Teaming with a Robot: Effects on Teamwork Quality and Human-Robot Trust

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ABSTRACT

The growth of unmanned systems deployment in the U.S. military has created an even higher demand for human-robot interaction (HRI) research. Currently, unmanned systems implemented for military operations are non-autonomous and require collaboration with human teammates. In order to optimize the effectiveness of human-robot collaboration, it is important to consider the implications of introducing an unmanned system into team interactions. This paper summarizes the methodology and results of an experiment to investigate the use of a Remote Weapons System (RWS) in place of a human Fire Team member and its impact on teamwork quality and trust in unmanned systems. 144 U.S. novice and expert Army soldiers were divided into 4-person Fire Teams and performed simulated missions. Teams were either fully manned or consisted of three human members and one RWS. The results suggested that teamwork quality improved significantly within both novice and expert Fire Teams when the teams included the RWS. Trust in unmanned systems also improved among novice teams; however, there was no significant change in human-robot trust among experienced soldiers.

ABOUT THE AUTHORS

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INTRODUCTION

Unmanned systems have become an integral facet contributing to the Global War on Terror, performing military operations such as surveillance, target identification, target detection, and reconnaissance. As of October 2008, coalition unmanned aircraft systems (UASs) accumulated nearly 50,000 flight hours (Department of Defense (DoD, 2009). Additionally, unmanned ground vehicles (UGVs) have conducted over 30,000 missions while unmanned maritime systems (UMSs) have served numerous port security details (DoD, 2009).

The versatility and effectiveness of unmanned systems has resulted in a rapid increase in research and development efforts (DoD, 2007). According to the Department of Defense (2007), the potential of unmanned systems is yet to be reached. The *Unmanned Systems Roadmap* (DoD, 2007) presents the vision for the next 25 years of unmanned technology development. It identifies some of the major objectives toward efficiently deploying unmanned systems. One such objective includes a greater focus on human-robot collaboration within teams.

As the *Unmanned Systems Roadmap* (DoD, 2007) describes, the implementation of human-robot teams will be a major component of future military missions. In order to optimize human-robot collaboration, there needs to be a greater understanding of the effects robots have on team interactions and how these interactions ultimately relate to mission performance. Major steps toward ensuring optimal performance include improving the quality of teamwork among Fire Teams and creating a greater acceptance and sense of trust in the capabilities of unmanned technology. This experiment was conducted to inquire about two specific factors of human-robot teams: teamwork quality and human-robot trust.

Teamwork Quality

Hoegl & Gemuenden (2001) define teamwork as a social system of three or more people who collaborate on a common task. Teamwork is often considered a crucial factor for success in performing tasks; however, empirical research on the construct does not address the many facets of team functioning (Hoegl & Gemuenden, 2001). Interactions among teammates can exist in different forms, such as those that are task related and those involving social interaction (Hoegl & Gemuenden, 2001). The multifaceted nature of teamwork makes it a difficult concept to measure. Hoegl & Gemuenden offered one method of quantifying teamwork by developing the construct of Teamwork Quality (TWQ). The TWQ construct is a comprehensive concept involving the quality of team interactions and consists of six facets: communication, coordination, balance of member contributions, mutual support, effort, and cohesion.

Experimentation has provided empirical evidence that supports the TWQ construct. A study by Hoegl & Gemuenden (2001) used a self-report questionnaire that included multiple items aimed at assessing each facet of the TWQ construct. The results suggested that the TWQ has a strong relationship between success on innovative projects and personal satisfaction of individual team members.

Human-Robot Trust

One of the challenges facing the development of unmanned technologies is enabling humans to develop trust with the system (DoD, 2007). Lee and Moray (1994) define trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability." Thus, human-robot trust is the attitude that the robot will be able to contribute to an individual's goals. Much of the recent research on human-robot trust is focused on trust in automated systems (Lee & Moray, 1994; Lee & See, 2004; Parasuraman & Riley, 1997; Sheridan &

Parasuraman, 2006). Trust in automation is concerned with users perceiving the system as unreliable or becoming complacent and trusting the automated system more than is warranted (Parasuraman & Riley, 1997).

However, in the current military environment, most of the unmanned systems implemented are non-autonomous and remotely-operated, which require a human operator to directly control the system (DoD, 2009). Thus, instead of trusting the autonomy of a system, the concern should be whether the system is perceived as safe, reliable, and capable of performing at the same level as when a human operator is physically present.

Remote Weapons Systems

A Remote Weapons System (RWS) is a non-autonomous, remotely-operated unmanned weapon. RWSs utilize already available weapons and can be mounted on a variety of military vehicles and platforms. Several RWSs have been deployed for military operations, including the Common Remotely Operated Weapon Station (CROWS; Amant, 2005), the Stryker XM151 (Gourley, 2003), and the Special Weapons Observation Reconnaissance Detection System (SWORDS; Schachtman, 2007). RWSs are typically used to protect military Gunners, enabling them to operate their weapon from a remote location, such as the inside of a vehicle (Amant, 2005).

Experiment

In the current study, the effects of introducing a RWS to a fire team were investigated. Novice and experienced U.S. Army soldiers conducted simulated target neutralization scenarios. Fully manned teams were compared to teams with an unmanned RWS. Teamwork quality and trust in unmanned systems were assessed during the experiment through the use of either augmented or lab-developed self-report questionnaires.

Teamwork quality was measured by creating an augmented questionnaire implementing the six facets of the TWQ construct identified by Hoegl & Gemuenden (2001): communication, coordination, balance of member contributions, mutual support, effort, and cohesion. Human-robot trust was assessed using a lab-developed, self-report questionnaire that asked for participants' attitudes regarding their confidence and comfort levels working with unmanned systems.

Hypotheses

The current study was conducted to test the following hypotheses:

H1: Teamwork quality will improve within both novice and expert groups as a result of replacing a team member with an RWS.

H2: Trust in unmanned systems will improve within both novice and expert groups from before being exposed to the RWS to after being given experience using the system.

H3: Trust in unmanned systems will improve within both novice and expert groups from the manned to unmanned condition.

METHODS

Participants

Participants included 144 soldiers from two U.S. Army installations: Group 1 (n = 72) and Group 2 (n = 72)), consisting of 137 males and 7 females. Participants in Group 1 were novice, pre-deployed soldiers with an average of 4.3 months of experience (SD = 4.39). Group 2 consisted of experienced soldiers with an average of 28.3 months (SD = 24.64) of military experience.

Participants were divided into 36, four-person Fire Teams. Each Fire Team consisted of a Gunner and three Riflemen. Gunners operated either a simulated M240B machine gun or an RWS. Riflemen each used a simulated M16 assault rifle. All participants were required to have prior weapons experience using a M16 assault rifle and an M240B machine gun. They were not required to have prior experience using an RWS.

Simulation Materials

Engagement Skills Trainer 2000 (EST 2000) – The EST 2000 is an immersive virtual environment trainer used to present simulated scenarios on a projection screen (see Figure 1). It supports multiple training modalities, including rifle marksmanship, discriminatory firing, and collective instruction. In this experiment, the EST 2000 was divided into five parallel and adjacent lanes (see Figure 2) corresponding to the different roles among four Fire Team members.

Figure 1: EST 2000

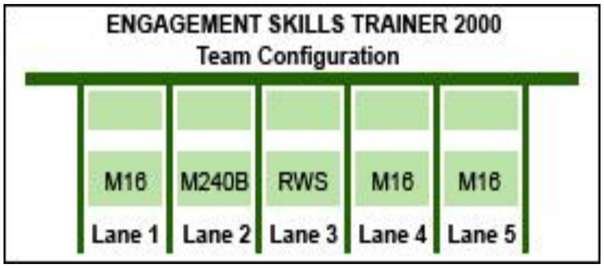

Figure 2: Fire Team Configuration

This experiment utilized a Gunner Practice Scenario and two team assessment scenarios. The Gunner Practice Scenario simulated a desert terrain and was used to familiarize Gunners with the functionality of the RWS. The team assessment scenarios included the simulation of a desert terrain (Desert Scenario) and an urban terrain (Urban Scenario). All scenarios consisted of entities that had timed exposures during the scenario. There were 94 entities presented in the Desert Scenario and 74 presented in the Urban Scenario. Both team assessment scenarios were altered for the expert group (Group 2), increasing the difficulty of the scenarios by making entities more obscured and exposed for a shorter period of time.

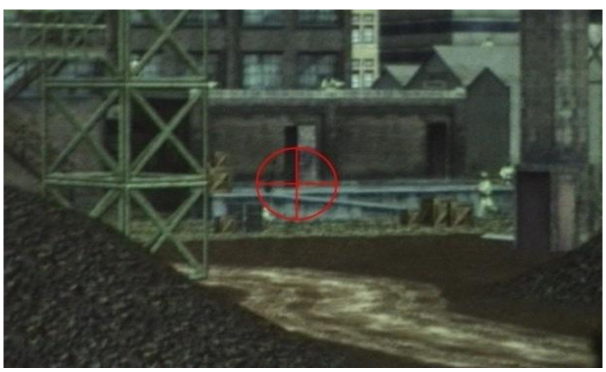

Figure 3: View of Scenario 2 from RWS

Weapons – Modified weapons were employed that could interact with the EST 2000 projection screen. Weapons included three M16 assault rifles, a M240B machine gun, and a lab-engineered RWS prototype.

The M16 Assault Rifle is used for short range, rapid fire environments (Department of Army, 2003). In this experiment, M16 Riflemen used the weapon to neutralize targets during simulated missions.

The M240B machine gun is used to support riflemen by providing a heavy volume of continuous fire to engage targets beyond the range of individual weapons (Department of Army, 2003). In this experiment, the M240B was used in bipod mode for manned scenarios. In the unmanned condition, it was implemented as the RWS.

The RWS consisted of a M240B machine gun mounted on a static pan-and-tilt platform. The RWS prototype (see figure 4) was modeled after a commercial version of the Stryker RWS (Cline, 2005). The RWS operator controlled the RWS in a room augmented from the EST 2000 simulator. A camera was mounted on the prototype in order for the RWS operator to view the EST 2000 projection screen.

Figure 4: RWS Prototype

Questionnaires

Demographics Questionnaire (DQ) – The DQ asked participants for various aspects of their biographical information. This included their age, gender, military experience, and weapons experience.

Teamwork Questionnaire (TQ) – The TQ was a lab-developed questionnaire that incorporated the six facets of the TWQ construct (Hoegl & Gemuenden, 1998) into a self-report measure of teamwork quality. The TQ consisted of a six-point scale, ranging from very poor to excellent, and was used to rate team communication, coordination, contribution, mutual support, effort, and cohesion. For example, participants were asked, “How would you rate your communication skills when working with this team?” and “How would you rate your team’s ability to coordinate with the other team members during these training exercises?”

Trust in Unmanned Systems (TUSQ) – The TUSQ is a lab-developed, self-report measure which was used to assess the perceived reliability and effectiveness of unmanned systems among participants. The TUSQ asked for participants’ attitudes regarding their confidence and comfort level toward the use of unmanned systems, as well as how the implementation of these systems might affect individual and team performance. For example, participants rated their level of comfort and confidence for the following questions: "I am comfortable working with unmanned systems" and "I can be confident in the unmanned system operator's ability to obey commands and follow instructions." The Pre and Post-TUSQ were administered before and after working with RWS.

Procedure

After completing the informed consent, DQ, and Pre-TUSQ, Gunners participated in familiarization training with the RWS by completing the Gunner Practice Scenario. The Riflemen were kept in a separate room while Gunners completed the scenario. Next, Fire Teams completed the Desert Scenario and Urban Scenario in both the manned and unmanned condition. The manned condition consisted of all four Fire Team members physically present, manning their respective weapons. During the unmanned condition, Gunners operated the RWS from a separate room. The TQ and Post-TUSQ were administered after each condition of the Urban Scenario.

RESULTS

The results of this experiment yielded several significant findings. A paired samples t-test was conducted to compare scores on the TQ from the manned to unmanned condition in Group 1 and Group 2 during the Urban Scenario. (The TQ was not administered after the Desert Scenario). The results indicated that TQ scores were significantly higher in both novice and expert teams after using the RWS compared to using the manned M240B machine gun; Group 1 $t(71)=-2.31$, $p=.024$; Group 2 $t(71)= -3.01$, $p =.004$ (see Table 3.1).

Table 3.1 Teamwork (TQ)

	Manned		Unmanned		
	M	SD	M	SD	p-value
Group 1	43.97	7.64	45.74	7.39	.024
Group 2	39.33	9.29	40.99	8.99	.004

A paired samples t-test was also used to compare scores on the TUSQ from prior to being exposed to the RWS to after working with the system during the two simulated missions. The scores of Group 1 improved significantly from the Pre-TUSQ to Post-TUSQ; $t(71)=-2.20$, $p=.031$. In Group 2, however, no significant change was noted; $t(71)=1.08$, $p=.282$ (see Table 3.2).

Table 3.2 Trust in Unmanned Systems (TUSQ): Pre/Post

	Pre		Post		
	M	SD	M	SD	p-value
Group 1	20.64	3.62	21.50	4.15	.031
Group 2	18.75	3.80	18.38	3.46	.282

Similar results were found when comparing TUSQ scores from the manned to unmanned condition during the Urban Scenario. A paired samples t-test revealed that scores again improved significantly in Group 1; $t(71)=-2.30$, $p=.025$, but there was no significant difference in the scores among Group 2; $t(71)=.64$, $p=.520$ (see Table 3.3).

Table 3.3 Trust in Unmanned Systems (TUSQ): Manned/Unmanned

	Manned		Unmanned		
	M	SD	M	SD	p-value
Group 1	21.03	3.89	21.50	4.15	.025
Group 2	18.26	3.52	18.38	3.46	.520

DISCUSSION

In this study, the impact of replacing a human team member with an RWS and its effect on the quality of team interactions and trust was explored.

The results of the current study indicated that teamwork quality significantly improved in both novice and expert teams after using the RWS compared to using the manned M240B machine gun. This suggests that individuals may have been more aware of the team's interactions during those scenarios requiring the use of the RWS. When working with the RWS, fire team members were in a novel environment, which may have led to greater contribution among the team members.

This experiment also revealed significant improvements in the trust of unmanned systems among novice soldiers. Novice soldiers increased trust in unmanned systems after having experience working with the RWS and from the manned to unmanned condition. The novices likely became more comfortable and confident in the capabilities of the RWS after as they gained experience. In contrast, no significant change in the trust in unmanned systems was found among expert soldiers. A possible explanation is that the experienced soldiers may have already had experience operating unmanned systems and therefore, their exposure in this study did not significantly change their existing perceptions.

CONCLUSIONS

This study produces many implications for research within human-robot teams. The results suggest that teams become more focused and alert when working with a robot because it involves performing in a novel environment. Therefore, individual team members may have been more inclined to communicate and coordinate with each other during missions. Team members may feel the need to contribute more or provide extra effort when working with an unmanned system.

Soldiers without experience or training working with unmanned systems may be uncomfortable working with them or lack trust in their ability to perform at the same level as a human team member. However, this experiment also indicates that after being given exposure and practice using an unmanned system, their trust in the system's capabilities and performance is improved.

As in any experiment, some factors may have served as constraints during this study. Sampling and measurement error must always be considered as possible explanations for the findings. The measures used for determining teamwork quality and human-robot trust were either adapted from previous work or lab-developed and the validity they contain in measuring their respective constructs is uncertain. Additionally, simulated scenarios in this experiment were always completed by teams in the manned condition first, and then using the RWS. This may have served as a possible confound, impacting the results of teamwork quality from the manned to unmanned condition. It is possible that team members may have felt more comfortable as they gained experience working together as a team.

Future studies should investigate additional domains regarding the interaction between robots and human team members. A possible area of study could include examining the effects of introducing an unmanned system on the stress and workload of team members and relating this information to individual and team performance during missions. This could provide a greater insight into the implications of teaming with a robot and the steps toward optimizing human-robot collaboration.

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