

Effects of Individual Differences on Human-Agent Teaming for Multi-robot Control

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Abstract. In the current experiment, we simulated a military multitasking environment and evaluated the effects of RoboLeader on the performance of human operators (i.e., vehicle commanders) who had the responsibility of supervising the plans/routes for a convoy of three vehicles while maintaining proper 360° local security around their own vehicle. We evaluated whether -- and to what extent -- operator individual differences (spatial ability, attentional control, and video gaming experience) impacted the operator's performance. In two out of three mission scenarios, the participants had access to the assistance of an intelligent agent, RoboLeader. Results showed that RoboLeader's level of autonomy had a significant impact on participants' concurrent target detection task performance and perceived workload. Those participants who played action video games frequently had significant better situation awareness of the mission environment. Those participants with lower spatial ability had increasingly better situation awareness as RoboLeader's level of autonomy increased; however, those with higher spatial ability did not exhibit the same trend.

Keywords: human-robot interaction, intelligent agent, military, individual differences, multitasking.

1 Introduction

Robots are increasingly utilized in military operations, and the types of tasks they are being used for are evolving in complexity [1][2]. In the future battlefield, Soldiers may be given multiple tasks to perform concurrently, such as navigating a robot while conducting surveillance, maintaining local security and situation awareness (SA), and communicating with fellow team members. In recent years, several research efforts have developed intelligent software agents that can assist human operators in managing multiple robots in military tasking environments [3]-[5]. Indeed, a recent report on the Role of Autonomy in U.S. Department of Defense Systems recommended that "increased autonomy can enable humans to delegate those tasks that are more effectively done by computer, including synchronizing activities between multiple

unmanned systems, software agents and warfighters—thus freeing humans to focus on more complex decision making” (p. 1) [6]. Such a robotic surrogate agent, RoboLeader, was developed under the U.S. Army Research Laboratory’s Director’s Research Initiative Program to support mixed-initiative decision making [3][7][8]. In typical mission situations, RoboLeader would recommend route revisions when encountering environmental events that require robots to be rerouted. The human operators, in turn, can accept the plan revisions or modify them as appropriate.

In the current experiment, we simulated a multitasking environment and evaluated the effects of RoboLeader on the performance of human operators (i.e., vehicle commanders) who had the responsibility of supervising the plans/routes for a convoy of three vehicles (their own manned ground vehicle [MGV], an unmanned aerial system [UAS], and an unmanned ground vehicle [UGV]) while maintaining proper 360° local security around their MGV (Fig. 1). The U.S. Army is currently developing 360° indirect-vision display capabilities to enable vehicle commanders to see their immediate environment via streaming video sent from cameras mounted outside the MGV. In the current experiment, the three simulated vehicles traveled in an urban environment as a convoy and the participants had to decide whether and how the routes for the convoy had to change based on environmental events (e.g., threats present, environmental hazards/obstacles) and/or intelligence reports. The paradigm followed Chen and Barnes [3][7] and there were three levels of autonomy (LOAs): the participants either performed the plan revisions manually (*Manual* condition) or with the assistance from RoboLeader (*Semi-Auto* condition: maintaining vehicle distance/separation only; *Full Auto* condition: vehicle separation + route planning). Concurrently, the participants monitored an indirect-vision display where the environment surrounding the MGV was visible. They were required to report any threats present in their immediate environment (i.e., target detection task).



Fig. 1. User interface of the convoy and 360 tasking environment

In the current study, we also sought to evaluate whether -- and to what extent -- operator individual differences in spatial ability, attentional control, and video gaming experience might impact the operator's performance. Significant individual differences in cognitive task performance and interaction with automation have been repeatedly documented in literature [3][9]-[11]. Szalma [12] suggests that individual differences should be considered more frequently in user interface designs and training intervention developments. In fact, based on empirical data, it has been observed that effects due to individual differences in cognitive abilities can sometimes be even greater than effects due to interface design manipulations [13]. Manzey et al. [14] observed significant individual differences in susceptibility to automation bias effects in the multitasking environments they simulated, although the authors did not identify what individual differences factors contributed to the observed behaviors. Previous research has shown that some individuals show more performance decrements than others when multitasking and these decrements may be related to their poorer abilities to control and allocate attention [15]-[17]. These results suggest that individual differences in attentional control seem to play a critical role in determining an operator's overall multitasking performance. Research also shows that individual differences in spatial ability and gaming experience play important roles in determining operators' SA in multi-robot tasking environments [3][7].

2 Method

2.1 Participants

Thirty individuals (21 males and 9 females, mean age 25 yrs) from the Orlando, FL area participated in the study. They were compensated \$15/hr for their time.

2.2 Apparatus

A modified version of the Mixed Initiative Experimental (MIX) Testbed was used as the simulator for this experiment [18]. The RoboLeader algorithm was implemented on the MIX testbed and it had the capability of collecting information from subordinate robots with limited autonomy (e.g., collision avoidance and self-guidance to reach target locations), making tactical decisions and coordinating the robots by issuing commands and waypoints etc. [8]. The MGV 360° indirect-vision display emulated the capability currently developed by the U.S. Army Technology Objective (ATO) Improved Mobility and Operational Performance through Autonomous Technologies (IMOPAT). The capabilities of the UGV and the small UAS as well as the behavior of the convoy (e.g., the formation of and the distances among the three vehicles) were simulated based on the concept of the ATO Safe Unmanned Operations in Urban Operations (SOURCE).

A demographics questionnaire was administered at the beginning of the training session. An Ishihara Color Vision Test (with 9 test plates) was administered via PowerPoint presentation. Since the RoboLeader OCU employed several colors to display the plans for the robots, normal color vision was required to effectively interact

with the system. A questionnaire on Attentional Control [19] was used to evaluate participants' perceived attentional control. The Attentional Control survey consists of 21 items and measures attention focus and shifting. The scale has been shown to have good internal reliability ($\alpha = .88$). The Cube Comparison Test [20] and the Spatial Orientation Test [21] were used to assess participants' spatial ability. The Cube Comparison Test requires participants to compare, in 3-minutes, 21 pairs of 6-sided cubes and determine if the rotated cubes are the same or different. The Spatial Orientation Test, modeled after the cardinal direction test developed by Gugerty and his colleagues [21], is a computerized test consisting of a brief training segment and 32 test questions. Both accuracy and response time were automatically captured by the program. Participants' perceived workload was evaluated with the computerized version of the NASA-TLX questionnaire, which used a pairwise comparison weighting procedure [22].

2.3 Procedure

Before the training session, the participants completed the preliminary tests (color vision and spatial) and surveys (demographic and perceived attentional control). Training, lasting about one hour, was self-paced and was delivered by PowerPoint® slides showing the elements of the operator control unit (OCU), steps for completing various tasks, several mini-exercises for practicing the steps, and exercises for performing the experimental tasks. The participants had to demonstrate that they could recall all the steps for performing the tasks without any help. The experimental session immediately followed the training session and consisted of three scenarios, each lasting approximately 30 minutes. During the scenarios, participants tried to get a convoy of three vehicles (his/her own MGV, a small UAS, and a UGV) from point A to point B. The participants were instructed to maintain certain distances among the three vehicles. In each scenario, there were initial waypoint plans for each vehicle when the scenario started, and the participants' task was to modify the plans based on environmental/intel "events" (described later) or based on hostile targets detected by the participants themselves. Simultaneously, the participants had to maintain 360° local security surrounding his/her own MGV by monitoring the 360° indirect-vision display and try to detect targets in the immediate environments. Once a hostile target was detected, the participants "lazed" the target by clicking on the target using the mouse. The "lazed" insurgent would then be displayed on the map. There were civilians and friendly dismounted soldiers in the simulated environment to increase the visual noise present in the target detection tasks. The order of scenarios was counter-balanced across participants.

During the scenarios, there were several events (e.g., intelligence that the human operator received from the intel network or environmental hazards such as fire or road blockages) that would require revisions to the plans for the manned and unmanned vehicles. Once an event transpired, the participants must notice and acknowledge that the event had occurred. In the Full-Auto condition, RoboLeader would recommend plan revisions for the events (by presenting the new waypoints on the map), which the operator could accept, or reject and modify as deemed necessary. In the Semi-Auto

condition, the participants modified the waypoints for the lead vehicle (the UAS) when the convoy's route needed to be changed. In the Manual condition, the operator made the revisions manually. In the Semi-Auto and Full-Auto conditions, the distance separations among the vehicles was maintained automatically based on the vehicles' own leader-follower algorithms.

Each scenario contained five SA queries, which were triggered based on time progression (e.g., 3 minutes into the scenario). The SA queries included questions such as "Use the provided paper to identify which areas have encountered the most Insurgents" etc. When an SA query was triggered, the OCU screen went blank, the simulation paused, and the SA query was displayed on the screen. Participants wrote their response to the query on an answer sheet. After participants responded to the SA query, it was removed from the OCU screen and the simulation resumed. There was a two-minute break between the experimental scenarios. Participants assessed their workload using the NASA-TLX immediately after each experimental scenario.

3 Results

A mixed-model ANOVA (within-subject: LOA; between-subject: participants' spatial ability [SpA]) on Target Detection revealed a significant effect of LOA, $F(2, 27) = 12$, $p < .0005$, $\eta^2p = .47$. Post-hoc (LSD) comparisons show a significant increase in Target Detection scores between both Manual and Semi-Auto conditions and Manual and Full Auto conditions (p 's $< .05$). There was no significant difference between Semi-Auto and Full Auto conditions.

A mixed-model ANOVA on Situation Awareness (SA) revealed a significant interaction of LOA and SpA, $F(2, 27) = 3.6$, $p = .04$, $\eta^2p = .21$. Participants with lower SpA had increasingly higher SA as the LOA increased; however, those with higher SpA exhibited the opposite trend. Participants who played action games frequently (daily or weekly) had significantly better SA than those who did not, $F(1, 28) = 4.5$, $p = .04$, $\eta^2p = .14$ (Figure 2).

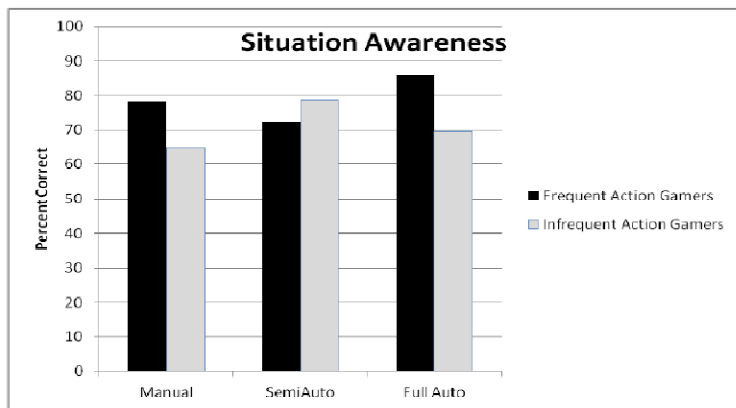


Fig. 2. Effects of gaming experience on situation awareness

A mixed-model ANOVA revealed that there was a significant main effect of LOA on Perceived Workload (NASA-TLX), $F(2, 27) = 24.8$, $p < .0005$, $\eta^2p = .65$. Post-hoc (LSD) comparisons showed that the differences between each pair were all significant (p 's $< .05$), with Manual being the highest and RoboLeader being the lowest. All three major dependent measures (target detection, SA, and workload) are graphically summarized in Figure 3.

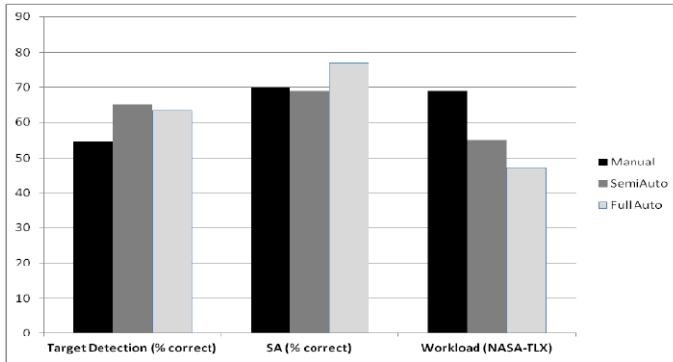


Fig. 3. Major dependent measures

4 Conclusions

In the current experiment, we simulated a military multitasking environment and evaluated the effects of RoboLeader on the performance of human operators (i.e., vehicle commanders) who had the responsibility of supervising the plans/routes for a convoy of three vehicles (their own MGCV, a UAS, and a UGV) while maintaining proper 360° local security around their MGCV. Results showed that RoboLeader (either semi- or full-auto) enhanced participants' concurrent target detection task performance while reducing their perceived workload (Figure 3). Those participants with lower spatial ability had increasingly better situation awareness as RoboLeader's level of autonomy increased; however, those with higher spatial ability did not exhibit the same trend. Frequent action gamers had significantly better SA of the mission environment than those who did not play action games frequently. This result is consistent with previous findings [3][7][23], suggesting that video game play is associated with greater visual short-term memory and faster information processing, which in turn, may have contributed to game playing participants' superior SA in the current study. These results also support the conclusion of a U.S. Air Force study [24] based on interviews of UAV pilots that gamers' superior SA may be able to translate into superior robotics management performance. These results may have important implications for system design and personnel selection for future military programs [24]-[26]. Future research can investigate training interventions (e.g. attention management) and/or user interface designs (e.g. multimodal cueing displays) to enhance robot

operator performance in challenging tasking environments [1][27][28]. Future efforts will also examine the feasibility of implementing RoboLeader-like agent in other military multi-robot missions such as building-mapping and clearing and swarm control.

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