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GEOGRAPHIC KNOWLEDGE ACQUISITION PROMOTED BY MAP STUDY AND REHEARSAL FLIGHT METHODS

BY

SCOTT THOMAS HUTCHINSON

B.S., University of Florida, 1990

THESIS

Submitted in partial fulfillment of the requirements
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WE HEREBY RECOMMEND THAT THE THESIS BY

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Abstract

Three methods of pre-flight navigational preparation were evaluated, to address problems of geographic disorientation. Thirty pilots either "actively" flew a rehearsal of an upcoming flight, "passively" watched a replay of an active rehearsal, or participated in a map study session in order to "learn" a low level navigation route and the surrounding region. Following training, subjects were then asked to navigate along the previously learned route in a high fidelity simulator, which depicted environmental aspects of a "real" flight. The results indicated that the spatial resource demands of active flight control while navigating in the training condition overburdened any potential learning benefits of "seeing" the training environment. The route and survey knowledge acquired in the active training condition were significantly poorer than the knowledge acquired in map study and somewhat inferior to that acquired by the passive group. All groups had equal difficulty applying survey knowledge to an unrehearsed and unexpected navigation task.

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Introduction

Overview

Navigation is a critical task that is essential to pilots of all types of aircraft. This task is generally performed by pilots quite successfully. However, pilots occasionally make navigation errors and these errors often result in a phenomenon called geographical disorientation. This occurs when accurate awareness of one's location in the world is no longer available to the pilot. This state may simply refer to when the pilot gets lost, whether the pilot is aware or unaware of this condition. Battiste (1993) defines geographic orientation as awareness of one's relationship to physical surface features of a region, awareness of one's relative location within that region, and one's temporal awareness of when one should be at a particular location within that region.

Williams, Tham, and Wickens (1992) recently completed a review of NASA's Aviation Safety Reporting System (ASRS) data on geographical disorientation and concluded that geographical disorientation is most prevalent among general aviation pilots, but that it occurs at all levels of flying experience. Williams et al. found that geographical disorientation occurs in both good and poor weather conditions. Leading causes were poor cockpit resource management (CRM) which led to inattention of awareness, bad weather, and poor decision making.

Maintaining geographical orientation is extremely critical in aviation settings. Loss of orientation can possibly lead to severe and fatal consequences such as fuel exhaustion, collision with the terrain and/or man-made structures, mid-air collisions due to entering congested airspace, or approaching/landing at an unintended runway. Several researchers have identified this type of disorientation as a key component of a pilot's loss of situational awareness (Battiste, 1993; Endsley, 1993; Harwood, Barnett, & Wickens, 1988; Sarter & Woods, 1991; Wickens, 1992).

While various methods of navigation exist, pilotage is a form of visual navigation that is commonly used by pilots and it will be explored in this paper. Pilotage involves visually locating a series of landmarks while flying at relatively low altitudes. A flight path is typically plotted out on an aeronautical chart before a flight is performed. While airborne, a pilot determines his/her route and position by comparison of map features to their corresponding visual counterparts in the outside world. Efficient use of pilotage includes a flight path which has landmarks that can be easily identified such as mountains, bodies of water, cities, and large man-made objects (Cessna, 1986).

An example of how pilotage is performed can be illustrated in Figure 1. Here the pilot would fly along the depicted course by making judgements of distance and orientation between landmarks (such as the mountain peak, the bend in the river, and the lake) and specify the relationship of these landmarks to their corresponding depictions on an aeronautical chart or map. The pilot needs to continuously use a process which confirms the location of outside visual landmarks relative to their location on a map in order to achieve and maintain geographic awareness. If the pilot cannot verify this relationship, then geographic awareness is lost.

Because helicopter pilots often fly low to the ground, pilotage is a critical component of their navigation task. The huge demands of visual navigation in helicopter flight were demonstrated in a study by Sanders, Simmons, and Hoffman (1979). They examined the visual workload of U.S. Army copilots/ navigators during nap-of-the-earth (NOE) terrain flight and found that over 92% of the copilots' total visual time was devoted solely to navigational duties. These results reflected the tremendous importance of geographical orientation and its maintenance, especially at low altitudes. In response to these results, a study by Cote, Krueger, and Simmons (1983) was performed, which tested if new automatic navigation equipment reduced geographic disorientation and high workload problems of NOE flight. The results of this study indicated that helicopter crews who only navigated with a hand held map made significantly more navigational errors than did crews using the map in conjunction with the new navigational equipment.

Geographic awareness needed for this type of low altitude navigation is usually assisted through some combination of map study and previous experience in an environment. For many years, map study was the only method of becoming familiar with the navigational aspects of an upcoming flight. However, recent technology has made available the possibility of participating in a "rehearsal flight" scenario (e.g., Bird, 1993; Williams & Wickens, 1993). A rehearsal flight is a relatively new method which uses a simulator, replicating every aspect of a future flight, so that a pilot can practice flying and navigating within the unfamiliar environment. This form of practice or training could possibly promote greater navigational performance on a real flight relative to a condition in which such training had not taken place. This rationale is based on the fact that the pilot can benefit from "seeing" aspects of an unfamiliar region which would otherwise only be available from a map representation. A strong argument can be made to develop such technology in if fact it proves to be an effective aid to promoting geographic knowledge and awareness.

There are, however, both theoretical and practical implications surrounding the potential adoption of this technology, relating to how geographic information is stored, processed, and operated upon by the pilot. For example, how "realistic" should a rehearsal flight environment be? Should pilots actively explore an environment to be learned, or can they be passively taken through it while watching a video? While exploring a new environment, should a map be held in a particular manner? Which of the many types of navigational tasks are best learned by rehearsal flights? These questions, partially addressed in an earlier investigation by Williams and Wickens (1993), will be the focus of the current study.

In the following pages, many different studies are reviewed in order to develop the background of particular topics which relate, to varying extent, to the issues addressed in the present experiment. The review in particular covers studies that have considered the nature of geographic knowledge and how this is influenced by the learning environment in which that knowledge is acquired. Much of it does not have a direct bearing on rehearsal flight technology, but since the effectiveness of that technology clearly depends upon the nature of geographic knowledge, its partial relevance is evident. In particular, we discuss two key issues: differences in the frames of reference between map knowledge and the need to use that knowledge in navigation, and the nature of geographical knowledge itself.

Frames of Reference

A critical component to specifying the relationship between visual landmarks and their counterparts, on either a physical map or a learned map stored in memory, is matching sources of information which have two different frames of reference. Several researchers have described two frames of reference used in navigation (Aretz, 1991; Battiste, 1993; Harwood & Wickens, 1991) and these are referred to as an ego-centered reference frame (ERF) and a world-centered reference frame (WRF). ERF's determine how a pilot orients himself relative to the surrounding environment and this reference frame is defined relative to a primary axis, the pilot's forward field of view. Landmarks or objects are defined to exist to the left/right, front/back, and above/below relative to the pilot. WRF's are usually established with a predetermined canonical orientation of north-up. Therefore, objects in the environment have an absolute, independent relationship in the world relative only to directional bearing (such as north, south, east, west).

The contrast between reference frames may be further exemplified in Figure 1. Here, the mountain peak is approximately 10 miles to the northwest of the lake. This relationship is permanent and it is independent of the pilot's view. However, the mountain peak may only be characterized as to the left (and more specifically at the 11 o'clock position) if and only if the pilot is flying along the depicted heading and course. The origin of the ERF is the pilot so while the pilot is constantly moving and changing, so are the ERF descriptions. Therefore matching the changing ERF with the non-changing WRF, to verify that the two are congruent, may be difficult.

Aretz (1991) and Battiste (1993) propose a model of navigation in which four cognitive operations are necessary to maintain geographical awareness via ERF-WRF comparisons. (1) Triangulation is the process where the geometries of the WRF and the ERF are established. This is done by comparing the pilot's forward field of view (ERF) with a map (WRF) and determining each reference's orientation. (2) Mental rotation then aligns these two frames of reference. (3) Image comparison then determines if in fact both reference frames are aligned. (4) Translation then monitors the ERF's position as it proceeds through the WRF.

Within the four step process, Aretz also speculates that two separate mental rotations are performed. A circular mental rotation parallel to the ground surface brings the WRF into a track-up alignment. Then a forward mental rotation translates the track-up information on the map into the forward field of view. This second process may be alternatively described as three dimensional "envisioning."

As described in the Aretz (1991) model, mental rotation plays an essential part in the discussion of ego and world-centered frames of reference. Several researchers have established that the time required for mental rotation is directly proportional to the angular disparity between two images to be compared. This finding holds true whether the images are two dimensional objects (Aretz & Wickens, 1992; Cooper, 1989), three dimensional objects (Shepard & Metzler, 1971; Barfield, Sandford, & Foley, 1988) or, in the case of navigation, a forward field of view with an ERF and a two dimensional WRF map view (Aretz, 1991; Evans & Pezdek, 1980; Sholl, 1987). Because time is required to carry out mental rotation, it is not surprising that judgements of ERF-WRF correspondence are facilitated when the map is physically rotated to a track-up orientation (Aretz, 1991). Hence the nature of map orientation (fixed versus rotated) may be anticipated to influence the quality of knowledge stored during a rehearsal flight, an issue we address in the current study.

Geographical Knowledge

While a discussion of ERF-WRF comparisons has focused most directly on comparing two visual stimuli, pilots can also be assisted in the ERF/WRF maintenance if they have accurate knowledge of the environment as well as an accurate physical map. It is this creation of knowledge that is, of course, the objective of rehearsal flights. It is generally accepted that the mental representation of this knowledge may consist of various types of geographic knowledge (Gluck, 1991). Thorndike (1980) proposed that 3 levels or stages of geographic knowledge are created as the navigator learns about a geographical environment. Landmark knowledge is the first stage of information to be acquired. Salient landmarks in the environment (such as large buildings, bridges, and lakes) are visually processed so that future recognition will aid in orienting oneself in a new and unlearned environment. This builds a foundation in memory which aids in the learning of Thorndike's second stage, route knowledge.

Route knowledge is used to navigate from one specifically known location to another. This knowledge is typically derived from direct navigational experience in the environment. A person has an internal "route list" which contains a sequential record of visually encoded landmarks to be used in a navigation task. Additionally, ego-referenced directional information (e.g., taking a left on First Street and then the second right after the bank) along the route of landmarks must also be known in order to successfully reach the next landmark on the route list. This information is usually first encoded by following a specific list of navigational or directional commands. A common example is following verbal or written directions to a particular, unfamiliar location. Thorndike and Hayes-Roth (1982), however, suggest that a person's route knowledge involves more than just knowing a particular list of landmarks and directions. Knowledge of the relative distance between two points, the angle of turns, and general terrain features along segments of the route are often encoded as well.

The building of a spatial data set in this fashion leads to the final level of spatial knowledge proposed by Thorndike (1980). Survey knowledge is described as a global understanding of the location of objects in the environment within a fixed world-referenced coordinate system, the interobject Euclidean (straight-line) distances, and the specific as well as the general features of a region. In essence, it is a culmination of many forms of landmark and route knowledge, but the difference is that exact positions are known relative to all others. This mental representation of spatial information has been described as a "cognitive map" (Tolman, 1948) which may be considered the mental analog of a traditional, physical map. Ideally, one can navigate and orient from this cognitive map equally as well as from a physical map. Williams and Wickens (1993) referred to this use of survey knowledge as functional survey knowledge. However, cognitive maps are sometimes distorted from their physical counterparts. Several studies have concluded that systematic distortions of geographical mental representations (or cognitive maps) do occur quite frequently (Battiste & Delzell, 1991; Chase & Chi, 1979; Stevens & Coupe, 1978; Tversky, 1991).

Thorndike and Hayes-Roth (1982) conducted an experiment which tested how the different types of spatial knowledge are derived from different sources. Subjects were assigned to either a map study or navigation condition. The map study condition required learning the floor plan of the Rand Corporation building until the subjects were able to draw a map of the floor plan without error. The map study subjects did not have any previous experience in the building. The navigation subjects acquired knowledge of locations within the building solely through direct navigational experience (i.e. walking). This group's navigational experience in the building was limited to either 1-2, 6-12, or 12-24 months. These subjects were not explicitly given map study experience, although there was nothing that would have prevented them from occasionally viewing a map of the building. Later, all subjects were then tested on a variety of spatial judgements. These included judgements of route distance, Euclidean distance, relative bearing (orientation) from an actual position or from an imagined position (simulated orientation), and indication of a relative position on an abstract map that contains only two reference points.

Generally, the investigators found that the type of learning (map study versus navigation) differentially influenced survey versus route knowledge learning early in practice, but not later. First, the map study group did perform better in judgments of Euclidean distance and object location than the low experienced navigation group. This was an intuitive finding since map learners acquire a "bird's eye" view of the environment and thus such global judgments would have been expected to be easier to perform. Conversely, the navigation group did better in judgments of route distance. This finding is also not surprising since the navigation group could mentally simulate past navigational experiences through the building while the map study group could only make estimates based on the bird's eye view. The navigation group also performed better on judgments of orientation bearing. Here, the investigators concluded that any difficulty in computing bearing by using knowledge of an indirect route (presumably learned by the navigation group) was outweighed by the more difficult task of mentally rotating a map representation (learned by the map study group) in order to compute bearing.

Secondly, the most experienced navigation group performed as well as or better than the map study groups on all tasks. This indicates that direct navigational experience eventually produces a superior cognitive map. Even when map study groups were given additional training they did not significantly improve on judgments of route knowledge. This lack of improvement suggests that there is a limit of spatial knowledge to be obtained from map study. Also, navigational experience would seem to be essential if the best results are required. There is a cost with navigational experience however. Thorndike and Hayes-Roth (1982) found that this process takes a long time to produce the superior cognitive map. The subjects with the highest navigational experience had between 1 and 2 years where as the map study subjects reproduced the map in approximately 20 minutes.

Evans and Pezdek (1980) found similar results in an investigation which map study subjects took longer to make correct judgements of orientation than did subjects who only had an active navigational experience. These results provided strong evidence that active experience in the environment may lead to a superior form of survey knowledge than would otherwise be gained from map study. The active subjects demonstrated that their "functional" survey knowledge may be used to make spatial judgments from several different perspectives, without suffering in speed or accuracy.

A study by Hirtle and Hudson (1991) evaluated the route and survey knowledge of subjects who had passive exposure to an environment or exposure only from map study. Passive group subjects were shown a 6 minute slide presentation of a route taken through an actual town while map study subjects studied a map with a route clearly marked. After the exposure, both the passive and map study subjects had demonstrated equivalent, and fairly accurate, judgements of route distance. However, the passive group had significantly poorer performance on judgements of straight line distance and landmark orientation. Hirtle and

Hudson concluded that the map study subjects acquired better survey knowledge than did the passive subjects while both groups developed equivalent forms of route knowledge. The results of this study clearly indicate that passive exposure to the environment without reference to a map may not provide the essential aspects necessary for accurate judgements of spatial relations. This is not surprising since the "cognitive geometry" needed to perform such judgements (from only a single passive route exposure) requires very complex calculations.

Another study which tested the effects of active and passive exposures to the environment was conducted by Gale, Golledge, Pellegrino, and Doherty (1990). Subjects between the ages of 9 and 12 years were exposed to two neighborhoods by either actively walking through the neighborhoods or by watching a videotape of an active subject's exposure. All subjects were later evaluated on scene recognition using photographs, a map drawing test, and an actual neighborhood navigation test. The results indicated that both active and passive subjects performed equally as well on the recognition and map drawing tests. However, the navigation test of a particular route revealed that the active subjects, with just a single exposure to the neighborhood, performed much better that the passive subjects who received five videotape exposures. Gale et al. suggested that these results could have been accounted for by two reasons. First, the active groups were required to make decisions and then produce the necessary motor responses in order to accurately navigate along the desired route while the passive subjects did not have any "decisions" to make. Also, the active subjects had a panoramic field of view along the route, while the passive subjects were restricted to a more limited the forward field of view presented by the videotape. These two explanations may have afforded the active group with a greater acquisition of route knowledge than was otherwise obtained by the passive subjects.

The studies described above have all involved ground navigation. Two studies with a greater degree of direct relevance to the current research, because they simulated airborne flight, were conducted by Terrell (1990) and Aretz (1991).

Terrell (1990) compared different forms of navigational training received by U.S. Army navigators. The control group received the standard, in-flight navigation training normally administered while another group received a new video/computer-based instruction called Map Interpretation and Terrain Analysis Course (MITAC). The MITAC program provided navigators with video footage of an actual NOE flight while the navigators tracked the flight's progress with a hand held map. The video occasionally stopped and identified useful landmarks as well as tested navigators judgements of current position within the environment. This allowed the navigators to match the video footage (an ERF) with the map (a WRF) without the burden of time constraints characteristic of an actual NOE flight. Both groups were later given an in-flight navigational test in an unpracticed and unfamiliar region. The results indicated that the MITAC groups made significantly fewer navigational errors than did the control group. Terrell concluded that the video/computer-based training (a passive exposure) improved navigational performance over the groups who received in-flight navigational training (an active exposure). However their research did not fully generalize to the rehearsal flight scenario, since the region in which subjects were tested, was different from that in which they were trained. That is, they were studying the acquisition of general navigational skills, rather than specific geographical knowledge.

Aretz (1991) also contrasted active with passive exposure to an environment as subjects actively controlled or passively watched a flight simulation through a computer-generated environment. Spatial knowledge was assessed by having subjects indicate a direction to a landmark, determining if a particular forward field of view (ERF) matched a particular position on a map (WRF), and by drawing a map of the experienced environment. The two groups differed only on the map drawing task. The passive groups seemed to produce better maps of the environment (measuring survey knowledge) than did the active groups. Aretz suggested that the active role of controlling the flight simulation (maintaining altitude and heading) may have overburdened limited spatial resources needed for navigating, and therefore the passive subjects were able to devote all of their spatial resources to learning the environment.

Obviously, a key component distinguishing map study knowledge from active or passive exposure is the reference frame by which the geographic information is learned, processed, and stored, and we have seen that the ability to integrate geographic information based on WRF and ERF's is a crucial aspect of geographical awareness. Previously mentioned research in this field suggests that there are unique differences between ERF's and WRF's (Aretz, 1991). Thorndike and Hayes-Roth (1982) made a similar suggestion that people operate off of different reference frames depending on how spatial information is originally encoded. Therefore, certain navigational tasks may be easier to perform depending on which type of reference frame is utilized. The results from the Thorndike (1980) and Evans and Pezdek (1980) studies indicate that both active and passive exposure to an environment (an ERF exposure) provides better survey knowledge than does map study. Several other studies (Aretz, 1991; Gale, Golledge, Pellegrino, & Doherty, 1990; Hirtle & Hudson, 1991; Terrell, 1990) concluded that passive exposure may be better than active exposure for the acquisition of survey knowledge.

Rehearsal Flight Research

While the research described above addresses the effectiveness of different features of navigational training, in the acquisition of different components of navigational knowledge and skill, none of these studies explicitly examined the benefits of rehearsal flights in transferring to more operational flight environments. A review of the literature suggests that this area has benefitted from little systematic studying. A preliminary study by the U.S. Air Force (Martin & Lidderdale, 1983) explored the use of rehearsal flight simulations of the F-16 aircraft. Experienced fighter pilots were briefed and they prepared for two attack plans using standard, non-rehearsal preparation techniques. These pilots later flew their planned combat attacks using a rehearsal flight system instead of actual aircraft and data from these flights indicated that several rehearsal attack flights improved the success of these missions.

Martin (1993) stated that many of the pilot recommendations for improving the rehearsal system were used in a more advanced rehearsal system, implemented in a study by Nullimeyer, Bruce, Conquest, and Reed (1992). There investigators hypothesized that the addition of flight rehearsal, to the mission preparation process, would enhance the performance and success of an actual attack mission. A rehearsal flight trainer, simulating an MH-53 helicopter, was used in conjunction with the efforts of many specialists (such as weather, intelligence, communication, and weapons) for mission preparation. Pilots reported that an especially useful option used during the mission rehearsal was the capability to "freeze" and then "slew" the simulation in order to study the attack scenario from many different perspectives without the time pressures of flight. Following the preparation process, 10 pilots flew their actual helicopters on a night attack mission. Post mission debriefing, analysis, and pilot reports indicated that the addition of the rehearsal system was effective in improving their actual performance relative to past experiences without such rehearsals, thereby testifying to the potential benefits of rehearsal flights. However, it is important to realize that these conclusions were based upon subjective data rather than actual performance measures. Furthermore, since there was no control group that flew the transfer flight without the benefit of rehearsal flight, it was impossible to validate the true value of the latter in developing route knowledge for rehearsal flight. While these studies demonstrate an interest in rehearsal flight systems, they do not clearly establish the effectiveness of rehearsal flights for the purposes of promoting route or survey knowledge.

As we have noted, none of the research on geographical representation of knowledge specifically examined a navigation flight transfer task. While the U.S. Air Force research did use such a task, it did not systematically vary the features of training (active/passive/map study) in such a way as to allow conclusions to be drawn regarding which of these are most important. Only a study by Williams and Wickens (1993) has coupled both of these elements, as well as the topics in the previously reviewed material, in the context of a rehearsal flight scenario. Since this study set the foundation for the current experiment, it will be described in some detail.

In Williams and Wickens (1993), subjects (all current pilots) were placed into three environmental exposure groups which were classified as either map study, active, or passive rehearsal. Map study subjects were given 30 minutes to specifically learn the route and region depicted on the map. The other subjects either "actively" controlled a rehearsal flight of the depicted route or "passively" watched a replay of an active subjects' rehearsal flight. These rehearsal flight groups were further differentiated by two levels of scene detail (high or low) simulated by the rehearsal flight. After subjects participated in learning the route and region, they were transferred to a very high fidelity simulator (simulating environmental aspects of a real flight) and they were examined on their ability to fly the same route, again with use of the same map. The map was not constantly available, but it could be illuminated at the subjects' discretion.

Horizontal and vertical tracking errors, recorded during the transfer flight, indicated that there was a significant effect of the type of initial exposure. Further analysis indicated that the active subjects navigated more accurately than did the passive subjects, while the map study subjects did not significantly differ from either of the rehearsal flight groups. Also, the level of scene detail did not appear to influence the performance of either the active or passive subjects.

At the end of the transfer flight, all subjects were challenged to fly back to the initial starting point when they reached (what they thought would be) the last point on the depicted route (a test of functional survey knowledge). Analysis of this performance did not indicate any significant difference between any of the groups. After the transfer flight, all subjects were then requested to reconstruct the map used during the previous sessions. The maps were later scored by two measures. A Landmark score was composed of the sum of landmarks placed in their correct, relative position and a Mapscore was composed the Landmark score divided by the mean bearing error of the landmarks' true location. Map study subjects were found to have significantly higher Landmark scores compared to the other groups. However, the Mapscore measure did not differ significantly between any of the groups. Williams and Wickens observed that while the map study subjects did well on both of the map reconstruction scores (a typical assessment of survey knowledge), they were no more successful than the other groups in applying this knowledge in order to fly back to the initial starting point (a measure of functional survey knowledge). They also concluded that the ability to reconstruct the maps (a measure of survey knowledge) may be independent of the ability the accurately navigate along the route (a measure of route knowledge).

The results of the Williams and Wickens (1993) study were both informative and provocative, suggesting that simple map study could provide just as effective route knowledge and more effective survey knowledge, as the more expensive computer-based training methods. The results also suggested that "traditional" methods of assessing survey knowledge (map drawing), do not necessarily assess the ability of that survey knowledge to solve functional navigation problems. The present study was designed to replicate many of the aspects of Williams and Wickens research, but also to specifically address two potential shortcomings in their methodology. First, in the Williams and Wickens study, all subjects had ready assess to the map during the transfer flight. This might have "diluted" differences between groups, providing the two rehearsal groups with additional access to survey knowledge. Second, no control was exerted to ensure that the map study group actually devoted the same effort to study the route and region, as did the rehearsal flight groups. An equivalent period of time (30 minutes) was made available for all three groups, but they were not specifically instructed to use it all. Finally, Williams and Wickens' final measure of functional survey knowledge (accuracy of returning to the starting point) did not fully capture all aspects of this task. The experiment reported here uses essentially the same procedure as the Williams and Wickens study, but addresses these three shortcomings. In addition, the time allocated for geographical learning (by map study or rehearsal flight) was shortened from 30 minutes to 20 minutes, a change that has some important implications.

In the present experiment, subjects (all of whom were private pilots) were again divided into three groups and tasked to learn a predetermined navigational route, very similar to the route used in the previous study. The subjects were exposed to the navigational route either through a 20 minute map study session, an "active" rehearsal flight simulation with the assistance of a hand held map, or a "passive" viewing of a replay of an active subject's rehearsal flight, also with the use of the map. Unlike the procedure employed in the Williams and Wickens study, active and passive groups were directed to use the map (in the rehearsal flight) either in a north-up or a track-up fashion. Previous research has indicated that the use of a north-up as opposed to a track-up map yields more accurate map reconstructions (a measure of survey knowledge). Also, subjects in the map study group were explicitly exhorted to use their full 20 minutes for studying and envisioning the terrain.

Following training, all subjects were later challenged to fly the exact same route, as prescribed earlier on the map, but without the use of the map. This transfer flight was flown on the high fidelity E&S visual simulator. Williams and Wickens (1993) suggested that such a test without the use of a map might provide a "pure assessment" of route and survey knowledge promoted by different training exposures of an environment. Only a short list of the turn points along the route was available. This task of flying the route without the map was assumed to provide a measure of subjects' acquired route knowledge. At the end of the entire route, subjects were challenged to fly back to the original starting point via the most direct flight path (an unplanned and unrehearsed event), thus measuring functional survey knowledge. After the transfer flight test, subjects were asked to reconstruct the map of the entire region solely from memory, providing a measure of survey knowledge.

Method

Subjects

Thirty pilots were paid $5.00 per hour for a single three hour experimental session. Of the 30 subjects, 26 were males and 4 were females. Flying experience ranged from 60 to 1500 total flight hours with a mean and median of 199 and 111 hours, respectively. All subjects had a minimum of a private pilot's license with a single engine type rating. These subjects flying experience can be further classified as follows: 6 subjects were active certified flight instructors, 6 subjects were instrument rated pilots all actively pursuing an instructor license, and 18 subjects were actively pursuing an instrument rating. All subjects also had current medical certificates and were screened for corrected/uncorrected vision of 20/20 or better. Subjects were also current with respect to flying experience (see FAA's Federal Aviation Regulation Part 67 for a further explanation).

Apparatus and Stimuli

A two axis Flightstick brand joystick was used by subjects to control several flight simulations throughout the entire experimental session. Subjects manipulated the joystick to control the pitch and angle of bank, thereby directly controlling altitude and heading respectively. Yaw and thrust were not readily controllable but were automatically set by the computer simulation. The joystick was mounted to the right arm of the subjects' chair.

The joystick was used in conjunction with 2 different flight simulators. The first simulator used was a Silicon Graphics IRIS 4D-70GT workstation with a 1280 x 1024 pixel color monitor. The monitor's screen measured 34.4 cm horizontally by 27.5 cm vertically. When viewed from the seating distance of 110.0 cm, a 17.4 x 14.0 visual angle (VA) resulted. The minimum screen update for simulations on the IRIS was approximately 5 Hz. The IRIS depicted three flight variables of attitude, altitude, and heading. An attitude indicator was presented in the form of a head-up display or HUD. The HUD displayed normal attitude symbology, of a fixed aircraft symbol with a rotating artificial horizon and pitch ladder, in the center of the screen. An altitude indicator was presented vertically along the right portion of the display. A moving arrow was used with a fixed analog scale, measuring 0 feet on the bottom to 200 feet on the top. Altitudes of 140 through 160 feet were highlighted. Altitudes above 200 feet were illustrated by the pointer disappearing and altitude appearing digitally at the top of the scale. A heading indicator was presented digitally, in the bottom right portion of the computer screen. All IRIS flight simulations approximated a ground speed of 115 knots. In addition to the instrument depictions, the IRIS also depicted the "visual contact" scene of the world through which the subjects flew.

The other simulator used was an Evans & Sutherland (E&S) SPX 500T image generator and was employed for the transfer flight. Two Electrochrome ECP 3000 color projectors were powered by the

E&S and were used with two large projection screens, each measuring 304.8 x 228.6 cm. Both screens were joined at an angle of 115 degrees. One screen was placed directly in front of the subject, while the other was joined on the left side (see Figure 2). This provided subjects with a view spanning from 27 degrees right to 85 degrees left of centerline. This gave subjects a continuous viewing field of 112 x 38 degrees visual angle when viewed from the seating distance of 300 cm. This configuration was chosen because most of the required turns in the experiment were to the left and also because the simulated aircraft always crabbed to the left in the E&S conditions. The screen update for the E&S was 50 Hz. All E&S flight simulations approximated a ground speed of 85 knots. It is important to note that both simulation systems exhibited very similar flight control dynamics, in response to stick inputs.

In addition to differences in visual realism, a second difference between the two simulation systems was in the location of the flight instruments. As mentioned earlier, the IRIS presented the flight instruments on the same monitor that displayed the outside visual world. The E&S, however, presented only the outside world on the large projection screens. The same 3 flight instruments mentioned earlier were displayed on a separate monitor, directly located 90 cm in front of the subjects. This monitor was located beneath the view of the projection screens so that it did not block any view of the projection screens. This head-down type monitor was the same type used in the IRIS system for the rehearsal flight.

This experiment exposed subjects to two different geographic regions, created specifically for the purposes of this experiment. Both simulations systems were capable of presenting each of the two geographic regions. The first region was called the "warm-up region" and was so named because all subjects flew through this region to familiarize them to the control dynamics of the flight simulation used throughout the experiment. This region was also used to establish a baseline performance measure of subjects' simulator control ability.

The warmup region consisted of a single path appearing on the ground which was to be followed in the simulation. The path was a continuous course made up of 7 legs (see Figure 3). These legs were characterized into 3 categories:

- straight and level (legs 1 and 5)
- straight and hilly (legs 2, 3, and 6)
- curved and level (legs 4 and 7)

The second geographic area was called the Freemont region, and was named so after a small town located in the north-central portion of the region. The Freemont region is a square area of diverse terrain, measuring approximately 13.5 nautical miles on each side and was developed by Williams and Wickens (1993). A map of the region was used to initially expose subjects to the region (see Figure 4). The map was similar to the VFR aeronautical charts commonly used by pilots. The map measured 33 x 33 cm and was printed to a scale of 1:75618. A specific route was clearly marked on the map as well as many geographic landmarks. Topography was indicated by a scale of discrete color codes, which made mountain-like formations easily interpretable. The topography scale as well as a 1 nautical mile distance scale was printed on a section connected to the bottom of the Freemont map. When rendered on either the IRIS or the E&S simulation system, the features of the world appeared in a three dimensional perspective in either an abstract, or highly realistic form, respectively.

Procedure

Before the experimental procedure began, subjects read and signed an informed consent form. They also filled out a personal data form which asked for their name, age, sex, handedness (left/right), FAA flying license/type rating, total flying hours, and total cross-country flying hours.

Subjects were then placed into one of 10 cohorts, based on similar flight experience. Within each cohort, subjects were assigned to one of 3 experimental conditions known as active rehearsal, passive rehearsal, and map study. These conditions will be described shortly.

Next subjects were given a set of instructions. The experimenter read these instructions aloud while subjects followed along with their own set of instructions.

Spatial Ability Tests

Subjects were then given two spatial ability tests called the Surface Development and the Cube Comparison tests (Ekstrom, French, Harmon & Dermen, 1976). This session lasted approximately 20 minutes.

IRIS Warm-up Flight

Next subjects participated in the IRIS warm-up flight session which consisted of 3 flights in the warm-up region (see Figure 3). Subjects were told of their two goals in this session. They were to fly directly over the path depicted on the screen and to maintain an altitude of 150 feet above ground level (AGL). It was explained that the altitude indicator acted liked a radar altimeter, which measured altitude above the ground as opposed to above mean sea level (MSL). Subjects were also warned that the IRIS was very sensitive to abrupt stick inputs. The instructions stressed that the subjects should use small, smooth, and precise stick movements to avoid pilot induced oscillations (caused by abruptness).

The first IRIS warm-up flight lasted one minute and it exposed subjects to a portion of the warm-up region which was characterized as a level path with some turns. This was used to demonstrate the control dynamics and the visual flight information. The experimenter gave verbal feedback, relating to the subjects' initial performance, and reiterated the written instruction's advise.

The second IRIS warm-up flight covered the entire course in the warm-up region. This flight lasted approximately 9 minutes. At the end of the flight, the monitor presented vertical and horizontal RMS errors. This feedback was explained to subjects and it was used as a goal to improve performance. The third IRIS warm-up flight was identical to the second except that light turbulence was simulated.

Freemont Training Session

This was the only session that differed between the 3 experimental groups. The active group was told that they would perform a rehearsal flight in the Freemont region, which would be later tested on the E&S system. It was explained that a map of the Freemont region would be provided and that a specific route was clearly marked on the map (see Figure 4). Their job was to fly the most precise route by using both the map and also the "outside" landmarks depicted in the simulation. There was no path depicted on the ground as in the warm-up region so subjects were to use their pilotage navigation skills to complete the flight successfully, just as in real cross country flights. In addition to course precision, subjects were also told to maintain an altitude of 150 feet AGL at all times. It was further explained that they would be asked to fly the exact same route on a later E&S flight, except that the map of the Freemont region and route would not be available. Subjects were strongly urged to familiarize themselves with as many geographic landmarks as possible. They were told that this strategy could strongly aid their success on the E&S flight when they would not have the map available.

The map of the Freemont region and the depicted route were then thoroughly explained by the experimenter. While true course headings were printed on the map for each leg, the instructions stated that the memorization of such headings would not be a guarantee of successful course completion. The possibility of simulated winds aloft and turbulence were also mentioned. Again, it was stressed that the ability to maintain geographical awareness was heavily dependent on the subjects' ability to recognize many different landmarks throughout the route and region. While successful completion of the route was the primary goal, subjects were told to also process the entire region so that geographical awareness could be maintained in the event that they flew off the route's path. The entire experiment was briefly reviewed again. Any questions concerning the map or any task were answered.

The passive group was given very similar instructions except it was explained that they were going to view a replay of an active subject's rehearsal flight. The map was to be used in conjunction with viewing the replay in order to learn essential details of the route and region. The ensuing E&S flight without the map was fully explained as well.

After either active or passive subjects were fully briefed, subjects were each shown a 2 minute simulation on the IRIS that exposed them to many different aspects of the Freemont environment. This short simulation showed all of the symbols (such as bridges, towers, mountains, and lakes) that might be encountered throughout the region on their respective rehearsal flights. When the simulation ended, it was explained that it was just an artificial sample of landmarks (arbitrarily placed along the flight path) and that it was not part of the Freemont region. Active and passive subjects were then given 1 minute to study the map before their rehearsal flight began. The rehearsal flights lasted approximately 20 minutes. Within each cohort, the rehearsal flight path flown by the active subject was digitally stored and then replayed for the passive subject.

Both active and passive subjects were further directed to use the map in either a fixed north-up or rotating track-up fashion. Cohorts were balanced so that there were an equal number of combinations of the 2 factors (rehearsal type/map orientation) within each level of relative flight experience. Out of the 10 subjects per rehearsal group, 5 subjects were instructed to use a track-up map orientation and 5 were to use a north-up orientation throughout the rehearsal flight session.

The third experimental group was the map study group. Again, very similar instructions were presented so that this group was informed of the same future task of flying without the map on the E&S simulator. Through a pure map study session, they were to familiarize themselves with the same critical features mentioned earlier. A visualization technique was recommended in which subjects were told to try to "visualize" flying along each leg of the route. The entire route and region was stressed again. The map study subjects were given 21 minutes to study the map and they were encouraged to devote the full time to active study. This 21 minute time was derived in order to equal the 1 minute map study and the 20 minute rehearsal flight of the active and passive groups. All map study subjects reported that they made efficient use of the entire map study session.

E&S Warm-up Flight

After completion of the Freemont training session, all subjects were given a 10 minute break and then moved to another laboratory for the remainder of the experiment. The identical instructions were presented to all three groups for the next two sessions, which were flown on the E&S simulator. First, the E&S simulator was briefly introduced and the following differences between the E&S and IRIS simulations were discussed. The most apparent difference was that the E&S used 2 very large projection screens. Also, a head-down display was used for the flight instruments. The E&S flew at a ground speed of 85 knots, which was 30 knots slower than the IRIS simulations. The E&S had a much greater graphics capability therefore many features would appear more realistic. There was also a simulated haze, so that visibility was limited to 5 nautical miles, instead of an unlimited visibility as in the IRIS. The E&S would also have a direct left crosswind, varying from 6 to 8 knots. This crosswind did not come from a fixed world direction (such as from the north) but rather it came from a 90 degree angle based on the current direction of simulated flight. This created a constant crosswind and therefore the flight simulation required a crab in order to fly a straight, point to point course.

The warm-up flight on the E&S was in the same warm-up region as used earlier on the IRIS. The subjects were told that they would participate only in one warm-up flight and that this flight would be used for the same purposes of familiarization as on earlier flights. After the warm-up flight ended, feedback was again given. Performance on this flight was used to establish if all subjects entered the following transfer flight with approximately equivalent simulator control abilities. The E&S flight through the warm-up region lasted approximately 9 minutes.

E&S Transfer Flight

Instructions were given to brief all subjects on the final flight, the E&S evaluation (transfer) flight. The subjects were reminded that they would be challenged to fly the exact route depicted earlier, but without the aid of the Freemont map. However, a reference card listing all of the 7 turn points on the route was provided for the subjects to use throughout the evaluation flight (see Figure 5). These 7 points were also briefly reviewed. A few guidelines to follow were also explained. For instance, if subjects had realized that they flew off the desired course they were to do their best to reintercept the exact course depicted earlier and not to simply fly a direct route to the following turn point. Subjects were also briefed on the possibility of getting geographically disoriented or lost. This was discussed simply as a possibility and it was not represented to them as a "bad" event. If subjects were certain that they had become lost, they were to immediately inform the experimenter. In this case, the experimenter would then issue vectoring instructions to steer subjects back to the desired route. The subjects were told to verbally declare when they were able to continue on the route. If they continued to remain disoriented, the experimenter would continue to give directions to the subject until they were able to continue. Unknowing to the subject, the experimenter would record all pertinent information such as location, headings, length of disorientation, etc., which would be used for later analysis.

When subjects had nearly completed the entire route (i.e., nearing the end of leg 7 in Figure 4), they were told to perform a unexpected task of flying back to the initial point (IP). Once subjects were approximately 30 seconds from the final point (the lake), they were told to visualize the entire map of the region, where the final point (the lake) was located and where the initial point (IP) was located. In addition, subjects were told to do their best to quickly establish the correct relationship between the lake and the IP. Once subjects actually arrived at the lake, they were instructed to fly as directly as possible to the IP. Subjects were reminded, as they were flying, to use their heading indicator to aid them in flying in a particular direction. Any maneuvers, such as S turns and 360 degree turns, were allowed if deemed necessary. Finally, subjects were told that they had to navigate within a 1/4 nautical mile radius of the IP in order for the simulation to automatically stop. Subjects were allowed to end the simulation if they felt that they were not able to successfully arrive at the IP. The experimenter was also able to end the simulation and did so if a subject was about to fly off the edge of the simulated region. The total time to fly the route in the transfer task and the attempt to the IP lasted approximately 35 minutes.

Immediately after the simulation, subjects were moved to a desk and were told to reconstruct the map of the Freemont region. The reference card of the turnpoints was not available for use. A standard sheet of white paper, a pencil, and a large eraser were provided. The top of the paper had a small margin for the subjects name, while the bottom portion was sectioned off by a black line so as to form an 8 1/2 inch square area. Since the map of the Freemont region existed as a square, the same proportional area was given to the subjects. Subjects were asked to replicate every single detail from the Freemont map, including both the route and terrain features. Before subjects were allowed to start, they were informed of a potentially useful strategy to use while drawing the region. This strategy involved first sketching out the route on the back side of the paper. This would allow subjects to visually see if their first drawing of the route matched their memory of how the route actually existed. If they interpreted their route as being skewed or out of scale, subjects would then have the opportunity to make the necessary corrections on the front side of the paper. After the route was proper placed, the remainder of the landmarks could then be placed throughout the region. This strategy was utilized by 21 of the 30 subjects and it was reported to be very helpful.

The use of an eraser was highly encouraged as well, so that the representation of subjects' memory could be accurately recorded. Subjects were given 10 minutes for this task.

After the map reconstruction task was completed, subjects were then fully debriefed on their performance throughout the entire experiment.

Dependent Measures

Vertical and horizontal deviations scores were recorded for all flights in both the warm-up and Freemont regions. These error scores were in the form of root mean square error (RMSE) and mean absolute error (MAE). The horizontal or tracking error was measured from the ideal ground track while the vertical error was measured from the ideal altitude of 150 feet AGL. Both types of error scores were recorded for vertical and horizontal deviations and this data provided evidence for subjects' route knowledge.

The RMSE method has been traditionally used to measure error dispersion in tracking tasks (Kelly, 1969). However, the statistical assumptions (of a normal distribution with a mean of zero) of the RMSE method may not be suitable for the horizontal tracking scores in this experiment. This is because subjects tended to err generally to one side of any particular leg. In other words, subjects' flight path error was characteristic of being to one side of the desire route and not crossing back and forth over the ideal ground track. RMSE calculations also tend to inflate large error scores, such as the horizontal scores in this experiment. Given these circumstances, the MAE method was used to statistically analyze the horizontal error scores while the RMSE method was used for the vertical scores. These choices were consistent with the methods used by Williams and Wickens (1993).

Subjects' performance on the surprise challenge of flying back to the IP was recorded by a computer plot of subjects' actual flight path, relative to the lake and the IP (see Figure 6 for an example). The initial heading errors flown by subjects were figured by using a protractor to measure the angular disparity between subjects' initial heading and the correct heading and this data was used to provide evidence for subjects' functional survey knowledge.

Finally, subjects' survey knowledge was measured from their hand drawn depictions of the Freemont map. These maps were scored by several methods. Given that the hand drawn maps were somewhat distorted and not ideally constructed, two prominent features were identified to exist in all of the hand drawn maps. These features were identified as (1) the series of roads/oil storage tanks (actually existing in the north-central portion of the region) and (2) the saddle-shaped ridge formed between the two large mountains (actually existing in the south-central portion of the region). Both of these prominent features also had the route depicted through them. A transparent template having an equivalently proportioned route and selected landmarks was then used to match the two prominent features previously described. These two features on the hand drawn maps were aligned with their corresponding counterparts on the template and a newly defined north-south axis was defined. The angular disparity between the new (distorted) north-south axis and the actual north-south axis was measured. Furthermore, the template was accordingly fastened to the hand drawn maps in order to determine other measurements. The other measurements consisted of scores called Landmark, Placement, and Angle. The Landmark score was computed by the number of preselected landmarks actually drawn by a subject. A Placement score was calculated by the sum of the difference in distances between where landmarks were drawn and where their corresponding representation was located on the template. An Angle score was calculated by measuring the absolute angular disparity between where each of the 7 legs existed on the template and how these legs were drawn on the maps.

Results

During the experiment, there were certain circumstances that required the replacement of four subjects, and therefore a total of 34 subjects actually participated in the experimental process. These four subjects were replaced for the following reasons. First, equipment failures in the E&S system did not allow two subjects to complete the entire experiment. Secondly, two other subjects did not meet minimum pre-transfer flight criteria relating to simulator control and ability to navigate on the rehearsal flight. These two subjects were not able to successfully "control" the simulator on the IRIS warm-up flights. (Control was defined as being able to follow the depicted line in the warm-up region and not become totally disoriented from following the line.) Furthermore, the substandard simulator control abilities of these subjects influenced their performance on the following IRIS rehearsal flight so that these two subjects were not able to navigate on the IRIS rehearsal flight.

All results in the following analyses will be reported as significant, if in fact p values are less than .05. However, all p values less than or equal to .15 will be reported to insure that any "marginally" significant results effects are brought to the reader's attention.

Spatial Ability Tests

The scores for each of the two spatial ability tests were subjected to one-way ANOVA's to determine if any differences existed between the three training groups. The analysis of each test did not reveal any significant difference between the training groups.

E&S Warm-up Flight

In order to establish whether all groups entered the transfer flight with equal levels of simulator control ability, a two-way fixed effects ANOVA (3 levels of training group by 7 levels of leg) was performed on each of the horizontal and vertical error data sets (SAS Institute Inc., 1985). Both the horizontal MAE and vertical RMSE data used in the following analyses were transformed by a logarithmic based 10 function, in order to meet assumptions of normality. For the horizontal MAE, there was a significant main effect for leg ($F(6, 189) = 11.3$, $p < .001$), no main effect for training group, and no leg by training group interaction. The effect for leg was expected and similar to that observed by Williams and Wickens (1993) since the highest horizontal MAE occurred on the curved legs, which are more difficult to follow than the straight legs (see legs 4 and 7 on Figure 3).

The ANOVA performed on the vertical RMSE data showed a significant main effect for leg ($F(6, 184) = 33.0$, $p < .001$), no main effect for training group, and no leg by group interaction. The effect for leg was expected since the highest vertical RMSE occurred on the hilly legs (see legs 2, 3, and 6 on Figure 3). Due to a minor malfunction with the E&S system, some vertical error data for one subject (five of seven legs) was not included in the vertical RMSE ANOVA and was treated as missing values in the analysis.

The absence of significant effects or interactions involving training group, up to this point, indicates that all three training groups entered the transfer flight with essentially equal spatial ability and equal ability to control the E&S simulator. Hence subsequent differences can be more directly attributed to differences in training conditions.

E&S Transfer Flight

Out of the 30 subjects participating in the transfer flight, there were 8 times when a subject declared being lost or disoriented. These incidents occurred in each training group as follows: 4 active subjects, 3 passive subjects, and 1 map study subject. No subject was disoriented more than one time per flight. Of the seven subjects in the active and passive rehearsal training groups who became disoriented, six of those subjects had been trained in the north-up map condition.

In order to meet assumptions of normality, both the horizontal MAE and vertical RMSE data were transformed by a logarithmic based 10 function. Next, the horizontal MAE data were subjected to a two-way fixed effects ANOVA (3 levels of training group by 7 levels of leg) in order to assess how accurately the three training groups navigated along the route in the Freemont region. A graph of the group by leg horizontal MAE means is depicted in Figure 7. Both main effects of training group ($F(2, 189) = 4.6$, $p = .012$) and leg ($F(6, 189) = 3.9$, $p < .001$) were found to be significant. Additionally, there was a marginally significant interaction between training group and leg ($F(12, 189) = 1.6$, $p = .090$). The source of this interaction appears to be the generally greater variability of performance across legs experienced by the map study group, in contrast to the two rehearsal flight groups.

In order to determine the extent to which differences between pairs of training groups contributed to the overall effect on horizontal MAE, three separate two-way fixed effects ANOVAs (2 levels of training group by 7 levels of leg) were performed on the horizontal MAE data. These ANOVAs revealed that the map study group had significantly less horizontal MAE than the active group ($F(1, 126) = 8.3$, $p < .005$) and that the passive group had less horizontal MAE than the active group at a marginally significant level ($F(1, 126) = 3.4$, $p < .069$). (It should be noted that these tests were post hoc. If a more conservative adjustment of significance level were undertaken, the latter effect would be considered insignificant and hence it might be concluded that there were no differences in learning between passive and active rehearsal flights.) The two level ANOVA revealed no difference between map study and passive groups.

A two-way fixed effects ANOVA carried out on the vertical RMSE data did not reveal any significant main effect or interaction involving training group. However it did reveal a significant main effect for leg ($F(6, 189) = 21.4$, $p < .001$). This effect was predicted from the warm-up flight and was consistent with the results in Williams and Wickens' (1993) experiment. The legs which included mountains suffered the greatest vertical RMSE.

Since the independent variable of map orientation (north-up versus track-up) was only manipulated among the two rehearsal flight groups (active and passive), a three-way fixed effects ANOVA (2 levels of training group by 2 levels of orientation by 7 levels of leg) was performed on the horizontal MAE data for these two groups. This analysis revealed a significant interaction of training group by orientation ($\underline{F}(1, 112) = 4.0$, $\underline{p} = .048$) as well as a marginally significant main effect of group ($\underline{F}(1, 112) = 3.4$, $\underline{p} = .068$). This interaction is depicted in Figure 8, and reveals that the cost in lateral tracking performance for the active training group was experienced exclusively by those subjects who were requested to fly the rehearsal flights with their map held in a fixed, north-up orientation.

Last Leg Performance

Subjects' performance on flying the "surprise" last leg from the lake to the initial start point was analyzed from the data of the last leg plots. A typical plot of a subject's track following this request is shown in Figure 6. From these data plots, the absolute values of the angular disparities between subjects' initial headings and the ideal heading were calculated for each subject and these deviations were subjected to a one-way ANOVA. This analysis did not reveal a significant effect for type of training group. Next, a correlation was calculated between how subjects drew the last leg relationship on the hand drawn maps and the initial direction in which subjects actually flew the last leg (i.e., the vector calculated in Figure 6). This calculation resulted in a nonsignificant correlation coefficient of $\underline{r} = .13$.

<u>Map Reconstruction</u>

The hand drawn map reconstructions were graded on three separate scores of Landmark, Placement, and Angle. A single one-way ANOVA (3 levels of training group) was performed on each of the three map reconstruction scores. The first analysis was based upon the number of significant landmarks correctly placed which subjects in the rehearsal flight group could have seen within their forward field of view while navigating along the desired route. This analysis revealed a significant main effect of training group for Landmark score ($\underline{F}(2, 27) = 6.46$, $\underline{p} < .006$). In order to determine which groups differed significantly, a Bonferroni multiple comparison t-test was performed on the training group means. This test revealed that the map study group had a significantly larger Landmark score average of 18.0 than the active group average of 13.7 ($\underline{t}(.99, 25) = 2.57$, $\underline{p} < .05$). The average score of the passive group (15.9) fell in between the two other scores and did not significantly differ from either.

In order to assess the accuracy of placement of the landmarks that were drawn, it was first necessary to "orient" the subject drawn map to the frame of reference of the true map.

This was done by aligning the primary north-south axes of the maps. In order to make such an alignment, two prominent north and south features, universally common to all subject drawn maps, were identified to exist. These features were the vertical stretch of roads/oil tanks which intersects the route in the north central portion of the region, and the mountain pass crossing which the route traverses on the first leg in the south central region (see Figure 4). This alignment was accomplished by rotating a subject drawn map so that these two landmarks were aligned with the corresponding landmarks on the map template. Furthermore, the placement of the subject map along this defined axis was fixed so that these two prominent intersections were placed equidistantly apart from their counterparts on the map template. Once this alignment was established, the absolute distances between the drawn and true landmarks were calculated from the critical landmarks identified in the first analysis. The mean value of these distances was then computed for each subject, as the Placement score.

The second ANOVA revealed that the training groups differed significantly with respect to Placement score ($F(2, 25) = 5.0$, $p = .015$). A Bonferroni t-test indicated that the passive group Placement score error of 15.3 was significantly less than the active group error of 21.8 ($t(.99, 25) = 2.57$, $p < .05$). Also, a marginally significant difference existed between the map study group Placement score average of 17.2 and the active group average of 21.8 ($t(.98, 25)$, $p < .10$).

The third ANOVA, testing the Angle score, did not reveal significant differences between the training groups.

Discussion

The main purpose of this experiment was to evaluate the type and amount of geographic knowledge promoted by different training methods. The performance of groups receiving the three different training methods (map study, active rehearsal, and passive rehearsal flight) was measured on several transfer tasks, that were designed to assess route knowledge, survey knowledge, and the use of survey knowledge to solve functional navigation problems.

Pre-Transfer Flight Performance Measures

It was important to verify that the three training groups entered the transfer portion of the experiment with equal spatial ability and equal simulator control ability. These two assumptions were validated by the findings that there were no significant differences between training groups on either the two spatial ability tests or on the E&S warm-up flight.

Route Knowledge

The E&S transfer flight was used to assess the "pure" transfer of route knowledge which was promoted by each of the three training methods. The results revealed that the map study group performed significantly better than the active group and performed as well as the passive group, thereby reaffirming the real benefits of map study (specifically found in the Williams and Wickens, 1993, study). In fact, the benefits of map study compared to the other methods may have even been enhanced in the present experiment, relative to the findings of Williams and

Wickens. In their study the map training condition was no better than the active training condition in supporting route knowledge, whereas in the present study it was superior.

Two reasons may be offered for the improvement in map study performance observed here. First, the methodology employed in the current experiment allowed for a "pure assessment" of route knowledge in the transfer flight. Map access was not available during the transfer flight, whereas all training groups in the Williams and Wickens study had such access. Therefore those rehearsal flight training groups did not have to rely solely on their memory (geographic knowledge) in order to successfully navigate along the route. Those training groups were also aware of the map's future availability therefore they knew that they could simply reference the map throughout the transfer flight. The training groups in the current study, however, did not have any outside reference in order to confirm position on the route and within the region on the transfer flight, therefore these groups had no other option but to adequately learn the route during the training session. Without a perceptual representation of the region to refer to on occasion, their performance may have suffered accordingly.

A second explanation for the enhancement of the map study group's performance is based upon the increased motivational measures used to exhort subjects' effort to learn the route and region (as compared to the Williams and Wickens, 1993, study). In the training session of the present experiment, all three groups were repeatedly reminded of the absence of the map in the forthcoming transfer flight. These multiple "warnings" of the map's absence were specifically used to maximize the learning of the critical geographic aspects necessary for successfully navigating on the transfer flight, and in particular to encourage all subjects in the map study condition to take full advantage of the study time available to them. Corresponding instructions were not issued to the map study group in the Williams and Wickens study leading, perhaps to a selectively greater improvement in knowledge for this group in the current study.

The finding that the active group navigated more poorly than the other groups was surprising since Williams and Wickens (1993) found that the active group performed as well as or better than the two other groups. Two possible explanations are offered that may account for this reversal of findings between the two studies. First, the increased workload of a shorter flight duration (20 minutes as compared to 30 minutes to cover the same distance) may have hurt the active group more than the passive group. The task of navigating the route (with reference to the map) while actively flying at a faster speed and trying to hold a particular altitude may have exhausted valuable spatial resources of the active group, which are necessary to encode the geographical cues of route knowledge into memory. The passive group did not have to contend with this complex task and therefore could devote their full attention to learning the route. Williams and Wickens speculated that the added effort of active involvement in the environment (during their training session) required the investment of more effort by the active subjects than was required of their passive counterparts. Therefore such added effort was inferred to result in a more accurate mental representation of the region for the active group. However, the faster training flight (resulting in a shorter training session) in the present experiment may have overtaxed the spatial resources of the active group to the extent that their acquisition of route knowledge suffered. We speculate here that the detrimental effect of a shorter time (and therefore a faster flight) would only exert itself as a workload stressor on those subjects who were actually in the control loop, actively flying (i.e., the active group; not the passive nor map study group). The reduced "study time" for these latter two groups would have a less disruptive effect on learning, since it was not accompanied by the higher workload of a higher bandwidth flying task.

The second explanation as to why the active group performed more poorly in the present study is based on the fact that half of the subjects in the active group also had to mentally rotate the information from a fixed, north-up map while actively flying the rehearsal flight simulator. Figure 8 reveals that it was only this subset of the active subjects that was responsible for the poorer performance of the active group. The added spatial cognitive demands of mental rotation (Aretz, 1991) are assumed here to compete, both with the spatial demands of controlling the simulation flight and of storing in memory, the surrounding navigational features. This argument is further supported by the extent to which the rehearsal flight groups using a north-up map became lost during the transfer flight. Four of the five active training subjects who became lost, were using north-up maps during the training flight.

The analysis of the vertical RMSE data revealed no significant differences between the three training groups, indicating that there were no tradeoffs between horizontal tracking performance and vertical control accuracy. If, in fact the spatial resources of the active training groups were overburdened during the rehearsal training session (leading to a poorer acquisition of route knowledge), their subsequent altitude control performance on the transfer flight was not significantly affected.

In conclusion, the advantages of actively being "in the loop" may have not only been neutralized, but may have actually been reversed, by the excessive workload demands of controlling a fairly difficult rehearsal flight.

Survey Knowledge

As Thorndyke (1980) has described, survey knowledge is a global, map-like representation of the geographic properties of an environment. It is then reasonable to assume that people with the strongest survey knowledge should be able to accurately illustrate this knowledge by drawing a map of a particular environment.

Three scores were computed to compare the accuracy of subject drawn maps, and these data showed that the active group performed significant worse than either the map study group or the passive group, with respect to the Landmark and the Placement score. These results are only partially congruent with the findings in the Williams and Wickens (1993) study. In agreement with the current study, they found the map study group had better survey knowledge than the active group. However in contrast to the current study, Williams and Wickens found the passive group to show survey knowledge that was equivalent to that of the active subjects, and not to the map study subjects. Why the passive group subjects improved their performance here, compared to the Williams and Wickens study, is not immediately apparent.

The other significant difference in survey knowledge was found in the Placement score, which resulted in the active group exhibiting significantly larger landmark placement errors than the passive group. These results were again inconsistent with the findings of Williams and Wickens (1993) since they did not report any significant differences between these two training groups. The fact that the active group in the current study, again performed significantly worse on a measure of survey knowledge than one of the other groups may be attributed to the same phenomenon of spatial resource competition discussed previously. The map reconstruction data from Aretz (1991) supported the existence of a spatial resource competition between the acquisition of survey knowledge navigation and flight control demands. Such competition was used to explain his finding that a passive (autopilot) group correctly placed more landmarks on a recalled map than an active (manual control) group.

If, in fact, the active group in the current study was spatially overburdened during the rehearsal training session, they may not have been able to develop a strong survey knowledge of the environment. Their lack of survey knowledge may have been further hindered by their subsequent poor performance on the transfer flight (i.e., for those trained with a north-up map, getting lost more than other groups and poorest performance on navigating the route). It is reasonable to assume that the development of survey knowledge by the active group may have been disrupted by their attempts to keep oriented and navigate along the route in both the training condition and in the transfer flight. These difficulties would be far less pronounced for the other two groups, who did not encounter the competing demands of flying during training.

Williams and Wickens (1993) did draw the general conclusion that the map study group had acquired a stronger survey knowledge than both of the rehearsal flight groups. The results of Thorndyke and Hayes-Roth (1982) also supported that conclusion based upon the fact that the low time navigation groups were outperformed by the map study groups in survey knowledge judgments of straight line distance and object location. In the current study, while the map study group also performed better than both rehearsal flight groups in Landmark recall, the superiority over the passive group was not statistically significant. For the Placement error measure, the passive group actually performed slightly better. The reason for the overall improvement in survey knowledge for the passive training group, is not immediately apparent.

Functional Survey Knowledge

Williams and Wickens (1993) tested subjects' ability to apply their survey knowledge for the purposes of navigating on an unanticipated task. Their results were interesting in that the conditions (i.e., map study) that promoted good survey knowledge (map drawing) did not appear to be particularly effective in promoting the functional use of this knowledge. Furthermore, they found that neither of their different groups were very successful on this sort of navigational task. The present study tested subjects' performance on the same task (returning directly to the starting point of the flight), and measures of initial headings were compared between the three training groups. Consistent with the Williams and Wickens study were the findings that the three training groups did not significantly differ on this task, despite their differences in performance on the subsequent map drawing task. Additionally, the correlation between subjects' initial headings and their hand-drawn bearing relations to the initial point did not indicate a significant relationship. For example, if subjects depicted (from their map drawings) the lake-IP relationship with a correct bearing (080 degrees) or even an incorrect bearing (100 degrees), there was no evidence that subjects applied this correct (or incorrect) survey knowledge with any corresponding equivalency to the initial portion of the flying task. These results suggest that what may be considered subjects' "inferred" survey knowledge on the basis of their reconstructed map features, may be difficult to access and use in the solution of a navigation flying task.

Conclusions

The key finding in this study is that the active training group consistently performed more poorly than, or at least no better than either of the two other groups for every dependent measure. This finding generalizes the conclusion that the active training group acquired the weakest versions of route, survey, and possibly functional survey knowledge. Conversely, the value of map study was highlighted by poorer performance of the two rehearsal groups on certain measures of geographic knowledge assessment. Another interesting finding was that the passive group tended to fall in between the other two groups on many of these tasks. The potential benefits from "seeing" the three-dimensional aspects of a future flight's environment did not seem to outweigh the performance based on knowledge acquired from a two-dimensional map study session, particularly when this "seeing" process was coupled with continuous active flight control, and resource demanding mental map rotation.

If, indeed, spatial resources are in high demand for the rehearsal flight groups (specifically the active training group) then the question might be raised of how to properly alleviate this potential problem. One answer to this may be to simply decrease spatial workload during a rehearsal flight session. In terms of the present study, this might be accomplished by several methods. First, the flight speed can be decreased (as it was in the Williams and Wickens, 1993, study) such that rehearsal groups are less burdened when learning a particular route. Slowing down the speed for the active rehearsal flight group may allow more resources to be diverted from flying to learning of the route and region. A somewhat related option of reducing time was highlighted in the Martin and Lidderdale (1992) study where rehearsal flight pilots had the option to "freeze" and "slew" in the simulation.

A second remediation may be to reduce the demands of flight control skills of the active rehearsal flight group. For example, eliminating the need for altitude control will allow the active group to only have to make horizontal tracking inputs, thereby reducing the competition between spatial demands for flying, navigating, and route learning. A further reduction of flight control demands may be accomplished by having an "autopilot" option, which keeps the simulation flying along a programmed heading with active learner inputs only occurring at key "checkpoints" on the route. If the harmful effects of limited spatial demands in the active condition can be circumvented, then the potential benefits of "seeing" the environment and "actively" making navigational decisions may outweigh the benefits of other methods of passive viewing or map study preparation.

For applied purposes, these three training methods should not be considered to be an "all or none" decision for the uses of flight preparation. Although lacking experimental control, the U.S. Air Force studies (Martin & Lidderdale, 1983; Nullimeyer, Bruce, Conquest, & Reed, 1992) mentioned earlier, indicated that active rehearsal flights may be a beneficial addition to a thorough map study session. The current results have called attention to the critical role that navigational workload may play in inhibiting or neutralizing the value of those rehearsal flights.

The results of this study also have real theoretical implications for the understanding of how people, not only acquire geographic knowledge, but how they act upon such knowledge. The discrepancies between subjects' reported survey knowledge (through hand drawn maps) and how they used this knowledge can perhaps be explained by the spatial resource competition described earlier. In order to gain a more in-depth understanding of this apparent production problem, a future experiment should be designed such that the spatial demands are systematically varied to determine their influences.

However, the current methods in which survey knowledge is obtained (i.e., through hand drawn maps) may need to be re-evaluated or possibly replaced. Distortions existing in hand drawn maps from their true states have been clearly documented (Battiste & Delzell, 1991; Chase & Chi, 1979; Stevens & Coupe, 1978; Tversky, 1991). Maybe such a method is not appropriate for the measurement of survey knowledge. Also, there may exist significant differences between individual map drawing ability skills (i.e., manual dexterity differences) which can influence the "score" a hand drawn map would receive. Differences in individual renderings of a geographic environment may only be filtered out by the recruitment of large subject pools. If such distortions in hand drawn map can be clearly accounted for and possibly transposed, hand drawn maps may then be an efficient method of measuring one's survey knowledge.

Figures

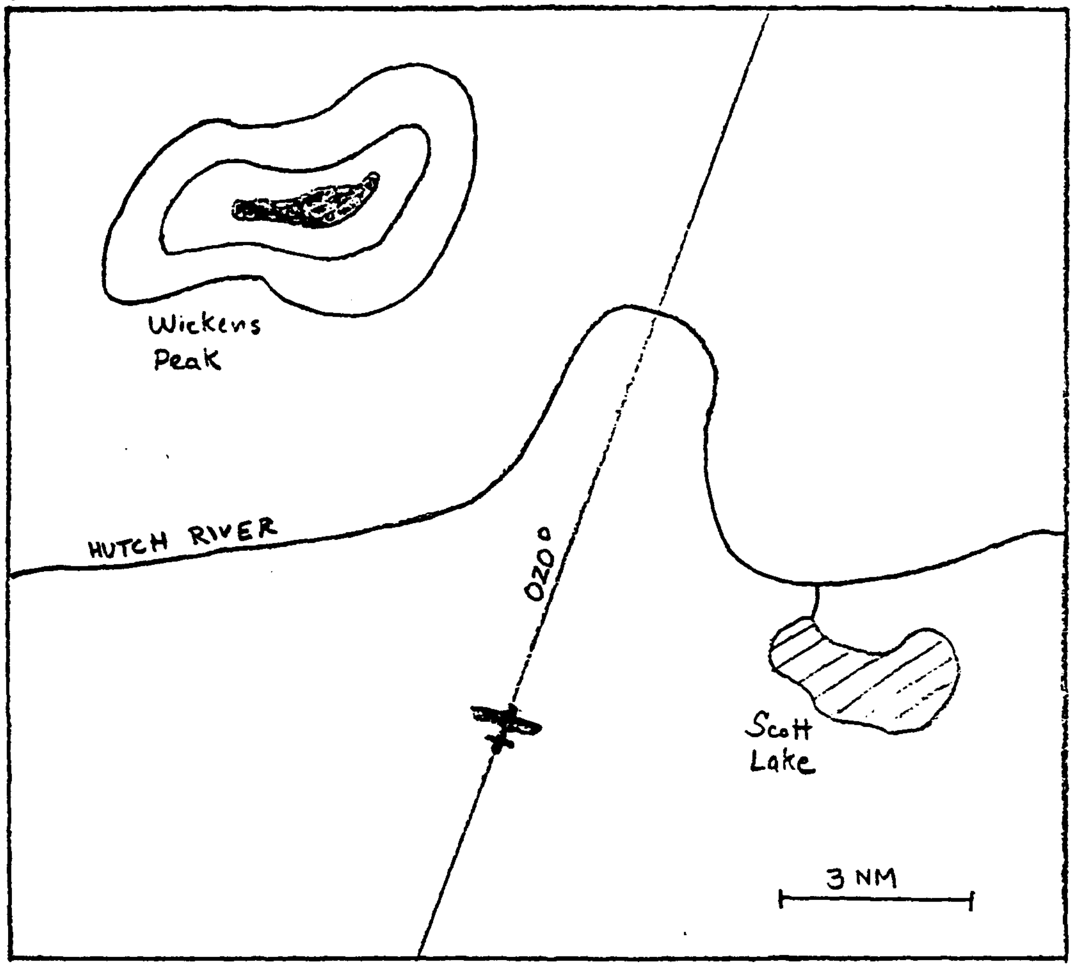

Figure 1. A fictitious map used to illustrate the method of navigation by pilotage.

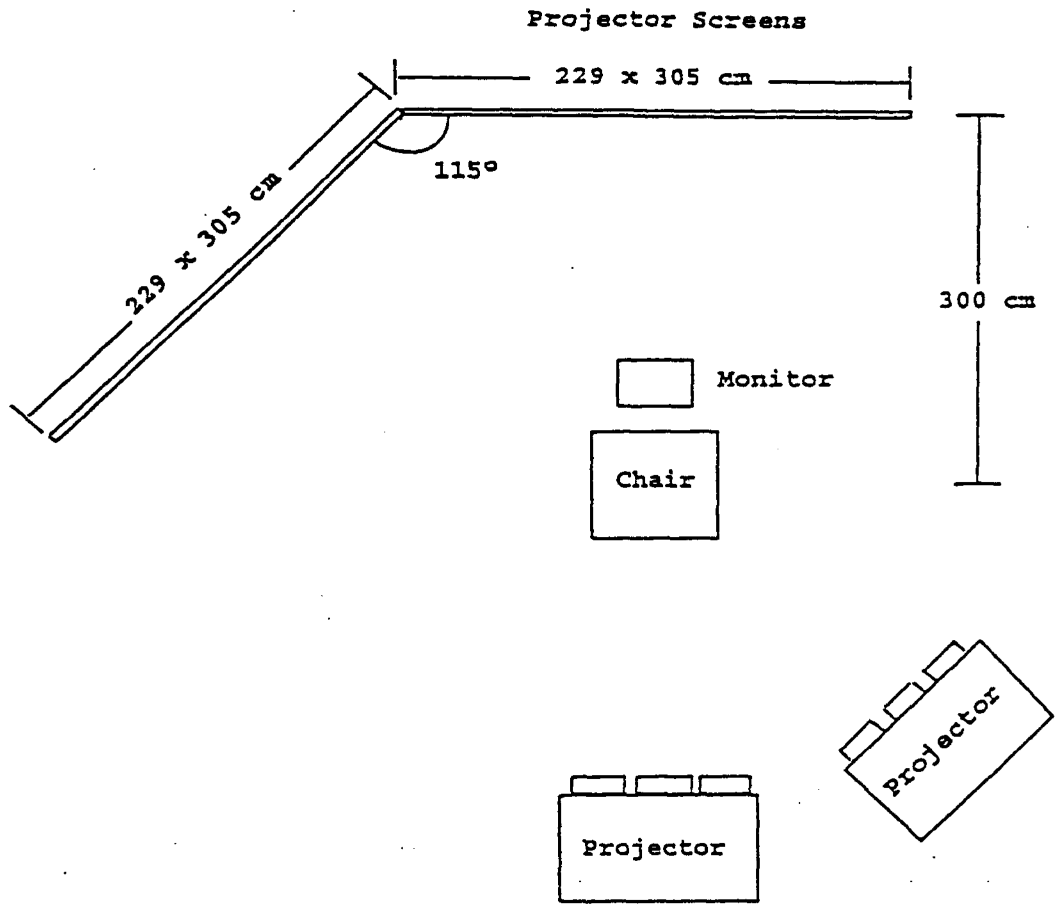

Figure 2. Floor plan drawing of the E&S simulator configuration.

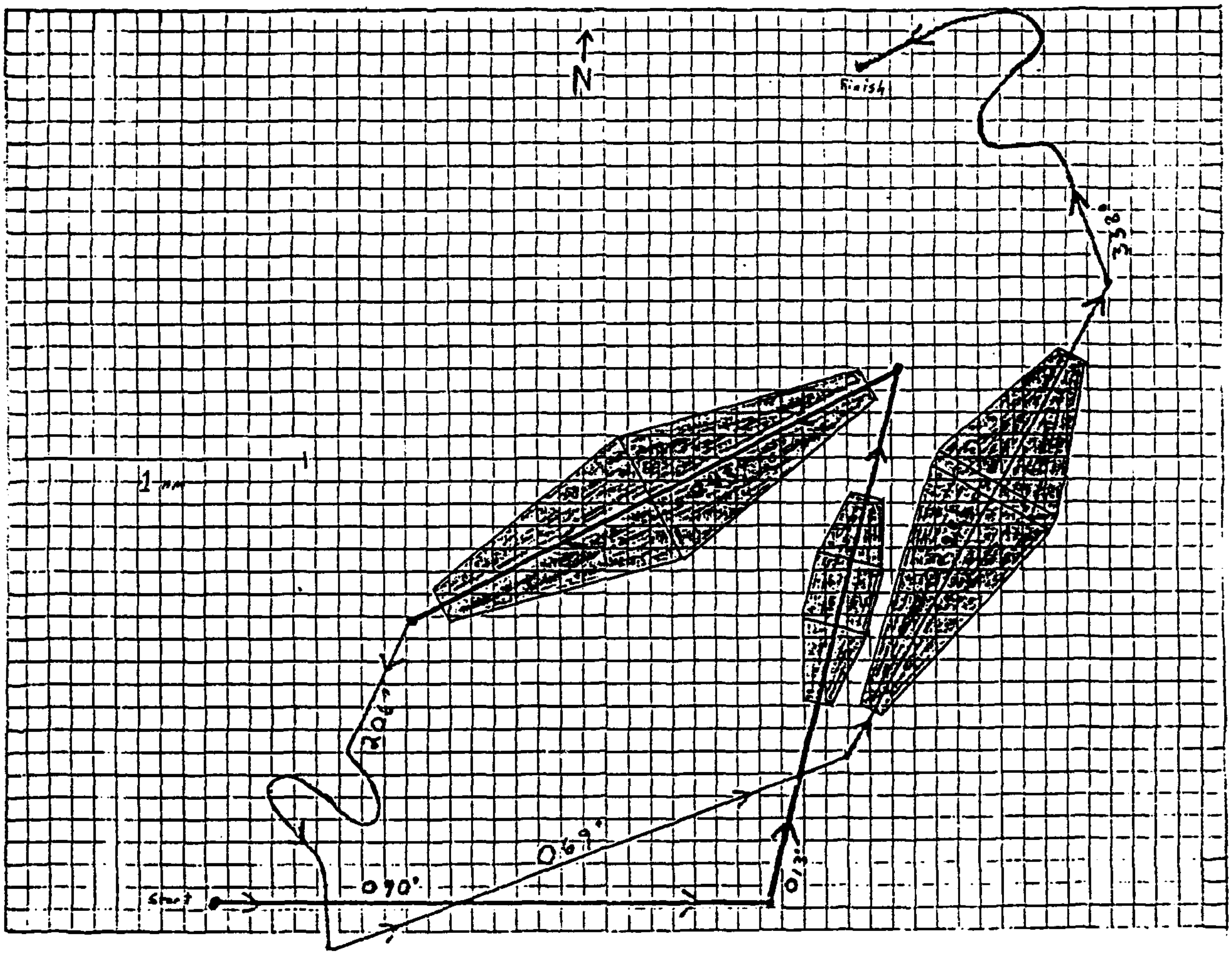

Figure 3. Map of the Warm-up region and route used on both simulators.

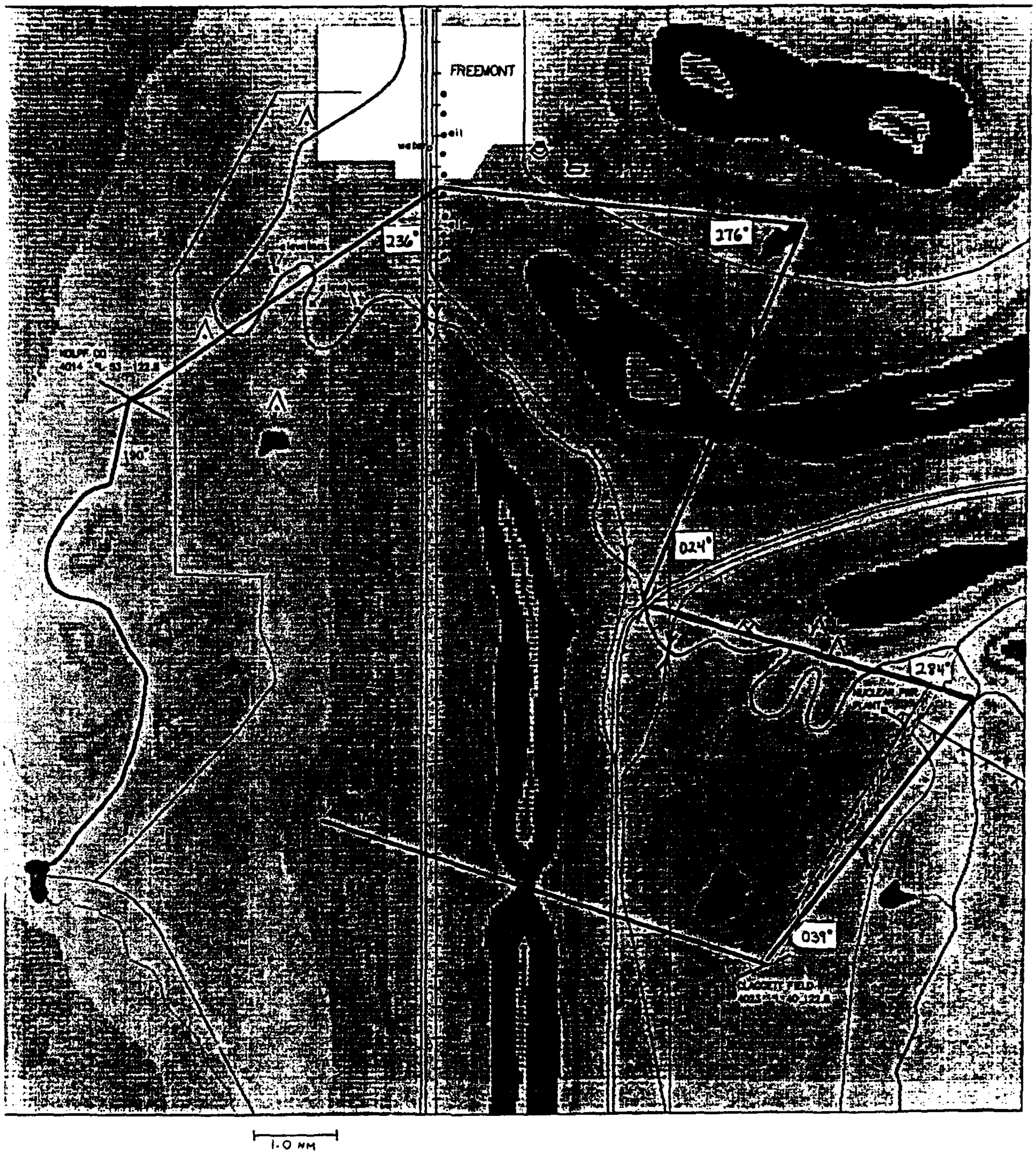

Figure 4. Map of the Freemont region and route.

FREEMONT ROUTE TURN POINTS

FROM INITIAL POINT (IP) TO:

1. **AIRSTRIP**
2. **RIVER INTERSECTION**
3. **BRIDGE**
4. **LAKE**
5. **OIL TANKS**
6. **AIRSTRIPS**
7. **LAKE**

Figure 5. Reference card of the route's turnpoints available during the E&S transfer flight.

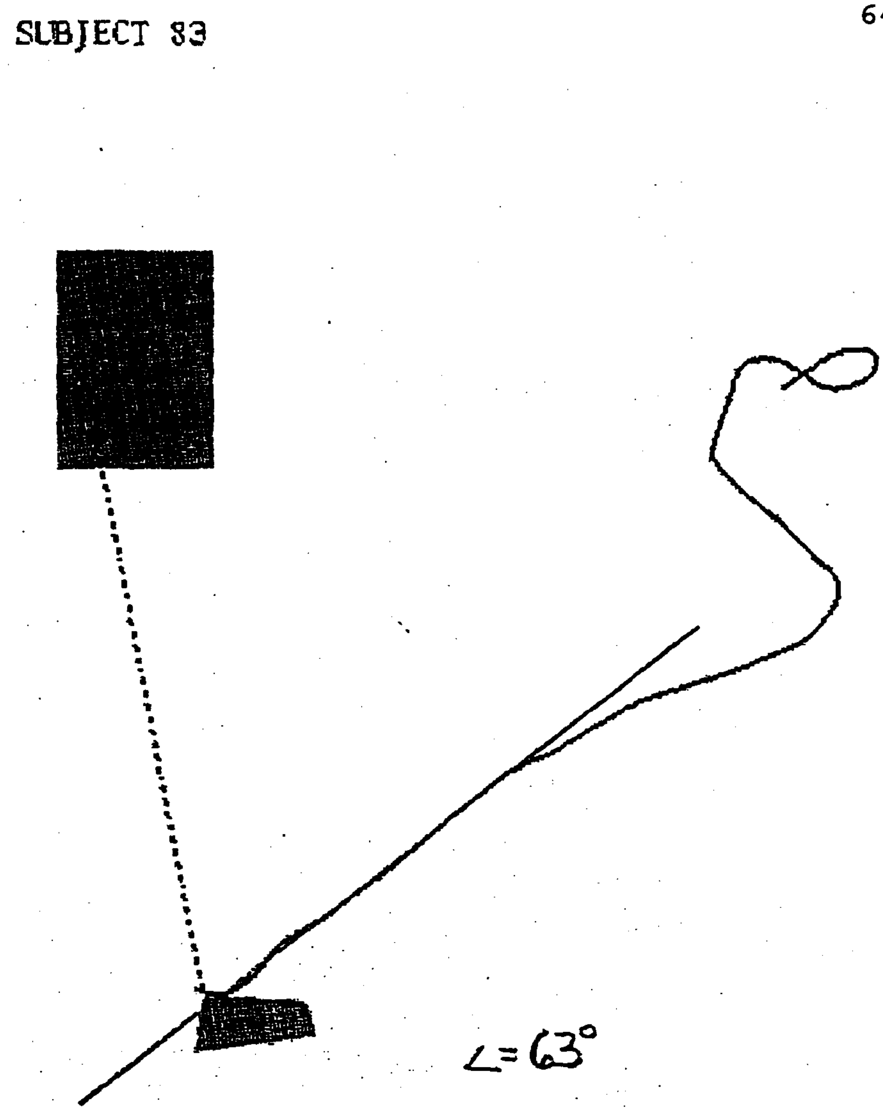

Figure 6. An example of a plot used to calculate the initial heading flown on a subject's last leg.

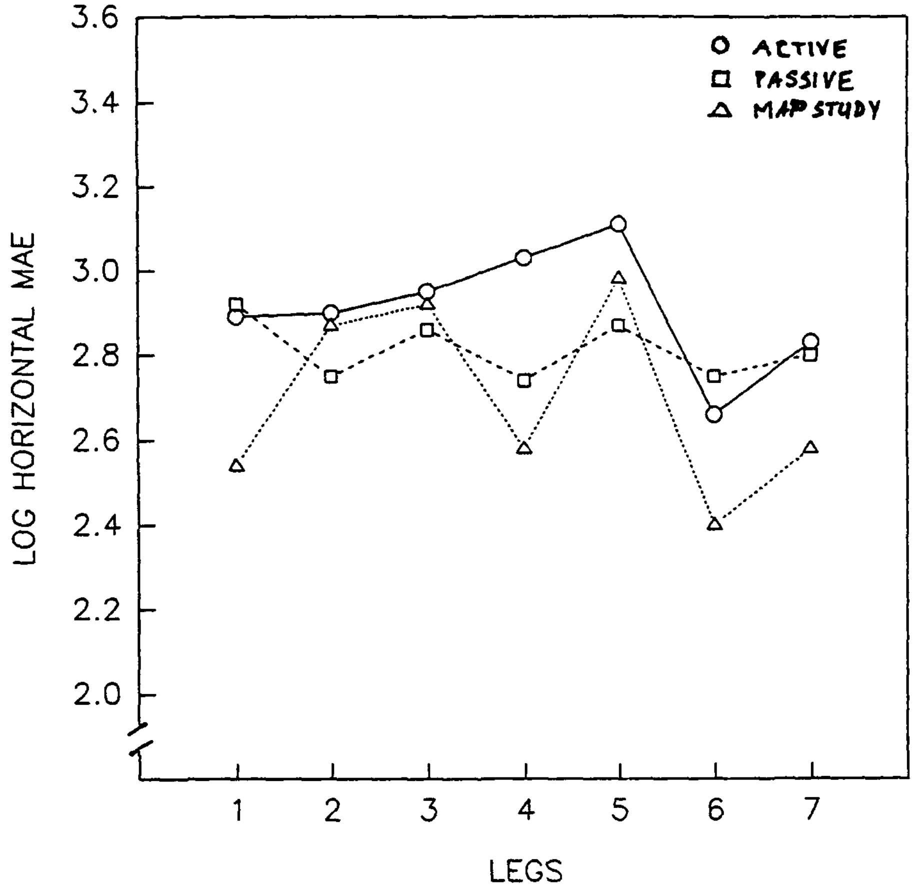

Figure 7. Mean log horizontal MAE as a function of leg for the three training groups on the transfer flight.

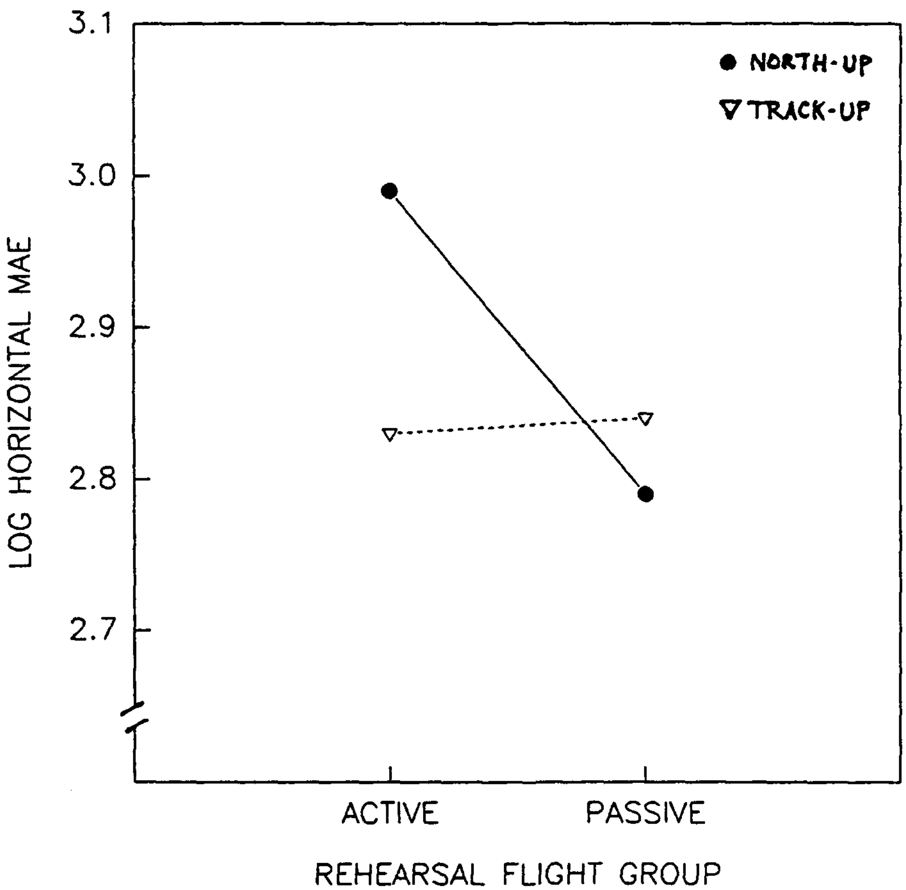

Figure 8. Mean log horizontal MAE as a function of map orientation used by the two rehearsal flight training groups on the transfer flight.

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