OPERATOR WORKLOAD AND HEART-RATE VARIABILITY DURING A SIMULATED RECONNAISANCE MISSION WITH AN UNMANNED GROUND VEHICLE

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ABSTRACT

In this study, we simulated a generic mounted crewstation environment and conducted an experiment to examine the workload and performance of the operator of a ground robot. Participants were randomly assigned to four tasking conditions: robotics tasks only, robotics plus an auditory task, robotics plus a visual monitoring task, or all three tasks simultaneously. Participants completed four mission scenarios. In two of these scenarios, their robot was semi-autonomous. In the other two scenarios, they had to teleoperate the robot. An Aided Target Recognition (AiTR) system was available to help them with their target detection tasks in only two of the four scenarios. Results showed that operators' situational awareness and perceived workload were significantly worse when they teleoperated the robot. Individual differences factors such as the operator's spatial ability and attentional control were also investigated. Implications for military personnel selection were discussed.

1. INTRODUCTION

A mandate passed by the United States Congress in 2002 called for 1/3 of all Army systems to be unmanned by 2015. This mandate included an assessment which covered four classes of vehicles: 1) reconnaissance, monitoring, and recovery operations; 2) transportation of supplies and equipment; 3) an armed vehicle to augment manned systems; and 4) a fully autonomous combat vehicle (National Research Council, 2003). The introduction of unmanned systems (i.e., robots) to the battlefield has obvious advantages (extend manned capabilities, act as force multipliers, and most importantly save lives) but will also create unique challenges. Operators in complicated environments will have to handle a new variety of complex issues posed by the use of unmanned systems (Jentsch et al., 2004). Often, while utilizing technology, operators are required to assess the current state of the given system and operating environment while quickly making decisions and executing an appropriate course of action. While the utilization of a suitable technology, such as unmanned ground vehilces (UGVs), can increase the likelihood of successful operations, operator performance can be adversely impacted by the task load associated with use of the technology.

Future unmanned system operators are likely to require some level of automation to complete complex robot missions. Appropriately applied, automation can enable operators to perform at greater capacity. The key will be to apply automation to tasks that require assistance or by automating simple tasks to free up operator resources and allow them to attend to more challenging or cognitively demanding tasks. Further, automation must be applied within the appropriate context or time. Through the integration of physiological measurement, it should be possible to identify the appropriate context or time to apply automation. The resultant automation process would create a system capable of detecting and utilizing the state of the operator resulting in a truly 'human-in-the-loop' system. This current effort examines the impact of automation on a UGV operator's performance in a simulated military multi-tasking environment. The goal is to identify the high workload peaks and performance decrements during a robot mission through objective physiological means.

2. METHOD

2.1 Participants

A total of sixty-four college students from the University of Central Florida and the United States Military Academy (25 female, 39 male) participated in this study. The participants ranged in age from 18 to 49 (*M* = 20.42, *SD* =4.51). The experiment lasted approximately 3.5 hours and volunteers received compensation in the form of extra course credit or $35.00 for their participation.

2.2 Apparatus

2.2.1 Simulation

The simulated robotic task environment was provided by the Mixed Initiative eXperimental (MIX) Testbed. A detailed description of the design, implementation, and capabilities of the MIX Testbed is provided in Barber, Davis, Nicholson, Finkelstein, and Chen (in press) and Barber, Leontyev, Sun, Davis, and Nicholson (2006).

Robotic Vehicle Control. One of the main components of the MIX Testbed is the Unmanned Vehicle Simulator (UVSIM), which generates the robotic systems in the simulation. For this study, an UGV was selected as the simulated robotic vehicle. The UGV provides manual control and two types of vehicle automation, waypoint navigation (i.e., semi-autonomous control) and aided target recognition (AiTR) (Figure 1a). In conditions requiring manual navigation of the vehicle (teleoperation),throttle, steering and direction (forward or reverse) was controlled through the use of a standard joystick. In contrast, the vehicle automatically followed a pre-planned path (i.e., mission route) and paused at four designated checkpoints in the semi-autonomous conditions. In conditions utilizing the AiTR capability, the vehicle automatically scanned for targets, by panning the vehicle's camera, and provided a list of all targets (enemy and friendly) in the area, whereas the manual control conditions required participants to teleoperate the vehicle in the designated checkpoint area in order to properly position the vehicle for target observation. In the current study, the two types of vehicle automation were combined with the associated manual control conditions to produce four control conditions: teleoperation with and without AiTR and semi-autonomous with and without AiTR.

Operator Control Unit. Another main component of the MIX Testbed is the Operator Control Unit (OCU), which is the graphical user interface that enabled participants to interact with the unmanned vehicle (see Figure 1b and c).

The OCU also provided two additional tasks, which were used to vary the participants' task load. The visual monitoring task displayed four gauges that were constantly in motion (shown in Figures 1b and 1c- four green gauges at the bottom). Based on pre-specified timings contained in a settings file, one or more of the gauges would enter an upper or lower limit at various times throughout each of the missions. The gauge(s) would return to normal levels when a "Reset" button was pressed. The auditory communications task presented pre-recorded audio cues (i.e., a call sign) at various times throughout each scenario. Participants used a keyboard to enter a response to the audio cue into the communications panel located beneath the visual monitoring task on the OCU. Four pre-recorded questions, which were designed to assess participants' situation awareness (SA), were also presented by the OCU when the unmanned vehicle entered a pre-specified region of the map. Participants used the keyboard to enter a text response to the SA probes.

The OCU also provided the ability to automatically time stamp and log the data for various simulation events (e.g., audio cue presentation), user interactions (e.g., keyboard input), and physiological sensors data.

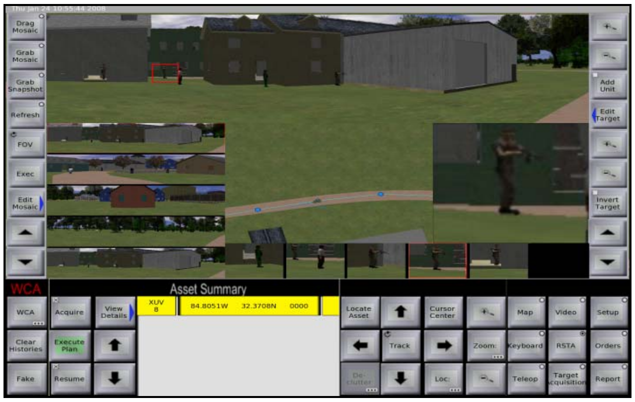

Figure 1a - Aided target recognition scan

Figure 1b - Operator control unit (map view)

Figure 1c - Operator control unit (video view)

2.2.2 Wearable Arousal Meter

The wearable arousal meter (WAM) is a portable, non-intrusive device that measures interbeat heart rate interval. The WAM's associated software provides an assessment of the wearer's state of arousal derived from the high frequency values of the interbeat interval (Hoover & Muth, 2004). (see Figure 2). Continuous data sampling was provided by three electrodes (two for active recording, one for signal noise reduction) that were connected to the WAM and attached by the participant to their sternum, first rib on the right side of the torso, and first rib on the left side of the torso.

Figure 2 – Wearable arousal meter

2.2.3 Spatial Tests and Questionnaires

A questionnaire about attentional control (Derryberry & Reed, 2002) was used to evaluate participants' perceived attentional control (PAC). The attentional control survey consists of 21 items and measures perceived attention focus and shifting. The scale has been shown to have good internal reliability (α = .88). Derryberry and Reed conducted an experiment to examine the relationship between self-reported (i.e., attentional control survey score) and actual attentional control. They found that participants with a high survey score could better resist interference in a Stroop-like spatial conflict task. In our previous studies (Chen & Joyner, 2006), we observed a positive, although somewhat weak, relationship between attentional control survey score and some multitasking performance measures.

The Cube Comparison and Hidden Patterns tests (Ekstrom et al., 1976) as well as the Spatial Orientation test were used to assess participants' spatial ability (SpA). 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 Hidden Patterns test measures flexibility of closure and involves identifying specific patterns or shapes embedded within distracting information. The Guilford-Zimmerman Spatial Orientation test (Guilford & Zimmerman, 1948) provides a measure of a person's ability to identify changes in direction and position. The paper-and-pencil test consists of 60 forced-choice test items; for each question, the change in a motorboat's heading in one image must be determined from the original position in a reference image.

Participants' perceived workload was evaluated with the computer-based version of National Aeronautics and Space Administration-task load index (NASA-TLX) questionnaire (Hart & Staveland, 1988). The NASA-TLX is a self-reported questionnaire of perceived demands in six areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants were asked to evaluate their perceived workload level in these areas on 10-point scales. They also assessed the contribution (i.e., weight) of each factor to the perceived workload by comparing the 15 possible pairs of the six factors. According to Noyes and Bruneau (2007), computer-based NASA-TLX tends to generate higher workload ratings compared with the traditional paper-based survey. However, since the ratings were used to compare the workload levels across the experimental conditions, the elevated ratings should not affect these comparisons.

2.2.4 Experimental Design

The overall design of the study is a 2 x 2 x 2 x 2 mixed design. The between-subject variables were Taskload - Audio (With Audio task vs. No Audio task) and Taskload – Visual (With Visual task vs. No Visual task). Participants received one of the following four levels of task load: (1) robotic tasks only; (2) robotic tasks and visual monitoring; (3) robotic tasks and auditory monitoring; and (4) robotic tasks, visual monitoring, and auditory monitoring. The two within-subjects variables were the level of autonomy for the robotic vehicle navigation (Robotics Task condition: Semi-Autonomous vs. Teleop) and the level of aiding for target identification (AiTR condition: With AiTR vs. No AiTR) in a preplanned scan area. In order to examine these two within-subjects variables, the two types of automation were factorially combined to produce four mission scenarios, each lasting a maximum of 20 minutes. Thus, the levels of automation included: 1) semi-autonomous mode with AiTR; 2) semi-autonomous mode without AiTR; 3) teleoperation with AiTR; and 4) teleoperation without AiTR.

2.2.5 Procedure

Upon arrival to the laboratory, participants were assigned to one of the four experimental groups. After receiving a briefing about the purpose of the study, the required tasks and any risks associated with participation, all volunteers were given an informed consent form to read and sign. Participants then were asked to complete the demographics form and the attentional control survey followed by the three spatial ability tests (Cube Comparison, Hidden Patterns, and Spatial Orientation).

After completing the spatial ability tests, participants were instructed on the proper placement of the three WAM electrodes and asked to affix the WAM electrodes to their torso; assistance was provided if required. The WAM calibration process was then initiated. Participants were asked to sit quietly with their eyes closed for 10 minutes in order to provide a resting baseline for the WAM. After the 10 minute period, participants received a three-phase training session on the proper operation of the UGV and the specific tasks they would need to accomplish during each of the four experimental missions.

In the first phase of training, participants viewed a slide show that demonstrated the proper operation of the UGV. During the slideshow, participants were able to interact with the UGV in the MIX Testbed for familiarization. During the second training phase, participants completed a test mission and were encouraged to ask for clarification on any tasks or operations they did not understand. If a participant became “lost” and did not ask for help, the experimenter provided unsolicited instruction. The final phase of training required the participant to complete a practice mission without assistance. If the participant needed assistance, they returned to the second phase until they were able to demonstrate the ability to complete the practice mission without assistance. Once the training session was complete (approximately 45 minutes), calibration of the WAM was completed by retrieving participant specific baseline data from the WAM’s accompanying software and initializing the WAM to the participant.

Once the WAM was calibrated, the participant began the first of four experimental missions. The test missions were presented in the same order for each participant allowing participants to complete a mission with each level of autonomy. The order of presentation for the level of autonomy was counterbalanced for the experimental missions.

Each mission was conducted in the same urban terrain but differed in the pre-planned route and placement of specific checkpoints, non-targets (civilians), and targets (dismounted infantry soldiers). Each route was comprised of a start point, an end point, and four checkpoints. Participants were instructed to follow the route to each checkpoint. While traveling between checkpoints, participants in all conditions were required to identify four targets, which were encountered along the route and outside of a designated scan area, by pressing the “Threat Detected” button. Additionally, when a participant arrived at each of the checkpoints, they were required to identify targets in a designated scan area. Once a target was identified, participants were required to plot the location of each target on their virtual terrain map and complete a spot report describing the target. While traversing between checkpoints, participants were also asked four prerecorded situation awareness probes. When participants received a probe, the simulation would pause, the screen would black out, and participants were allowed 12 seconds to type their answer into the designated text box and press the ”Send” button. Once the timer expired, the blackout was removed and the mission continued exactly as it was prior to the situation awareness probe.

In addition to the basic mission tasks common to all conditions described above, those participants in the visual monitoring task condition were required to monitor the gauges that indicated the “health” of the UGV batteries (the performance of the simulation was not affected). If one or more of the gauges moved to the critical zone, the participant was required to press the “Reset” button. Participants in the audio monitoring task condition were required to monitor a continuous series of communications for their designated call sign, determine if they had heard their call sign, and enter ‘Y’ or ‘N’ in the Communications panel, and press the ‘“Send” button in response to each communication. Participants who were assigned to the visual and auditory monitoring task condition were required to perform both tasks while executing the common mission tasks. Immediately following the conclusion of each mission, participants completed the NASA-TLX.

Once the final NASA-TLX was completed after the fourth mission, participants completed the Simulator Sickness Questionnaire (SSQ) to ensure they were not experiencing any symptoms of simulator sickness as a result of exposure to the simulated environment. Participants then removed the WAM electrodes and were debriefed and thanked for their participation in the study.

2.2.6 Dependent Measures

The dependent variables measured during the study included: target identification performance (i.e., the proportion of targets identified at the checkpoints), threat detection performance (i.e., the proportion of correct enemy threats detected outside the designated target scan areas), performance on the situation awareness probes, perceived workload, and average physiological arousal level.

3. RESULTS

3.1 Operator Performance – Targets Identified at the Checkpoints

Table 1 lists the percentages of targets identified at the checkpoints. A mixed analysis of covariance (ANCOVA) was performed to examine the participants’ target detection performance (percentage of targets detected and identified at the checkpoints), in the AiTR condition (with AiTR vs. no AiTR) and the Robotics Task condition (Semi-Auto vs. Teleop) being the within-subject factors, the Taskload conditions, Audio (Audio task vs. No Audio task) and Visual (Visual task vs. No Visual task) as the between-subject factors, and participants’ SpA and PAC as covariates. None of the main effects were statistically significant. There was a significant AiTR x Audio interaction, $F(1, 57) = 4.699$, $p < .05$. Figure 3 shows the effects of Robotics and AiTR, and Figure 4 shows the interaction between AiTR and Audio. Participants' performance appeared to be worse when they had to simultaneously perform the Audio task without the aid of AiTR compared to the With-AiTR condition.

3.2 Operator Performance – Threats Detected along the Route

A mixed ANCOVA was performed to examine the participants' threat detection performance (percentage of threats detected along the route), with the AiTR condition and the Robotics Task condition being the within-subject factors, the Taskload conditions as the between-subject factors, and participants' SpA and PAC as covariates. There was a significant Robotics x PAC interaction, $F(1, 57) = 10.638$, $p < .05$. Figure 5 shows the interaction between Robotics and PAC. Participants with high PAC performed better with the Teleop, while low PAC participants performed better with the Semi-auto robot. There was also a significant Robotics x AiTR x SpA interaction, $F(1, 57) = 4.616$, $p < .05$.

Table 1. Operator Task Performance (mean percent of targets detected at the checkpoints)

		Semi-Auto		Teleop	
		AiTR	NoAiTR	AiTR	NoAiTR
Audio	Visual	.976	.858	.881	.893
	No Visual	.836	.778	.918	.764
No Audio	Visual	.884	.910	.860	.872
	No Visual	.884	.860	.820	.926

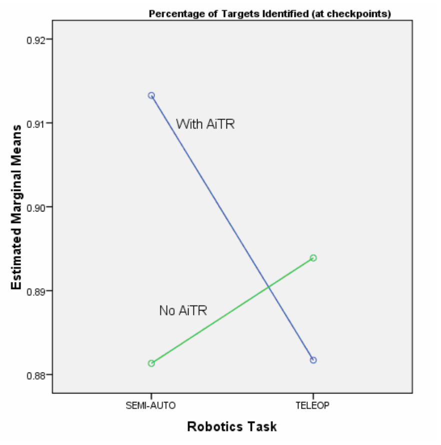

Figure 3 – Targets identified at checkpoints.

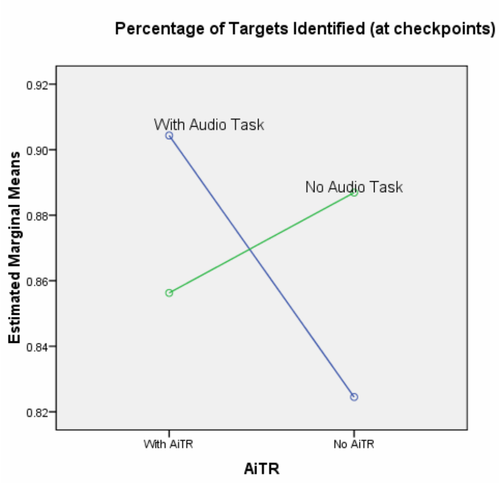

Figure 4 – Targets identified at checkpoints – interaction between AiTR and Audio task.

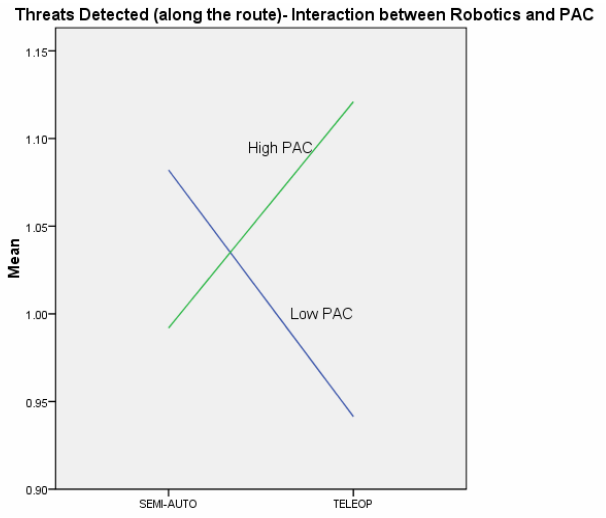

Figure 5 – Threats detected along the route – interaction between Robotics and PAC.

3.3 Operator Situational Awareness

A mixed ANCOVA was performed to examine the participants' SA (composite score of SA Level 1, 2, & 3 queries), with the AiTR condition and the Robotics Task condition being the within-subject factors, the Taskload conditions as the between-subject factors, and participants' SpA and PAC as covariates. The analysis revealed a significant main effect for Robotics, $F(1, 57) = 5.485$, $p < .05$ and SpA, $F(1, 57) = 7.515$, $p < .01$. Participants' SA was significantly better in the Semi-Auto conditions than in the Teleop conditions. Additionally, participants with higher SpA significantly outperformed their lower-SpA counterparts. There was a significant Robotics x AiTR x SpA interaction, $F(1, 57) = 5.242$, $p < .05$. Figure 6 shows the effects of Robotics and SpA.

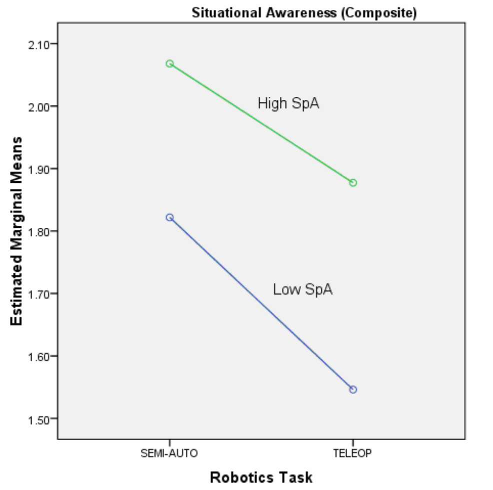

Figure 6 – Situational awareness – effects of Robotics tasks and operator spatial ability (SpA).

3.4 Operator Perceived Workload

Table 2 lists the participants' perceived workload. A mixed ANCOVA was performed to examine the participants' perceived workload (weighted NASA-TLX scores), with the AiTR condition and the Robotics Task condition being the within-subject factors, the Taskload conditions as the between-subject factors, and participants' SpA and PAC as covariates. The analysis revealed a significant main effect for Robotics, *F*(1, 56) = 30.585, *p* < .01 and AiTR, *F*(1, 56) = 6.765, *p* < .05. Participants' perceived workload was significantly higher in the Teleop conditions than in the Semi-Auto conditions. They also had significantly higher workload when there was no AiTR, compared with the AiTR conditions. There was a significant Robotics x AiTR interaction, *F*(1, 56) = 5.053, *p* < .05. Figure 7 shows the effects of Robotics and AiTR.

Table 2. Operator Perceived Workload

		Semi-Auto		Teleop	
		AiTR	NoAiTR	AiTR	NoAiTR
Audio	Visual	48.7	57.9	60.9	60.5
	No Visual	52.6	57.4	62.6	65.5
No Audio	Visual	46.5	50.0	53.5	60.2
	No Visual	44.7	50.9	54.3	54.2

Figure 7 – Operator perceived workload – effects of Robotics and AiTR.

3.5 Operator Physiological Arousal Level

A multivariate analysis of variance (MANOVA) was performed to examine the participants' physiological state of arousal (average arousal level), with the AiTR condition and the Robotics Task condition as the within-subject factors, the Taskload condition as the between-subject factor. The analysis revealed that there were no significant effects of levels of AiTR, Robotics Task, or Taskload (*p* > .10).

4. DISCUSSION

In this study, we simulated a generic mounted crewstation environment and conducted an experiment to examine the workload and performance of the operator of a ground robot. Participants were randomly assigned to four tasking conditions: robotics tasks only, robotics plus an auditory task, robotics plus a visual monitoring task, or all three tasks simultaneously. Participants completed four mission scenarios. In two of these scenarios, their robot was semi-autonomous. In the other two scenarios, they had to teleoperate the robot. An Aided Target Recognition (AiTR) system was available to help them with their target detection tasks in only two of the four scenarios. It did not appear that any of the main factors affected the percentages of targets that participants identified at the checkpoints. However, if participants had to simultaneously perform the Audio task, they performed worse when they did not have access to the AiTR compared to the With-AiTR condition. In contrast, an opposite trend was observed for the No Audio task conditions. It is likely that the attentional demand from the Audio task competed against the RSTA task. Therefore, when participants had to concurrently perform both the targeting and the auditory tasks without the aid of the AiTR, their targeting performance degraded. However, the same degradation was not observed for the No-Audio conditions.

The number of threats that participants detected along the route provided an estimate of the participants' visual attention of the environment while they were conducting other tasks. The results showed that participants with high PAC performed better with the Teleop, while low PAC participants performed better with the Semi-Auto robot. These findings are consistent with Chen and Terrence (2008b) that high PAC operators tend to perform better with manually operated systems than do low PAC individuals in multi-tasking environment.

The results showed that participants' SA was significantly better in the Semi-Auto conditions than in the Teleop conditions. These results are consistent with past findings that robotics operators demonstrated higher SA when the robot's level of automation was higher (Chen, Durlach, Sloan, & Bowens, 2008; Dixon, Wickens, & Chang, 2003; Luck, Allender, & Russell, 2006). These findings suggest that the attention on (manual) robotics control might have distracted the operators from paying attention to the environment.

Participants' workload assessment was found to be affected by the type of robotics task as well as whether their RSTA task was aided by AiTR. They reported a higher workload level when their RSTA task was unassisted by AiTR. They also experienced significantly higher workload when they teleoperated the robot. These results are consistent with Chen et al. (2008), Chen and Joyner (2006), Chen and Terrence (2008a), and Schipani (2003), who evaluated robotics operator workload in a field setting. Although many of the ground robots in the U.S. Army's Future Combat System (FCS) program will be semi-autonomous, teleoperation will still be an important part of any missions involving robots (e.g., when robots encounter obstacles or other situations requiring operator intervention). Therefore, the higher workload associated with teleoperation needs to be taken into account when designing the user interfaces for the robotic systems. For potential user interface design solutions, see Chen, Haas, and Barnes (2007).

The analyses of participants' physiological arousal level failed to detect a significant difference between conditions. One potential explanation for the lack of the anticipated effects of varying task load levels on average arousal may be due to the nature of the dependent variable. That is, the average level of arousal for each condition (i.e., mission) does not appear to have the sensitivity required to capture changes in arousal that occurred throughout the mission. Consequently, additional investigational analyses will be examined around specific points in the mission where task load is likely to be elevated.

5. FUTURE RESEARCH

Automation will likely be required to support human-robot performance, but when automation aides should be invoked may vary based on individual differences of the unmanned system operator and changes in the task load imposed upon them throughout a mission. Adaptive automation, in which the system initiates task automation based on criteria such as critical events or operator performance, has been proposed as an effective means to enhance human-robot system performance (Parasuraman, Barnes, & Cosenzo, 2007). Although there is a paucity of empirical investigations on the efficiency of adaptive automation for unmanned systems, a recent study of operator performance with multiple uninhabited systems demonstrated a beneficial effect of performance-based adaptive automation on workload and performance (Parasuraman, Cosenzo, & DeVisser, in press).

In our upcoming experiment, which is designed to expand upon the Parasuraman et al. (in press), the differential effects of various types of automation on operator performance, workload, and situation awareness will be empirically evaluated. Four automation conditions will be compared during a simulated high workload reconnaissance, surveillance, and target acquisition mission: manual, static automation, and two methods for invoking adaptive automation. Specifically, in the performance- and physiological-based adaptive automation conditions, real-time assessment of operator performance and physiological indicators will be used as triggers for task automation.

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