performed to operational standards within the EST 2000.

THE PRESENT STUDY

This study was designed to explore HRI by examining how performance differs between human-only teams and human–robot teams.

Participants

Participants included 144 Soldiers from two different U.S. Army installations (Group 1 (n = 72) and Group 2 (n = 72)). They ranged in age from 19 to 26 years with a mean of 23 years (SD = 4.18). There were 137 males and 7 females included in this study. Group 1 participants were pre-deployed novice Soldiers, with an average of 4.3 months experience (SD = 4.39). Soldiers in Group 2 had an average of 28.3 months (SD = 24.64) experience in the military. To be included in the study, all participants were required to have prior training with both the M16 rifle and the M240B machine gun but were not required to have team experience or experience using a RWS.

Equipment/Materials

Weaponry
M16 Assault Rifle – The M16 is an approximately 8 lbs, 40 inch long 5.56 mm caliber, gas-operated assault rifle (Department of the Army, 2003) used for its rapid fire availability in a short range area. In this experiment, the weapon was used by the Riflemen teammates to neutralize enemy targets in the simulated missions.

M240B Machine Gun – The M240B is an approximately 27.6lb 49 inch long 5.56 mm caliber 7.62 mm, gas-operated, belt-fed, medium action machine gun (Department of the Army, 2003) that was used in two forms for this experiment. In the manned condition, the gun was used in bipod mode and operated manually by a Gunner. In the unmanned scenarios, the gun was mounted on the medium fidelity RWS.

Simulation Testbed System
EST 2000 – The EST 2000 marksmanship simulator provided the immersive testbed for this experiment. It facilitates multi-echelon training in a virtual environment. It consists of basic rifle marksmanship, discriminatory firing, and collective instruction. Simulated mission scenarios can run on the system and can employ actual weapons modified to interact with the projected display. The EST 2000 is divided into parallel lanes. This experiment used five adjacent lanes (see Figures 3 & 4).

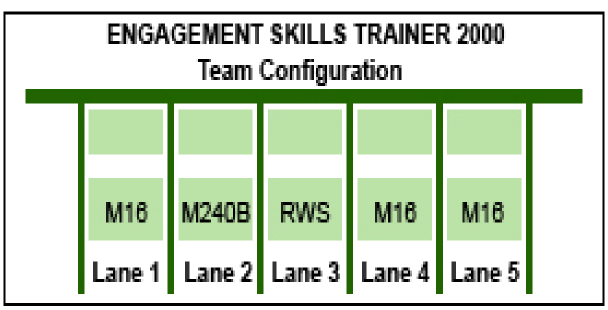

Figure 3. Sample of EST 2000 Team Configuration

Figure 4. View of EST 2000

Remote Weapon System – As discussed above, The RWS prototype consisted of an M240B machine gun, modified to function within the EST 2000, and mounted on a pan-and-tilt framework on a stationary platform. The RWS was set-up in lane three. During the manned scenarios the Gunner was positioned in lane two. During the unmanned scenarios, this Gunner operated the RWS from another room leaving lane two empty.

Scenarios
Three scenarios were utilized in this study. The Duck Shoot (practice and experimental) scenarios are pre-designed defensive combat missions that simulate a sandy terrain requiring Gunners to neutralize Computer Generated Forces (CGF) in rapid fire succession. The Duck Shoot scenarios were used solely with the Gunners in this experiment.

For the team experimental scenarios, two customized training scenarios, Desert Dunes and Quarry (each having a manned and unmanned version), were developed that concentrated on collective, defensive, kinetic operations with timed target exposures. In both scenarios CGF were dynamic entities attacking the Fire Team. All entities had timed exposures; thus if the team failed to destroy the target within its finite existence, no credit was recorded for a catastrophic kill. A total of 94 (Desert Dunes) and 74 (Quarry) CGF were presented in each scenario. The Desert Dunes scenarios simulated a desert terrain with sand dunes and CGF attacking in rapid progression down the sand dune in a stochastic-like pattern. The Quarry scenario simulated an urban setting in which CGF appeared to run and hide behind barrels, buildings, and pipes (see Figure 5). To account for the difference in experience between the two groups, the scenarios in the second U.S. Army installation were increased in difficulty by making the targets more obscured in the simulated field.

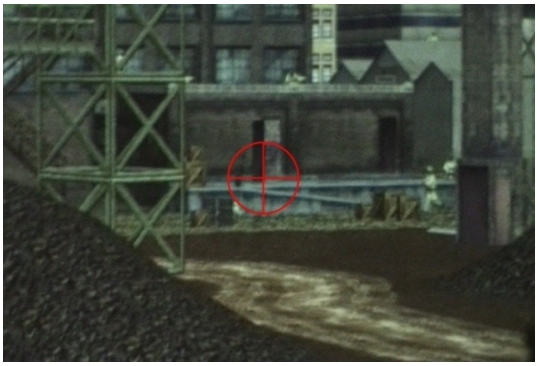

Figure 5. View of Quarry Scenario

Training

As each team arrived, they were read the task, conditions, and standards explaining the day's activities. All participants were moved into a separate room to observe the OCU for the RWS. Participants were instructed on the mechanics of the RWS and taught how to use the system. Specifically, they were instructed on how to traverse the RWS using the joystick and engage targets using the RWS. Traversing enabled Gunners to move around the screen so they could view the simulated mission scenarios located in the other room of the EST 2000. Engagement allowed Gunners to activate the trigger pull mechanism so they could remotely neutralize targets in the scenarios. Subsequently, participants were moved into the EST 2000 where a demonstration took place on how to lock and load and use the M240B in bipod position (manual position) to engage CGF on the screen.

Gunner Training

Following the demonstration of the RWS and M240B in bipod mode, Gunners were allowed to practice the Duck Shoot scenario with each apparatus; Gunners replayed the practice scenario until a military SME determined they were qualified with the equipment. Upon completion of the practice sessions, Gunners executed a recorded fire session using the experimental Duck Shoot scenario as their baseline.

Riflemen Training

Riflemen were read the day's task, conditions and standards and given a demonstration of the RWS, typically observing one of the Gunners executing his/her RWS recorded fire. However, because they were already pre-qualified to use the M16, no further training was provided to the Riflemen team.

Procedure

Thirty six, four-person Fire Teams completed the study each day for six days. In each Fire Team, one Soldier was designated as the M240B/RWS Gunner; another was designated as the Fire Team leader, while the other two Soldiers served as Riflemen. This study was conducted in two locations, over a two week period, three days each week.

The Soldiers arrived and were read the task, conditions, and standards; and then separated into teams. Following the Gunner training and baseline establishment, the experimental phase involved the Gunners and Riflemen engaged in the two team scenarios (Desert Dunes and Quarry). The first Fire Team executed the Desert Dunes experimental scenario in a manned configuration (four human team members physically co-located) and then again in an unmanned configuration. In the unmanned scenario, the Gunner was removed from the room and replaced with the RWS. The Gunner controlled the RWS from a remote location, but retained verbal communication with the team leader using a radio. Each team had four and a half minutes to negotiate through the first scenario and four minutes for the second scenario. This process was repeated with the Quarry experimental scenario for a total of four recorded sessions per Fire Team.

TEAM PERFORMANCE DATA ANALYSIS

This initial analysis focuses on team performance, which for this investigation is defined as the aggregate number of entities destroyed by a Fire Team. A paired two-sample *t*-test on each sample population was performed, and the null hypothesis was not rejected. The hypotheses were:

Let ***Ho*** = team performance was the same for manned and unmanned team configurations
and ***Ha*** = team performance was not the same for manned and unmanned configurations

Group 1 $t(35) = 0.093$, $p = 0.926$
Group 2 $t(35) = 1.085$, $p = 0.285$
at $\alpha = 0.05$

Thus, this initial analysis found no appreciable impact of the RWS on team performance, since no significant difference was found between conditions.

DISCUSSION

The *Unmanned Systems Roadmap* (OSD, 2007) outlines critical issues of study for the future of military unmanned systems, such as developing a better understanding of HRI. The present study was undertaken to explore some basic issues of HRI among human–robot Fire Teams. Specifically, how the presence of an unmanned RWS affected team marksmanship performance was investigated. This study involved participants from two U.S. Army installations, allowing us to capture data from Soldiers with different levels of training and time served.

The results showed no significant difference in performance between the manned and unmanned team configurations. There are several reasons why this may be the case. First, the presence of an unmanned RWS simply may not impact Fire Teams' behaviors; however, this scenario seems unlikely, both from a theoretical position and given anecdotal evidence (such as the SWORDS incident in 2007) from the military.

A second possibility is that the presence of an unmanned RWS in a safe setting—with no potential for physical harm or other negative outcomes—may not impact Fire Team's behaviors. If this circumstance proves true, one can roughly assume that the physical presence of the RWS is a nonissue; that is, its sounds and movements do not physically distract the human teammates. Instead, the focus should be on the psychological impact of the RWS, such as how to design RWSs so that their teammates feel safe around them or whether training or other preparative interventions can help build trust among human and unmanned team members.

As with all research studies, failing to disprove the null hypothesis may be an artifact of the experimental design. For instance, aggregate team performance was used as the comparison measure between conditions. Thus, it may be that some individual team members' scores (e.g., the Solider directly adjacent to the RWS in the unmanned condition) were significantly affected by the presence of the RWS, but the overall team was able to compensate for any individual performance issues. Another possibility is that the order of conditions (i.e., manned preceding unmanned) created a learning effect, where performance in the unmanned condition was bolstered merely because it was the second trial of the scenario.

Clearly, additional experimentation is required to better comprehend the impact (or lack thereof) of an unmanned system on individual and team performance. However, this study represents a strong first step toward better understanding the HRI of integrated human and RWS Fire Teams.

NEXT STEPS

Although the results from this study show promise for the inclusion of RWSs in human teams, it is only a small portion of the total project scope. A critical factor in the future integration of unmanned RWSs in the military is the Soldiers' acceptance of an unmanned system as a member of the Fire Team. As technology advances, the notion of incorporating unmanned systems into human teams operating in hazardous situations will likely strengthen. The current study was performed within the simulated environment of the EST 2000. However, this simulated environment does not contain any of the physical hazards that could be present in combat, enabling Soldiers to perform their mission without fear of harm to themselves or their teammates. Consequently, it would be advantageous to conduct a follow-on study in which situational stressors are systematically introduced during the mission in order to determine whether the integration of an unmanned RWS affects team performance in comparison to the baseline data from this study. The results from such a study may be the only way to truly gauge a Soldier's comfort level while interacting with a RWS.

Another step towards advancing the future integration of a RWS in human teams is to conduct a study in which participants are unsure of the RWS operator's location. In the present study, participants knew that the RWS operator was a member of their own team who was located in an adjacent room. However, it is important to determine whether team performance is affected when the operator is located in an unspecified or remote location (e.g., a mile away, a state away, or country away from the rest of the team). Additionally, teams were aware of whom the RWS operator was, having interacted with them before the study and during the manned scenarios. Future work should determine if the absence of this dynamic can affect team cohesion and performance. Furthermore, as previously noted, the levels of experience between participants differed. Subsequent studies should attempt to identify the differences attributed with levels of experience between groups when a RWS is introduced. A future capability yet to be explored in this study is the use of an autonomous RWS within a human team. As stated before, the Fire Team knew a human being was behind the scenes working with them. A follow on study may identify changes in team behaviors if the weapon is controlled by a computer instead.

The sole focus of the current study was to test team performance in response to incorporating a RWS into a human team. However, the results suggest that there are numerous possibilities for future training and operational strategies. Future unmanned RWSs may support an ultimate goal of enabling Soldiers to successfully complete their mission while keeping them safe and out of harm's way. New training coupled with new tactics, techniques and procedures must be developed to maximize the effectiveness of the RWS operator, reduce casualties and team workload. To make these strategies a reality, future efforts must improve a RWS operator's ability to engage targets while also training Soldiers for new combat methods with unmanned systems.

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