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Wide Area Search Munitions (WASM) combine the attributes of unmanned aerial vehicles with those of traditional munitions. The WASM concept envisions artificially intelligent munitions that communicate and coordinate with one another and with human operators to effectively perform their tasks. This study examined target acquisition for unaided operators with that of an automated cooperative controller for a complex task involving the prosecution of ground-based targets. Participants completed nine trials for each control mode (manual and cooperative) by number of WASMs (4, 8, and 16) combination. Target hit rate was not affected by control mode or number of WASMs. However, target acquisition efficiency degraded under manual control and as the number of WASMs increased. Workload was greater for the manual mode and increased as number of targets increased. Self-ratings of the ability to perform a simultaneous attach were lower for the manual mode and decreased as the number of WASMs increased.

Future unmanned aerial systems are expected to be more autonomous than those that are currently operational. In these systems, a single operator may be expected to monitor and exert executive control over several unmanned systems (Barbato, 2000; Clough, 2002; Prieditis, Dalal, Arcilla, Groel, Van Der Bock, & Kong, 2004). The US Air Force is considering advanced system concepts that could deploy multiple semi-autonomous unmanned weapons systems into the battle zone. One such system, the Wide Area Search Munitions (WASM), is a hybrid that combines the attributes of an unmanned aerial vehicle (UAV) with those of traditional munitions. The WASM concept envisions artificially intelligent munitions that communicate and coordinate with one another and with human operators to perform their tasks more effectively. WASMs can be deployed individually or in groups from larger aircraft and are capable of searching for, identifying, and attacking targets. Cooperative control concepts have been proposed to enhance coordination among these systems leading to optimal resource allocation (Goraydin, 2003; Scerri, Liao, Lai, Sycara, Xu, & Lewis, 2004; Schumacher, Chandler, & Rasmussen, 2002; Schumacher, Chandler, Rasmussen, & Walker, 2003). Research into strategies for controlling them presents a challenging problem that is being addressed by simulating WASMs as accurately as possible and evaluating them in human-in-the-loop (HITL) simulations and concept of employment scenarios. The Low Cost Autonomous Attack System (LOCAAS) was the first generation of such search munitions and served as the basis for the WASM testbed used to conduct HITL simulations.

Researchers have applied teamwork theory to build large teams that can accomplish complex goals using completely distributed intelligence. Algorithms have been developed to evaluate the ability to simultaneously deploy 200 WASMs to search and destroy ground-based targets in a coordinated support role with manned aircraft (Scerri et al., 2004).

The objective of this study was to examine target acquisition performance for unaided human operators with that of an automated cooperative controller in accomplishing a complex task involving the prosecution of ground based targets with WASMs. This purpose of the study was to provide empirical data on an operator's ability to simultaneously manage multiple WASMs while performing a target search, identification, and weapon assignment task. This information will provide valuable insights into concepts of employment and technology requirements for future munitions and semi-autonomous systems (e.g., how much automation is acceptable, information requirements, need for decision aiding software, manpower and personnel qualification requirements).

Method

Participants

Twelve full-time civilian and military employees stationed at Wright-Patterson AFB OH participated in this study. The sample consisted of 12 men who ranged in age from 20 to 45 years with a mean of 30.3 years. All participants reported being in good to excellent health and having vision correctable to 20/20, normal color vision, and normal peripheral vision. Most participants indicated that they had prior simulator (67%) and video game (92%) experience. Participation was voluntary and no compensation was offered in exchange for participation in this study.

Measures

Task performance and questionnaire data were collected.

Task performance measures. Several objective measures of target acquisition performance were collected. The *Number of High Priority Targets Attacked* and *Number of False Alarms* are self-explanatory. *Mean Time on Target* is the average of the actual time on target for the WASMs. *Mean Time on Target Error* is the average error between the actual time on target and requested time on target; that is, how close the attacks were to the requested time. This score could be computed only for the cooperative control condition. *SD of Time on Target* is the standard deviation of the actual time on target compared with mean time on target (i.e., how close the attacks were to each other). *Time to Plan* is the time from when the first target was selected to attack authorization or cancellation. *Time to Complete* is the time from authorization to when the last target was attacked.

Questionnaires. The questionnaires were a demographic data/background questionnaire, confidence ratings, the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988), and a post-test questionnaire that elicited a self-assessment of the ability to perform a near simultaneous attack under the manual and cooperative control conditions and comments regarding the operator interface.

Equipment

Figure 1 shows a test participant interacting with the experimental station. Participants were seated directly in front of a 13.3 inch CF-73 Panasonic laptop computer that presented the simulated WASMs attacking targets on a Falcon View map. Still images of potential targets were displayed on a poster next to the laptop to aid the participants during target acquisition. Participants used a mouse with a scroll wheel to designate targets and make weapon assignments. A second laptop computer was placed nearby where participants entered questionnaire responses.

Figure 1. WASM experimental station.

Procedures

The study began with a pre-briefing, informed consent, and the biographical questionnaire. The pre-briefing provided information regarding the purpose of the study, equipment, controls, and displays to be used, procedures, and the mission scenario. Following the pre-briefing, training was conducted to achieve familiarity with test equipment, procedures, and tasks. Participants completed three practice trials for each control mode (manual vs. cooperative control) by number of WASMs (4, 8, or 16) combination using a representative target set. Prior to starting the test trials, participants were fitted with electrodes to measure electrical brain, eye, and heart activity[1]. There were nine test trials for each control mode by number of WASMs combination. Immediately following each test trial, participants rated the level of confidence in their target acquisition decisions and subjective workload. After conclusion of the final test session, participants completed the post-test questionnaire regarding their experience.

Analyses

Analyses compared the objective and subjective data on the target acquisition task for manual versus cooperative control over three levels of mission complexity (4, 8, 16 WASMs). Related samples t-tests and repeated measures analyses of variance were performed since participants were exposed to all control mode by number of WASMs combinations.

Objective measures of performance included number of hits, number of false alarms, and target acquisition efficiency scores. Subjective measures were overall workload, confidence in target acquisition decisions, and self-assessment of the ability to accomplish near simultaneous attack. It was assumed that task difficulty would increase going from cooperative control mode to manual control mode and as the number of WASMs increased from 4 to 8 to 16. As a result, all analyses were performed using a .05 Type I error rate and a directional hypothesis.

Results

Target Acquisition Performance

Number of hits and false alarms. It was expected that performance under the cooperative control mode would equal or exceed that under the manual mode. Contrary to expectations, the number of high priority targets attacked was not affected by control mode. Although we intended to examine number of false alarms, we were unable to because the rate was extremely low with only 2 false alarms across all participants.

Time on target, time to plan, and time to complete measures. Means and standard deviations for the time on target, time to plan, and time to complete measures are presented in Table 1. It should be noted that mean time on target error (i.e., average error between the actual time on target and requested time on target) cannot be computed for the manual control mode because a requested time on target cannot be specified in manual mode.

No statistically significant effects were observed for *Mean Time on Target* for control mode, number of WASMs, or their interaction. *Mean Time on Target Error* (i.e., how close the attacks were to the requested time) generally increased as the number of WASMs/targets increased ($F(2, 10) = 6.96$, $p < .05$). The low value for the 8 WASM condition may have occurred due to the closer placement of targets in this condition relative to the 4 WASM/targets condition.

SD Time on Target Error (i.e., how close the attacks were to each other) was affected significantly by level of control ($F(1, 11) = 40.69$, $p < .01$), number of WASMs/targets ($F(2, 10) = 49.63$, $p < .05$), and their interaction ($F(2, 10) = 11.30$, $p < .01$). An examination of the means in Table 1 showed that time between attacks was greater for the manual versus cooperative control mode and generally increased as the number of WASMs/targets increased.

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[1] The physiological data had not been processed and analyzed in time for inclusion in this paper.

Significant effects were observed for both *Time to Plan* and *Time to Complete* for control mode and number of WASMs/targets. *Time to Plan* was greater for manual control ($F (1, 11) = 20.70$, $p < .01$) and increased as the number of WASMs/targets increased ($F (2, 10) = 19.76$, $p < .01$). *Time to Complete* was *less* for manual control ($F (1, 11) = 490.81$, $p < .01$) and increased as the number of WASMs/targets increased ($F (2, 10) = 6.89$, $p < .01$). At first, it appears counterintuitive that *Time to Complete* was lower for the manual versus the cooperative control mode. However, it should be noted that in the manual control mode, target authorization and attack occur separately for each WASM/target combination and once authorization has occurred, the WASM takes a direct flight path to the target. In the cooperative control mode the attack does not occur until all target/WASM combinations have been authorized and it is necessary for some WASMs to employ longer flight paths to enable simultaneous attack.

Table 1. *Means and Standard Deviations: Number of High Priority Hits, Time on Target, Time to Plan, and Time to Complete Scores.*

		Cooperative Control		Manual Control	
Score	N WASMs	Mean	SD	Mean	SD
N High Priority Hits	4	3.33	0.00	3.27	0.12
	8	6.66	0.00	6.55	0.38
	16	12.30	0.09	12.52	0.33
Mean Time on Target	4	494.00	83.88	573.84	327.90
	8	488.57	55.83	446.71	67.35
	16	540.15	75.55	552.56	288.37
Mean Time on Target Error	4	2.04	1.22	-------	-------
	8	1.30	0.53	-------	-------
	16	8.58	4.44	-------	-------
SD Time on Target Error	4	2.24	2.11	10.17	4.21
	8	1.45	1.44	17.58	7.16
	16	9.09	6.16	27.43	11.89
Time to Plan	4	22.47	4.00	39.40	15.66
	8	36.01	7.63	61.26	26.83
	16	70.16	13.71	105.24	51.05
Time to Complete	4	117.22	11.89	63.06	10.45
	8	124.63	7.49	65.64	5.43
	16	148.09	26.76	74.96	10.90

N = 12

Confidence Ratings in Target Acquisition Decisions

Examination of the mean confidence ratings indicated an overall high level of confidence, with a mean score across all level of control by number of WASM/targets conditions of 4.75 out of a possible 5. Although confidence ratings varied, they were in the “fairly confident” to “very confident” range for all level of control by number of WASMs/targets combinations, even for the manual control mode with 16 WASMs/targets, which had a mean of 4.33 out of a possible 5. Although there was a trend toward greater confidence for decisions made using the cooperative control mode, this trend was not statistically significant. It should be noted that the observed power for this test was low, suggesting that if a larger sample were tested the effect might reach statistical significance. Mean confidence level was related significantly to the number of WASMs/targets ($F(2, 10) = 9.52$, $p < .01$). An examination of the means showed a general trend toward lower confidence as the number of WASMs increased, especially for the manual control mode.

Subjective Workload

Subjective workload was measured using the NASA TLX. As previously discussed, the NASA TLX has 6 subscales (Mental, Physical, Temporal, Performance, Effort, and Frustration) that are combined to create an overall workload index. Examination of the means revealed a consistent trend toward increased workload going from the cooperative control mode to the manual control mode and from 4 to 8 to 16 WASMs. This trend was statistically significant for the Total workload score and for all of the NASA TLX scales except Physical workload. For Total workload, significant effects were obtained for control mode ($F(1, 11) = 32.06$, $p < .01$), number of WASMs/targets ($F(2, 10) = 13.16$, $p < .01$), and their interaction ($F(2, 10) = 8.09$, $p < .01$). Mean Total workload for the cooperative control mode was relatively low with values of 13.91, 15.37, and 21.20 respectively for 4, 8, and 16 WASMs/targets. Mean Total workload for the manual control mode was 28.81, 38.97, and 51.15 for 4, 8, and 16 WASMs/targets.

Post-Test Questionnaire

Following completion of the test trials, participants completed a post-study questionnaire regarding their experience. They rated ease with which they were able to use the operator interface to identify targets and their ability to classify the priority level of targets. Both ratings were on a five point scale: 1 – poor, 2 – fair, 3 – good, 4 – very good, and 5 – excellent. Although ratings for ease of use and ability to classify the target priority level varied, the mean ratings for both approached "very good." Ratings for ease of use ranged from 3 to 5 with a mean of 3.92; those for ability to classify the target priority level ranged from 2 to 5 with a mean of 3.83.

Participants then rated their ability to perform a simultaneous attack using the cooperative control and manual control modes for the 4 and 16 WASMs/targets conditions. Ratings were on a five point scale: 1 – poor, 2 – fair, 3 – good, 4 – very good, and 5 – excellent. There were significant effects for control mode ($F(1, 11) = 66.00$, $p < .01$), number of WASMs/targets ($F(1, 11) = 61.90$, $p < .01$), and their interaction ($F(1, 11) = 28.94$, $p < .01$). Inspection of the means showed a strong trend toward lower ratings of ability to perform a simultaneous attack for the manual control mode and for the 16 WASMs/targets condition. The means for the cooperative control mode were 4.83 and 3.83 for the 4 and 16 WASMs/targets. The means for the manual control mode were 4.17 and 1.50 for the 4 and 16 WASMs/targets.

Participants had the opportunity to provide open-ended comments regarding the WASM interface and procedures. Seven of the 12 participants made one or more comments. These focused on ways to improve the manual control mode and the interface design. Suggestions regarding the manual control mode included adding the ability to insert waypoints and timing points to improve simultaneous attack. Suggestions regarding the interface design focused on providing multiple data input options in addition to the mouse and using a larger screen or multiple screens.

Discussion

Participants were able to acquire and attack nearly all of the targets even under the most demanding condition, that is, manual control of 16 WASMs. As expected, unaided operators were not able to achieve simultaneous attack of the targets as efficiently as the cooperative controller. Time between attacks was greater for the manual versus cooperative control mode and generally increased as the number of WASMs/targets increased. The decrement in performance efficiency between the manual and cooperative control modes is important under the circumstance when it is crucial to limit the amount of time an adversary has to respond to a first attack. Even in the least demanding condition involving 4 WASMs/targets, participants' ability to manually perform a near simultaneous attack was degraded compared to the cooperative control mode. These results also are reflected in participants' self-assessments of workload and their ability to perform a near simultaneous attack.

Additional studies are needed to examine factors that may affect performance differences between the manual and cooperative control modes. For example, the extent to which targets are clustered (or dispersed) in the search area may affect the relative efficiency of the manual and cooperative control modes. Also, it would be informative to examine additional numbers of WASMs/targets (1, 2, 3, … n) to better determine performance differences between the manual and cooperative control modes.

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