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EXAMINING MEMORY FOR SEARCH USING A SIMULATED AERIAL SEARCH AND RESCUE TASK

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In this paper, we report on the development of a synthetic task environment (STE) representing wilderness search and rescue using unmanned aerial vehicles (UAVs) for investigating human unmanned aerial search behavior. Participants navigated using a north up topographical map and detected targets using a more detailed track up satellite image representing the view through the UAV's camera. Participants then completed (1) a path reconstruction task and (2) a memory test in which they indicated locations where they found targets. These tasks aim to address two information types that map onto distinct visual processing pathways afferent to the hippocampus. We discuss example applications using this paradigm, including several methods for scoring memory and navigation performance. Finally, we discuss how the STE enables assessment of the effects of combining or separating pilot and sensor operator roles, search behaviors and strategies, and other human factors limitations faced by operators in aerial search tasks.

Wilderness search and rescue (WiSAR) is the search for missing persons in remote environments. WiSAR operations are often carried out by volunteers on foot aided by resources such as canines, rotary and fixed wing aerial platforms, and marine assets. WiSAR operations begin with the report of a missing person. WiSAR personnel begin by establishing the point last seen, then create a map of probability for target locations distributed according to factors including terrain features, characteristics of the missing person, and current weather (Ferguson, 2008; Lin & Goodrich, 2010; Perkins, Roberts, & Feeney, 2003). Personnel and other assets then begin to search those locations and update the probability map, typically in a Bayesian fashion that considers both the background probability imposed by the terrain and the case based evidence about the missing person (e.g., Lin & Goodrich, 2010).

Recent research has focused on the use of unmanned aerial vehicles (UAVs) in WiSAR (Adams et al., 2007; Adams et al., 2009; Goodrich et al., 2008; Goodrich, Morse, Engh, Cooper, & Adams, 2009). While manned aerial search in general is beneficial to WiSAR operations, the costs of manned aircraft often exceed the resources of WiSAR organizations, which are staffed largely by volunteers (Hoekstra, M. [West Michigan Search and Rescue], personal communication, July 25, 2012). Therefore, WiSAR is an ideal domain for unmanned aerial search.

A typical UAV team in WiSAR consists of a navigator, who is responsible for directing the UAV, and the sensor or payload operator, who examines the video feed from the UAV's sensor package. UAV teams sometimes also incorporate a third individual who oversees the navigator and sensor operator to increase situational awareness (Adams et al., 2009). These characteristics are also found in military UAV teams; however, WiSAR personnel were selected for the present study as a more convenient and accessible population. The goal in both domains (and perhaps others) is to reduce the personnel required to control a single UAV, with a long term goal that a single operator may eventually control multiple UAVs (for a review of this literature, see Cummings, Nehme, & Crandall, 2006). To this end, Cooper and Goodrich (2008) tested multiple control interfaces and found that, with the appropriate interface changes, one human can effectively control a UAV.

One platform for studying unmanned aerial search is the open source Aviones UAV flight simulator (<http://aviones.sourceforge.net/>). The software has been used to simulate both highly automated algorithmic flight (e.g., Bhatia, Graziano, Karaman, Naldi, & Frazzoli, 2008; Collins, Stankevitz, & Liese, 2011) and human controlled flight (Cooper & Goodrich, 2008). We created a lower fidelity synthetic task environment (STE; Perelman & Mueller, 2013; available at <https://sites.google.com/a/mtu.edu/aerialste/>) in the Psychology Experiment Building Language (PEBL; Mueller, 2013) to approximate the cognitive requirements of unmanned aerial search tasks while affording greater control over experimental variables related to testing. STEs differ from simulations in that the chief goal in their design is not to replicate environmental characteristics, thus while they are lower fidelity than simulations, STEs permit a greater deal of experimental flexibility and control (Cooke & Shope, 2004). Finally,

because the STE is comparatively easy to control and requires very little training to operate, it will permit the inclusion of untrained participants in domain relevant research. One example of this is expert novice differences between untrained undergraduate students and trained UAV pilots. Whereas a high fidelity simulation would require the acquisition and operationalization of novice and expert trained pilots, the present STE would allow untrained participants to fill the control group. While the remainder of this paper pertains specifically to unmanned aerial search in the WiSAR domain, the STE discussed herein may be used to study aerial search in other domains, such as military and law enforcement, as well.

General Features of the STE

The STE consists of two main windows – a north up topographical display with an overlaid probability map, used for navigation, and a track up high resolution satellite image display representing the view through the UAV's sensor package (hereinafter “camera view”) (see Figure 1, panel A). At any given time, the entire topographical display is visible, while the camera view display is constricted to only the area directly underneath the UAV. Since the goal of the present study is to analyze search behavior rather than target detection or piloting ability, sensor quality and flight characteristics were approximated arbitrarily to maximize usability during the task. However, these characteristics can be parametrically manipulated to meet specific research requirements.

Gross control of the STE is accomplished either via touchscreen or mouse. Participants navigate the UAV using a carrot and stick method. The UAV orbits the target destination once it arrives until a new destination is selected. Participants designate targets by touch or mouse click inside the camera view display when the target appears, and sound effects provide participants with auditory feedback on hits or misses.

Experimental Tasks

In its current revision, the STE permits two types of tasks: a multiple target search task and a probability density decision test (hereinafter “decision test”). The multiple target search task was created to resemble search and rescue for multiple missing persons using an approximated probability map, while the decision test is intended to test participants' preference for weighing cost versus reward in a more controlled fashion (see Figure 1, panels A and B, respectively). The tasks were parameterized to provide the data necessary for a study in human memory and navigation. However, these tasks may be easily parameterized for additional experiments, and serve as a base from which future experimental tasks may be developed.

During the multiple target search task, participants search for targets, representing lost boy scouts, depicted as blue tents (see Figure 1, panel A). Probable target locations, distributed randomly in each trial, are indicated by blue circles on the north up topographical map. This paradigm is designed to require similar strategic decision heuristics to those required of UAV operators in WiSAR for searching probability maps. Since the present study investigated search behavior and navigation, and not detection, targets were drawn to maximize salience so that if a participant flew over a target, it would be easily spotted. PEBL affords a number of ways with which to adjust target salience in a controlled fashion, such as image alpha (i.e., target transparency), that will permit investigation of probability of detection in future studies. Trial duration is set by a “fuel” variable. In the present study, participants were provided 1,000 fuel units, equating to 79.5 seconds of flight time. This fuel was sufficient for participants to cover roughly 40 % of the total area, assuming that the flight path did not intersect with itself (i.e., areas were not flown over more than once). Fuel was intentionally limited to force participants to make strategic choices during their search.

The multiple target search task contains two subtasks: a path reconstruction task testing spatial memory, in which participants attempt to recreate the path flown by the UAV, and a target memory task testing semantic memory, in which participants indicate which of the possible target locations contained targets (see Figure 1, panels C and D, respectively). These tasks are intended to test performance on tasks requiring processing via dissociated hippocampal afferents, with the path reconstruction and the target memory tasks engaging the dorsal (spatial) and ventral (object) visual processing pathways, respectively (Haxby et al., 1991).

During the decision test, participants search for a single target in two probability regions, one rectangular high density region, representing an oasis, that can be explored in its entirety by flying over a single point, and a long linear low density region, representing a road, for which exploring fully requires a greater time investment (see

Figure 1, panel B). The distances of these two regions from the starting location are parametrically varied (see Figure 2) to test participants' evaluation of temporal cost versus reward.

Data Collection and Analysis

At the beginning of each trial, for both the multiple target search task and the decision test, the STE records target (and foil, in the case of the multiple target search task) locations, the trial number, and parametric and scaling information. Throughout each trial, the STE records the remaining fuel, the UAV's current position, and records the targets that are flown over and reported. Following the multiple target search task, the STE records the coordinates of each point indicated during the path reconstruction task, and a list of the probability locations indicated as containing targets by participants. From these data, the flight trajectory, target information, and the results of the two subtasks can be easily reconstructed.

Data analysis for the path reconstruction subtask of the multiple target search task was accomplished using a path correspondence algorithm (Mueller, Perelman, & Veinott, 2013) that computes congruity between the flown and reconstructed paths (see Figure 3). Since the algorithm simply requires Cartesian coordinates for two paths, it has additional utility as a performance metric in future applications, such as flight formation conformity. Target memory data were analyzed in terms of the temporal serial position in which the targets were discovered.

Demonstration Experiment Methods

Two experiments were conducted to demonstrate using the STE to test participants' performance, and to examine human performance in memory and navigation. Participants in both experiments were drawn from the Michigan Technological University undergraduate participant population. Both experiments were methodologically identical with the exception of the parametric settings during the decision test. In the first experiment ($n = 30$), the parameters were varied as a 3 x 3 design (road [close / medium / far] x oasis [close / medium / far] in distance from the starting location), whereas in the second experiment these parameters varied according to a 3 x 4 design (road [close / medium / far from starting] x oasis [very close / close / medium / far] in distance from the starting location). The locations of the features during these two experiments are available in Figure 2. In both experiments, participants completed five trials of the multiple target search task in which they searched 12 probability regions, six of which contained targets and six of which were foils (i.e., probability regions not containing targets).

Demonstration Experiment Results

Multiple Target Search Task

Across all trials, participants exhibited a significant improvement in flight performance, as measured both by percent map coverage, $F(4, 22) = 4.60, p = .008$, and target flyovers, $F(4, 26) = 4.32, p = .008$ (see Table 1). Generally, participants reported (i.e., clicked) a large percentage of targets that they flew over ($M = .87, SD = .22$). Across all trials, participants identified a mean of 2.97 targets per trial ($SD = 1.32$) and remembered a mean of 1.88 ($SD = 1.45$) of those identified (see Table 1 for specific trial by trial memory scores). Sample results for the path reconstruction task are shown in Figure 3. Since the present study is exploratory and did not use a between groups design, no statistical tests involving the path reconstruction results are presented. However, no statistical relationship was found for performance on the two memory tasks (*results not shown*).

Decision Test

Results of the decision test revealed a strong preference for searching the high density probability region. To test the efficacy of participants' behavior, we developed an optimal model that computes the cost of preferentially searching the high and low probability regions, and then compares these two costs to generate a cost ratio and declare the optimal route. Participants' behavior, in aggregate, correlated strongly with the cost ratio derived from the optimal model in the initial ($r = .97, p < .001$) and follow up studies ($r = .89, p < .001$). Participants, in aggregate, probability matched the cost ratio of the two choices generated by the optimal model.

Discussion

The present study describes the development and preliminary evaluation of a STE for unmanned aerial search. Preliminary evaluation indicates that participants generally improve with practice. Additional research is needed to determine consistency with memory effects, such as recency, in the present task and the literature concerning memory in other tasks. Finally, in aggregate, participants appear to be probability matching the cost to reward ratio associated with each route when forced to weigh probability densities.

Potential limitations of the STE include, but are not limited to, the following. First, the STE is not a high fidelity simulation; it attempts to approximate the cognitive requirements of unmanned aerial search in WiSAR. It is possible that this loss of fidelity fundamentally changes the way in which the task is approached cognitively. For example, the STE uses distinct points of probability, whereas probability maps generally produce distributions that are less uniform (i.e., not perfect circular regions). Second, presently, features such as flight characteristics and scale do not map perfectly onto real UAVs. Fortunately, the STE is sufficiently malleable as to permit scaling. Finally, the ecological validity of the STE has yet to be experimentally tested. Therefore, a future study should investigate performance differences between experienced WiSAR professionals and control participants (i.e., college undergraduates).

In future research, the STE described here will allow us to test a number of issues specific to the WiSAR domain and others. Since the STE is highly controlled in its data collection and easy to use, it permits testing of the following phenomena at the basic level with minimal training required. First, the STE will allow us to explore differences between combined and dissociated pilot and sensor operator roles (for an analysis of this problem, see Cooper & Goodrich, 2008). Between groups differences in target identification, memory for the flight path, and memory for targets, can be investigated simply by automating the flight path of the UAV and telling participants that it is being controlled by another user.

Second, the STE allows us to test memory for specific types of targets found during the multiple target search task (i.e., the contents of each high probability region). This is relevant to all aerial search tasks. For example, in actual UAV trials in WiSAR, targets may include clues to the missing person's location rather than the target itself, such as discarded perishables or other items (Goodrich et al., 2009). In military reconnaissance, the precise nature of relevant military targets on the ground may be important for strategic reasons (i.e., remembering the location of an enemy troop transport versus a tank).

Finally, the STE will permit testing the effects of target salience of search behavior and memory. Since the STE can vary the α value (i.e., transparency) of any image object created from a portable network graphics (.png) file, varying target salience is easily achieved in a controlled fashion. Reduced target salience will make signal detection analyses applicable to the data generated by the STE, and probability of detection can be compared between different interface displays and role assignments.

Tables and Figures

Table 1.
Trial by trial data for coverage, flyovers, and memory for targets.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Map Coverage (<i>M, SD</i>)	.25, .06	.28, .06	.29, .06	.29, .06	.30, .06
Target Flyovers (<i>M, SD</i>)	2.80, 1.27	3.17, 1.68	3.60, 1.35	3.43, 1.57	3.67, .88
Targets Identified (<i>M, SD</i>)	2.47, 1.25	2.67, 1.67	3.23, 1.25	3.27, 1.51	3.23, .94
Target Memory (<i>M, SD</i>)	1.57, 1.28	1.67, 1.73	2.27, 1.48	1.87, 1.61	2.03, 1.16

Table 2.
 Number of targets remembered and identified, by serial position.

	1 st Target	2 nd Target	3 rd Target	4 th Target	5 th Target	6 th Target
Identified (<i>M, SD</i>)	3.70, 1.41	3.07, 1.44	3.00, 1.71	3.11, 1.45	2.44, 1.48	1.81, 1.57
Remembered (<i>M, SD</i>)	2.22, 1.42	1.74, 1.26	1.74, 1.29	2.00, 1.27	1.74, 1.40	1.15, 1.06
Proportion Remembered (<i>M, SD</i>)	.59, .34	.55, .34	.56, .41	.64, .36	.69, .46	.44, .47

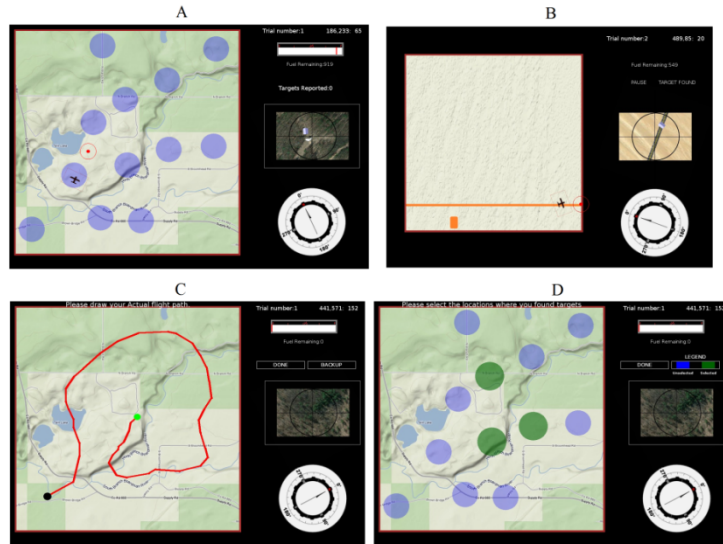


Figure 1. Panel A shows the STE running the multiple target search task. The UAV is depicted with the airplane icon. The UAV's current destination and orbit trajectory are indicated by the red dot and ring, respectively. The north up topographical map (left) permits navigation and depicts possible target locations as represented by the blue circles. Panel B shows the STE running the probability density decision test. The two orange regions represent possible target locations. Panels C and D show the path reconstruction and target memory tasks, respectively.

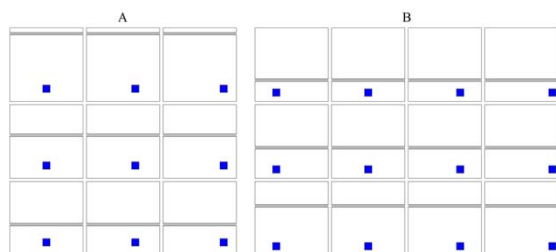


Figure 2. Feature locations for each study. Panel A depicts locations of the road (grey line) and oasis (blue rectangle) in Experiment 1, while Panel B depicts the feature locations in Experiment 2.

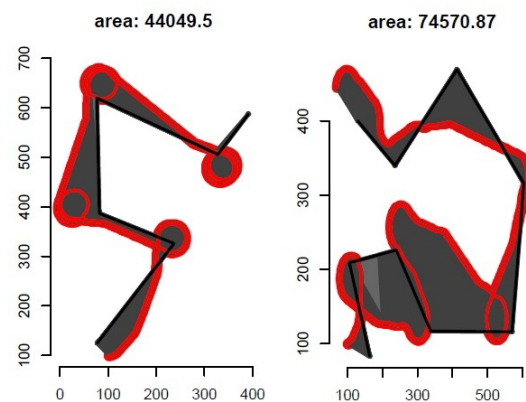


Figure 3. Sample results from the path reconstruction subtask. Participants' flight paths are shown in red, while the reconstructed paths are shown in black. The area of the polygon created by mapping analogous points on each path, shown above each panel, acts as a measure of path congruity and performance

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