Army Research Laboratory

Unmanned Aerial Vehicle (UAV)-Unmanned Ground Vehicle Teaming: UAV Guided Navigation

by Jessie Y.C. Chen and Bryan R. Clark

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14. ABSTRACT

We simulated a military reconnaissance environment and examined the performance of ground robotics operators who needed to use sensor images from an unmanned aerial vehicle (UAV) to navigate their ground robot to the locations of the targets. We also evaluated participants' spatial ability and examined if it affected their performance or perceived workload. Results showed that participants' overall performance (speed and accuracy) was better when they had access to images from larger UAVs with fixed orientations, compared to other UAV conditions (baseline- no UAV, micro-air vehicle, and UAV with orbiting views). Participants experienced the highest workload when the UAV was orbiting.

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1. Introduction

1.1 Background

In recent years, there have been growing applications of robotic technologies in fields such as space exploration, search and rescue, national defense, entertainment, police special weapons and tactics operations, health care, and personal assistance (Chen, Haas, & Barnes, 2007). These robotic systems will extend the ranges and capabilities of their human operators' perception and action and will have a major impact on future combat operations (Oron-Gilad, Chen, & Hancock, 2005). Future warfare employing robotic systems may need to integrate information from multiple platforms, potentially from aerial and ground sources. A human operator's perception of remote environments often relies on the video feeds from the camera(s) mounted on the robots. Unmanned aerial vehicles (UAVs) generally provide exocentric (perspective from outside the environment) views of the problem space (i.e., the battlefield) while the unmanned ground vehicles (UGVs) present viewpoints that are egocentric (perspective from within the environment) and immersed in the environment. The ideal view depends on the task; overall awareness and pattern recognition are optimized by exocentric views whereas the immediate environment is often viewed better egocentrically. According to Chen, Durlach, Sloan, and Bowens (in press), robotics operators tend to prefer using UAVs instead of UGVs to conduct reconnaissance tasks (i.e., target detection), which is consistent with the literature that exocentric perspective is more suitable for global awareness performance and search tasks than egocentric perspective (Wang, 2004). However, depending on the missions, targets might need to be examined at a closer range from the ground after they are detected by UAV operators. Displays for integrating information from different frames of reference (FORs) (e.g., exocentric and egocentric) present potential human performance issues that need to be carefully evaluated (Thomas & Wickens, 2000). Research has shown that integrating information across egocentric and exocentric views can be challenging for the operator (Olmos, Wickens, & Chudy, 2000; Thomas & Wickens, 2001). Essentially, dual displays with both FORs require effective scanning of the displays and integration of information from two different perspectives to form an accurate assessment of the situation. Furthermore, operators may be susceptible to saliency effect and anchoring heuristic/bias (Thomas & Wickens, 2000). In other words, salient information on one display may catch most of the operator's attention, and the operator may form an inaccurate judgment because information from the other sources is not properly attended to and integrated. In Thomas and Wickens (2000), participants were found to tunnel their attention into the egocentric view to the exclusion of information from the exocentric view.

Another potential human performance issue related to integrating information from different FORs is navigation. In order to successfully navigate in the remote environment, the robotics operator needs to have a good sense of orientation, both globally and locally. Globally, the operator needs to know where the areas of interest are relative to the location of the robot; locally, the operator needs to negotiate local turns and avoid obstacles in order to navigate to the robot's destinations. Navigation with a traditional (north-up) map can be challenging at times because of the demand of mental rotation. Studies comparing human performance, which use north-up maps (world-referenced; fixed viewpoint) versus track-up (ego-referenced; rotating viewpoints) maps, consistently show that track-up maps are better for local guidance (i.e., navigation) and north-up maps are better for global awareness (Aretz, 1991; Casner, 2005; Darken & Cevik, 1999; Lohrenz, Gendron, Edwards, Myrick, & Trenchard, 2004; Wang, 2004; Werner, 2002). User interface design guidelines generally recommend making both north-up and track-up maps available (U.S. Department of Transportation, 2006). It is also recommended that when one is in a route-planning mode, the default should be north-up; during navigation, the default should be track-up.

1.2 Current Study

The current study was designed to gain a deeper understanding of UAV-guided navigation. In military operations where UAVs are used to provide aerial views of the mission environments, human performance issues are likely to occur if entities on the ground (e.g., UGV operators, dismounted Soldiers, etc.) need to rely on the video feeds from UAVs to help them navigate in the environment. Depending on the class of UAV, several types of views can be provided. The class I UAVs such as the micro-air vehicle (MAV) can be manipulated to provide an aerial view that is more congruent with the view from the ground entities. For example, the MAV can travel ahead of the UGV to provide a near aerial view. However, for UAVs that are larger, it is more likely that the aerial vehicles are controlled remotely and the video feed can only be provided in a certain fixed orientation. It is also likely that the UAV will be traveling (e.g., circling in the same area) and the perspectives from the UAV will be constantly changing. If a ground entity (Soldier or Soldier via a UGV) needs to look for a target that is moving and needs to navigate based on video feed from a UAV that s/he cannot control, we can anticipate human performance issues such as disorientation to occur. As research shows, track-up maps/displays are more effective than fixed/north-up maps for land navigation. Therefore, potential disorientation issues that are associated with navigating with fixed/north-up maps can be anticipated with such scenarios as navigating with a fixed or (even worse) constantly changing (but not congruent with the direction of the ground navigation) aerial view. Lighting conditions (e.g., nighttime) could also exacerbate the disorientation problem since operators cannot rely on the color cues of their surroundings. In the current study, we sought to evaluate such performance issues and in ensuing studies, we will propose and examine potential mitigation strategies (e.g., user interface design and/or training) for such performance degrada-tions.

2. Method

2.1 Participants

A total of 28 college students (10 females and 18 males) was recruited to participate in the study. The ages of the participants ranged from 18 to 34 (mean *[M]* = 23.43, standard deviation *[SD]* = 4.88). Participants were compensated $15/hour and given class credit for their participation in the experiment.

2.2 Apparatus

2.2.1 Simulators

A first-person-shooter computer game, Half Life2[1], was used to provide the simulation for the MAV and the UGV (figure 1). The terrain database of the McKenna Military Operations on Urban Terrain (MOUT) at Fort Benning, Georgia, was used for this experiment. The first-person-shooter perspective of Half Life2 was used to simulate the view from the UGV. Participants used voice commands (e.g., forward, backward, turn left, turn right, scan for targets, engage target, etc.) to control the UGV's navigation. Half Life2 also provides a spectator's view, which was used to simulate the view from the MAV. Participants used a joystick to control the movement of the MAV.

Another set of simulations was used to provide the large UAV views. The large UAV with fixed view was simulated as hovering above the MOUT at 100 meters. The orbiting UAV was simulated as orbiting the MOUT at 15 miles per hour (mph) at the same altitude. We rendered the night vision condition by adjusting the color setting of the computer monitors to render scenes as though seen through night vision goggles. Participants were able to see the entire MOUT site from the larger UAV video. However, with the MAV, they could only fly at a lower altitude (roughly the height of a three-story building) and could not have a bird's eye view of the environment as good as that of the larger UAVs. This constraint was attributable to the limitation of the simulation program and does not reflect the capabilities of the current MAVs used in the U.S. Army. Figure 1 shows the UGV view (left) and the large UAV view (right). The MAV view was similar to the UGV view but with a higher/adjustable altitude.

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[1] Half Life2 is a registered trademark of Valve Software Corporation.

Figure 1. UGV screen (left) and UAV screen (right).

2.2.2 Questionnaires and Spatial Tests

A demographics questionnaire (appendix A) was administered at the beginning of the training session. The Cube Comparison and the Hidden Patterns tests (Ekstrom, French, & Harman, 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 six-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 Orientation test, modeled after the cardinal direction test developed by Gugerty and his colleagues (Gugerty & Brooks, 2004) 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. A map-reading test (Money & Alexander, 1966) was converted into a computerized test via the software program E-Prime[2] so that both speed and accuracy could be captured. A survey on perceived sense of direction (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), Santa Barbara Sense of Direction Scale (SBSOD) (appendix B), was also used to assess participants' perceived abilities on navigation and way-finding tasks. Hegarty et al. (2002) reported that this self-reported sense of direction is correlated with some spatial task performance (e.g., imagining oneself taking a different perspective in the environment and learning the spatial layout of the environment).

Participants' perceived workload was evaluated with the computer-based version of National Aeronautics and Space Administration task load index (NASA TLX) questionnaire (appendix C, Hart & Staveland, 1988). 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.

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[2] E-Prime is a registered trademark of Psychology Software Tools, Inc.

2.3 Experimental Design

The overall design of the study was a 2 x 2 x 4 mixed design. The between-subject variable was Lighting (day versus night vision). The within-subject variables were Target (stationary versus moving target) and UAV (no UAV versus MAV versus Large UAV Fixed View versus Large UAV Orbiting View).

2.4 Procedure

After being briefed about the purpose of the study and signing the informed consent form, participants completed the demographic questionnaire, followed by the SpA tests and the SBSOD survey. Participants then received training by going through a PowerPoint[3] based tutorial and practice on the tasks they would need to conduct. The participants then completed practice scenarios using the different types of UAVs. They practiced detecting the targets (both primary and secondary) using the UAVs and then navigating the UGV to the locations of the targets. They also practiced placing the targets on a map after the UGV engaged the targets. The training session lasted about 1 hour.

Participants then were randomly assigned to the day or night vision group. In the experimental session, the participants were asked to look for the primary target (an enemy vehicle, which was a sport utility vehicle [SUV]) by using the UAV first, and then they tele-operated their UGV (i.e., navigated by voice commands) to the location of the target to engage it. The voice commands were then executed by one of the experimenters. The video from the UAV was available when the participant navigated in the environment using the UGV. In the case of the baseline condition, the participant only used his/her UGV to locate the primary target. In the case of moving targets, the participants needed to ensure continuous monitoring of the targets. For example, they needed to control the MAV so that it followed the movement of the target. The large UAV could not be manipulated but the view covered the entire MOUT environment. Participants could request a change of view, in the case of the fixed view UAV, when targets were occluded by buildings. Only two orthogonal views were available. Participants could request a view change as many times as necessary. As described earlier, the fixed view UAV was simulated as hovering above the MOUT at 100 meters. The orbiting UAV was simulated as orbiting the MOUT at 15 mph at the same altitude.

Participants were instructed to find and navigate to the primary target (i.e., SUV) first, before the five secondary targets (i.e., stationary enemy soldiers). There were also friendly civilians in the simulated environment to increase the visual noise for the target detection tasks. Participants marked the locations of the targets on a blank map after the UGV engaged the targets. Participants were instructed to do this without studying the video image of the UAV screen.

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[3] PowerPoint is a registered trademark of Microsoft Corporation.

There were eight scenarios corresponding to the 2 (Target) x 4 (UAV) experimental conditions. The order of presentation for the experimental conditions was determined by a Williams design of Latin square (Phillips, 2005). There were 2-minute breaks between scenarios. Participants assessed their perceived workload (NASA TLX) after each scenario. After the eight scenarios, participants were administered a Landmark Location test. They were shown pictures of five buildings in the MOUT environment and were asked to mark the locations of these buildings on a blank map. The experimental session lasted about 1.5 hours.

2.5 Measures

The dependent measures included mission performance (i.e., the number of targets detected with the robotic assets and the amount of time it took the participants to find the targets) as well as participants' perceived workload.

3. Results

3.1 Operator Performance

3.1.1 Target Search Time

Participants were designated as high SpA or low SpA, based on their composite SpA test scores (median split). We derived the composite scores by summing the participants' rank on each spatial test. A mixed analysis of variance (ANOVA) was performed to examine the search time for the primary target (SUV), with the Lighting condition (day versus night vision) as the between-subject factor, the Target type (stationary versus moving target) and UAV type (no UAV versus MAV versus Large UAV Fixed View versus Large UAV Orbiting View) as the within-subject factors. The analysis revealed that UAV condition significantly affected the speed of the search, $F(3, 22) = 6.29$, $p < .005$. *Post hoc* (least significant difference [LSD]) tests showed that the NoUAV condition was significantly slower than the other three conditions, and the MAV condition was also significantly slower than the two Large UAV conditions (figure 2). There were no significant differences between those with higher SpA and those with lower SpA.

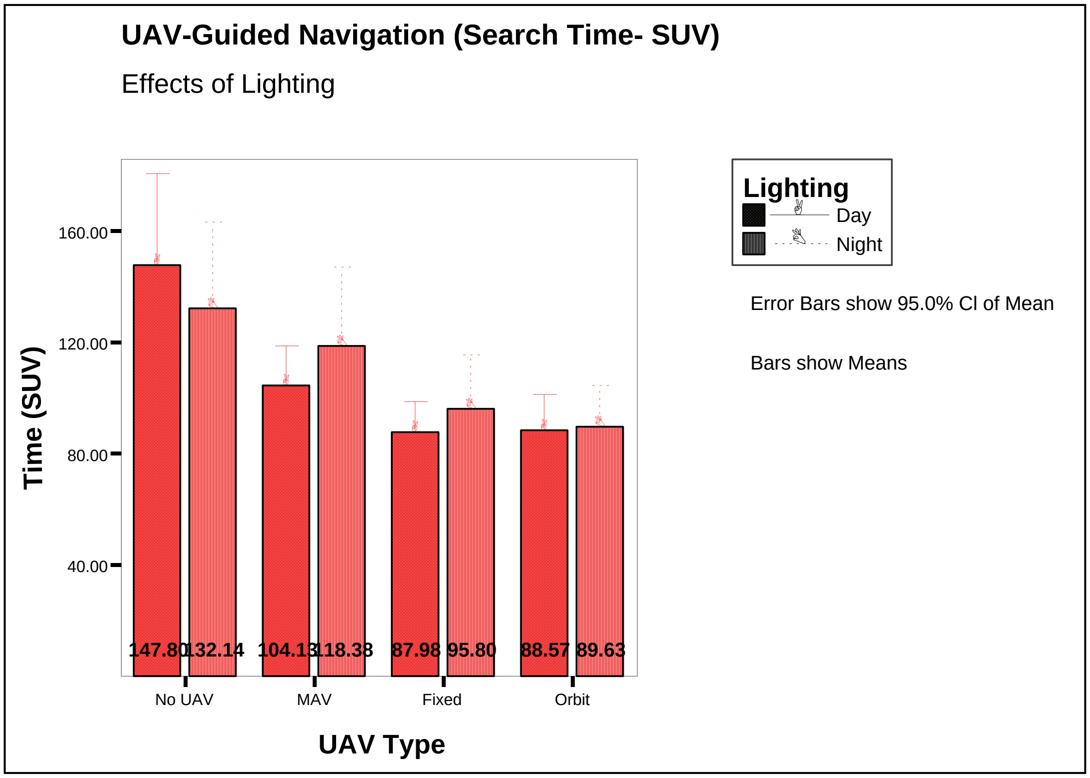

Figure 2. Primary target search time.

3.1.2 Map Marking Accuracy

3.1.2.1 Target Locations

A mixed ANOVA was performed to examine the map marking accuracy for the primary target (SUV), with the Lighting condition as the between-subject factor, the Target type and UAV type as the within-subject factors. The analysis showed that both UAV and Target type significantly affected the accuracy, $F(3, 22) = 3.803$, $p < .05$ and $F(1, 24) = 6.804$, $p < .05$, respectively. *Post hoc* (LSD) tests showed that the NoUAV condition was significantly worse than the two Large UAV conditions. Additionally, MAV was significantly worse than Fixed view UAV (figure 3). Participants' SpA did not affect their performance in the NoUAV and MAV conditions. However, in the two Large UAV conditions, it made a significant difference. Participants with higher SpA outperformed their counterparts with lower SpA, $F(1, 24) = 7.193$, $p < .05$.

We also evaluated participants' map-marking accuracy for the secondary targets. We found that those with higher SpA had a significantly higher accuracy than did those with lower SpA, $F(1, 24) = 7.873$, $p < .01$ (figure 4).

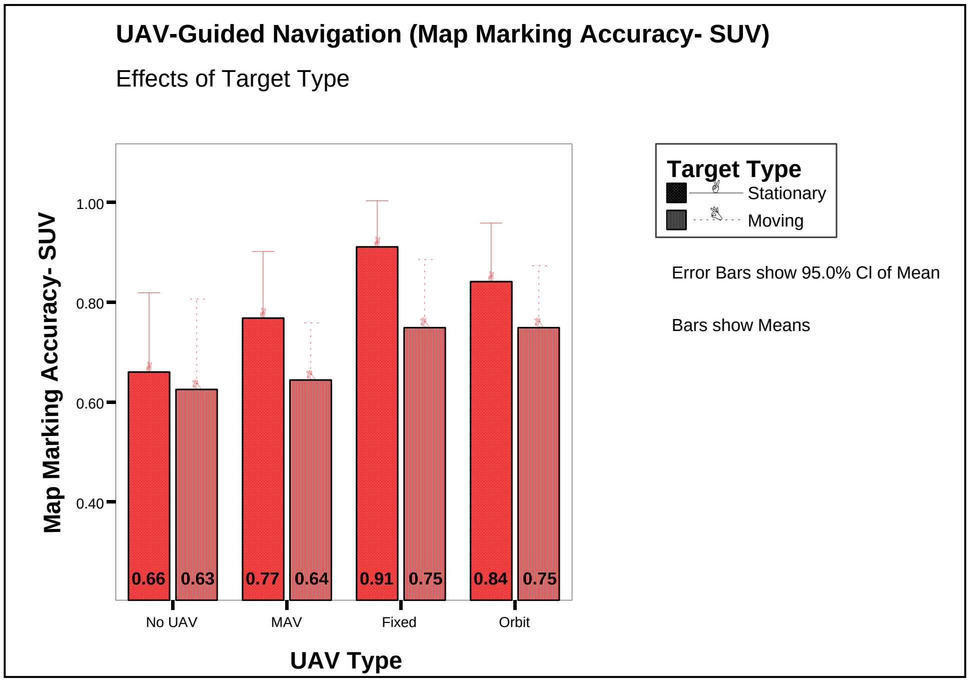

Figure 3. Map marking accuracy (SUV only).

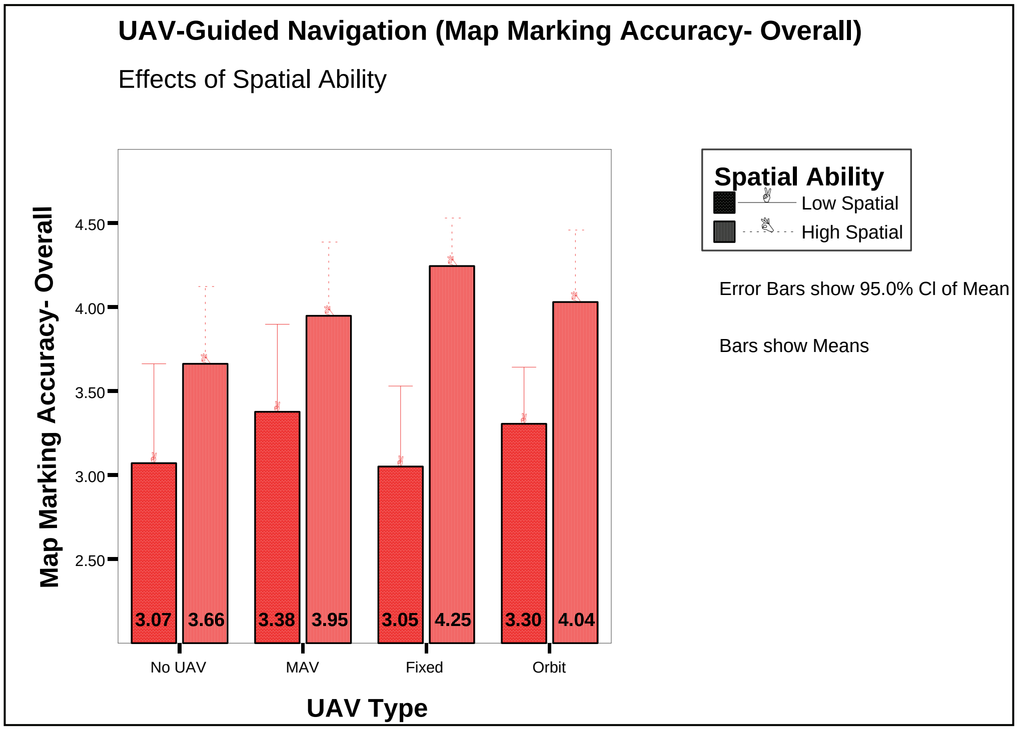

Figure 4. Map marking accuracy (secondary targets).

3.1.2.2 Landmark Locations

Of all the spatial tests and surveys, it was found that participants' Spatial Orientation Test (SOT) score best predicted their Landmark Location test scores (i.e., number of landmarks correctly marked on the map), $r = .478$, $p = .006$. To further test the accuracy of the SOT in predicting map-related performance, a multivariate ANOVA was performed to test the effects of SOT score on the 16 Map Marking Accuracy scores (8 on the primary targets and 8 on the secondary targets) as well as the Landmark Location test. The analysis revealed that there was a significant difference between those with high SOT scores and those with low SOT scores, $F(1, 19) = 5.838$, $p < .05$. Participants' self-assessed sense of direction (based on the Santa Barbara scale) was also an accurate predictor of their map-related performance (Map-Marking Accuracy for the primary and secondary targets and the Landmark Location test scores), $F(1,19) = 6.515$, $p < .05$.

3.2 Perceived Workload

Weighted ratings of the scales of the NASA TLX were used for this analysis. Participants' self-assessment of workload was significantly affected by UAV condition, $F(3, 22) = 4.684$, $p < .05$, as well as the Target type condition, $F(1, 24) = 4.548$, $p < .05$ (figure 5). *Post hoc* (LSD) tests showed that the participants experienced significantly higher workload when they used the Orbiting View UAV ($M = 59.5$) than when they used the MAV or the Fixed View UAV. Participants' SOT score was found to be an accurate predictor of their workload, $F(1,26) = 5.121$, $p < .05$. Those with higher SOT scores had a significantly lower workload ($M = 49.4$) than did those with lower SOT scores ($M = 61.7$).

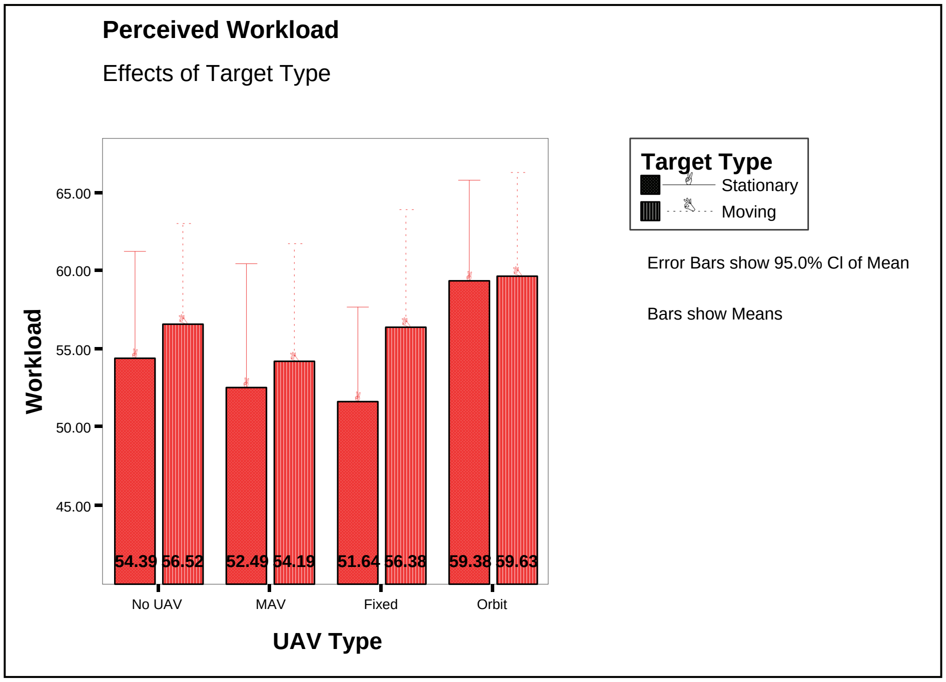

Figure 5. Perceived workload.

4. Discussion

We simulated a military reconnaissance environment and examined the performance of ground robotics operators who needed to use sensor images from a UAV to navigate their ground robot to the locations of the targets. We also evaluated participants' SpA and examined if it affected their performance or perceived workload. Results showed that (as expected) participants' target search was significantly slower in the NoUAV condition than in the other three UAV conditions. Additionally, participants' search was significantly slower with the MAV than with the two large UAVs. This could be because participants could see the SUV immediately from the large UAV screens, but they needed to search the environment (in a serial fashion) when using the MAV. There did not appear to be any significant differences between the two large UAV conditions. The Lighting conditions, Target type, and participants' SpA also failed to affect the performance.

For the map-marking accuracy performance, we found that both the UAV and the Target type conditions significantly affected the performance. The NoUAV condition, not surprisingly, was again the worst. The MAV condition appeared to be the worst among the UAV conditions, while the Fixed View UAV appeared to support the best performance. This performance difference was likely attributable to the limited view of the environment from the MAV, compared with the larger UAVs. When the targets were moving instead of stationary, participants' marking accuracy significantly degraded, possibly because of disorientation. Moreover, we observed significantly superior performance by those with higher SpA. The difference in performance appeared to be most pronounced when the Fixed View UAV was used. Those with lower SpA did not appear to take advantage of the larger UAVs (compared to the other two conditions) as much as their counterparts with higher SpA. Additionally, it appears that the SOT (Gugerty & Brooks, 2004) can accurately predict the level of survey knowledge (as indicated by the Landmark Location test) of our participants. It is interesting to note that some previous research (Hurts, 2006) did not find significant correlations between spatial abilities and survey knowledge. It is likely that the differences between the spatial tests used (the Differential Aptitude Test by Evers & Lucassen, 1991, was used in Hurts, 2006) contributed to these differences in findings. Indeed, we found that there was a significant difference in map-related performances (i.e., Map-Marking Accuracy for the primary and secondary targets and the Landmark Location test scores) between those with superior and poor SOT performance. Additionally, we found that participants' self assessment of their sense of direction (based on the SBSOD scale) was an accurate predictor of their map-related performance. Hegary et al. (2002) showed that the SBSOD scale was more related to self-orientation with the environment than distance estimation and map drawing. However, our data did not indicate the relationship between the SBSOD assessment and navigation-related measures (e.g., target search time). Only a difference in map-related performance was observed. Therefore, it appears that only the accuracy of mental representation of the environment was related to participants' SpA (as measured by SOT) and sense of direction. On the other hand, the speed of navigation (at least as measured in our current study) was not related.

In terms of perceived workload, both the UAV condition and the Target type condition had a significant impact. The Orbiting View condition produced the highest workload ratings. Moving targets also induced higher workload, although they did not appear to increase the workload when the UAV was orbiting. Again, the SOT seemed an accurate predictor of participants' perceived workload. Those with higher SOT scores perceived the tasks as significantly less taxing as those with lower SOT scores.

5. Conclusions

In the future, it is expected that Soldiers will rely heavily on video from a UAV to locate targets. It is also expected that it will often be necessary for Soldiers to further identify the targets or engage the targets after they are spotted through the UAV video by driving a UGV to the target location or by navigating to that location by themselves (e.g., for dismounted infantry). Either way, the ground navigation will need to rely on the video from the UAV for guidance. Our results showed that operators' overall performance (speed and accuracy) was better when they had access to images from larger UAVs with fixed orientations, compared to other UAV conditions (baseline-no UAV, MAV, and UAV with orbiting views). The UAV with orbiting view was associated with the highest workload ratings. The results of this research should increase our understanding of the costs and benefits of UAV guided navigation.

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Appendix A. Demographic Questionnaire

Participant # _______ Age ______ Major ________________ Date ___________ Gender ___

1. What is the highest level of education you have had?
Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School Jr. High High School
Technical School College Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other________ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:	
Use a mouse?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a joystick?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a touch screen?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use icon-based programs/software?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use programs/software with pull-down menus?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use graphics/drawing features in software packages?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use E-mail?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
_____ Novice
_____ Good with one type of software package (such as word processing or slides)
_____ Good with several software packages
_____ Can program in one language and use several software packages
_____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically? YES NO
If NO, please briefly explain:

8. How many hours of sleep did you get last night? ______ hours

9. Do you have normal color vision? YES NO

10. Do you have prior military service? YES NO If Yes, how long __________

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Appendix B. Santa Barbara Sense of Direction Scale

Sex: F M   Today's Date:________________
Age:_______ V. 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

2. I have a poor memory for where I left things.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

3. I am very good at judging distances.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

4. My "sense of direction" is very good.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

6. I very easily get lost in a new city.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

7. I enjoy reading maps.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

8. I have trouble understanding directions.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

9. I am very good at reading maps.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

10. I don't remember routes very well while riding as a passenger in a car.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

11. I don't enjoy giving directions.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

12. It's not important to me to know where I am.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

13. I usually let someone else do the navigational planning for long trips.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

14. I can usually remember a new route after I have traveled it only once.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

15. I don't have a very good "mental map" of my environment.
Strongly Agree |---|---|---|---|---|---| Strongly Disagree
1 2 3 4 5 6 7

Appendix C. NASA TLX Questionnaire

Please rate your overall impression of demands imposed on you during the exercise.

1. Mental Demand: How much mental and perceptual activity was required (e.g., thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

2. Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

4. Level of Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

6. Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

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Appendix D. Glossary of Acronyms

ANOVA	analysis of variance
ARL	Army Research Laboratory
FCS	Future Combat System
FOR	frame of reference
LSD	least significant difference
MAV	micro-air vehicle
MOUT	military operations on urban terrain
SBSOD	Santa Barbara sense of direction scale
SOT	spatial orientation test
SpA	spatial ability
SUV	sport utility vehicle
UAV	unmanned aerial vehicle
UCF	University of Central Florida
UGV	unmanned ground vehicle

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