IMAGING SYSTEMS IN SEARCH AND RESCUE: IMPLICATIONS FOR GEOGRAPHIC ORIENTATION

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Optical imaging systems have the potential to dramatically change the task of a search and rescue technician. An important difference between the traditional process of "looking out the window" and search conducted with the aid of an optical imaging system is that in the case of imaging systems the frame of reference for the viewed display is de-coupled from the technician's frame of reference. We examined the ability of a moving-map display that recorded the locations of designated targets to support geographic orientation in operators with and without knowledge of the modeled terrain. Participants who did not have knowledge of the terrain benefited from the moving map, as when it was present they were less likely to re-identify targets that they had already viewed, whereas those who were already familiar with the terrain model showed no benefit from this manipulation. Both groups had difficulty localizing targets on a map following flight, and the two groups did not differ in their ability to initially detect targets using the system.

INTRODUCTION

Optical imaging systems such as Forward Looking Infra Red (FLIR) and Active-Gated TV (AGTV) offer considerable potential to assist search and rescue (SAR) operations and will gain importance for many types of airborne operations in the coming years. However, they may introduce novel problems that affect the SAR technician's ability to search for, detect, identify and track targets.

With optical imaging systems search is conducted using a video monitor and joystick-controlled remote sensor (camera) rather than by direct visual inspection controlled by the technician's own direction of gaze. Use of video systems may challenge the technician's ability to maintain geographic orientation because the camera can point in any direction relative to the aircraft, and the technician does not have internal (proprioceptive) cues about camera direction. For instance, the aircraft may be moving north-east while the camera sweeps south-east to south, and the technician is looking straight ahead at a monitor facing west. These discrepancies between gaze, aircraft motion, and camera directions may produce disorientation or incomplete search of the region. Accordingly, a concern in the design of these systems is how best to provide a co-ordinate frame in which the technician can reference the sensor views to the geography of the search area, and integrate this information with aircraft position and search history.

To evaluate design concepts in a multi-sensor imaging system for SAR, the Canadian Department of National Defence (DND) created a prototype of the human-machine interface to be used by SAR technicians and adapted it to support experimentation (Gamble 2001; Neal, 1999). This prototype (Figure 1) includes a moving-map display that indicates camera direction, and an indicator of aircraft and camera direction displayed adjacent to the sensor windows. However, it is not known if a technician can use the available orientation cues and maintain the focal attention necessary for search.

The role of reference frames in orientation and navigation tasks has been examined in both aviation and computer gaming domains. The use of a dual-map display containing both a world-centered (exocentric) map and a tethered forward-field-of-view display (elevated but in the direction of the observer's heading) has been advocated for tasks that require integration of exocentric and operator-centered (egocentric) information (Darken & Sibert, 1996; Wickens & Hollands, 2000). For the DND system the tethered field of view can rotate in any direction relative to the aircraft (yaw and pitch), as well as zoom. Therefore, it is necessary for the SAR technician to integrate egocentric, exocentric, and sensor-centric information. Furthermore, transformation between reference frames is required whenever the technician communicates with the pilot about target location. This is traditionally accomplished using aircraft-centered hours of the clock (an egocentric reference frame for the pilot but not for the SAR technician). Thus, there are at least four frames of reference (sensor, egocentric, aircraft, and exocentric) involved in the technician's work domain.

Transformations from one reference frame to another are sources of time delay, errors, and increased mental workload, and should be minimized wherever possible (Wickens, 1998). Previous work has examined only two reference frames. Our study was designed to determine whether the cues to orientation provided by the moving-map interface were sufficient to ensure that the SAR technician could localize and recall target locations given the number of frames of reference involved in the task.

As people gain experience navigating through a geographic area they begin with egocentric representations based on viewed landmarks, and eventually gain exocentric "survey" knowledge of a region (Thorndyke & Hayes-Roth, 1982). Survey knowledge should help in coping with the multiple spatial transformations imposed by the optical imaging system.

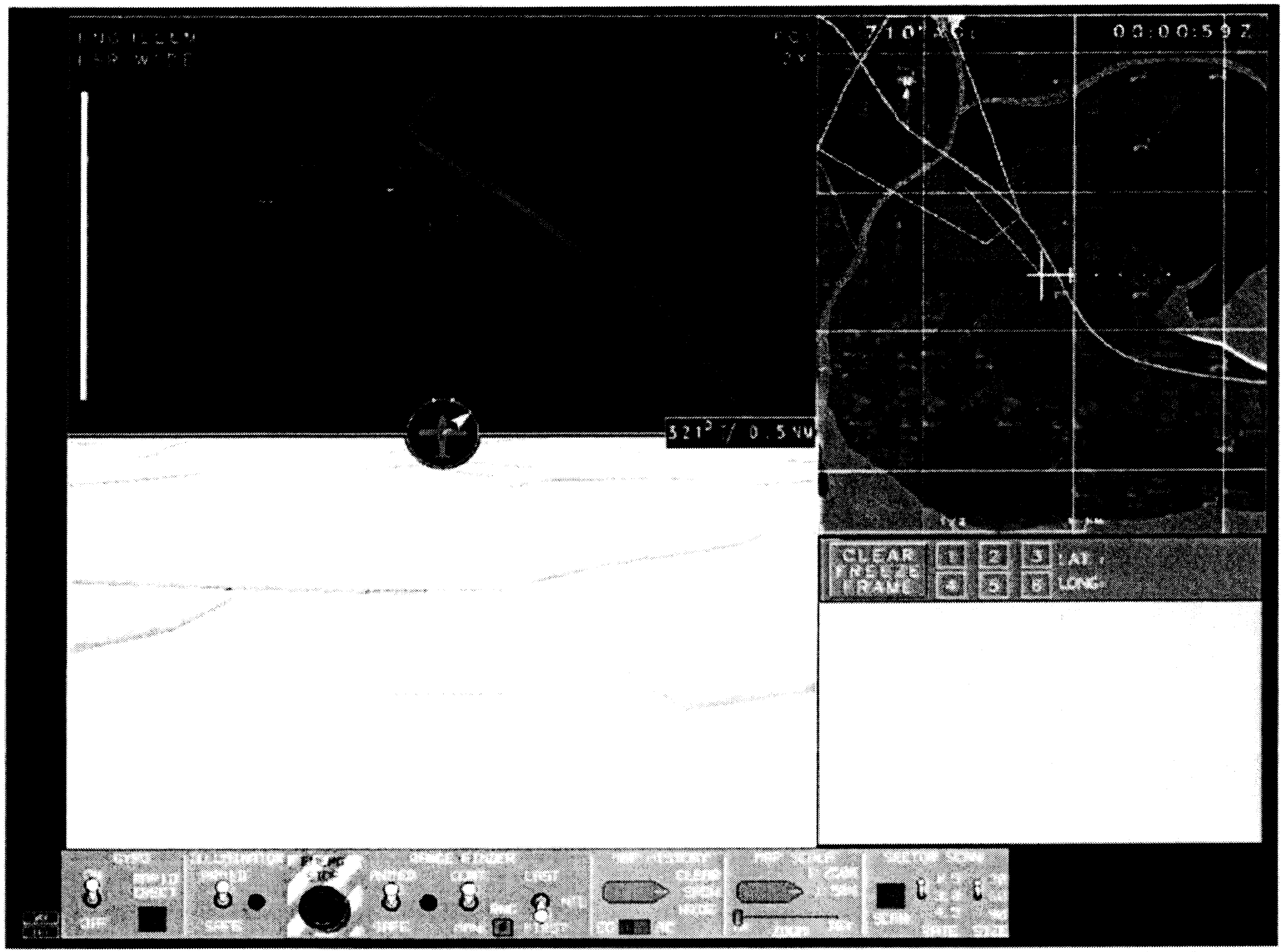

Figure 1: Screen Shot from the prototype interface. A world-centered (exocentric) map is shown in the upper right, and tethered egocentric views (AGTV and FLIR) are shown on the left. Participants saw only the AGTV window and map in the present experiment.

Therefore, we hypothesized that participants inexperienced with the terrain would show more benefit from the addition of the moving-map display than those experienced with the terrain. In a *search task*, we predicted that when inexperienced participants located a target they would have difficulty integrating its position into an exocentric representation of the modeled region. This failure to represent the location of a target should lead to a tendency to repeatedly designate the same targets as new. However, if a map display depicting locations of designated targets can overcome this problem, participants should perform equally well whether or not they have survey knowledge. In addition, we examined whether exocentric survey knowledge of terrain facilitates the initial detection of potential targets in the search task. SAR technicians working in a particular region may develop an exocentric representation, and may therefore minimize the time they spend examining the map in favor of the sensor windows, enabling them to find more targets overall.

In order to determine whether a map display of designated targets is adequate to support subsequent recall of target locations once the location markers are removed, a *target location task* was used. The ability to recall locations is an important element of the SAR work domain because the search may be guided by instructions from the SAR technician to the pilot to re-visit locations of previously viewed potential targets. This type of spatial situational awareness is also important in preventing the SAR technician from repeatedly investigating landmarks in the terrain as potential targets. To confirm that participants who were experienced with the terrain model possessed survey knowledge, a *map drawing task* was also included.

Tasks were ordered in so that map drawing was evaluated after an initial flight with no map and after a subsequent flight in which a moving map was shown. The target location task measured the ability of participants to recall the locations of detected targets following the completion of both flights.

METHOD

Participants

Participants came from two groups: 10 "experienced" participants had a minimum of 16 hours prior experience flying through the terrain database (as part of a separate experiment that required navigation of a helicopter simulator), and 10 "inexperienced" participants had not seen the terrain database prior to the experiment. Both groups had experience using an aircraft-mode joystick, and the groups did not differ in self-rated video game experience or spatial ability (as measured by the Vandenberg Test of Mental Rotation, Vandenberg & Kuse, 1978). All participants were males aged 17-51 (mean age was 28.5 years). Participants were paid for their participation.

Simulation

In the simulated search and rescue task participants flew at 75 knots through a 12 000 m by 13 000 m terrain model (Certain Impact©, 1996 Paradigm Simulation, Inc.) at an altitude of 600 m. The flight pattern was a fixed, creeping line search path in which participants flew in straight lines back and forth crossing the virtual terrain 4 times on each flight, such that the camera could be swept across the complete terrain in the time allotted. Search scenarios were presented on a 53.34 cm (21") Silicon Graphics (SGI) monitor controlled by an SGI Octane graphics workstation. The human interface (see Figure 1) was modified so that only an AGTV (21.8 cm x 15.5 cm) window was visible, depicting the terrain below the aircraft at a maximum 40° horizontal field of view. A north-up moving map window (13.5 cm x 15.5 cm) was presented only on the second of two flights, in the upper right corner of the interface. Designated items were indicated on the moving-map display in the form of a numbered square. An icon depicting camera orientation relative to the aircraft was present below the AGTV window. A joystick controlled the camera angle, and a joystick button was used to lock the camera onto a location in the terrain model. A second joystick button was used to designate targets. In the map-present condition Trucks were used as targets, and Hummers as distractors. Each target and distractor was rendered at nine separate mean luminances to approximate three levels of contrast relative to each of three background textures used in the simulation. This manipulation of search difficulty was included so that it could be determined whether any advantage demonstrated by the experienced participants would be largest when targets are hard to detect. A lever to the left of the joystick served as a zoom control to help participants discriminate between targets and distractors. The second flight used the same targets and target locations as the first flight but the targets were approached from a different angle due to a differing flight path (the second flight path was simply the first flight path flipped across both x and y axes).

Design

The experiment had a 2 x 2 x 3 between/within design with Experience (experienced vs. non-experienced) as a between-subjects factor and Map Condition (present, absent) and Contrast (low, medium, high) as within-subjects factors. Dependent measures varied with task and are described subsequently.

Procedure

Following completion of a practice flight through an unrelated terrain model, participants completed tasks in the following order: 1. search task without map, 2. map drawing task, 3. search task with map, 4. map drawing task, 5. target location task.

Search task. Participants were instructed to use a sweeping search pattern to locate potential targets in the display, then zoom in for identification. Neither of the groups had prior experience with this interface, so the amount of training was equated across groups. Participants were given practice searching for targets in another terrain before the experiment. Participants were instructed to remember everything they could about the searched area because they would be required to "know where things are" later. Participants were instructed to press the designate button whenever they identified a truck that was not previously designated. After instruction, each participant completed the two flights: the first without the aid of the moving map display, and the second with the moving map display (given the small number of participants it was not possible to manipulate map presentation order within groups). There were 18 targets (trucks) and 9 distractors (Hummers) placed at random orientations and locations on three different terrain types (fields, roads, and grass). The mean contrast of the stimuli was defined relative to each terrain type, and terrain type was fully crossed for targets and distractors.

Map drawing task. Participants were given seven minutes to draw the searched region including as many details as they remembered following each of the two flights.

Target location task. Following the completion of both flights, participants were given a printed map, told how many targets they had located, and asked to indicate with an "x" the location of those targets on the map. Participants were also informed that the targets were in the same locations on both flights, and that only the flight direction differed.

RESULTS AND DISCUSSION

Search Task

The number of target designations was computed for each participant and submitted to 2 x 2 x 3 between/within analysis of variance (ANOVA). As expected, experience affected the number of times participants designated the same target. Those with little experience improved from the first no-map flight to the second flight where the map recording designations was available, but those with experience flying in the terrain model demonstrated no such improvement *F*(1,18)=4.88, p=.04, (Figure 2). Given that participants were instructed to designate targets only once, the tendency of those inexperienced with the terrain model to re-designate targets suggests a failure to integrate viewed targets into an exocentric view of the region. Fortunately, the provision of a map that records designations along with extra experience in the terrain model alleviated this problem such that inexperienced and experienced participants performed similarly during the second flight. Overall performance at detecting targets did not differ as a function of experience F < 1, suggesting that the inexperienced participants' tendency to re-designate was not due to overall differences in workload between the groups, as that would affect the overall number of designations as well. Both groups found more targets on the second flight, *F*(1, 18) = 5.88, p = .026, but this difference did not interact with experience *F* < 1 (Figure 3). A greater number of targets were found when models were more salient (presented at higher contrast with the background), *F*(2,36)=167.01, p<.01, but this effect did not interact with group suggesting that findings of group differences are generalizable across a range of levels of search difficulty. Notably, performance for both groups was quite poor (those with no experience with the terrain model found a mean of 51% of the targets, and those with experience found 47% of the targets). This finding suggests that despite the simulation of realistic altitude, speed, and image quality, search using this system was highly challenging.

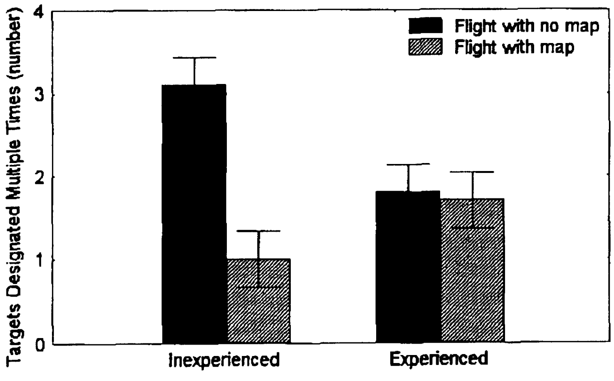

Figure 2: Mean number of targets designated more than once as a function of experience with the terrain model, and map condition.

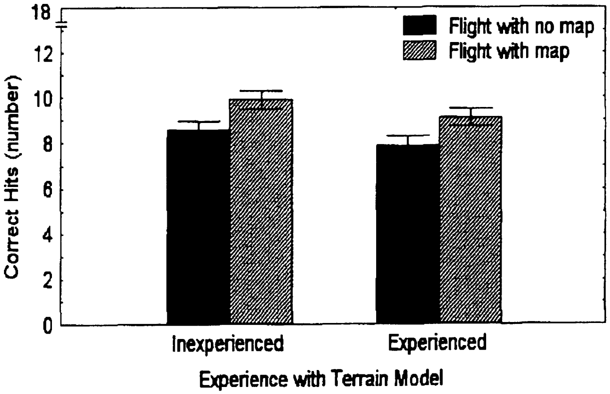

Figure 3: Mean number correct in the search task as a function of experience with the terrain model and map condition

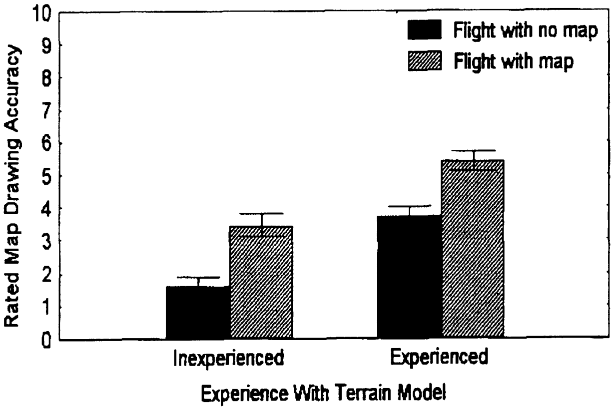

Figure 4: Quality of drawn map as a function of experience with the terrain model, and map condition

Map Drawing Task

Maps drawn following each flight were given a score out of 10 by two raters who were blind to each participant's level of experience; inter-rater reliability was 0.86. As can be seen in Figure 4, those experienced with the terrain model possessed more survey knowledge than the inexperienced participants F(1,18)=6.08, p=.024, and although both groups improved in their map drawing ability following the second (map-present) flight F(1,18)=18.23, p<.001 the difference between groups was not affected F<1.

Target Location Task

The accuracy of participants' memory for the location of targets they designated was scored by placing a transparent overlay on the map indicating a region around the target's actual location. When a conservative region with a 200m radius was adopted as a criterion, there was some suggestion that inexperienced participants performed more poorly than experienced participants who possessed a better exocentric representation of the region t(18)=1.88, p=.038 (one-tailed). However, the performance of both groups was quite poor despite the fact that targets were in exactly the same locations on two flights through the terrain model. Both groups correctly located less than 30% of the targets they had designated, even when a more liberal 400m criterion was adopted. This finding suggests that accurate recall of target locations is difficult regardless of one's level of survey knowledge of the mapped region.

GENERAL DISCUSSION

Taken together, these results suggest that the provision of a moving-map display that records target locations can successfully support the geographic awareness of SAR technicians to the extent that it may prevent them from repeatedly examining the same potential target. The results also suggest that the ability to form an exocentric view of the terrain around the aircraft does not have a significant impact on the ability of an observer to successfully find targets. From a design perspective, we recommend the provision of a moving map display that records target locations in SAR systems to reduce the likelihood of re-designation of targets.

However, the findings from the map drawing task and target location task indicate that even when a moving-map display is provided those without experience have difficulty extracting an exocentric view of the terrain and both groups have difficulty recalling the locations of targets they have found within that terrain. Further study is required to understand the causes and potential consequences of this lack of integration of viewed information into an exocentric coordinate frame. Such research has implications not only for onboard optical imaging systems but also for unmanned flight.

ACKNOWLEDGEMENT

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