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THESIS

THE TRANSFER OF SPATIAL KNOWLEDGE FROM VIRTUAL TO NATURAL ENVIRONMENTS AS A FACTOR OF MAP REPRESENTATION AND EXPOSURE DURATION

by

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September 1999

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ABSTRACT ***(maximum 200 words)***

Terrain navigation is a critical skill in the military. Virtual environments (VEs) have been suggested as a possible tool in training spatial knowledge. However, little research has been conducted into the ability of VEs to impart spatial knowledge of a real world area.

This thesis research addresses the utility of VEs to impart spatial knowledge of a natural terrain area compared to traditional methods. Twenty subjects were divided into four training conditions in two experiments. The first experiment had a VE and map-only group and trained to a set standard rather than to a time. The second experiment also had a map-only and VE group, but trained one hour with a low fidelity map (1:24,000 scale as compared to 1:5,000 scale in earlier experiments). Measures were taken of landmark, route, and survey knowledge.

The results suggest that, (1) subjects who trained-to-standard using a VE demonstrated superior route and landmark knowledge to any other group, (2) spatial ability plays a significant role in navigation performance, and (3) adjusting the fidelity of the map causes individuals to adjust their planned routes to the information that is provided. Furthermore, while good-map reading does not guarantee success, poor map reading skills invite failure. Finally, if time is limited, a detailed map is preferable to other methods.

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THE TRANSFER OF SPATIAL KNOWLEDGE FROM VIRTUAL TO NATURAL ENVIRONMENTS AS A FACTOR OF MAP REPRESENTATION AND EXPOSURE DURATION

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requirements for the degree of

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I. INTRODUCTION

A. PROBLEM STATEMENT

This thesis will attempt to answer a simple question: What is the value added (if any) of using a virtual environment (VE) as an augmentation to map study for terrain familiarization. The thesis will analyze and compare an individual's acquisition of spatial knowledge from a high-fidelity virtual representation of a specific area to those trained with traditional map techniques (See Chapter III Training). The research intends to investigate unexplained questions from earlier research and to study the validity of using virtual environments to acquire spatial knowledge of an area of real world terrain. If proved valid, future research could investigate the optimal level of fidelity, optimal level of immersion, and optimal interface control devices maximizing knowledge acquisition. If disproved, efforts in this area would be better focused on other types of tasks.

B. MOTIVATION

1. Army and DOD Relevance

The Department of Defense (DOD) is actively looking for ways to train personnel while conserving precious dollars and improving safety and performance. Many of DOD's explorations have involved Computer Based Trainers (CBTs). Virtual environment trainers and simulators have proven successful for combat aircraft simulators [ANGI 93][CRAN 93] and armored vehicle crews [BOLD 85][BROW 88]. They may also prove a useful technique for dismounted soldiers for both training and mission rehearsal. Such a system is hoped to give soldiers performing a mission better situational awareness.

General William Hartzog, commander of Training Command described situational awareness on the battlefield to be: Knowing where you are, knowing the location of friendly forces, and knowing the location of enemy forces. Critical to knowing where you are is knowledge of the ground around you [BANK 97]. This mirrors the advice of Sun Tzu some two thousand years before: "We are not fit to lead an Army on the march unless we are familiar with the face of the country - it's mountains and forests, its pitfalls and precipices, its marshes and swamps [SUN 83]." Any system that allows soldiers to better know an area before walking the ground for the first time would greatly influence operations. The Army's doctrine states that terrain is clearly not neutral in any conflict. The terrain provides an advantage to the side that better understands the features, advantages, and limitations of a given area and plans accordingly [FM10 93]. But as the American Army changes from a forward deployed force to a power projection one [CJCS 98], soldiers and leaders are afforded less opportunity to train or maneuver on the ground they may later have to fight over. By virtue of the enhanced movement ability in computer environments, individuals may be able to explore more of an area in a VE than if actually walking the ground. This would allow soldiers to train faster than before in some cases through time-compressed training. It may also allow them to become familiar with an area before actually arriving there in person. A VE would also allow users to train in areas that may not be accessible due to hostile forces or prohibitive travel costs. This is not to suppose that VEs could entirely replace real world ground training. No VE in the near future can replicate desert training down to the sand in your boots. The best VEs and simulators *augment* real world training, they do not replace it [SCHW 86][GATE 87][BROW 88].

One foundation of military forces is conducting rehearsals prior to performing a mission. The military has a long history of creating mockups as part of these rehearsals [GLIN 95] [MCRA 95] [FINN 97] [AMER 98]. These aids may be as simple as some circles drawn in the dirt to elaborate buildings and structures built for some missions. The one thing the military has not been able to do is make the terrain at the rehearsal site accurately match that found at the mission site. VEs may provide a cost-effective way of doing just that. While they would not replace the need for actual building models, they can allow soldiers to better prepare for the ground around target areas. As a mission rehearsal tool, they would allow soldiers to rehearse their movement to and from the target area, and perhaps explore alternative routes to ensure the optimal selection.

However, just because a training tool involves a computer, this does not automatically make in better than alternatives [KEAR 83]. Unlike the Army's Simulation Networking (SIMNET) program [SCHW 86][BROW 88] [BURN 90] [ANGI 93], there has been little research published or conducted into the ability of VEs to impart spatial knowledge of an area. The Air Force recently used VE systems in Kosovo to conduct mission rehearsal in a system strictly designed to give terrain awareness [THOM 99]. While this may seem useful based on "common sense," research has largely not validated the concept. If soldiers and pilots train and prepare more effectively (as defined by better task performance) with maps than with VEs, then it is a waste of time and resources to develop such systems for this purpose. Even if performance is better, the gain may not outweigh the increased cost in time and money such a system imposes. Another potential pitfall is the lack of an ideal interface to train dismounted soldiers. While vehicles confine soldiers to the vehicle's limitations, individual soldiers are much more flexible in their actions. VE researchers have yet to build an interface that allows the soldier to crawl, walk, and run through a computer environment as naturally as he can in the real one [DARK 97]. This lack of ideal interface has not precluded the inclusion of dismounted soldiers in models however [GOUR 99].

VEs may not be useful in all the ways proponents envision. They may not prove useful as mission rehearsal tools, or as route rehearsal tools. They may not assist in acquiring spatial knowledge of an area. They might not even be useful as a tool to teach general navigation skills. As with any computer training aid, they may not actually be any better than the methods currently in use [KEAR 83]. Without knowing the effects of computer training, both positive and negative, the Army cannot make accurate decisions on their implementation within the force. With today's declining budgets, the Armed Forces can ill-afford to waste money on hunches or intuition.

Before actually spending money to contract for such a system, it is critical to understand the desired effects and actual achievable benefits derivable from VE training systems. Without this, it is impossible to create an accurate set of parameters for the models. By doing this research, the Army can determine if such a system is beneficial and for what purposes (area familiarization, route rehearsal, mission rehearsal, or general land navigation training). It will help prevent the wasting of time and money on potentially expensive yet unproductive systems that do not achieve the desired benefit. It will also provide a common set of standards which the Army, civilian contractors, and programmers can consult during the development of such systems.

2. Important Applications for Spatial Knowledge Acquisition

A wide range of jobs and activities rely upon spatial knowledge acquisition. Most people would readily recognize the need for emergency personnel to use spatial knowledge to pick the quickest route to arrive at the scene of an accident. People easily see the requirements of police, firemen, and paramedics to possess this type of knowledge. Another good example is cab drivers using their knowledge to avoid delays. Some of the most mundane tasks also require this skill; finding specific items in a supermarket, for example, or in a stadium, locating the nearest restroom and then finding your seat again.

The military, more than most, relies heavily on spatial knowledge acquisition. Soldiers and other military services use their knowledge of the environment to assist them in accomplishing their mission, be that to attack, retreat, defend, or just observe [GOER 98b]. This requirement is not limited to foot soldiers. As seen recently in the Kosovo air war, pilots too need accurate knowledge of their operating environment to successfully accomplish their task in a safe and efficient manner.

In short, any activity that requires movement through space or through complex environments does in fact require spatial knowledge acquisition. These can be military or civilian but they are pervasive throughout our lives.

3. Spatial Knowledge Acquisition as a Proven Concept

Researchers have extensively studied spatial knowledge acquisition because it is such a prevalent and important requirement throughout the scope of human activity. The most accepted model of human ability to acquire detailed spatial knowledge is provided by Thorndyke who created a simplified model to explain the process [THOR 80](see Chapter II Spatial Knowledge Acquisition). Since we know that humans can acquire spatial knowledge about real world areas, researchers next studied if humans could do the same with VEs [GILL 97] [RUDD 98]. Following this, they also examined if this spatial knowledge could be transferred from the VE to the real world area [WITM 95] [BLIS 97]

[DARK 98] [WALL 98]. Because this concept was proven for VEs in general and the transfer from VE to the real world in man-made indoor environments, it was natural to next explore if this previous research holds valid when moved to natural unstructured outdoor environments.

4. Existing Research Shortcomings

While Chapter II discusses much of the existing background research for the thesis, several points are highlighted here. Many problems exist with current CBTs because there is a lack of research to back up their purpose. There is little proof that using certain CBTs is any better, if not worse, than current techniques. Furthermore, where there is proof, it is often the cost savings, not the benefit gain that is the advantage. For example, only about 59% of tasks trained in a flight simulator carry over into the real world, but at 10% of the cost of operating the actual plane [ANGI 93]. Many groups seem eager to jump onto the technology bandwagon and do not first see whether using the CBT results in "better" task performance. Users should justify any shift towards CBT in terms of cost or performance gain.

As computer-processing power has improved, so too has the achievable level of fidelity in VEs. They can be more accurate and more realistic looking than in past years. There has been much effort spent on increasing fidelity in the models, but little research to show how this increased fidelity affects performance. Determining the optimal level of fidelity will be critical for building future VEs that are efficient for training skills. More research into the area of fidelity is needed.

Because the study of transfer of spatial knowledge from VEs to the real world is relatively new, there are many questions remaining unanswered. The most important is how to maximize the transfer. In an ideal case, if a person performs the task in a VE, it would have the same learning affect as if he did it in the real world. Questions as to the ideal interface, display, fidelity, and movement within the virtual environment remain unanswered. VEs provide the user with the ability to do things impossible in the real world (e.g. travel at any speed, fly, and teleportation) but the most effective combination of these tools is unknown. Do these tools aid learning, or are they distractions? Finally, there is a lack of research extending the transfer of spatial knowledge from VEs to the real world in natural environments. This thesis intends to address that issue.

C. THESIS ORGANIZATION

The thesis is organized as follows: Chapter II provides background of the military's use of simulations, spatial knowledge acquisition, learning techniques, previous studies on the use of VEs, and the work of prior students that this thesis builds upon. Chapter III discusses the VE that MAJ Simon Goerger developed and used in this thesis' experiments. It also presents the details of all the tests, tools, and methods used in the two experiments. This section also discusses the two different experiments conducted as part of the thesis and their respective methodologies. Chapter IV analyzes the data collected from the two experiments and discusses the results. It also compares the results to the original Goerger experiment. Chapter V compares the findings of the two experiments and the original Goerger study, discusses their impact, and lays out future areas of interest for follow-on research.

The thesis includes numerous appendices that show the maps, participant instructions, and experiment's timelines. Information concerning route difficulties and common land navigational terms are also included as appendices. In addition the raw data from the experiments is included.

II. BACKGROUND AND PREVIOUS WORK

A. THE MILITARY AND MODELS/SIMULATIONS

1. Historical use of Simulations for Training

The military use of wargames or other simulations for training is only slightly younger than the history of organized warfare itself. Archeologists have discovered groups of miniature Sumerian soldiers in formation, as well as later Egyptian units [PATR 77]. While these may indeed have started as mere toys for the nobility, at some point the play with these soldiers became stylized, evolving into games such as Go and Chess. While the value of Chess as a direct simulation has obviously faded far in the past, the spirit lives on. In 1780, Helwig created the first wargame to expand beyond the set "chess-style" boundaries. It included 1666 squares representing different terrain, and players had 120 units per side, including cavalry, forts, and artillery.

In 1811, Herr Von Reisswitz did away with the idea of a game board entirely, introducing a game played on a sand table, where terrain matched a map at 1:2373 scale. His son later transformed the game to maps at 1:8,000 scale and in 1824 introduced it to then Chief of Staff of the Prussian Army General Von Muffling, calling it Kriegspiel (war play). After the demonstration, Von Muffling, who had been unenthusiastic before, exclaimed "It is not a game at all, it's training for war! I shall recommend it most emphatically to the whole army [PATR 77]." One of the major evolvements of the Reisswitz wargame was the use of umpires. These neutral parties were used to provide fog-of-war and resolve disputes. Wargames became even more popular in Prussia under Von Molke. After the stunning German victories in 1870, many nations rushed to include wargaming into their training programs as well. The Japanese in particular credit their victory in the Russo-Japanese war of 1904 in part to their wargaming.

Within the United States, the military first picked up on wargaming in 1867 and by 1882 the American Army produced it's own wargame, *The American Kriegspiel, A Game for Practicing the Art of War Upon a Topographical Map*. Later the American Army moved to force-on-force engagements that were more involved than the staff room training STX/CTXs (situational training exercises/combat training exercises). Here units maneuvered, dug in, and actually did everything but shoot. Historical events such as the Louisiana Maneuvers prior to World War II and the military's annual REFORGER exercises in the 1970/1980's are of this type. The US Army even developed a manual for its umpires, FM105-5 Maneuver Control, to standardize rules about casualties, advance rates, etc. One problem with this system is that often the training would break down into "I shot you, no you didn't" disagreements more reminiscent of children playing than an army training.

With the progress of technology, especially the introduction of the MILES (Multiple Integrated Laser Engagement System) system, the Army was able to remove the umpire from direct involvement in actual engagement training. This made the training more realistic and solved the "I shot you" problem. Now, the sensors determine if a hit was scored or not. It allowed for better training at night where before the umpires had been hampered. Different laser signatures were used for different weapons so that a rifle could not destroy a tank. The rise of SIMNET (see Section A.3) allowed the fighting to be removed from the field and into computers.

Currently, the US Army defines three different types of models and simulations that support training: live, constructive, and virtual. *Live simulations* are those that involve personnel and vehicles in the field. These may involve umpires or the MILES system to assist in results [DMSO 93]. *Constructive simulations* hearken back to the original wargames, and are used in staff planning and training exercises. They are useful in simulating large conflicts across a region, often involving the entire theater [DMSO 93]. Currently the Army uses such systems for its BCTP (Battle Command Training Program) and its WARFIGHTER exercises (evaluation exercises for Divisional Staffs). The final classification of simulation is *Virtual*. The SIMNET and Close Combat Tactical Trainer (CCTT) programs fall into this category (see Section A.3).

Why do units conduct simulations? General Gorman, the former commander 8th Infantry Division, said "The first battle of most wars fought by the Army of the United States was a disaster: a costly defeat or a Pyrrhic victory." [GORM 90] He added that simulations that can be rehearsed repeatedly to increase combat readiness, refine combat skills, and protect the force before actual combat are invaluable. The goal is to impart combat experience without the actual dangers of combat. In studies of real combat results, inexperienced soldiers and pilots suffered higher causality rates, but as they became more experienced, their survivability improved. The use of simulations for training can have dramatic impact upon battlefield results. For example, during the Vietnam War, one US fighter was lost for every two North Vietnamese fighters. This ratio improved to 12.5 to 1 after the Navy implemented its TOP GUN program, which was an engagement simulation [GORM 90]. The best reason behind using simulations is that "The bottom line is it prepares us to be the best we can." [BELC 99]

2. Model Usage for Mission Planing and Preparation

Throughout military history, forces have incorporated detailed rehearsals into their preparation for coming battles. The US Army's Ranger Handbook, the bible of its infantry forces, states "They [rehearsals] are essential to ensure complete coordination and subordinate understanding." The handbook adds that they should be conducted in an area as similar to the objective as possible. The rehearsals should include brief-backs over sand tables, or sketches [RHB 95]. While many of these rehearsals may involve merely simple checklists, or talk-through of the planned battle, others are more detailed. These may involve the use of sand tables, map-boards, dioramas, simple dirt maps, or even elaborate mock-ups, to better picture the terrain, as well as the individual unit's locations in time and space. For many operations, the military would actually build a life size model of the target so units could practice moving about the ground. This was what the Israeli Army did in its preparation for the Entebbe airport raid. They laid out the terminal using metal poles and burlap for walls to exact dimensions [MCRA 95]. The troops were also shown video footage of the terminal area (taken from a soldier's personal vacation footage).

Similar missions did not always have similar preparation time but always included at least some form of rehearsal. Consider the US Ranger raid on Cabanatuan in January 1945 in the Philippines in WWII and the Son Tay raid during the Vietnam War. The rangers liberating the Philippines had crude dirt-maps and sand table briefings conducted at patrol bases within gunshot of the enemy. They had less than three days to prepare their mission and much of that time was spent near the prison camp some 70 miles behind enemy lines. Despite this, their final preparations involved briefing all soldiers over the camp layout and objectives based on the most recently scouted information. The forces raiding Son Tay trained extensively for months on elaborate mock-ups [MCRA 95]. The entire complex was replicated in exacting detail for rehearsals, as well as all other aspects.

During World War II, the Army Air Corps prepared its pilots for air raid missions over Japan by showing them films of the precise routes they would be flying over enemy territory. These films were not produced from satellite imagery or over flights by American reconnaissance aircraft. Instead, the films were produced by the Air Corps film and production unit stationed in Hollywood, California [AMER 98]. The production unit built a model of Japan using over fifty ten foot square platforms, tons of plywood, modeling clay, burlap, and paint. Using reconnaissance photos of the island, crews worked twenty-four hours a day for weeks, expending thousands of man-hours, to construct and paint an exacting replica of the island so that camera crews could film bombing routes for pilots. In order to maintain security, the model was built and filmed entirely on a single sound stage that was placed off limits to everyone except the personnel working on the project. Pilots routinely commented on how easy it was to recognize the terrain as they flew their missions because it was as if they had been there before.

Many of the models used in recent military operations came from the CIA's Modeling Shop [FINN97]. This group specializes in creating detailed replicas of various sites and structures. They helped in the Son Tay raid in 1970, and made replicas of the US Embassy in Iran and the Kremlin in Moscow. The hours and expense in making these models was immense but considered valuable based on the requirement for detailed exposure to the environment prior to the mission. However, these models, in all their detail, lacked the ability to actually walk into the structure and move around. The Modeling Shop shifted to making computer generated models in 1997 [FINN 97].

3. The Military and VEs

The current military is smaller than at any time since WWII and has shifted from a forward-deployed force to a power projection one [DMSO 93]. The reduction in size and shift in missions has forced the military to change its training and doctrine. The military has become very interested in using simulations and VE in particular to augment traditional training.

As stated above, the military had always found simulations useful, but the advent of VEs allowed them to take advantage of the new technology. Among the first systems built were single vehicle trainers. Flight simulators were developed to allow pilots to train at a fraction of the cost of actually flying jets. The Army developed the UCOFT system (Unit Conduct of Fire Trainer), which was designed to train tank crews in gunnery operations. The fact that the UCOFT provided improvements in gunner proficiency was seen as validation of the use of simulators for non-aerial vehicles [BOLD 85].

The Army places great emphasis on training as combined arms or "training as we fight"[FM25 88]. While single vehicle simulators worked, the military fights as units and teams, so the military was looking for systems that would allow these groups to be brought together for collective training. Networking simulators were the result of Defense Advanced Research Project's Agency (DARPA) sponsored technology demonstration projects [DMSO 93] and were the obvious answer to the collective training problem. Among the products were those for the Army's tank and infantry fighting vehicle (SIMNET). Later systems were added for A-10s and attack helicopters. These systems brought the individual vehicle simulators into one virtual world and allowed them to maneuver together in real-time. This allowed the units to practice together in the simulators making them much more useful.

The Army's latest development is the Close Combat Tactical Trainer (CCTT). Using high fidelity manned modules, it represents combat between armored vehicles and dismounted infantry. The system is not designed to be an individual skills trainer [DMSO 93], rather one that trains teams, platoons, and companies. The goal of the system is to allow the platoon through task force/battalion level to train on collective tasks cheaper and more safely than they can in the field [GOUR 99]. While not designed to replace field training, it will be used to augment it, as training dollars become short. The envisioned advantage over the current SIMNET system is a much higher fidelity level, allowing for the inclusion of realistic smoke, noise, and debris effects [DMSO 93]. This will make the training more realistic and follow the guidance of FM25-100 *Training the Force*, which says all training should strive to be as realistic as possible [FM25 88]. The goal is that use of this system, while saving money, will not reduce the realistic training conditions. Note that the DOD has no evidence that the inclusion of these effects will result in better transfer of task learning, nor in increased performance. This follow-on to SIMNET is hoped to be fully functional by 2003.

Another system of note currently in use is the Topscene system. " Topscene is an aircraft simulation using real-time and real imagery to conduct mission planning, mission rehearsal, and pilot training"[DMSO 93]. The system's primary use has been in visualizing threat radiuses, planning egress routes, and terrain masking. It is not a combat simulation but more of a planning simulation. Recently, pilots in Kosovo used TOPSCENE during the conflict prior to conducting their missions [THOM 99]. While there is no statistical data to back their opinions up, pilots say it helps them identify landmarks and assists in mission rehearsal [THOM 99].

B. SPATIAL KNOWLEDGE ACQUISITION

Spatial knowledge or spatial cognition is a mental representation of a real or virtual environment [WICK 92]. Thorndyke theorized that there were three levels of spatial knowledge: Landmark, Route, and Survey Knowledge [THOR 80].

Landmark knowledge is defined as being able to recognize distinctive features or locations located at a specific location in an area. Landmark knowledge is the ability to memorize features in an environment, such as specific hills, road intersections, or buildings. Later, this knowledge is able to be recalled allowing individuals to quickly recognize the feature or location when they see it. Landmark knowledge is most often acquired by direct exposure to an environment, though it is also possible to gain it through study of a map or photograph of the area. Individuals successfully demonstrate landmark knowledge by their ability to recognize distinct locations or unique objects within an area [DARK 95] [THOR 80]. Figure 2.1 shows an example of an individual with landmarks knowledge of an area. The subject would recognize that the area has three distinct features X, Y, and Z and will recognize these features if he sees them. The subject would not necessarily know any information concerning the relative positions of these features.

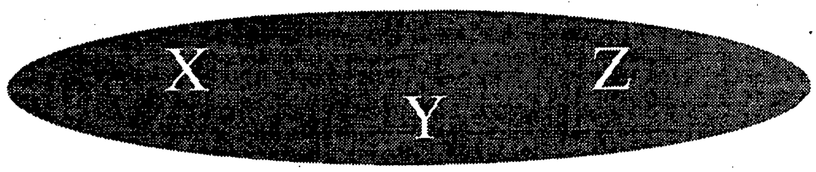

Figure 2.1. Landmark Knowledge

Route knowledge is identified as the ability to navigate along a route or path between landmarks or distant locations [GOLL 91]. It expands the recognizing of specific areas from landmark knowledge into a more complex arrangement of linking those areas by a path or route. Route knowledge is derived from an *egocentric* (inside-out) viewpoint and is characterized by being able to move from one landmark to the next following a prescribed path. Like landmark knowledge, route knowledge is gained through repeated exposure to an environment or through the study of a map or overhead photograph. The exposure to a video route of the environment has also been shown to develop this knowledge [GOLD 82]. This was also shown during WWII by the Army Air Corps' produced "films" of bomber routes over Japan. The pilots credited these films, which showed the pilots the routes they would follow on their attack, with making it easy to confirm they were in the right place. The fact that these films were not of the actual mainland but were created from an extensive model had no effect on the results [AMER98]. Figure 2.2 shows an example of an individual with route knowledge of an area. The subject not only has knowledge of certain landmarks and distinctive features (X, Y, and Z), but they also have the knowledge to traverse from one landmark to another along at least one set path (the route from X to Y and then to Z).

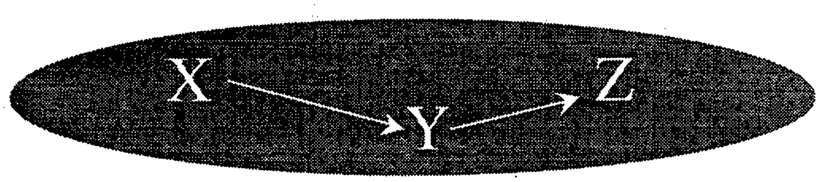

Figure 2.2. Route Knowledge

Route Knowledge does not necessarily confer the ability to conduct the reverse of the learned route, nor does it mean they may know of alternate routes or shortcuts. It does not imply that the subject knows the orientation of Y from X, just that they know a route or path on how to travel from one to the other [KOH 97].

The final and highest level of spatial knowledge is *survey* (or configurational) *knowledge*. It represents a map–like or top down mental encoding of the environment and is based on an *exocentric* (outside-in) viewpoint. In survey knowledge an individual can not only recognize specific locations or landmarks, but can accurately place them in his environment even if he cannot see them. Individuals can also traverse throughout their area without having to pre-plan the exact route because they know the layout of the region [BANK 97]. Because of its exocentric nature, survey knowledge is most often gained through map or aerial photograph study. Extensive exposure to an area has also been demonstrated to develop this knowledge [THOR 80]. Figure 2.3 shows an example of an individual with survey knowledge of an area. The subject can describe the relative distances and locations of all major objects in the area in relation to the subject and each other. The subject at d can tell how far he is from X, Y and Z, even if he cannot see them. He can also plot a route to any feature without needing prior study.

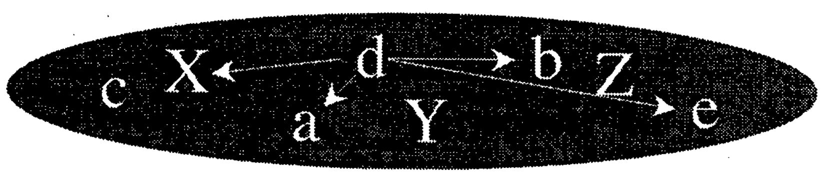

Figure 2.3. Survey Knowledge

Thorndyke's theory on the process by which humans acquire spatial knowledge, displayed in Figure 2.4, is generally accepted. It explains how humans use the spatial information of their surroundings to create a mental map or representation of the world around them. Thorndyke explains how each level is not self-inclusive, but in fact builds upon the knowledge of previous levels [THOR 80].

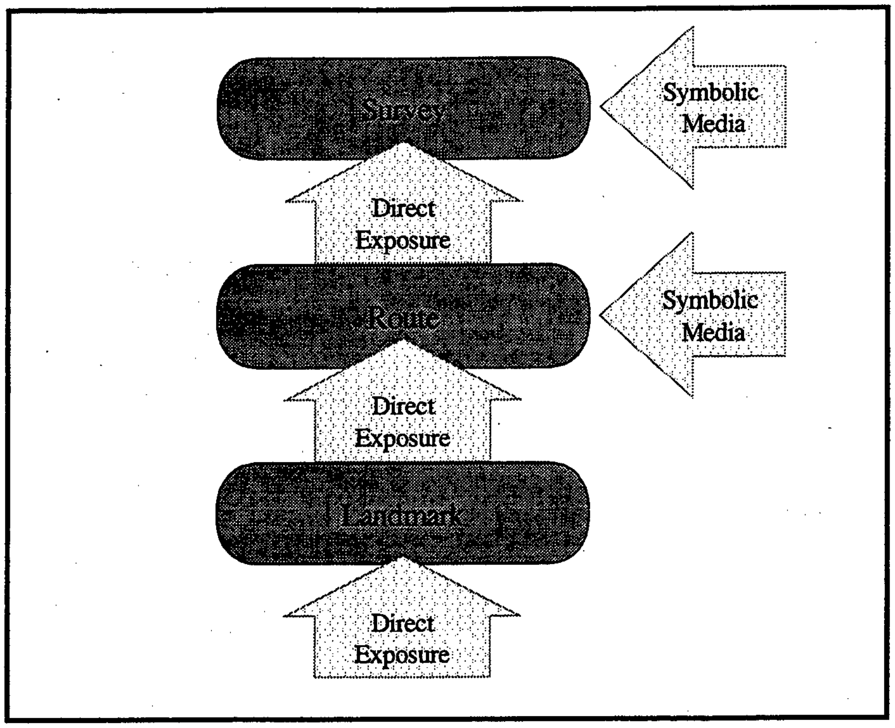

Figure 2.4. Navigation Knowledge

C. VIRTUAL ENVIRONMENTS

1. Definitions of VE

In order to discuss the effectiveness of VEs it is important to have an understanding of several of the major component definitions.

Any model which provides frame rates of eight to ten frames per second (fps) for static environments and 60 fps for more dynamic environments can be said to have real-time graphics [DURL 95]. Real-time graphics over a network also must have a minimum of network latency (less than 0.1 seconds).

Fidelity is more a qualitative than a quantitative classification. No defined scales or agreed upon distinctions exist. Waller et al. described environmental fidelity as the degree to which the variables in the model matched those in the real world [WALL 98]. Goerger defined high fidelity as "a model that represents lines of sight and terrain masking, provides realistic depictions of the vegetation and structures, and can provide a real-time interactive environment for the user" [GOER 98b]. Past studies have shown that increasing the fidelity of a model leads to an improved transfer to the real world [HAYS 89][CAIR 96], but these results do not concern outdoor environments in particular. For proving the validity of the transfer of spatial knowledge, Goerger wanted to use as realistic looking a model as possible [GOER 98b]. Examples of the model used in this research and the corresponding real world photo are shown in figures 2.5 and 2.6.

Figure 2.5. Model Photo

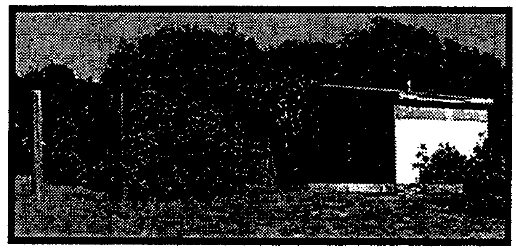

Figure 2.6. Real World Photo

Goerger described *landmark models* as "virtual representations of real world objects or locations that are easily identified, with defining characteristics, and are used by the participants as cues to navigate through the model" [GOER 98b]. These are in effect key landmarks, which must be included in any model built of a particular environment if that model is to allow the acquisition of landmark knowledge based on Thorndyke's theory. Failure to include these essential features could result in the model's ineffectiveness in representing an area and potentially inhibit the acquisition of landmark knowledge, which in turn may inhibit route and survey knowledge development.

2. Prior Studies of Spatial Knowledge and Virtual Environments

Chase examined the differences between individuals who had significant exposure to an environment, but had never seen a map or exocentric view of it, versus those who had only seen a map but had no direct exposure to the environment [CHAS 83]. In the study, those with no direct exposure tended to have better survey knowledge, while those with only direct exposure tended to display better landmark and route knowledge. Chase reported that the repeated exposure to an area develops landmark and route knowledge, but that this exposure does not automatically develop survey knowledge. The results showed that use of a map provided the best survey knowledge but that the repeated exposure group outperformed the map group in landmark and route knowledge development. Chase's findings support how Thorndyke believed spatial knowledge to be acquired (see Section B. Spatial Knowledge Acquisition). The use of a map to rapidly acquire survey knowledge of an environment without prior exposure to it is also reported by Hirtle and Hudson [HIRT91].

Bliss, et al. examined the use of VEs in acquiring spatial knowledge [BLIS 97]. They wanted to see if exposure to a VE was the same as exposure to the real world. They broke up 30 firefighter subjects into three groups and experimented performing simulated rescue operations in an office building. One group was map-only and was given a map to study first. A second group could first explore the building with a VE. The final group (the control) was given no training at all. Both the Map and VE groups clearly performed better than the control group in the results. Though the experimenters had tests and performance measure for landmark and route knowledge, they had no corresponding test for survey knowledge. Nevertheless, they concluded from their results that landmark, route, *and* survey knowledge could be gained from VEs. Their research did not show any advantage for the VE over the map.

Waller, Hunt, and Knapp conducted a series of studies on the transfer of spatial knowledge in virtual environment testing [WALL98]. They devised a test involving the exploration of a real world maze. Subjects were divided into six different groups. The blind group had no exposure prior to the test. The real world group had one minute to explore while the map-only group had one minute to study a map. Three different VE groups were used: a desktop based VE, an immersive VE using a head mounted display, and a long-term immersive VE. Both the desktop and immersive VE groups were given two minutes to study. The long-immersive group was given five. The results indicated that the low fidelity VE system used did allow subjects to "develop useful representations of a large scale navigable space"[WALL 98]. The study found that with only short exposure, VE training was not more effective than map training. However, after significant exposure, the long-term VE group did outperform the map group.

On the subject of the effect of immersion and presence on training, the results are mixed. Ruddle, Randal, Payne, and Jones showed no significant differences between the performance of immersive and non-immersive VEs groups in exploring virtual buildings

[RUDD 96]. Wickens and Prevett showed that aviators who had an immersive viewpoint had better navigational performance over those who were given external non-immersive views [WICK 95]. This is possibly due to the more natural representation or intuitive viewer interpretation based on the field of view [WICK 98]. Other studies have shown that users estimate distance much more accurately if they are in an immersive VE where they physically rotate than if in one where they merely imagine they rotate [PRES 94].

Williams, et al. investigated the area of active versus passive control during flight mission preparation and its effect on performance [WILL 95]. The experiment looked at those subjects who actively controlled their flight of the aircraft in the VE versus those who passively watched a flight. The results indicated that those subjects actively involved performed better than those who merely observed. The researchers concluded from their data that the optimal VE designed to acquire spatial awareness would include active control by the user and not merely passive playback.

Witmer's study into the transfer of spatial knowledge turned up useful information regarding the importance of the user interface [WITM 95]. He examined 64 subjects in navigating a large building. He divided his subjects into three groups: a real world group, a VE group, and a verbal directions only group. His results showed the VE group performing poorer than the real world group, but ahead of the verbal directions group. The results also indicated that spatial skills learned in a VE could transfer to the real world in some cases. Some VE subjects had their training seriously impeded by difficulties with the interface. These same individuals had difficulty performing the navigation task in the actual building, lending to speculation that poor interfaces can diminish the training effectiveness of a VE [WITR 95].

Darken and Sibert have conducted several experiments on wayfinding and virtual environments. In "Navigating Large Virtual Spaces" [DARK 96b] they concluded that in exploring a large VE without aids, subjects quickly became lost and disoriented. They found that inclusion in the model of a map, compass, or grid helped overcome this difficulty. They also found that the map provided superior navigational performance while the grid provided superior directional performance [DARK 96b]. In "Wayfinding Strategies and Behaviors in Large Virtual Worlds" [DARK 96a] they determined that individuals provided with supplementary aids in the VE, such as maps, were able to more quickly regain their starting position and maintain their orientation than when no aids were provided. They also noted that when exploring a VE, subjects tended not to revisit places they had already been.

In the first iteration of this thesis experiment, Banker theorized that a combination of map study and VE exposure would provide the optimal solution for providing total spatial knowledge of an environment. Using a non-real-time model, he concluded that subjects of intermediate ability could successfully gain and transfer spatial knowledge from a VE to a real-world outdoor environment [BANK 97]. Banker's study had three different groups: map-only, real world and VE. All of the subjects were active in orienteering though of different ability levels. None of the subjects was familiar with the specific testing area though many had been in similar terrain. Subjects were given one hour of study with which to plan and memorize a route through the environment. All of the subjects had exposure to the map during their study phase. After study, subjects were taken to the course and had to run their route from memory. Banker's results showed that ability level had a greater impact on the results than method of training, with advanced level subjects doing best overall. He noted a significant increase in performance for those classified as intermediate level orienteerers. Little increase in performance was noted in the advanced level or beginning level. Banker theorized that the ability and experience of advanced orienteerers allowed them to gain significant information from the map, which was not greatly augmented by the VE. He also concluded that the beginners were overwhelmed with information and too inexperienced to correctly focus on which information to study for success.

Goerger, et al. conducted two studies similar to the Banker experiment. The first experiment used a complex man made environment to compare two groups: a map-only study group and VE study group. The study followed a similar pattern to the Banker experiment [GOER 98a]. Thirty minutes were given to both groups to study floor plans of the seven-story structure. The VE group also had a high fidelity real-time computer representation of the building, which they could explore during the thirty-minute study phase. The results of the experiment showed the map-only group significantly outperformed the VE group. Goerger theorized that the short exposure limited the performance of the VE group. He concluded that "performance on spatial knowledge tasks after brief exposure to a high fidelity, real-time VE does not always exceed results gained from traditional navigation training techniques" [GOER 98a]. This theory is backed up by the results of Waller, Hunt, and Knapp. They found "short periods of VE training were no more effective than map training; however, with sufficient exposure to the virtual training environment, VE training eventually supersedes the map" [WALL 98]. Ruddle, et al. also found users performed better the longer they used the system and the more familiar they were with it [RUDD 98].

Goerger's second experiment mirrored the Banker experiment in all details except that the model was a real-time model that allowed total freedom of movement, and that the subjects were not all active in orienteering. Like Banker's experiments there were three groups: map-only, real world, and VE. The experiment used the same map and training area as the Banker experiment. After the individual's one hour of training, they were tested the same as in Banker's experiment. Goerger concluded from his results that the spatial ability of an individual plays a "significant role" in the individual's performance. He also concluded that training conditions showed no significant effect on the ability to "obtain and demonstrate spatial knowledge of a natural environment" though the map group did perform better based on observation. Finally, he concluded that the 1:5,000 scale map in the study was so effective and useful that it was hard to beat [GOER 98b].

The above studies allow us to conclude at least some benefit to using VEs for the acquisition of route and landmark knowledge. Map's, or other top-down representations, still seem to be the best at providing survey knowledge. Ideally, a VE would combine these advantages, allowing the user to either quickly use an external map or have one incorporated in the model.

3. Model Classifications

It quickly becomes apparent, given the vast scope of fields and tasks that are being explored with VEs, that no one set of standards fits all models. Much as with any real world building, different models must be designed for their express purpose and have different features depending on that purpose. We would expect a VE for flight training not to expend great effort on modeling vegetation appearance since it is not the most crucial part of that task. In contrast, a VE designed for dismounted soldiers has to pay more attention to vegetation, but less to dynamic physics of falling objects. Goerger used the term "complex natural environment" [GOER 98b] to describe the areas of terrain complex enough to require detailed representation to portray them. While such a system may not be needed in flat desert or plains areas, it becomes more desirable in other terrain.

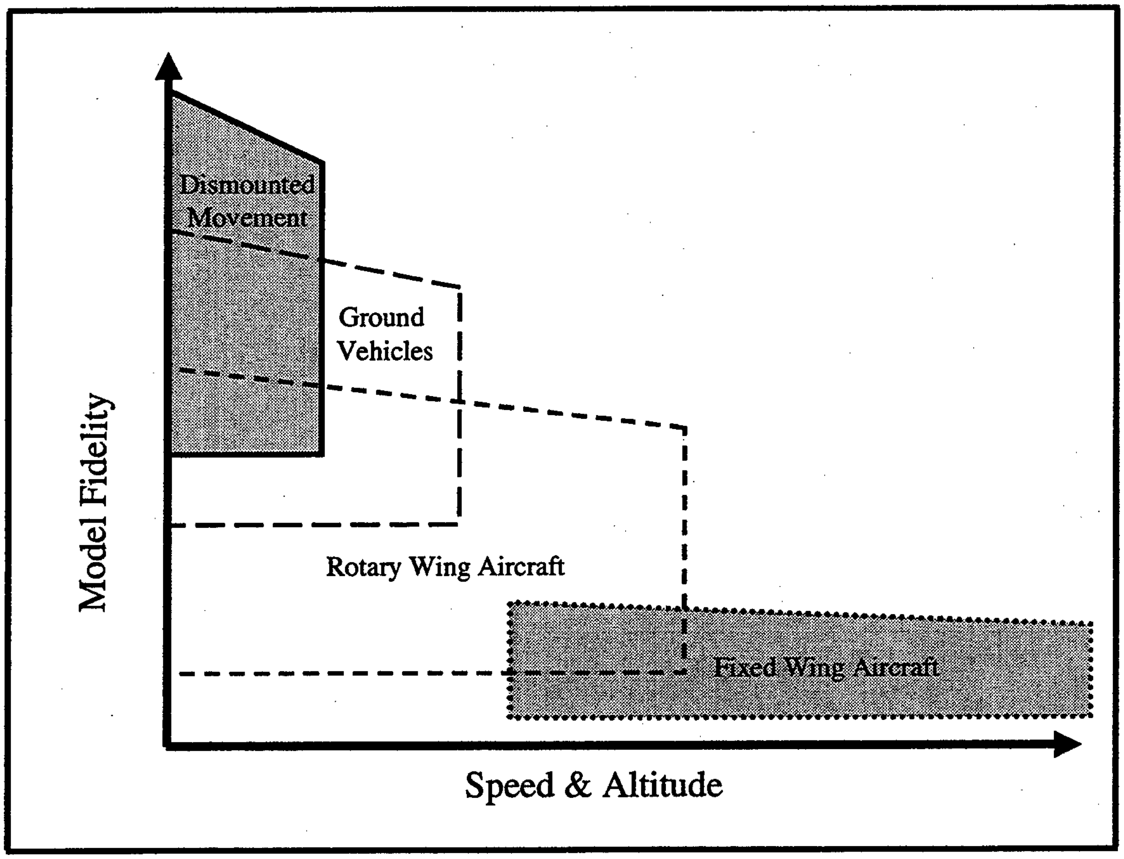

Figure 2.7. Fidelity vs. Movement Method

Most VEs can be placed into one of four broadly defined categories based on terrain requirements. These levels are Fixed Wing Aircraft, Rotary Wing Aircraft, Ground Vehicles, and Dismounted Movement [SULL 98]. While there may be overlap between the fidelity and detail of terrain representation between the four levels, Fixed Wing

Aircraft is generally the least detailed with Dismounted VEs being the most detailed (Figure 2.7).

Knowing the principal movement target of the model can help the model designers limit their work to the correct scope, and not add unnecessary details or leave out critical information. The model used for this thesis would fall into the dismounted movement category [GOER 98b].

D. LAND NAVIGATION AND ORIENTEERING

1. Military Land Navigation

Navigation is "the theory and practice of navigating" which means in turn, "to make one's way" or "to follow a planned course" [WEBS 88]. Good navigation requires knowing the current location, the destination, the direction of travel (orientation), and a means of travel [WICK 92]. This closely matches the military definition of route planning which is "knowing where you are, where you are going, and how you are going to get there" [ARNG 83]. Navigation plays a critical role in the military, and as such an entire manual devoted solely to the training of map reading and navigation skills is maintained (FM21-26 Military Land Navigation).

Army doctrine regarding land navigation says it is trained in a building block approach. First, basic map reading skills are trained, followed by dead reckoning. The more efficient, but more difficult to learn, terrain association follows. Later, soldiers develop route selection skills and techniques involving unit placement and planning tactical movements [FM21 93]. The military focuses on two basic techniques for navigation: dead reckoning and terrain association. Both have advantages and disadvantages.

Dead reckoning involves first determining where a soldier is (based on their map-reading skills and compass readings), and then determining the direction and distance they need to go. Soldiers who are dead reckoning do not deviate from their path unless they come upon an uncrossable obstacle. In that case, they "box" around the obstacle and quickly return to their original route. The essential skills to the dead reckoning method are reading a compass and keeping pace count (for determining distance). While this method is easy to learn, it is difficult to implement. Soldiers need to pay particular attention to the compass or they may veer. This is increasingly difficult on long movements where small errors in the beginning can have a dramatic effect at the end. Dead reckoning is also very unforgiving. Without any intermediate terrain association or landmarks, an error is only discovered once the prescribed distance is reached and the soldier is not in the right place. Dead reckoning can be useful for short movements, in dense terrain (jungle/forest), in featureless areas (desert/plain), or at night when other terrain features are not clearly visible. It can also be highly accurate over short distances. It has the advantage of being the easiest to learn and teach. Because of these characteristics, the Army advises soldiers to dead reckon a series of short distances between "known" points and locations [FM21 93] to reduce the chance of error.

The military prefers terrain association because it is more forgiving and less time consuming [FM21 93]. The essential aspect of terrain association is the ability to adjust the route on the way based upon confirmation of expected terrain features or landmarks. The steps in terrain association consist of first determining current location, and the desired destination. The map is examined for unique or distinctive feature of the terrain that can be used to guide the movement. Soldier's plan their route to take advantage of these features to provide feedback. Terrain association allows them to take advantage of handrails, attack points, expanded objectives, checkpoints, catching features, and even vegetation [FM21 93][ARNG 83]. See Appendix P for definitions of these terms. To properly terrain associate, individuals should make sure they keep the map oriented properly, and they should refer to it often. The obvious disadvantage of terrain association is that the individual must be able to interpret the map and translate the world around them into topographic terms [FM21 93]. The ability to estimate distance and direction to a terrain feature, and quickly estimate position accurately are difficult to teach, learn, and most important, retain. Often these skills are only developed after long hours of practice.

Often it is useful to combine techniques during navigation. The soldier may first terrain associate to an attack point (see Appendix P for definition) such as an intersection or bridge close to their desired objective, and then dead reckon from there. Army doctrine recommends not becoming dependent on any one method but being capable of all [FM21 93].

The recent emergence of Global Positioning Systems (GPS) technology has not diminished the Army requirements for land navigation training. While GPS can prove useful for determining location, the Army still requires that soldiers learn traditional methods. The seriousness that the military places on these skills can be viewed in the requirement for successfully completing the land navigation course prior to graduation of any of the basic military schools for officers and soldiers alike. Indeed, many of the more advanced schools have land navigation tasks that are essential to pass and are considered among the most challenging requirements (Ranger School and the Special Forces Assessment Selection course respectively).

2. Sport Orienteering

Orienteering is competitive land navigation. The sport of orienteering was first developed in Sweden in the 19th century and was brought to America in 1946 [FM21 93]. The International Specification for Orienteering Maps (ISOM) describes orienteering as a sport where runners complete a course of control points (or controls) in the shortest time aided by map and compass [ISOM 90]. In fact, there are four common types of orienteering events.

The most common, and the one that most people think of as orienteering, is *cross-country* orienteering. Here, numerous points are spread out along the area. Contestants must visit the points in order but are not constrained as to which route they use to get there. Usually staggered start times are used. The runner with the best time who reaches all the controls in order wins.

A variation of cross-country is *score* orienteering. Here the control points are again spread out but runners do not have to visit them in any order. Each control is given a numeric point value with the farther controls worth more. The runner who has collected the most "points" after a set time limit is judged the winner.

Route orienteering is more of a training session. Here a leader will lead the group along a route. The participants have to draw the route followed on their maps and annotate the locations of all the controls they saw. At the end of the route, all the maps are compared to the accurate master map. The closest map to the master map wins.

Line orienteering is similar to route except that there is no leader. The participant follows a route drawn on his map to the best of his ability and annotates the locations of all controls along the route.

For the speed events (cross-country and score orienteering) runners are usually provided with a clue sheet to assist them. This sheet provides data about the terrain feature the point is located in/on. The controls themselves are usually three-sided to be recognized from any angle of approach.

Competition orienteering has different levels of competition. These color-coded levels increase the distance and difficulty of the locations. White is the easiest, followed by orange and then red. It is common for multiple courses to be run over the same area with different controls for the different courses littering the same area. Unlike military land navigation, which recommends at least 300 meters between points, orienteering has no such restriction. In any case, no two controls should be within 25 meters of each other and no two controls on the same course should be closer than 75 meters unless they are on different terrain features [FM21 93].

Another difference between most military and orienteering courses is the map itself. Most military navigation is done at 1:50,000 [FM21 93] or 1:25,000 at best. In FM21-26, the Army considers 1:50,000 to be reasonable for orienteering. Competition orienteering is usually done at 1:15,000 scale. This is a profound difference. Military navigators are looking to recognize major terrain features. Sport orienteerers are expected to distinguish between minute differences and the potentially close proximity of the points adds to the difficulty of this competitive sport.

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III. METHODOLOGY

A. EXPERIMENT OVERVIEW

In order to determine whether Virtual Environments are useful for transferring spatial awareness of natural regions, a series of experiments was conducted. This section will provide an overview of the conduct of the experiments, while succeeding sections describe the tools, techniques, and methodology in more detail. The general sequence for the experiment was the in-briefing, battery tests, spatial orientation test, model familiarization (VE only), training in-brief, training, pre-course test (only for subjects in experiment #1), actual course test, and then debriefing.

Upon the subject's arrival, they were read the basic in-brief by the research monitor and had to fill out the initial consent forms. The in-brief is shown in Appendix C. The consent forms, including medical waiver are in Appendix D.

Once the subject had filled out the consent forms, the next step was the battery of tests. Subjects had to complete a test on basic terrain identification, as well as a standard medical color-blindness test. Subjects completed a short informational questionnaire that asked where they first learned to navigate, how long they had been navigating, and at what level they would classify their ability. On a separate page, subjects had to complete a bar-line evaluation of their navigational ability. The redundancy of having the same information in two places provided a confirmation and removed any bias that may have been associated with the word descriptions of navigational level. Lastly, in this phase, subjects completed the Santa Barbara sense of direction scale questionnaire (see Appendix E). This 15-question questionnaire, developed by the University of California at Santa Barbara, asks the user to rate themselves on such topics as "I remember directions well" or "I always know where I am". This test helps assess how confident the subject is on navigational tasks. The map test, the navigation history and bar-line are in Appendix E.

The next stage of the experiment was giving each subject the Guilford Zimmerman (GZ) spatial aptitude test [GOER 98b]. This test would determine a subject's ability to sense changes in direction and orientation. It was a 60-question test, with ten minutes allowed for completion. Subjects had to answer as many questions as they could, but 1/4 point was deducted for each wrong answer from the total they answered correctly. No points were deducted for unanswered questions. The GZ test cover sheet with an example question is shown in Appendix E. The test was used to segregate the subjects into high and low ability groups. Because past experiments proved a correlation between spatial ability and navigational performance, the goal was to equally distribute the high and low ability individuals into the map and VE groups.

Once subjects were tested, their group was designated based upon GZ ability. Those chosen for the VE groups were now given 15 minutes of model interface orientation. For this training, they were put in an environment that did not resemble the actual model area. This training VE did have the same interface controls and allowed the user to become familiar with the various functions and capabilities available to them through the model. Prior to their completion of the interface orientation, they had to complete an interface familiarization checklist or, failing that, they would be required to conduct more training at the controls. During the course of this familiarization period, the monitor would note if the subject was having any noticeable difficulties with the model.

Now all subjects were ready for their training phase. First, they were read a series of standardized instructions based upon their groups (Map or VE) and their experiment (Train-to-standard or Map Fidelity). In all cases, subjects were given a participant task list and important information on marking their map (see Appendix G and H respectively). This clearly laid out what the subject was supposed to do when they arrived at the testing site. This information helped focus the subjects during their training on what task they were preparing for. For the train-to-standard group, they were also informed of the pre-course test (see Section N.1. Train-to-standard) and the requirement that they pass this at the end of their training before they would be taken out to the actual course. The in-briefs for all four of the experiment groups are located in Appendix C. At this point the monitor would present the subjects their training aids, explaining each in detail. For the train-to-standard experiment group, these aids included a 1:5,000 orienteering map, an orienteering clue sheet, and side by side photo comparisons between the control points in the real world and in the model. The map-only group photographs only showed the actual points and not those of the model. For the map fidelity experiment, the 1:5,000 orienteering map was excluded. In its place was an overhead photograph of the area, as well as a 1:24,000 map of the region. To allow for easier reading, this map was also provided at 1:5,000 scale but with no additional information being provided on the map. These training aids are discussed in more detail in the following sections.

Individuals would then actually conduct their training based on the standards of the experiment they were participating in. At the end of the training period, all subjects were to have their proposed route clearly marked on the map, showing the exact route they intended to follow on the actual course. During the training period, the monitor remained close at hand, recording the time they were taking, and answering any questions that the subject needed clarified. For VE subjects, monitors also noted any interface difficulties and if the subject appeared to be disoriented or lost in the VE. Upon the successful completion of the training period (which may have been an hour or more), all of the training materials, except for the clue sheet, were taken from the subject. The monitor and subject then left the training room and drove to Fort Ord. Once they neared the road leading to the test area, subjects were blindfolded to ensure that they would not arrive at the testing area already oriented. This was also done so that they could not see any of the control points in route (two points were directly visible from the boundary road under the right conditions).

Once they were at the course location, subjects were again shown the target control point markers to remind them of what they were looking for. Subjects donned the GPS backpack that would record all of their movements on the course so that any error deviations could be accurately recorded. Subjects were read the Navigation Course task briefing, which outlined the exact task conditions and standards they should follow. See Appendix C for the briefing. The monitor initially oriented the subjects using the map and compass. The monitor also ensured that the subject had their clue sheet. The monitor encouraged the subject to speak aloud, so that the monitor could understand and record what the subject was thinking. The subject would have one hour to complete all the tasks. The monitor kept the official time. At control points two and four, the monitor would stop and have the subject answer questions. Time was stopped during these periods. The subject could also request the compass, the map, or the map and compass together at any time. All of these checks were timed and recorded. As the subject traversed the course, the monitor recorded their comments, and noted when and where they made errors. As subjects completed a task, the monitor would read their next task from the Navigational briefing to ensure uniformity across the group. Subjects would have only one active task at any time. If subjects desired to change their route, they could do so. Once a subject found the control they were looking for, the monitor would read the next set of instructions. If the subject reached control point nine in the one hour time limit they were given the unplanned route task (see Section L). Once that task was complete, or upon being timed out at any portion of the test, subjects were guided back to the vehicle by the monitor where they performed the whiteboard test (see Section K. Whiteboard) regardless of whether they actually finished the course or not.

Once the testing was finished, subjects were driven back to NPS. There they were given a detailed questionnaire about the experiment and the training tools they had been given. Subjects were also shown the route they had traveled by downloading the GPS data into ARCVIEW and presenting the data plots. Subjects were asked to elaborate on their thoughts at the times they made errors or mistakes during the course. Subjects were also asked the debriefing questions. These questions are shown in Appendix E. Once this was all finished, subjects were thanked for their participation and reminded not to talk of the experiment specifics to anyone. In total, the experiment took approximately four hours to complete. This could be much longer for the train-to-standard experiment.

B. TEST ENVIRONMENT

The area used for the experiment was a 1200 meter by 700 meter section of land located on what used to be Fort Ord in the coastal area of central California. The terrain in that region is characterized by shallow rolling hills and grasslands. The area used for the course varied from 90 meters to 123 meters in elevation providing for distinct navigational terrain features yet not being so extreme as to impose a physical challenge component to the experiment. The Fort Ord region of California has three predominant vegetation types, all of which can be found on the course (see Appendix F)

Oak Forest covers much of the area (40%). Inland and coast live oaks of 25 to 45 feet in height are dominant. These trees have large canopies that often touch their neighbor, which can inhibit undergrowth and allow for easy traversal though poorer lighting. Some tree canopies can extend almost to the ground providing a visual as well as physical impediment. Where the trees are more scattered there is often thick undergrowth that can slow travel.

Another 40 percent of the course is covered by maritime chaparral, a plant that grows in dense thickets that provides an extreme impediment to cross country travel. Movement in chaparral is almost always limited to the roads and trails in the area unless individuals plan to painfully "fight" their way through the dense brush. It is possible to traverse through Chaparral in some places but the rate of travel is very slow and the density limits visibility. Most travelers prefer to avoid these regions entirely or stick to roads. No test subject attempted to go through a section of chaparral more than once. Depending on the height of the chaparral, visibility ranges from excellent to poor. Often travelling on a trail through dense tall chaparral is the same as walking a corridor.

The third category is perennial grassland. It covers the remaining 20 percent of the course and has knee high grasses with a scattering of trees and patches of dense underbrush. Excellent visibility and mobility characterize the region.

The testing area is crisscrossed by a series of dirt roads, trails, and footpaths. Some date back to when the army trained in the area, others have come about due to public mountain biking and other outdoor recreation. The condition of these trails varies as they wind through the testing area, and it is not uncommon for a trail to be well beaten at one point only to be overgrown at another. The area also has numerous decaying outhouses, shacks, wooden pavilions, telephone poles and other manmade structures that scattered throughout the course, but usually located along roads or trails. The number of these structures and trails provides ample opportunity for parallel errors (see Section H. ERRORS). The area is also dotted with old foxholes, trench lines, pits, and cement pads. These features can aid navigation but can also induce parallel errors.

Roads bound the testing area on all four sides. The northern road is paved but the other three are dirt. Many of the trails inside the course connect with one or more of the boundary roads. Travel into the area is prohibited to vehicular traffic without special approval.

C. MODEL

The model is a real time replica of the test environment and was developed by MAJ Simon Goerger [GOER 98b] based on the aerial photograph, the Banker course map, and ground reconnaissance. Goerger built the model using the OpenGL language, EasyScene software, Coryphaeus, Inc. The model itself runs on a Silicon Graphics Industry (SGI) Onyx Infinite Reality workstation. This machine has four processors running at 194 MHz, 256 Mbytes of main memory, and 4 Mbytes of texture memory [GOER 98b]. Goerger studied extensively the required accuracy and developed his model at one meter resolution [SULL 98] [GOER 987b]. In order to have the model run in real time, Goerger made extensive use of level of detail (LOD) modeling. This meant that if some objects were far away they were not drawn, or were drawn in a simpler manner to save polygons. Goerger discusses at length the thought process he went through in deciding upon where exactly his transition points would be [GOER 98b].

To impart realism in the model, Goerger used digital photographs of trees and bushes attached to billboards to populate the vegetation in his model. Four different trees, three types of bushes, and two types of underbrush were used [GOER 98b]. These vegetation billboards were not placed to exactly match the individual trees found in the real world, but rather in a representational manner. Areas of dense vegetation in the real world would subsequently have more billboards in the model.

In order to accurately place the roads, as well as give a sense of shadowing, Goerger overlaid the terrain with the 1993 aerial photo. He then hand placed the roads in their appropriate locations. All trails in the model are displayed the same, regardless of their real-world condition. This can lead to the "yellow-brick road" effect where subjects later doubted they were on the right trail because in the model it was clear, and in the real world it was overgrown.

For the man-made objects, Goerger used digital photos and hand taken measurements to accurately build and locate the structures into his model. All told, the model included five outhouses, two shacks, two pavilions, nine cement pads, and three rock piles. It also had over 20 individual telephone poles, telephone lines, two trench lines, and 200 sandbags. Over 9,000 meters of trails/roads were included, as were over 14,000 tree billboards [GOER 98b]. Two military HMMWVs were added in an attempt to offer a sense of scale to the model.

The interface uses a flybox (see Figure 3.1) as its interaction device. Users were allowed to independently turn their head to their right or left, or look up and down without affecting direction of movement or orientation. The users could designate a run or a walk mode.

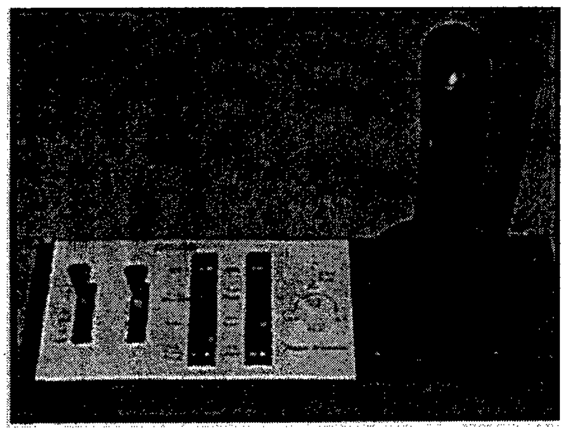

Figure 3.1. Flybox Interface

The model's avatar was set to a standard height of five feet eight inches above the ground, but users could toggle a 15-meter pop up view that enabled them to get above the trees. Users could also toggle an overhead "you are here" style map that showed their exact location and direction of travel. The maximum speed allowed in the model was roughly 10 miles per hour. Other features in the model were the ability to instantly teleport to the start or end points, as well as to any of the control points. Users could also get a quick view of any of the control points without actually moving there. Goerger designed the model so that the lighting could be adjusted to any one of six levels (night to bright daylight)[GOER 98]. Goerger did not implement any collision detection so users could unrealistically move through buildings and trees. Other than the 15-meter pop-up view, there was no way for users to raise or lower the avatar's eye height. This created some difficulties in locating controls in the model, as subjects could not lower their head to see under tree branches.

To aid in navigation and to help the user orient themselves in the model, Goerger included a standard compass. This compass could be used during rotation, but could not be used while moving. If the user toggled the compass while moving, he would stop. The necessity of the compass in the VE was evident given the difficulty of ensuring accurate body movements in the VE (e.g., like turning around).

For the visual display, Goerger decided upon a three-screen configuration with 103-degree field of view [GOER 98b]. These three 40 inch screens were set up exactly 67 inches from the subject to ensure the 103 degrees was achieved. He felt that this would give the user the best feeling of immersion and enable them to use their peripheral vision to maximum effect. Without this expanded viewing area, users of the model would be much more likely to make parallel errors or be forced to constantly turn their head. Figure 3.2 shows the three-screen configuration.

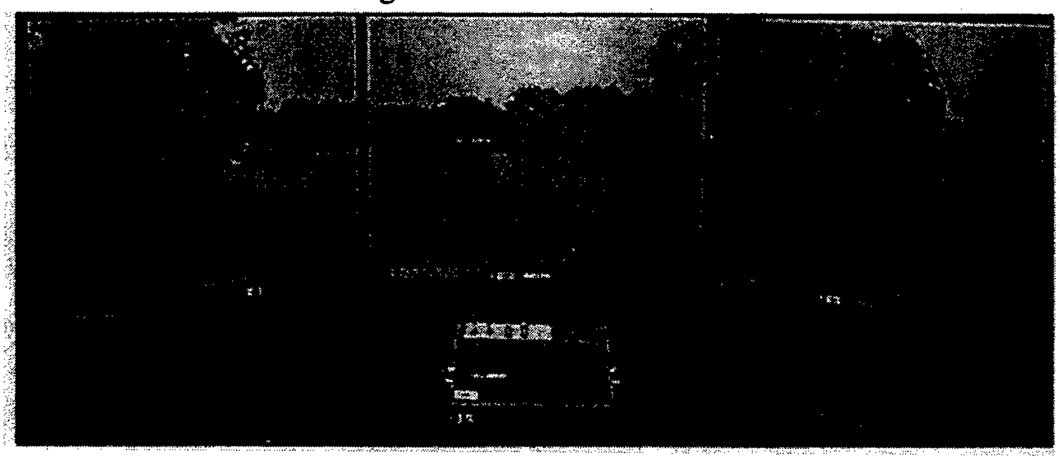

Figure 3.2. Three-Screen Configuration

In summary, based on his extensive research into FOV, LODs, and his detailed measurements, Goerger was able to make an extremely accurate real-time model of the Fort Ord testing area. This allowed the user to seamlessly explore the region both on foot and in the air to quickly traverse to areas of interest.

D. MAPS

The experiments used two different maps. MAJ William Banker [BANK 97] developed the map used in the first experiment. This was the same map used in both the

F. DATA GATHERING TOOLS

In order to measure whether subjects were following their planned path within the margin of error a differential global positioning system (DGPS) backpack was used. This system would take location information transmitted from satellite and record it in a Newton MessagePad 130 (see Figure 3.3). These data plots were taken every five seconds. Once the experiment was finished, the location plots were downloaded from the MessagePad into a PC. Using FieldWorker software, the data was overlaid onto an overhead photo of the region. This enabled the monitor to accurately measure exactly how far off route subjects had traveled during errors. This program was also invaluable during the out-briefing for showing the individual exactly what they had done, and for discussing exactly where they made mistakes.

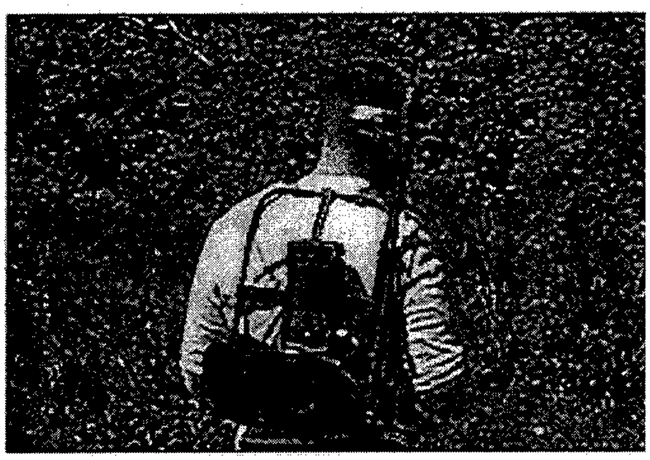

Figure 3.3. DGPS Backpack and MessagePad 130 [GOER 98b]

A second means of data collection was the monitor himself. He would record the actions of the subject as they progressed through the testing environment. All map-checks and route changes were recorded, as was the time it took individuals to arrive at control points. The monitor also recorded the exact time that subjects left their planned route, where the error occurred, and the type of error. This was needed in case of DGPS failure. Subjects were encouraged to "think out loud" (Appendix K) and the monitor recorded their comments and actions.

G. COURSE

The testing course itself was design and set-up by MAJ William Banker [BANK97]. He used the International Orienteering Federation's specifications [ISOM 90] to develop the course and the course map (Appendix F). In all but one respect, the course conforms to thee standards of an orienteering "orange" course [ISOM 90]. The only deviation from the standard is the level of map detail. Orienteering competition normally uses a 1:15,000 scale map. The official specification allows the use of 1:10,000 in exceptional cases. MAJ Banker's map (Appendix F) is of 1:5000 scale (see Section B. MAPS). The other map provided was a 1:24,000 scale map that was not detailed enough by sport orienteering standards. However, the military considers 1:50,000 to be the standard navigation map and they seldom see anything better than 1:25,000 [FM21 93]. The course greatly differs from standard military land navigation courses in that the control points are not at least 300 meters apart and the overall course is not over 2500 meters in length.

The start point for the course is the intersection of Gigling and Watkins roads on old Fort Ord. The course consists of the start point and nine control points which must be found in order. If a point is discovered out of order, no credit is given until the point is found again is the proper sequence. The points were placed so that there were numerous routes to the controls. No controls were located directly on a road or trail as per ISOM standards. Because of the layout of the course, it was not efficient to reuse previously traveled routes during the conduct of the course. Three points were located below ground level. Control point two was in a narrow pit, point four in a wide shallow depression, and control seven in a dry ditch. No points were hidden in dense brush or inside man-made structure. All controls were located near identifiable terrain features or objects. The first three controls in the course are located relatively close together. This often allows the subjects to gain a sense of confidence. Direct line distance between the points on the course is just over 2000 meters, though a route following only roads and trails could easily double this.

H. ERRORS

There are five different classifications of errors that individuals commit during the course. Again, as noted earlier, individuals are assessed an error if they travel more than five meters off of their designated path (if path was planned on a trail/road) or if more than 15 meters off of a cross-country route. Once an individual is assessed an error, the distance he travels is calculated until he returns to his preplanned route, marks a new route, finds the control point, or his one hour time limit for the experiment expires. Individuals can commit multiple errors if they move off their route, correct themselves, and move off their route again. In addition, if they mark a new route and then veer off that they also get multiple errors. Each of these errors was recorded and weighted differently as noted in the following discussion.

By far the most common type of error encountered was a *mirror error.* This is where the subject, upon reaching a decision point (a branch in the trail for instance) chooses to follow the incorrect one. Given the numerous intersecting trails and roads in the course, it was quite common for individuals to make this mistake. Given the high potential for this type of error, it was given a basic weight. Figure 3.4 shows a mirror error.

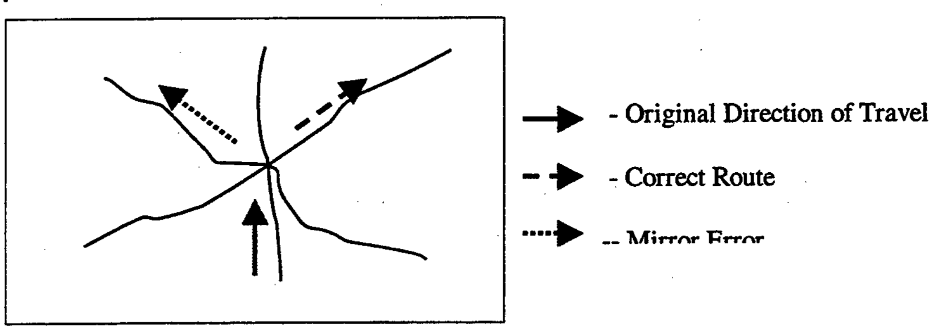

Figure 3.4. Mirror Error Example

Another common type of error is a *parallel error*. This occurs when the individual thinks he is at one location but is actually at another. The subject may be looking for a building next to an intersection and find a different location with the same features. The subjects mistakenly thinks he is at his desired location.This course has numerous similar trail intersections, buildings, and locations that make this type of error common (see Section A. EXPERIMENT OVERVIEW).

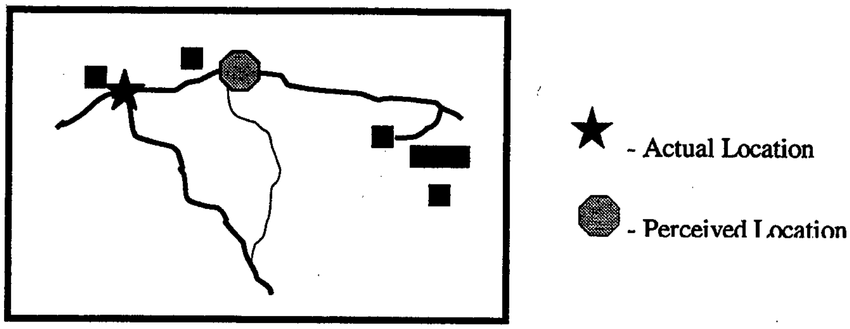

Figure 3.5. Parallel Error Example

A *compound error* occurs when individuals make a mirror or parallel error off a newly planned route. This can occur after a reorientation error (see later), or if an individual himself requests a new route and then errs off it.

An *out-of-bounds error* occurs when a subject leaves the course boundaries. While there is no restriction against using the boundary roads, should an individual take even one step off the wrong side of a boundary road he is assessed an error. The individual is not oriented as to where he is on the map if he makes this error. He is only informed that he has left the course. There is no error distance recorded with this type of error. Because being told you left the course boundary provides some information and since error distance is not calculated, this type of error is tracked under map-checks.

Should a subject leave their planned route for more than 15 continuous minutes and not be making progress towards their next control point, they will be reoriented as per Navigation Course task briefing (Appendix C) and be assessed a *reorientation error.* At this time the subject will be shown their location on the map, and given one minute to plan a new route to their next control point. Since the subject uses the map and is shown their exact location, this type of error is recorded under map-checks and not distance errors. No error distance is recorded for this type of error since individuals may make compound errors later, which would result in the double counting of error distance.

Note that when individuals made an error, only the initial cause of the error was recorded not any subsequent misjudgments they may make during the course of the error.

Thus if a person makes a parallel error and thinks he is at a different location, and he takes a wrong trail based on that, it will be a parallel error and not a mirror error. Also, if a subject, after taking a wrong trail (mirror error) then assumes they are at a different location (parallel error) and make decisions based on this erroneous conclusion, it is still recorded as a mirror error. Once an individual has made an error, error distance continues until: the subject returns to their planned route for the control point they are looking for (at any point along the route), the subject finds the control point, the subject creates a new route (though they may start a new error if they plan this new route not from their actual location) or the experiment's one-hour time limit expires.

I. SUBJECTS

The subjects for this experiment consisted of 20 individuals ranging in age from 29 to 40 with an average of 33. All were active duty Army (11) or Marine (9) officers of either Captain (17) or Major (3) rank. 75% of them had ten or more years of experience navigating, with the rest having five or more years. 95% of the subjects rated above average on the Santa-Barbara sense of direction scale. Most self-assessed their ability as intermediate, with several claiming expert. None felt they were beginners. However, when evaluating themselves using the bar-line, two subjects did place themselves in the beginner category. None scored lower than 17 out of 20 on the map reading test. Only one was color-blind. Two subjects were female. All the subjects had no prior knowledge of the testing area, nor had they any experience with the maps used or the virtual environment. There was no tangible compensation for the subjects. Data was collected from 22 April 1999 to 23 July 1999. The subjects were divided into four groups: train-to-standard VE (VE1), train-to-standard map-only (MAP1), low-resolution-map VE (VE2), low-resolution-map map-only (MAP2).

J. WHEEL TEST

The wheel test was used twice during the conduct of the actual course as a means of determining if the subjects acquired survey knowledge. The tests were taken at control points two and four. At both points, subjects were asked to point towards one location they had already visited and two they had not. In no instances were these locations the ones just previous or next in line. At control point two subjects point to the start point, control point five, and control point nine. At control point four they point to control point one, six, and eight. The time it takes the subject to complete this task is recorded. Also what direction they face is recorded. Once the subject finishes, the results are photographed and measured on the spot. During this procedure, the official clock is stopped so that the individual is under no time constraint pressure. The actual wheel consisted of a 12 x 12 sheet of laminated cardboard with a seven-inch full color wheel (see Figure 3.6) and three numbered arrows. The wheel had 16 colored segments. Colored segments were used so that the individual would not confuse the wheel with a compass [GOER 98b]. Individuals were allowed to orient anyway that they choose during the test.

Figure 3.6. Wheel Test

K. WHITEBOARD TEST

At the completion of the course, all subjects are given the white board test regardless of whether the found all the control points or not. Like the wheel test above, this test evaluated the subject's survey knowledge of the course area, but in a more exocentric manner. This test consists of a blank white board and ten colored chits representing the control points. Subjects are instructed to lay the chits out in spacing and orientation to match the real world layout of the course. Figure 3.7 shows a subject doing the whiteboard test. This layout is photographed and then analyzed later to determine how far off from the real world it is.

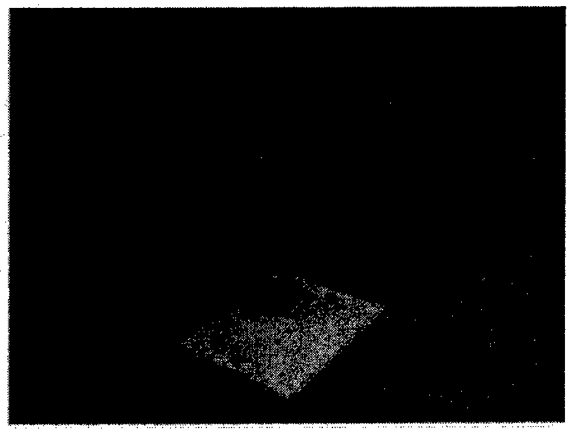

Figure 3.7. WhiteBoard Test

L. UNPLANNED ROUTE TEST

Upon completion of the course, subjects who successfully found all nine of the control points would have their survey knowledge tested again. They would be asked to point to control point four, and how far they thought they were from it. They would be asked to describe how they would get back to control point four if they had to go there again. After describing the route, subjects would be given ten minutes to follow the route they had described. The monitor would record if they followed the route that they described, what errors (if any) they made, and if they found the control point in the ten minute time limit. If the subject made an error, the cause of the error and the error distance would be recorded. This data would later be analyzed to see how well they knew their environment and could they conduct an unplanned movement without aid of map or compass.

M. RESEARCH MONITOR

The research monitor followed the text in the experimental outline to the letter to ensure uniformity of test experimental conditions to all subjects. During the train-up period, the monitor observed the subjects to see how they conducted their time. He was on hand to answer specific questions about the course, record where individuals had difficulty during the train-up time, as well as administer the pre-course test.

The purpose of the research monitor during the course was to record the comments and actions of the test subject (in addition to the tracking tools) while remaining in the background. This meant prompting the subject for their thoughts but not distracting them from their task. The monitor kept the official time, which he stopped only when recording information or asking the subject questions. The monitor also needed to record when errors, map checks, and route changes occurred, and to ask the in-course questions (see wheel test, whiteboard test, and unplanned route test). The monitor recorded the time the subject arrived at the various control points and had to be prepared to orient the individual as necessary (see re-orientation error). Finally, the monitor carried all the water and supplies other than the clue sheet, which was carried by the subjects.

N. TRAINING

1. Experiment # 1: Train-to-Standard

In his conclusions, Goerger speculated that the limited training time may have had an effect on the outcome [GOER 98b]. Based on his data he felt VE subjects who actually performed multiple runs through the simulated environment did better, at least in terms of finishing the course. In addition to the lack of iterations, Goerger also felt that the short training time may not have allowed VE subjects to both explore the environment, practice potential routes, and build a valid mental map of the environment all in the span of one hour [GOER 98b]. He envisioned that as exposure time increases, the performance of both the VE and real-world groups would exceed that of the map-only group. Based upon these conjectures, the training portion of the experiment was ripe for variation.

Educational studies involving VEs have shown that students learn best when "multiple practice" is included. In this case multiple practice includes not only "repeated practice of a topic" but also "practice from multiple representations"[MCLE 96].

The Army places heavy emphasis on training. It is how they prepare for war and the commonly repeated mantra is "Our top priority is training" [FM25 88]. Army doctrine demands that training be performance-oriented, hands-on, and challenging. Since training is so important to the Army, it requires that all training events have tasks, conditions, and standards. The Army feels soldiers perform better when given these guidelines [FM25 90]. The tasks are the concepts to be trained. The conditions are the tools that can be used and the surrounding area. The standards are what the soldier must be able to do in order to be considered "trained."

FM25-100, *Training the Force* describes the Army's view of training to time versus training to standard:

> Demand training standards are achieved. Leaders anticipate that all tasks will not be performed to standard. Therefore design time into training events to allow additional training on tasks not performed to standard. It is more important, however, that they achieve the established standard on a limited number of tasks during a training event than to attempt many and fail to achieve the standards on any [FM25 88].

The Army also says training becomes more effective when it is standard based than when it is time based or procedure based [FM25 90].

When designing the original experiment, Banker arbitrarily chose the one-hour training time. No analysis was done to determine if this was an optimal time, or even if it was sufficient. The Goerger experiment continued the use of this arbitrary time limit to training. Based upon Goerger's suspicions, as well as the supporting research from other VE studies, and most importantly, from the Army philosophy towards training, the first experiment did away with the arbitrary time limit to training and instead incorporated a standard based system.

Having decided to implement a standard based system, it was necessary to decide exactly what the standard should be. Because the experiment used two different group with two entirely different media (maps-only vs. VE) it was apparent that the standard for each group would be slightly different, yet had to be as similar as possible. The first step in this area was determining what exactly the experiment was testing. While the context of the experiment would be looking at survey knowledge at many places, the most important aspect to completing the course was developing the landmark and route knowledge. Thus, the experiment needed a standard that tested this learning.

For each group, a pre-course test was developed. When the subject was read their training instructions they would be informed of the pre-course test and told its standards from the start. They were informed of the requirement to pass this pre-course test in order to finish their training period. There would be no time limit to their training. When they felt they were ready, they would attempt the pre-course test. If they passed to standard then their training would end and they would proceed out to the course. If they did not pass the test to standard the pre-course test would be stopped and they would be told why/how they failed. They would then be given the opportunity to conduct more training before attempting the test again. There would be no limit on the number of times the person could potentially test.

For the VE group, the design of the pre-course test was straightforward. The subject would be forced to run their selected route in the VE and actually prove that they could find all the points (at least in the VE). They had to be allowed access to their map during this training period, as map checks were available out on the course. However, the experiment didn't want individuals to run the test with map in hand, so they were limited to two thirty-second map checks. As in the real experiment, they would not be allowed to move during a map check. During the pre-course test, the subjects were also not allowed to use the 15 meter-overhead view, the top-down view, nor the teleportation features of the VE. These, while potentially useful for training, would not be available in the actual course so were prohibited to ensure that the subjects were not reliant on them. Due to the difficulties of determining exact orientation in a VE, the use of the compass could not be prohibited during the pre-course test. However, subjects were informed that their usage was monitored and if it were found that they were overusing the compass, they would be failed. Overuse in this case was regarded as constantly stopping to check direction of movement. All compass checks during the pre-course test were recorded as well.

As it was possible for people to get lost and recover in the actual course, this possibility was incorporated into the pre-course test. If subjects left their designated route (based on monitor observation) they were assessed an error. After five minutes if they had not corrected themselves, then they were stopped and oriented by the monitor. Subjects would be allowed to be oriented twice. If they required a third orientation they were considered to have failed. In addition, if subjects left the course boundaries, they failed. Note that due to the inability to actually see through the branches of the trees in the model, individuals actively searching for a point in the correct vicinity were not assessed to be in error. The pre-course briefing for the VE group is shown in Appendix C.

For the map–only group, devising the pre-course test was more difficult. Clearly, the subject had to show that they in fact had a clear understanding of where they wanted to go and how they would travel between the points, just as the VE group had to do. The map group, however, lacked the simulator with which to demonstrate this knowledge. The best way for the subjects to pass along this information was to verbally talk their way through the route they would follow. Appendix C shows the instructions the Map group was given. As with the VE group, the map-only group was given two map checks so that they could refresh their memory of their route if necessary. The monitor encouraged the subjects to be as detailed as possible on how they would travel, but did not ever define a necessary style for fear of biasing the results. For instance, if the instructions required the subject to mention distance, then that may have perhaps changed their planning. Thus no examples were given to the subjects; they were just encouraged to be as detailed as they could be. Thus, it was left to the monitor's judgement if the subject had a clear picture in his mind of how he would travel between the points. If the subject was vague or described a route other than what they showed on their plan, the monitor would ask them to describe the route segment again, preferably in more detail. More than two errors of this type would result in failing the pre-course test and return to the study time. It is important to note that while the monitor would ask for clarification if the subject described a wrong turn, the monitor did not notify subjects if they had misidentified a terrain feature on the map (i.e., a road as a stream, or a depression as a hill). This was done so as not to remove on of the potential hazards of reading a map, the misidentification of a feature. This was felt to be fair, as it was also possible for the VE group not to correctly associate the terrain or to misidentify a landmark and still find the points [GOER 98b]. The test was to determine if the subject had a clear picture in his mind as to how they planned to conduct the test, not a guarantee that it was correct or would be successful.

2. Experiment # 2: Varying Map Fidelity

For the second experiment, it was decided to go back a focus on the map given to the test subjects. As explained earlier in Section D. MAPS, Banker designed a 1:5,000 scale orienteering map for the experiment which Goerger also used [BANK 97] [GOER 98b]. Goerger had suspected that the fidelity of this map might have skewed the performance of the subjects in his experiment [GOER 98b]. He estimated that performance would decrease for a map-only group based on map scale. Figure 3.8 visualizes Goerger's supposition.

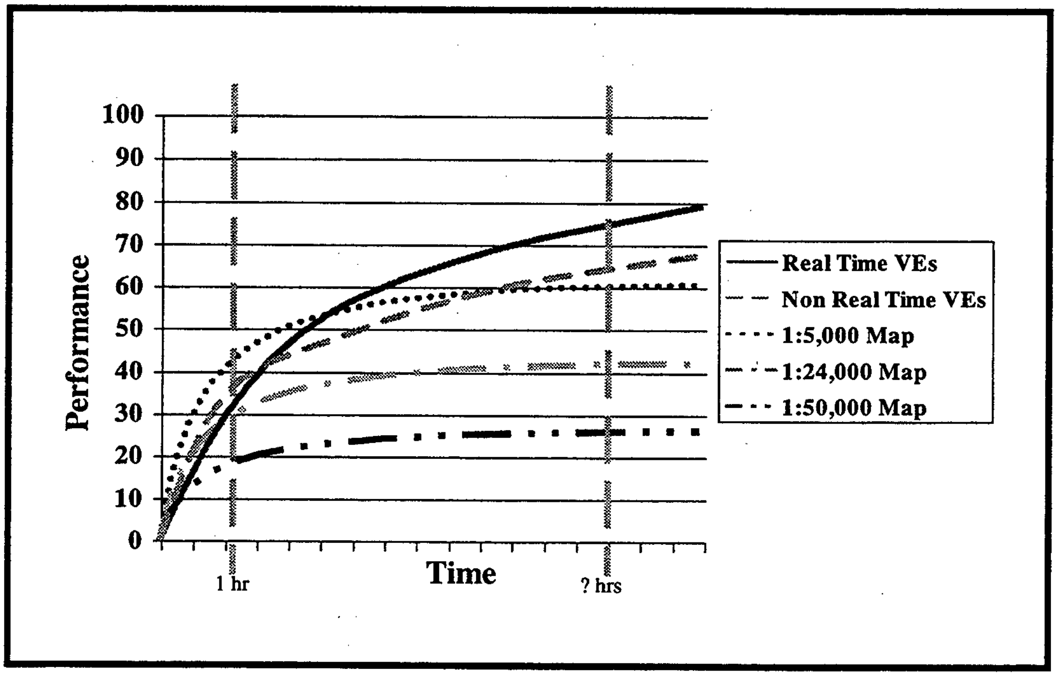

Figure 3.8. Goerger's Performance vs. Map Resolution Theory

Remember that the Army considers 1:50,000 to be the standard and sufficient scale for land navigation, with 1:25,000 being the absolute best available for training and operations [FM21 93]. Also, keep in mind that ISOM states that maps should be at 1:15,000 scale for competition, with 1:10,000 scale maps being allowed in exceptional cases and requiring official approval [ISOM 90]. In all cases, Goerger's subjects were military officers or civilians with orienteering experience. This group was either familiar with navigating given 1:15,000 orienteering maps or with 1:50,000/1:25,000 topographic maps. The subjects, when presented with a greater detail of information and in a format they were used to, may have been able to gain an advantage based on the level of detail alone. This is based, in part, on the observation of real world and VE subjects using part of their time to explore possible routes, not merely memorizing the selected route. Map-only subjects seemed to quickly decide upon a route and then spend their time memorizing it [GOER 98b]. This can also be observed in the after action questionnaire results. The subjects rated the map as more than adequate with it averaging a 4 out of 5.

In order to determine if the scale of the map had an impact on the results, the experiment went back to the methodology of the original Goerger experiment [GOER 98b] (see Chapter II). While the same methodology was used, the map itself was changed. Instead of the 1:5,000 map created by Banker, subjects were given a more realistically scaled two-sided map sheet. On one side the map sheet was a to scale 1:24,000 map of the course taken from the commercially available 1:24,000 scale map of the Fort Ord/Seaside California region. This map was purchased from the National Geological Department. Its basic terrain data was surveyed in 1929. It was last updated in 1983. On the flip side of the map-sheet was this same map blown up to 1:5,000 scale. However, no additional information was added. In effect, it just made the map easier to read. While this showed the same basic terrain as the Banker map, there were some significant differences. First, the 1:24,000 map showed one kind of vegetation, compared to the seven different types on the Banker Map. In addition, the trail network shown on the new map was nowhere near as extensive as the Banker map. One thing the new map did make much clearer, however, was the depression surrounding control point four. This had been difficult to discern on the Banker map, but was readily visible on the new map.

The second training aid added was the overhead photo of the region. This photo was used in the VE model where it provided shading in the top-down capability [GOER 98b]. In order to ensure fairness, this information had to also be provided to the map group. This is not entirely unrealistic either. For most important missions, units will be provided with aerial photographs of the objective area, even if not recent. This photograph was taken circa 1993 and the area had had minor changes to the trail network from what was shown in the photo. While the control points were shown on the photo, no legend was provided concerning vegetation or distance. While the photo was close to 1:5,000 scale it was not an exact match, so subjects could not directly transfer distance measurements from the map to the photo and vice versa. Neither the new map nor the photo showed any of the mad-made structures that had been so clearly shown in the Banker map. They also did not show the breaks in the vegetation, the tree lines, nor the small depressions, pits, trenches, or rock piles.

As mention earlier in this section the conduct of the experiment was the same as the Goerger experiment. The exact wording of the various experiment sections are found in Appendix C. In addition to the map changes, one additional change was made in the conduct of the experiment. Because of the inclusion of two different training aids for the map (the map and the photo), the time allowed for a map check and for the map and compass check together was increased. For this experiment map checks were given one minute, while map and compass checks together were given one minute and thirty seconds. This extra time was allocated to allow the individuals to peruse both training aids during any map checks. Other than the change in training aides and the difference in the time for the map checks, all other aspects of the training period and testing were the same as in both the Banker and Goerger experiments.

IV. ANALYSIS

A. RESULTS

1. General Information

The two different experiments used in this thesis were designed to test the two hypotheses regarding the spatial knowledge gained by participants exposed to different training methods. Participant's overall performance was evaluated based on the data acquired during their conduct of the actual orienteering course. This data comes from the results of the participant's performance on the landmark, route, and survey tasks.

a. First Experiment Hypothesis (Train-to-Standard):

Given extended exposure to training materials and the requirement to meet a set standard before continuing, individuals with access to a real-time virtual environment will outperform those who are only exposed to a map and photos of the control points with a similar standard.

b. Second Experiment Hypothesis (Map Fidelity):

Given an hour exposure to training materials to include a 1:24,000 scale map of the region, individuals with access to the VE will perform less poorly compared to their counterparts with a 1:5,000 map than those of the map-only group to their counterparts with the same conditions.

2. Power Analysis

The results of the experiments are presented as box plots with the mean, standard deviation, and standard error shown. Often extreme outlying data is depicted as dots on these plots. Most of the tests conducted on the data were two way analysis of variances (ANOVA). The primary analysis was based on the training group, but a host of possible factors were analyzed and are discussed in Section B. The sample size of this experiment combined with the Goerger experiment [GOER 98b] is 35 subjects in seven different groups. An α value of 0.05 was used to determine significance. The resulting power value ($1-\beta$) was 0.3051. Due to the high number of degrees of freedom and relatively low sample size, it may be unwise to draw conclusions based solely on the failure to determine a positive effect. Note that as with the Goerger experiment [GOER 98b], the simultaneity of effects was not considered so only ANOVA tests were conducted. This is not to say that there are no multiple factor effects, just that this was not examined as part of this thesis. Future work may wish to reexamine the data using multiple analyses of variance (MANOVA).

Note that for the charts shown, the following symbology is used: MAP is used to represent those subjects who were map-only in the original Goerger experiment. MAP1 is those subjects who were map-only in the train-to-standard experiment. MAP2 is those subjects who were map-only in the low-fidelity map experiment. RW represents the real-world subjects from the Goerger experiment. VE represents the Goerger study VE participants. VE1 is those subjects who were in the VE group for the train-to-standard experiment. VE2 is the VE group for the low-fidelity map experiment.

3. Normalization of Data

Some of the participants in the experiment were unable to complete all of the tasks because of the one-hour time limit during execution of the actual course. This is because some of the measurements occur at various locations spaced out over time and space. To make the subject's data comparable, many of the measures were normalized over the number of controls attempted to put the data into a format for comparison analysis. This normalization technique was used in evaluating average number of errors, average error distance, average distance per error, and average mapcheck scores respectively.

4. Landmark Knowledge

A subject's landmark knowledge was determined by their ability to locate the control points during the experiment. Subjects were given one point for each control they found (points had to be found in order). If the subject was timed out prior to completing the course, they could receive partial credit for the next point on their route. Subjects who had been heading to the next point and who were on their planned route received 2/3-point credit. Subjects who were off their planned route received 1/3 point credit. Subjects received no credit for points that they did not visit nor attempt. This scoring criterion is the same as in the original Goerger experiment [GOER 98b]. This score was combined into each subject's landmark score.

The landmark scores for all seven training groups are shown in Figure 4.1. Statistically the means are not different to our α standard of 0.05, $F(6,35) = 2.395$, P =

0.054. However, statistical differences were noted between the VE and MAP1, VE and MAP2, and VE and VE1. Observation of the results suggests that the train-to-standard groups perform the best with the VE1 train-to-standard group achieving a perfect result (all subjects finished the course finding all the controls). The map-only train-to-standard was not far behind with all subjects finding eight or more controls. This suggests that subjects who trained to a standard, and not just for an arbitrary time, learned the course better. Furthermore, those that had time to explore in the VE were able to gain the most landmark knowledge. It also lends credibility to the first hypothesis of this thesis.

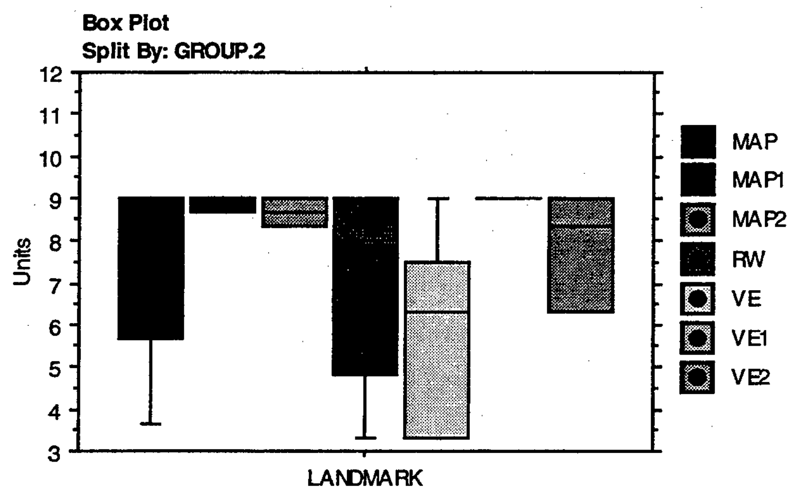

Figure 4.1. Box Plot of Landmark Score (Group)

The strong landmark performance of the MAP2 group (map-only group low-fidelity map) does not fit the experiment's hypothesis. The most likely explanation involves route simplification. This explanation is described in Section B.

When evaluating the results strictly from the macro-group perspective, the analysis is far less distinct, with F(2,35) = 1.236, P= 0.304. We are thus not able to state any conclusive results from any given treatment source (RW, VE, or MAP). This lack of significance is not surprising given the very strong differences noted above between the various treatment groups. Figure 4.2 shows the box plot of the macro-group.

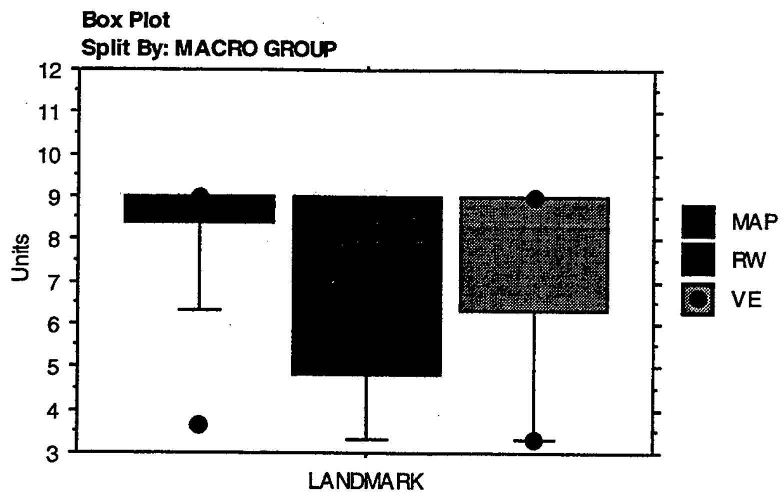

Figure 4.2. Box Plot of Landmark Score (Macro-group)

5. Route Knowledge

For this thesis, a subject's route knowledge was determined by evaluating how well they followed the path that they planned during their initial training period (see Chapter III, Section A. Training Overview). Three different measures were judged to determine exactly how well the subjects kept to their route.

a. Normalized Error per Control

First, the number of errors committed, averaged per control point (and normalized as mentioned earlier) was compared. The types of errors were discussed in Chapter III Errors. For this analysis, only mirror, parallel, and compound errors were included. Reorientation errors and out-of-bounds errors were included in the map check results, to be discussed following. Individuals who made fewer errors per control point were considered to have performed better.

Figure 4.3 shows the normalized average error score for all seven of the subject groups. All three of the map groups are about the same with between 0.6 and 0.7 errors per control attempted. This is followed by the real world at 0.78. The biggest difference between the groups comes from the VE groups. The train-to-standard VE outperformed everyone with 0.40 errors per control. This was followed closely by the low-fidelity map VE group at 0.48 and the original VE group trailed everyone with 1.0 errors per CP attempt.

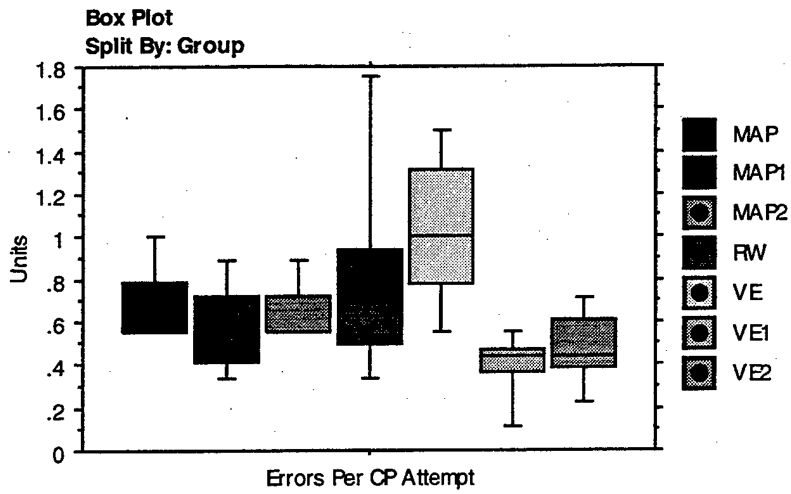

Figure 4.3. Box Plot for Errors per Control Attempted (Group)

The means between groups are statistically different, F(6,35) = 2.497, P = 0.0462, with the significant differences coming between the VE and VE1 group, VE and VE2, RW and VE1, VE and MAP1, and VE and MAP2. The analysis of the data seems to show a remarkable improvement for the VE subjects when trained to a standard as opposed to just a time limit, as in Goerger's experiment. Direct observation of the results suggests that the map-only subjects for the train-to-standard condition also showed improvement over the other map-only counterparts, but to a much lesser degree. Subjects who train-to-standard with maps had slightly lower average number of errors compared to the other map-only subjects (0.600 vs. 0.676[MAP] vs. 0.644[MAP2]). This result would tend to support Goerger's theory that the information that can be gained from a map will level off over time [GOER 98b]. These results seem to support the first hypothesis of this thesis; subjects who trained to standard with the VE not only found more controls than the other groups (see Section A.4. Landmark Knowledge) but made fewer errors than those who trained to time. This superior result would have been even lower had not one VE1 subject (VE1-3) twice decided to go down follow a path he believed to be wrong, just to confirm that it was wrong! The results of the VE2 and MAP2 groups are surprising and unexpected. A possible explanation is found later in Section B.1.

When the results are examined using the macro-groups (MAP, VE, and RW), no statistical difference between groups is found, F(2,35) = 0.411, P = 0.6662. However, direct observation shows the MAP macro-group with a much smaller standard deviation over the course of the experiments. This implies that regardless of how long they studied, or the level of information on the map, the map-only group performed about the same, at least as far as number of errors. One of the reasons for this is the familiarity of the military officers in this study with maps and map reading. Figure 4.4 shows the box plot of the macro-groups.

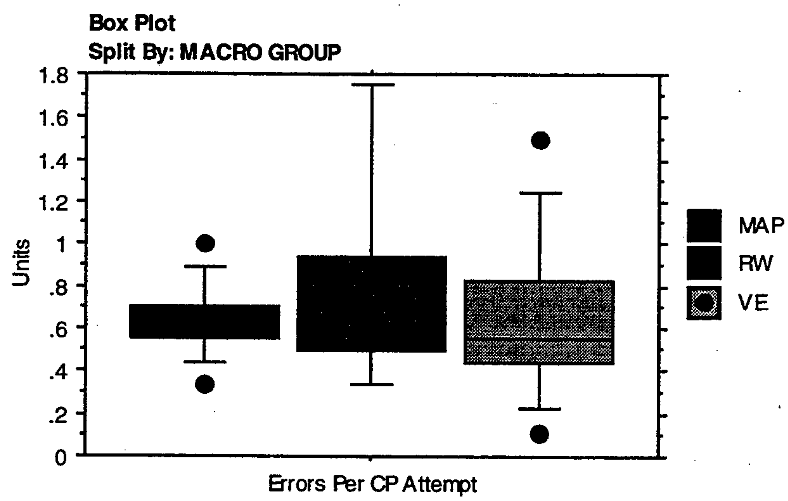

Figure 4.4. Box Plot of Errors per CP Attempt (Macro-Group)

b. *Distance Traveled per Error*

The number of errors a subject makes is just one factor of route knowledge. Just as important is determining how long it takes a subject to determine they have made an error and recover. While no exact time measurements were taken to determine how long this took, this was evaluated in terms of distance traveled from the point of the error until the individual returned to their planned route or found the correct control. It was possible for subjects to never recover from an error; either because time ran out, or because 15 minutes elapsed and the monitor reoriented them. For purposes of this test, all of a subject's error distance for a point was added and then divided by the total number of errors for that point. Adding the subject's totals for each control point and then dividing by the number of controls attempted (to normalize the data) gives the average distance per error per CP attempted. Goerger called this the Total Error Score [GOER 98b]. Figure 4.5 shows the results of this split by training group.

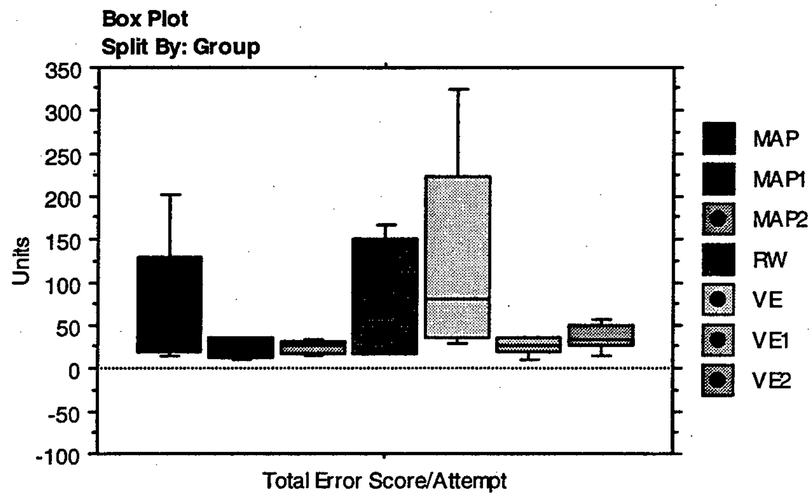

Figure 4.5. Box Plot for Total Error Score per CP Attempt (Group)

The results of the analysis of means is not statistically significant overall, F(6,35) = 2.188, P= 0.0743, but there were major differences between the VE1 and VE, VE2 and VE, MAP1 and VE, MAP2 and VE, and VE1 and RW. Direct observation of the data shows that subjects of the train-to-standard groups (VE1, MAP1) not only made fewer errors than other groups (as mention in the previous section), but also traveled less distance on those errors before they corrected themselves. This seems to show that these subjects had a better understanding of the route they planned to follow and where they were on that route at all times. It also means they recovered quickly if they did veer off course. The low-fidelity map groups also performed very well. The rationale for their improvement is explained in more detail in Section B.1.

The results of the macro-groupings were also analyzed to see if any significance could be found from the overall training group. With a variance of means of F(2,35) = 0.422, P = 0.662, no significant effect can be concluded based on the macro grouping. Figure 4.6 shows the box plot of the distance per error based on the macro-groups. While no statistical conclusion can be reached, direct observation shows that the map as a whole resulted in much less standard deviation among the various groups. Again, this can be attributed to the familiarity of the subjects with map reading.

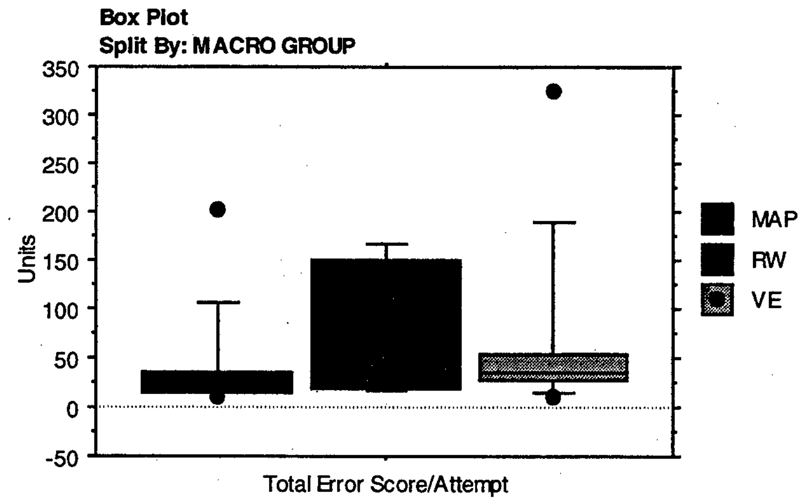

Figure 4.6 Box Plot for Total Error Score per CP Attempt (Macro-Group)

c. *Map and Compass Checks*

Subjects had their map check scores calculated for each leg of the course. As mentioned in Chapter III Map Checks, subjects were allowed to make three different kinds of map checks during the course of the experiment. These were map only, compass only, or map and compass together. These checks were timed and recorded by the monitor. Subjects were not limited in the number of map checks they were allowed to take, and they could take back-to-back checks if they desired additional time. Subject's instructions were to "minimize" the number of map-checks, which clearly meant different things to different people. Some subjects refused to request the map, even if they realized they had left their route or when they were confused. Others requested the map at each control, even if they had been performing well.

The weights of the mapcheck scores are the same as in the Goerger experiment to allow for comparison of results [GOER 98b]. Subjects who took a map or a compass check got one point. Map and compass checks combined were 1.5 points, since the two in combination allowed more information to be gathered. Subjects who desired to change their route were assessed a 0.5 point penalty. While additional information can be gained from the map during the one minute allotted to mark the new route, this is offset by the relatively limited study time the individual has to plan a new route. Goerger stated that the subject must already have knowledge of their location and destination in order to correctly plan an effective new route [GOER 98b]. Accordingly, this value was set lower so as not to penalize the subjects for information they ideally already had. The marking of a new route from a misidentified location immediately gave the subject a parallel error when they started to move. If a subject left the course boundaries, they were given a two-point error because they demonstrated a lack of knowledge of that area. Knowing they moved out-of-bounds, they discover that their current mental map is in error. This lets them know that they are not where they think they are, thus giving information that may not be gleaned from looking at the map alone. Finally, if subjects had been lost for 15 continuous minutes they were awarded a reorientation error with 3.0 points. This extreme penalty is because they were shown their exact location on the map, and were then given the opportunity to plan a new route to the next control.

The lower the mapcheck score, the better the overall performance. Figure 4.7 shows the box plot of the groups using a normalized map check. This number was the total number of mapcheck points the subject was awarded divided by the number of controls attempted. The means between training groups are statistically different with

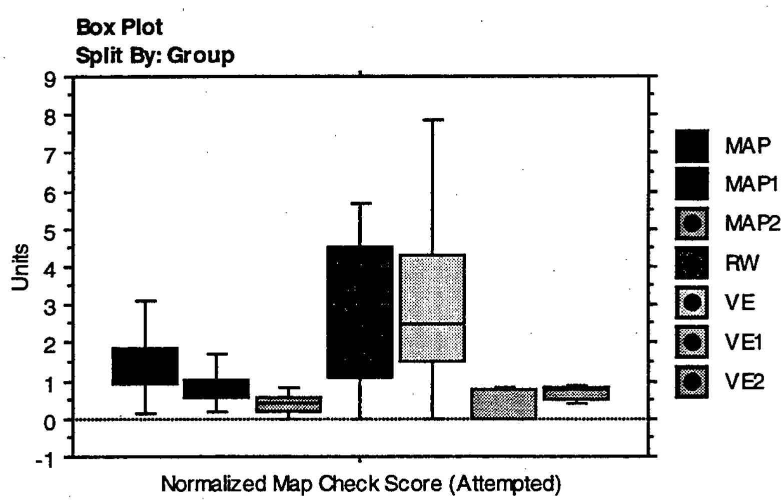

Figure 4.7. Box Plot for Normalized Map Check Score per CP Attempt (Group)

F(6,35) = 3.078, P = 0.0193. There were significant differences between the means of the VE1, VE2, MAP1, and the MAP2 groups and the RW and VE groups. These results indicate two different things. First, in the case of the low-fidelity map groups, subjects tended to not consult the map as much because of the scarcity of detail on the map. Also, those subjects tended to choose simpler routes that kept to the exterior boundary roads and thus had lesser chance to make parallel errors and need to make map consultations. This finding is explored in more detail in section B. Second, as noted in the original Goerger experiment, subjects who had more confidence in their mental maps required less checks to resolve differences. The map-only group is merely demonstrating the same effect as shown in the Goerger experiment [GOER 98b]. The results suggest that the train-to-standard VE group was also able to develop this superior mental map during training. This suggests that training-to-standard developed an individual's mental map more than the hurried one hour study period previously allowed.

6. Survey Knowledge

As explained in Chapter II Spatial Knowledge, survey knowledge is considered to be the highest level of spatial knowledge and is the most difficult to acquire. In order to determine the subject's level of survey knowledge of the environment, three different tests were conducted.

a. Wheel Test

Chapter III, Section J. Wheel Test describes the conduct and reasoning behind the wheel test, which was conducted at controls two and four. All subjects in the experiments conducted for this thesis performed these tests. In the original Goerger experiment, four subjects failed to reach control point four and thus did not take the second wheel test. For the test, the subject's answers were compared to the actual angle of the controls. The absolute value of the difference was calculated and summed for each test (CP2 and CP4 respectively). A lower angle difference equates to better performance. Figure 4.8 shows the total average angular difference based on the groups. Figure 4.9 shows the group results for CP2 and Figure 4.10 shows the CP4 results.

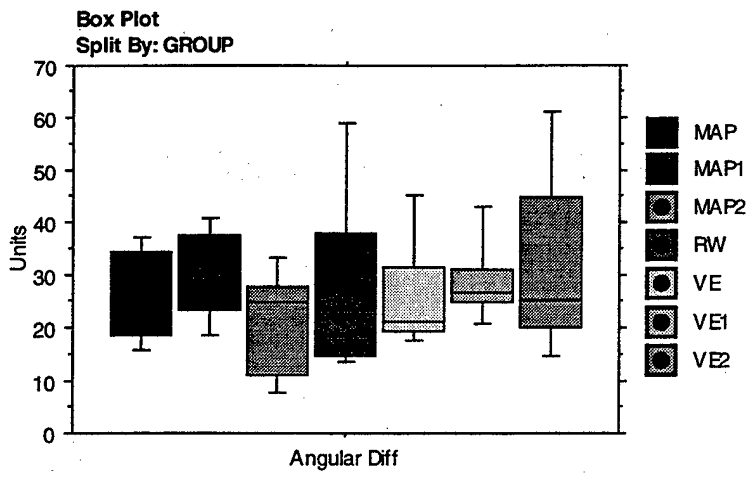

Figure 4.8. Box Plot for Average Wheel Test Angular Difference (Group)

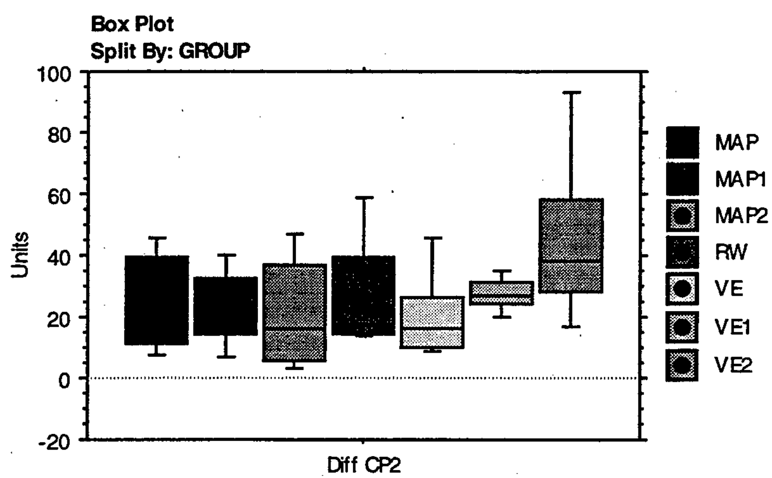

Figure 4.9. Box Plot for CP2 Wheel Test Angular Difference (Group)

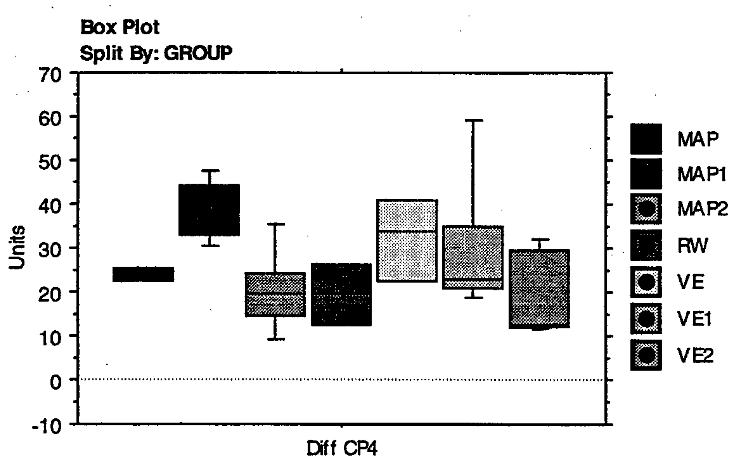

Figure 4.10. Box Plot for CP4 Wheel Test Angular Difference (Group)

For the total average, the means between the groups show no statistical difference, F(2,35) = 0.425, P = 0.859. The same is true for the individual tests evaluated separately: CP2 (F(2,35) = 1.162, P = 0.354) and CP4 (F(2,31)= 2.488, P = 0.0514). Direct observation of the results suggests that overall there was no discernable pattern. At CP4, both the MAP2 and VE2 averaged the least angular difference of any of the groups. Perhaps the clear depiction of the depression resulted in a clearer mental map at this point.

As a further check regarding survey knowledge, the data was examined at the macro-group level. Figure 4.11 shows the box plot of the results. All of the groups averaged a total of about 27 degrees off in their estimation. While not statistically valid (F(2,35) = 0.231, P =0.794), direct observation suggests that subjects who used only the map had less deviation in their answers, resulting in more uniform performance. This does not show that any group had better survey knowledge.

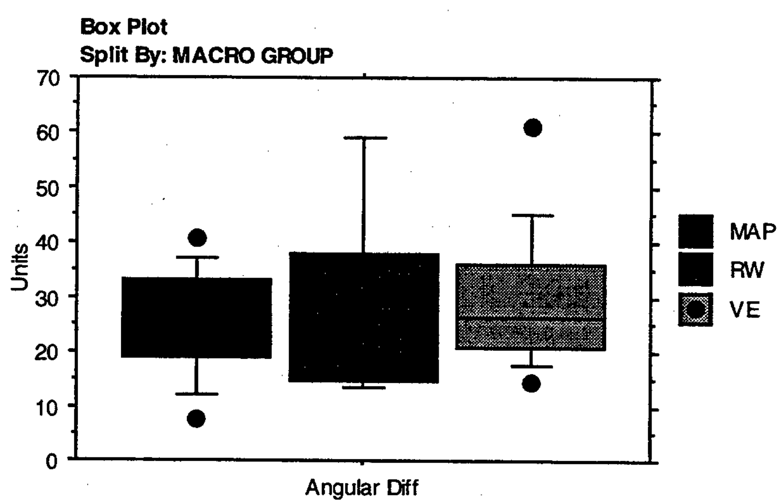

Figure 4.11. Box Plot for Average Wheel Test Angular Difference (Macro-Group)

b. White Board Test

Upon the conclusion of the experiment, every subject was given the whiteboard test (see Chapter III White Board Test). The analysis of the whiteboard results allowed a subject's level of exocentric survey knowledge to be evaluated. This was done by following the same procedures in the Goerger experiment [GOER 98b]. The angle between the control points was measured by determining the distance the subject judged the points to be apart in the XY plane. This distance was normalized using the total distance and then, using the Pythagorean Theorem, the angles between successive points were calculated. The subject angle results were compared to the actual course angles. Figure 4.12 shows a box plot of the resulting angular differences by group.

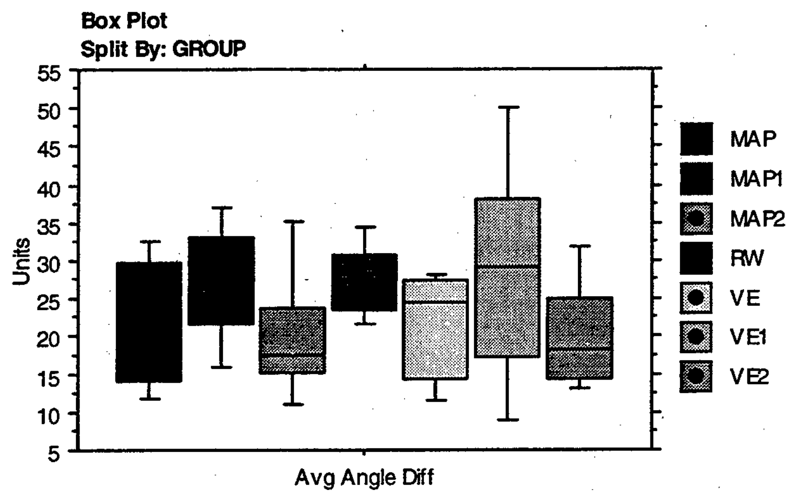

Figure 4.12. Box Plot for Average Whiteboard Angular Difference (Group)

Statistically there was no difference between the means with F(6,35) = 0.789, P = 0.586. Direct observation seems to show that the real world had less variance between their answers, but by no means did they perform better than any other group. Figure 4.13 analyzes the results based on the macro-group.

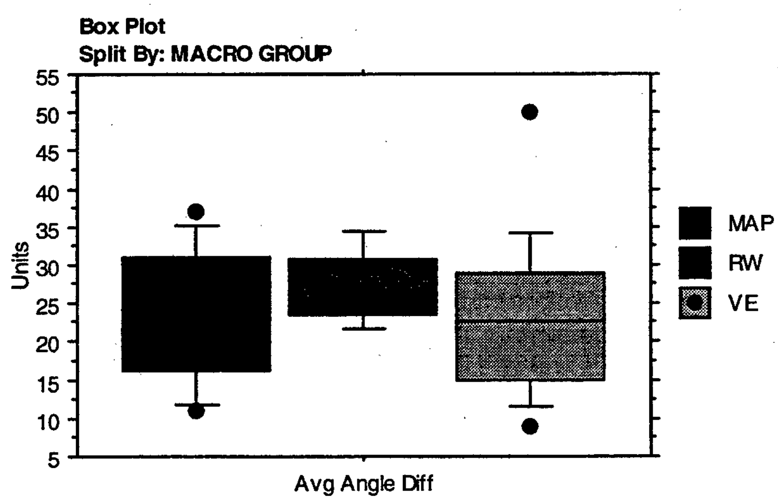

Figure 4.13. Box Plot for Average Whiteboard Angular Difference (Macro-Group)

No statistical variation is noticeable (F(2,35) = 0.480, P = 0.624), nor do any differences appear in direct observation. The results seem to suggest that there is no difference between the groups in survey knowledge based on the angle error.

The distance difference from the normalized distance of a leg and the user's normalized distance from the whiteboard was also analyzed and compared. As with the angle analysis, no statistical differences were noted among either the groups (F(2,6) = 2.19, P = 0.0732) or the macro-groups (F(2,35) = 1.37, P = 0.268). Figure 4.14 shows the box plot for the group average distance difference. Direct observation of the data shows that the MAP2 group averaged lower errors on this task. The VE1 group also had the most variation, suggesting that the VE did not play a significant role in imparting survey knowledge. It also suggests that the lack of means of distance estimation in the VE particularly hurt those who spent extended time in the model.

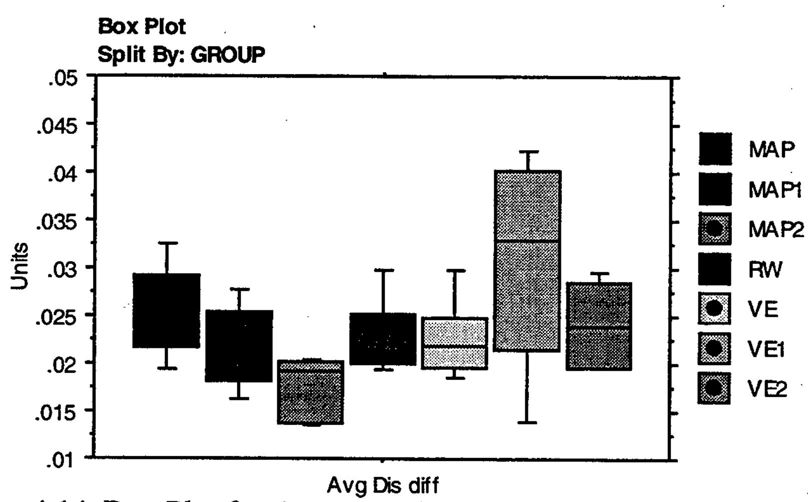

Figure 4.14. Box Plot for Average Whiteboard Distance Difference (Group)

Overall, there does not seem to be a large difference between the various groups in the survey knowledge evaluated by the whiteboard. This may be in part because this test was given at the very end of the course, after all individuals had been exposed to the area. This exposure may have equalized any benefit or hindrance imparted by the various training methods. It might be better for future experiments to conduct the whiteboard test prior to running the course, so that the subject will not have modified their mental map based on the actual terrain.

c. Unplanned Route Execution

If, and only if, the subjects successfully complete the course in one hour were they given the unplanned route test. For this task the subject would have to first explain how they would go from their current location, control point nine, to control point four. They had to give this explanation without first looking at a map. The subjects were then given ten minutes to move from CP9 to CP4. Most of the subjects planned this route to allow them to go over terrain they had been over once before, whether from a previously planned route, or from travelling through the area while in error. For the experiments done for this thesis, every subject who reached control point nine was able to successfully complete the unplanned route in the time allotted and none made errors off their planned route. This was also the result of the Goerger study [GOER 98b]. While there was a slight difference in the time subjects took to accomplish the task, it was not significant.

These results seem to indicate there is no discernable difference in acquiring survey knowledge based on training method. However, because the test was not given to every subject, it is impossible to draw any conclusions concerning this task performance and training grouping. There is also the possibility that since subjects had actually traveled the ground, that any survey knowledge gained was the result of this direct exposure.

One interesting caveat to this experiment: One test subject (M1-1) was timed out 51 meters short of CP9 and was on his route when time ended. Because he was so close to finishing, the subject was given the unplanned route test (though because he did not finish, his results were not included). Surprisingly, the subject was not able to accomplish the task. Instead, he become disoriented and missed his planned turn. Whether this result was due to an incomplete mental map or some other factor is unknown.

7. Navigational Performance by Training Condition

The results of the analysis do indicate statistical significance based upon the training condition. The results show that those who trained using the VE1, VE2, MAP1, and MAP2 generally performed landmark and route tasks better than the original VE and RW group. Direct observation of the results showed the train-to-standard groups performed better than the Goerger training groups (RW, MAP, and VE) and the low fidelity map group (VE2, MAP2). Direct observation also showed that the train-to-standard VE group appeared to outperform all other groups in the route and landmark tasks.

Caution is advised when using these for conclusion for a number of reasons. The relatively small sample size in each group allows the results to be thrown off by one or two outlying results. Also, it is difficult to compare the results of broad categories of errors and distances given the vastly different routes subjects used. If subject A made his errors on a short but difficult route, how comparable is the mistake to subject B's mistake on a longer easier route? Another reason for caution is that the standards for judging errors in the study required navigation to standards that are vastly different from most military subject's experience. Most military navigators use terrain association and do not hesitate to perform quick detours to confirm they are on their route. In this experiment, this technique results in an error. Many subjects would also adopt a wide, circular search pattern for the controls, adding error distance.

The low fidelity map group's (MAP2, VE2) switching to the boundary road approach was unforeseen, and resulted in their better performance than the original Goerger groups. While travelling the boundary road was not always considered a simpler route (see Appendix L) it was easier to follow than the numerous twisting interior trails. Perhaps prohibiting use of the boundary roads would have produced results more in keeping with the second hypothesis of this thesis. However, because no such restriction existed for the other groups this would have made the results incomparable.

With regards to survey knowledge there was no discernable difference between either the training groups or the macro groups. This may be in part due to the nature in which most of the tests were conducted. Since only those who finished the course were given the unplanned route test, only those with a better overall picture of the environment were able to attempt this test. It is no surprise that they completed it. The exposure to the actual course also may have blurred potential distinctions between the training groups in the whiteboard results. Future research may need to focus more on the survey task directly in order to better discern the differences, if any.

B. DISCUSSION

1. Effect of Lowering Map Fidelity.

As explained in Chapter III, Section N. Training, the second experiment was conducted to examine possible inherent bias in the highly detailed map given subjects of the earlier experiments. The expected results were that everyone would perform more poorly, but that the VE group's performance drop would be less severe than that of the map-only group. As was noted earlier in Sections A.4, A.5, and A.6, the low fidelity map-only and VE groups did better than their corresponding groups in the original Goerger experiment. What would explain this?

First, it should be noted that while the map had a lower overall fidelity, one thing the map improved upon was in clearly showing control point four was in a depression. Nevertheless, how much effect did this clarification have on performance? Figure 4.15 shows the seven groups number of errors on control point four.

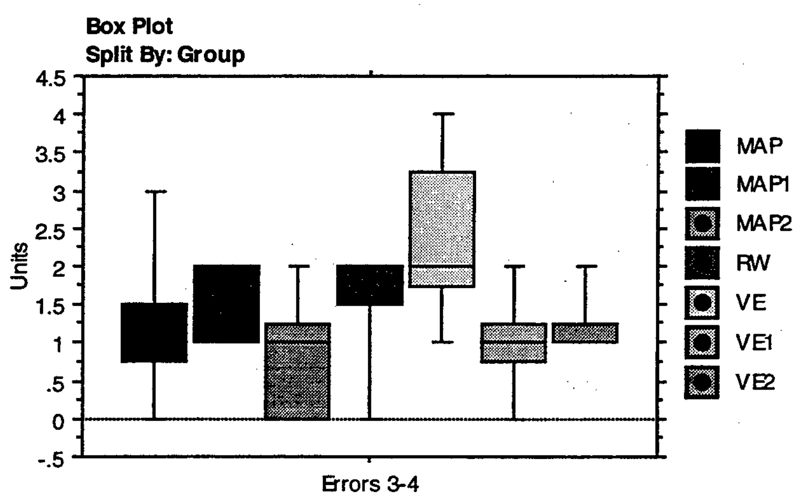

Figure 4.15. Box Plot for Number of Errors CP4 (Group)

This figure shows that on average, the low fidelity map groups made one less error than the original VE group. In fact, the original VE group's average for CP4 is twice that of their overall average (see Figure 4.3). This is a higher percentage than for the other groups. Both the MAP1 train-to-standard and the MAP group also had much higher error rates for this control than their other points. Note that neither the low fidelity map, nor the extended exposure to the virtual environment for VE1, eliminated errors. The real effect is seen in Figure 4.16, which shows the average amount of error distance for each group at CP4.

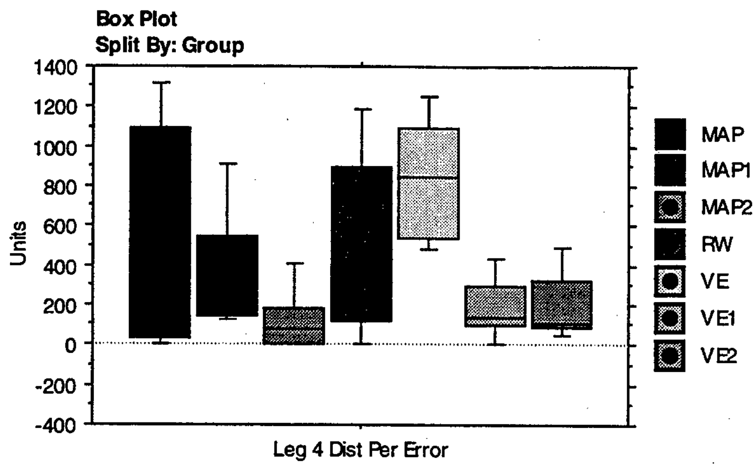

Figure 4.16. Box Plot for Average Distance per Error CP4 (Group)

From these results, we clearly see that the original VE, MAP, and RW had much higher error distances at CP4 compared to the low fidelity map. This raised their overall total error score considerably. The train-to-standard VE group escaped this problem, most likely due to the extended exposure to the area during training allowing them to overcome the poor map representation.

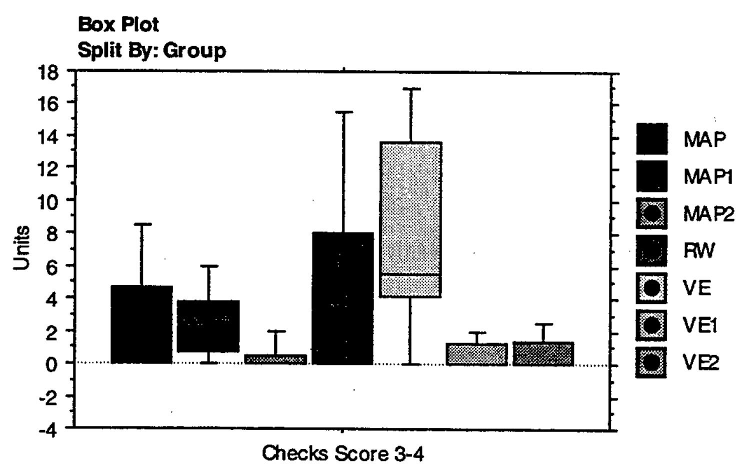

Figure 4.17. Map Checks Score for CP4 (Group)

Figure 4.17 shows the map check scores for CP4. From the box plot, the results show that every group other than the low fidelity map groups and the train-to-standard VE1 group had much higher map checks score than average at CP4. Since the low fidelity group did not have this large statistical jump, their overall performance was lower.

The other reason for the improved performance is that the low fidelity map groups adjusted their routes based on the information provided. Since this group was provided almost no information about the interior trails in the area, they tended to avoid internal travel whenever possible and stuck to the boundary roads more than the other groups, even for short movements. While staying on the boundary roads was not always considered the easier route (see Appendix L) it did have the effect of reducing complexity and reducing the chance of parallel errors. There tended to be limited trail and path intersections with the boundary road, so individuals could easily discern their location. Since those intersections that did exist were prominent, the low fidelity group tended to have good attack points when they left the boundary road to begin their search. Figures 4.18 and 4.19 show the box plots of the planned difficulty of the routes for the two groups. While there is no statistical difference, direct observation suggests that the low fidelity groups planned easier routes. Again, remember that using the boundary road was not always considered the easier route since in many cases it added significant distance. Section B.2. Route Complexity shows how simpler routes improve performance.

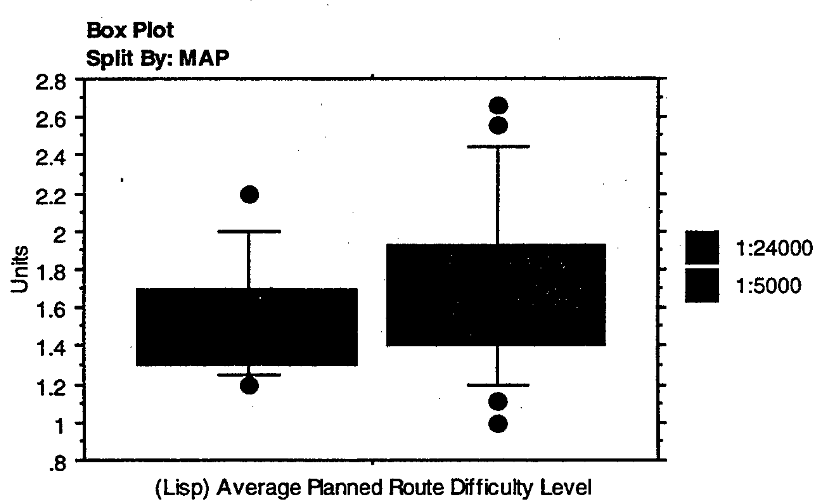

Figure 4.18. Box Plot for Lisp Planned Route Difficulty (Map Fidelity)

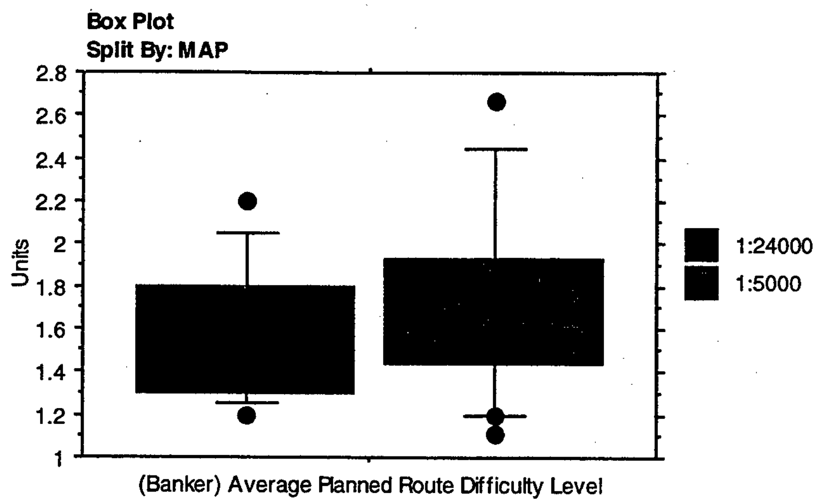

Figure 4.19. Box Plot for Banker Planned Route Difficulty (Map Fidelity)

Many subjects were aware that their strategy of using the boundary roads was adding distance. Within VE2, both subjects who failed to find CP7 determined that they were "eating" too much time by using the boundary roads. They planned to incorporate a shortcut while enroute from CP6 to CP7 along the boundary road by cutting through the woods to save time. In both cases, the subjects never recovered from their "shortcut."

Figure 4.20 clearly shows that the low fidelity map group conducted less map checks as well. This was most likely due to the lack of detail on the map.

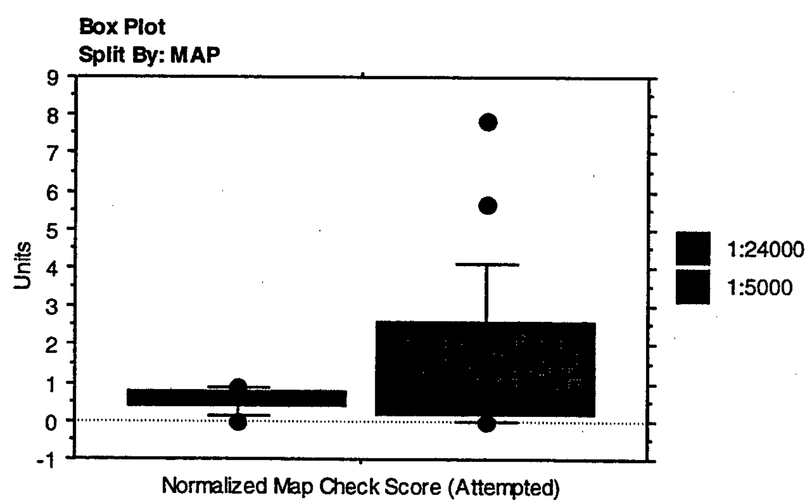

Figure 4.20. Box Plot for Normalized Map Check Score per CP Attempt (Map Fidelity)

Overall, the fidelity of the map had no effect on survey knowledge tasks. Figure 4.21 shows the box plots of the average angular difference from the wheel test (discussed in Section A.6 previously). No difference is discernable. Likewise, there is no difference for CP2. This is shown in Figure 4.22.

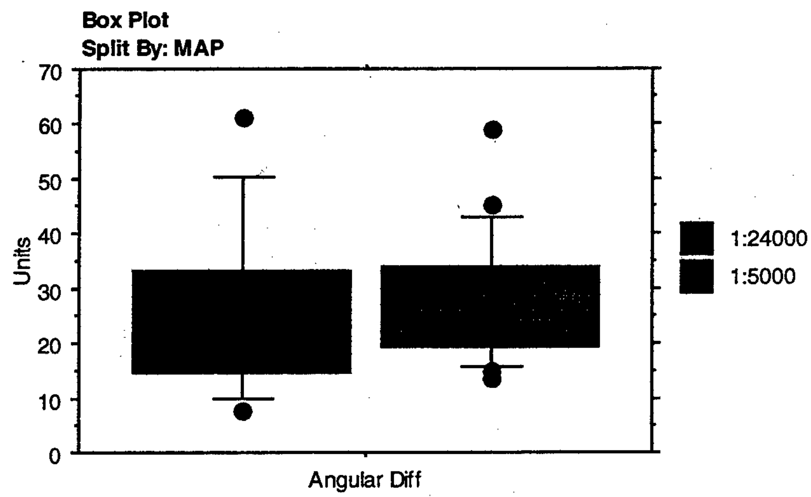

Figure 4.21. Wheel Test Angular Difference (Map Fidelity)

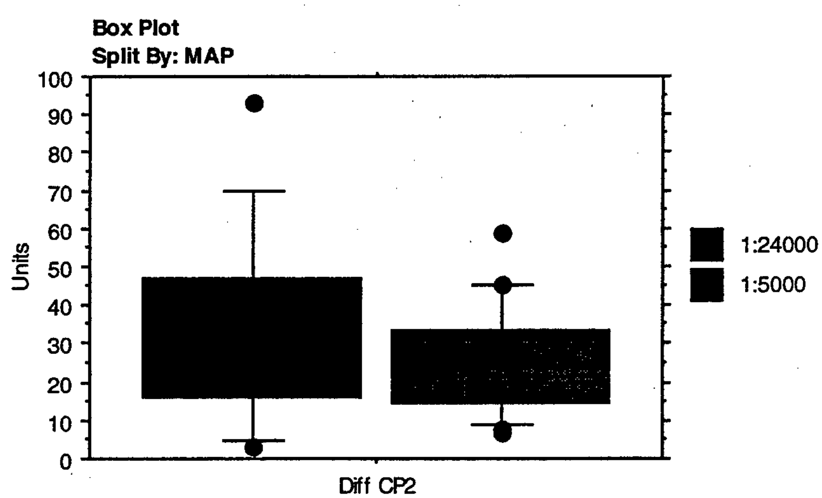

Figure 4.22. Average Wheel Test Angular Difference CP2 (Map Fidelity)

There is a statistical difference between the means at CP4, however, $F(1,31) = 4.736$, $P = 0.0373$. Observation of the data suggests that the 1:24,000 scale map users had less angular difference than those with the 1:5,000 scale map. Figure 4.23 shows this result. The low fidelity scale map users averaged ten degrees less difference than the other group. The likely explanation for this was the confusion that many 1:5,000 scale users suffered over the location of CP4. In mistakenly looking for CP4 on a hilltop, when they finally located CP4, they had very recently changed their mental map. This may have resulted in their overall worse performance.

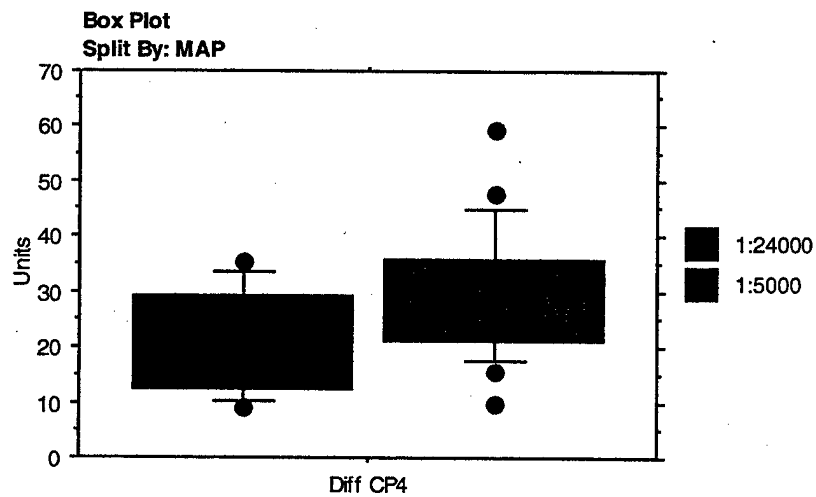

Figure 4.23. Average Wheel Test Angular Difference CP4 (Map Fidelity)

Examining the results of the whiteboard test, we see no statistical difference between those with the high fidelity map and the low fidelity map. Direct observation suggests that the low-fidelity map averaged slightly less error.

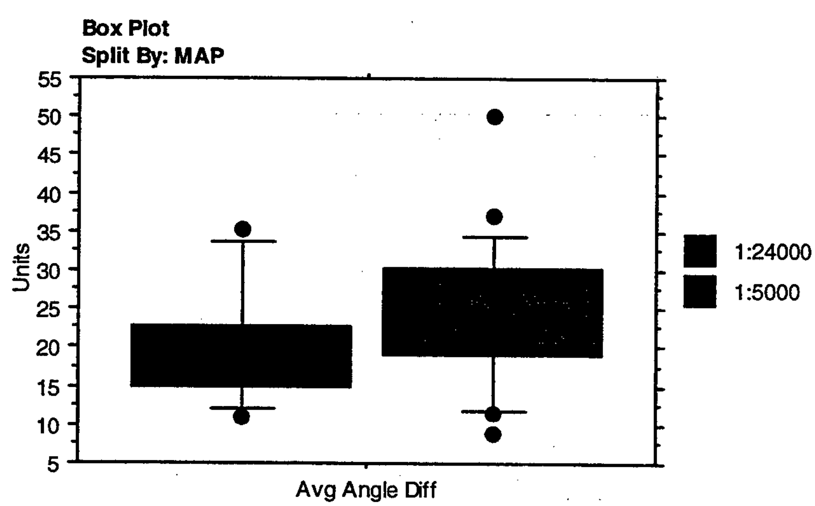

Figure 4.24. Average Whiteboard Angular Difference (Map Fidelity)

2. Route Complexity

As mentioned in the preceding section, the fact that the low fidelity map groups shifted to the boundary roads resulted in giving them better performance than the original Goerger groups. In many cases, following the boundary roads was not considered the "simplest" route. What correlation, if any, exists between route difficulty and performance?

Figure 4.25 shows the regression plot of the planned route difficulty of both the Lisp and Banker scales versus the Landmark results (see Appendix L). Direct observation of the plots suggests that as the planned difficulty of the route went up, the subject's score

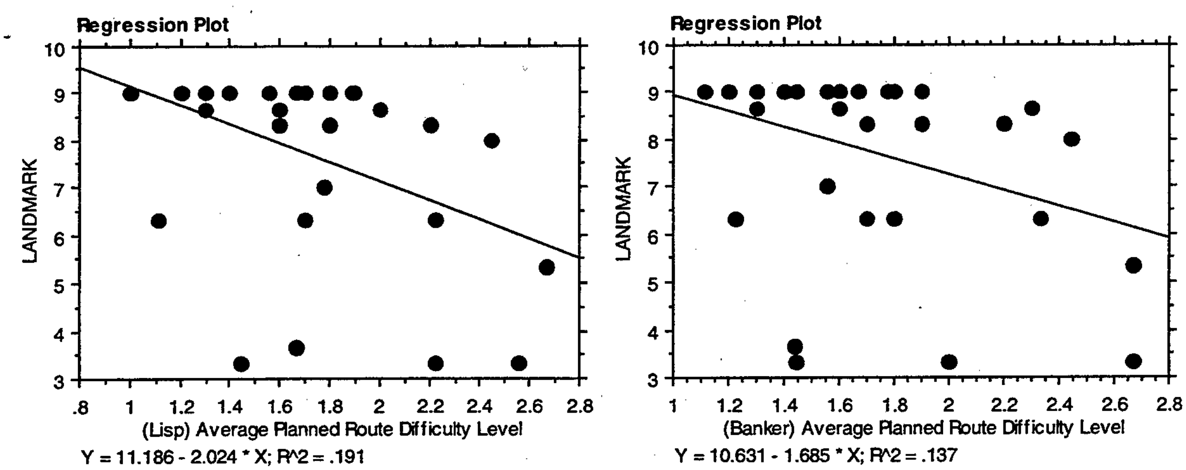

Figure 4.25. Regression Plot for Landmark Results vs. Planned Route Difficulty

went down. These results are statistically significant with the lisp results F= 7.78, P = 0.0086, and Banker F= 5.223, P = 0.0289. This suggests that subjects with "easier" routes were less likely to make errors they could not recover from, nor were they disoriented as much. It also suggests that "easier" routes were more readily memorized and recalled. Similar results occurred for the errors per control point attempted, with both scales achieving statistically valid results (Banker: F= 7.815, P = 0.0086, Lisp: F= 10.584, P = 0.0026). In both cases, subjects with easier routes made fewer errors. This is shown in Figure 4.26, with the lower number of errors indicating better performance.

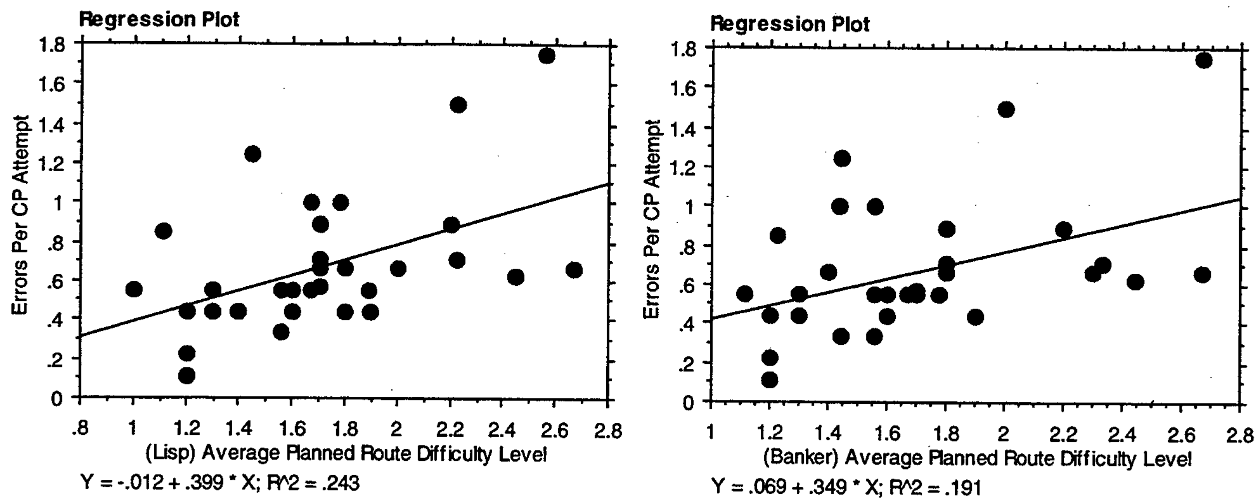

Figure 4.26. Regression Plot for Errors per CP Attempt vs. Route Difficulty

The results of simple regression of the route difficulty versus both the normalized map check score and the total error score, while not resulting in statistically valid results, did suggest a similar pattern. Direct observation of the data seemed to show that those with easier routes made less map checks and traveled less distance per error than those following routes that were more difficult.

These results indicate that the difficulty of the route that subjects planned did have an effect on their route and landmark task performance. They also provide anecdotal support for the first hypothesis. In all three experiments in this series, real-world and VE subjects with a one hour planning limit often ran out of time during their training before adequately planning their route. This was often caused by the subject actively exploring possible routes from the start, as opposed to solely using the map. Because they spent much of their time exploring, they often had extremely limited time to plan and memorize the final legs of their route. Often this led to them just drawing a "straight-line" between points, as opposed to finding an easier route. Such "straight line" routes were almost always among the most difficult, and, from the above results, the most error prone. Thus, the one-hour time limit for the VE/real-world tended to force harder routes, which in turn resulted in poorer performance. Removing the time constraint resulted in easier routes and better performance.

The user's route difficulty had no bearing on their survey task performance. Regression analysis of route difficulty versus angular difference resulted in no significant pattern. Nor were there valid differences in the whiteboard test.

3. Effect of User Ability Level

Individual differences can have a large effect on performance, and one of the major differences between the subjects in this experiment was their level of navigational experience. Subjects evaluated their skill level both written and by using a bar-line. The bar-line was used for our comparison analysis, as no subjects evaluated themselves as beginners (possibly due to bias against the word "beginner") with their words, but several fell into this category by the bar-line.

Examining the landmark results based on the subjects, there is no statistically valid difference between the three ability levels, $F(2,35)= 1.938$, $P = 0.1605$. However, direct observation of the data, shown in Figure 4.27, suggests that those subjects in the expert category found more control points. The expert group also had less variation. Beginners averaged the least number of controls found, and the most variation.

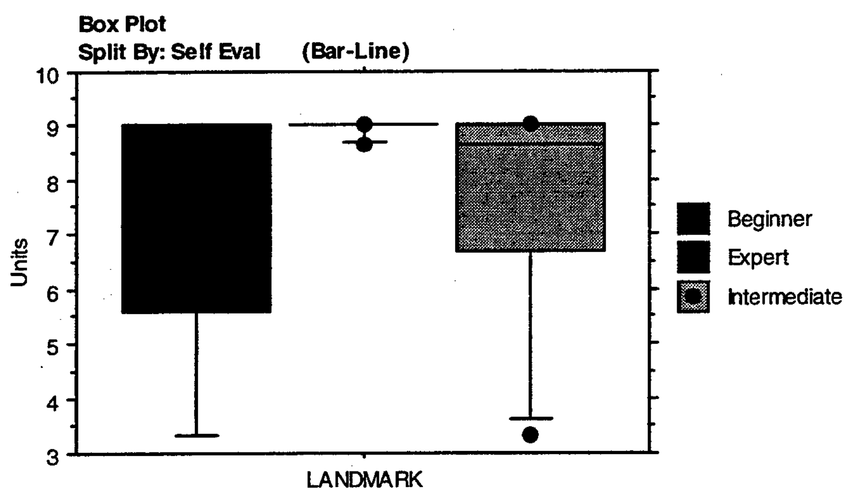

Figure 4.27. Landmark Score (Self-Eval)

Figure 4.28 displays both the errors per control attempted and the total error score for the user's navigational ability level. The lower score represents better performance. Neither analysis resulted in statistically valid difference of means. Direct observation of the results suggests that expert classification subjects traveled less distance after making an error before they realized their mistake. The data also suggests that beginners made the most errors per CP attempted.

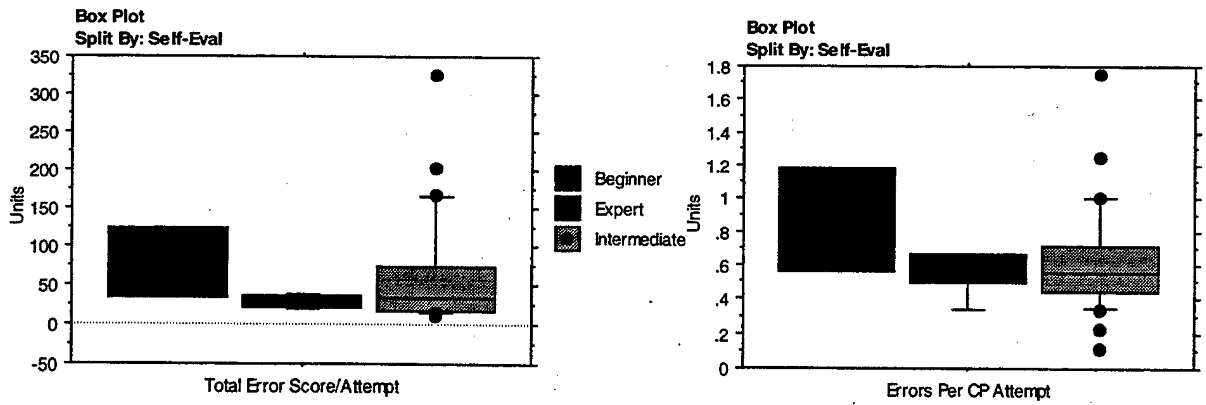

Figure 4.28. Total Error Score/Attempt and Errors per CP/Attempt (Self-Eval)

The results of the normalized map check scores, analyzed by self-evaluated ability group, are shown in Figure 4.29. There is no correlation apparent upon direct observation. Intermediate ability users had the widest variation. Beginners averaged the same map check score as experts, but for different reasons. Experts were less likely to be lost and require a map check. Beginners were less likely to realize they needed one.

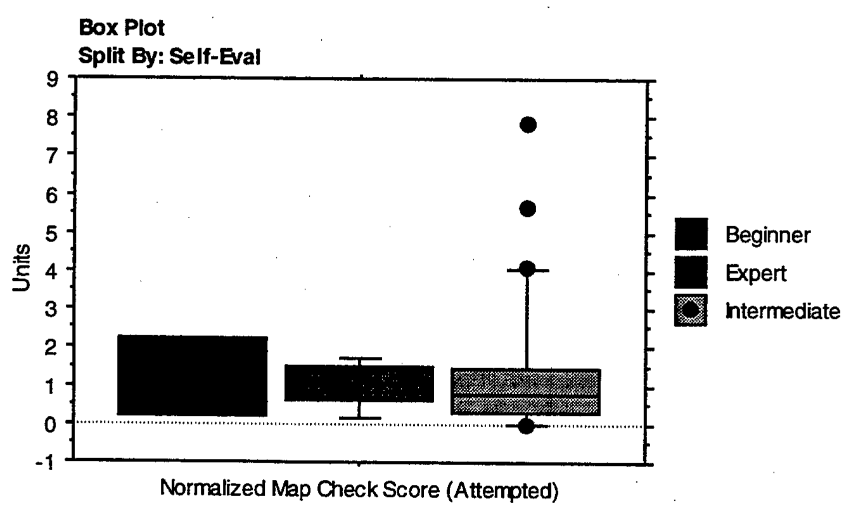

Figure 4.29. Normalized Map Check Score/Attempt (Self-Eval)

No differences were determined in the survey knowledge of subjects based on their self-evaluated ability level. Nor was there a statistical difference in the difficulty level of the subjects chosen routes.

4. Spatial Ability Post-Hoc Correlation

Goerger found a significant difference in the performance between the high spatial ability subjects and the low spatial ability subjects [GOER 98b]. These results were confirmed by this experiment. Examining the landmark results based on the subject's GZ spatial ability showed a significant difference between the means based on performance, $F(1,35) = 8.221$, $P = 0.0072$. These results are shown in the box plot in Figure 4.30.

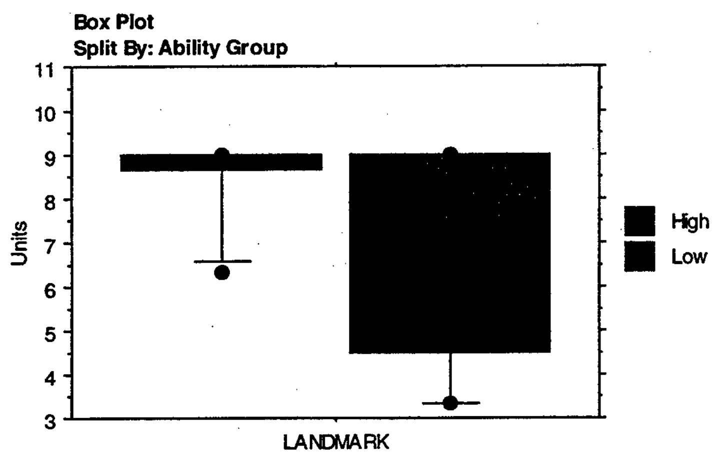

Figure 4.30. Landmark Score (GZ Ability Group)

Figure 4.31 shows the total error score per CP attempted for the GZ ability group. The groups show statistical significance, $F(1,35) = 7.698$, $P = 0.0092$, Subjects who scored higher on the GZ traveled less distance per error, meaning they realized their errors faster than low GZ subjects and recovered sooner. Direct observation of high GZ ability subjects suggests they made less overall errors, as shown in Figure 4.32. These results were not significant at $F(1,35) = 3.393$, $P = 0.0557$. Overall, the results suggest that high ability subjects made fewer errors, and recovered faster from their errors, than low GZ subjects. This in turn enabled them to attempt more controls and achieve higher landmark scores. The exact cause of their better performance, whether better memory, mental map, route selection, or overall organization, is not precisely determined at this point. Future research should examine exactly why those with high spatial ability perform better.

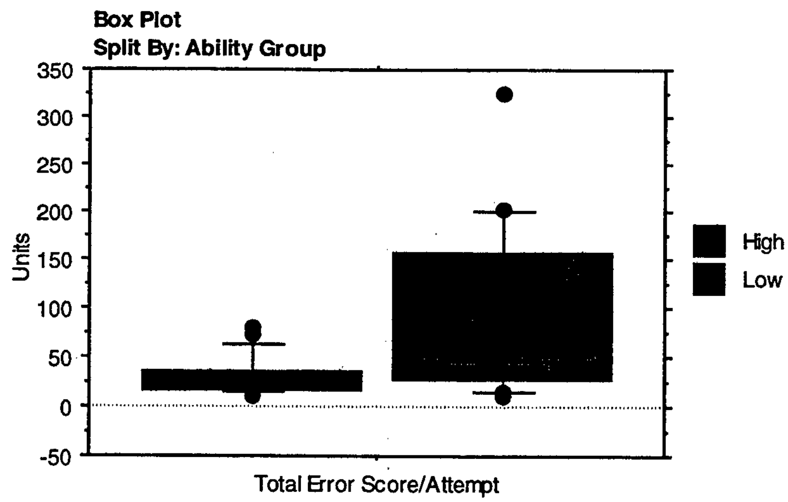

Figure 4.31. Total Error Score/Attempt (GZ Ability Group)

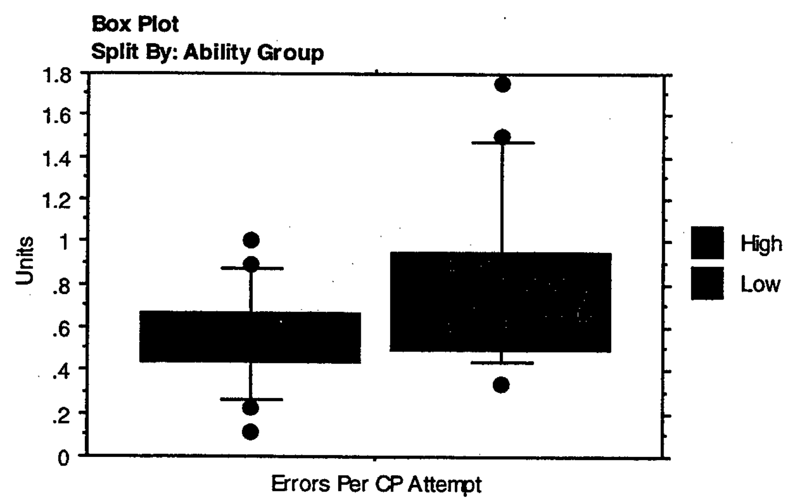

Figure 4.32. Errors per CP Attempt (GZ Ability Group)

High GZ ability subjects also had lower normalized map check scores than their counterparts by a statistically significant margin, $F(1,35) = 4.728$, $P = 0.0465$. This is shown in Figure 4.33. These results suggest that high GZ score subjects realized their errors quickly enough that they did not need a map to confirm this. There was no difference in the normalized non-error map check scores between the groups ($F(1,35) = 0.712$, $P = 0.4048$). These results are shown in Figure 4.34. This result casts doubt on

Goerger's assertion that the low GZ map check score is a result of better memory or more confidence in their route. High GZ subjects averaged roughly the same number of maintenance checks per control as the low ability group.

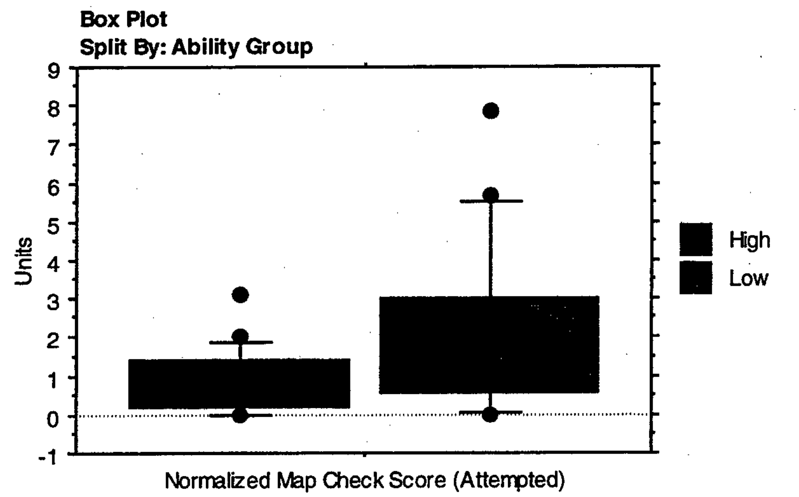

Figure 4.33. Normalized Map Check Score/Attempt (GZ Ability Group)

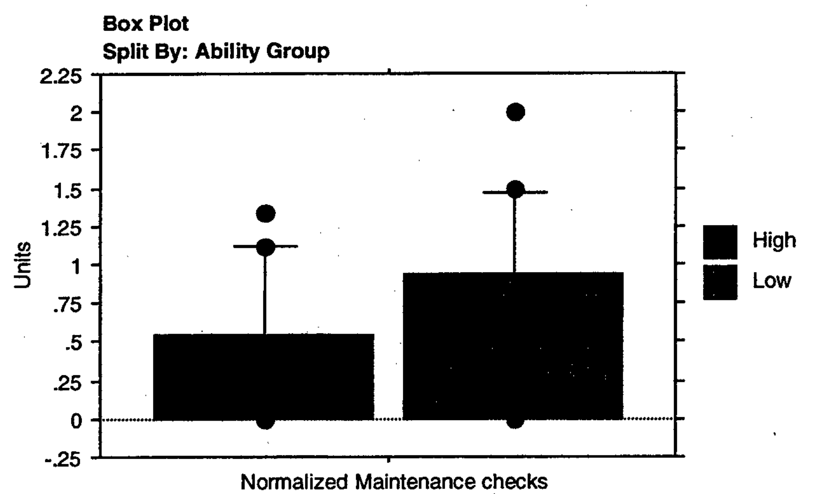

Figure 4.34. Normalized Maintenance Checks/Attempt (GZ Ability Group)

There was no difference in the map reading skills of the two groups, however analysis showed that the high GZ group did select less difficult routes. This is shown in Figure 4.35. This significant difference (Banker F= 7.93, P = 0.0081, Lisp F = 8.141, P = 0.0074) suggests that high GZ ability subjects were able to recognize easier routes and simpler movements than their counterparts. They were able to discern which routes offered easily recognizable features and landmarks that could be used as progress indicators. This allowed them to confirm their position as they went, helping to reduce their overall number of errors.

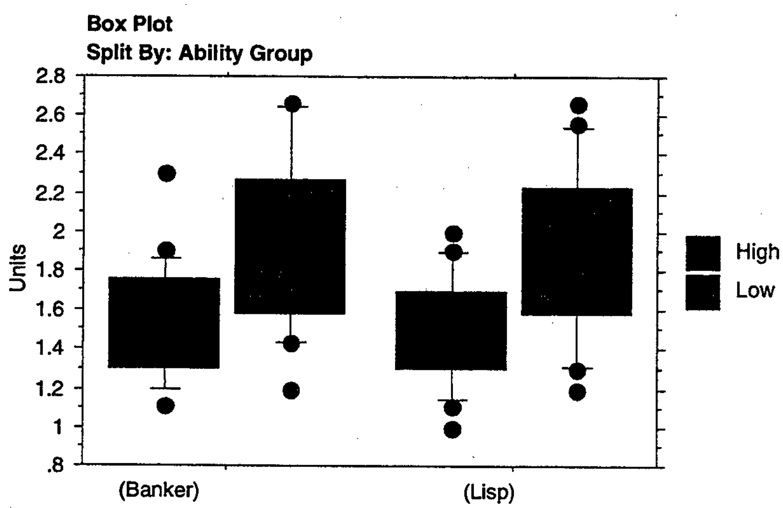

Figure 4.35. Banker and Lisp Route Difficulty (GZ Ability Group)

With regards to survey knowledge, there was no difference between the GZ ability levels and the whiteboard results. There was no statistical difference between the wheel test angular deviations (F (1,35) = 1.364, P = 0.2513). Direct observation of the wheel test results suggests that high ability subjects did average slightly less error than their low ability counterparts. This is shown in Figure 4.36. This implies that high spatial ability allowed subjects to better orient their mental map of the environment on demand to determine the location of other landmarks in regards to their own position.

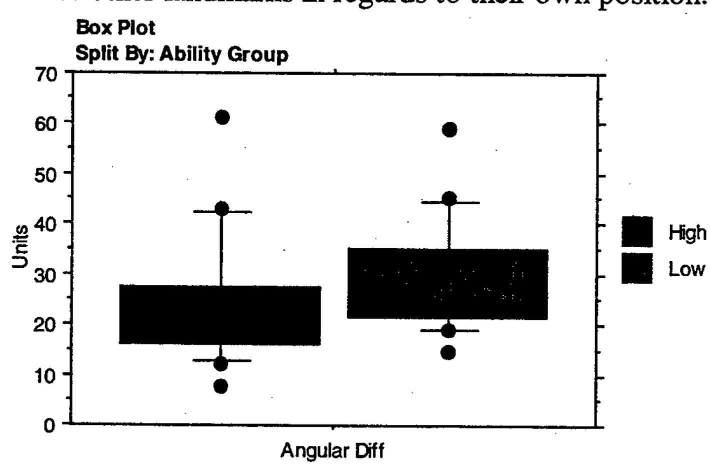

Figure 4.36. Wheel Test Angular Difference (GZ Ability Group)

5. Analysis Based on Santa Barbara

Goerger, in his experiment, did not determine any discernable results based on the Santa Barbara sense of direction scale [GOER 98b]. The results of this experiment did show a significant difference between the results. Note, however, the very low number of subjects who were classified as *low.*

Figure 4.37 displays the landmark results based on the Santa Barbara scale. The results are statistically different with F(1,35) = 7.093, P = 0.0119.

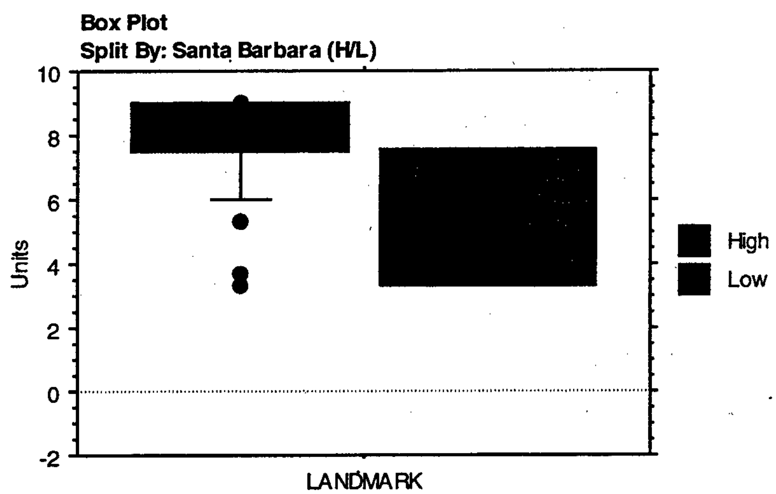

Figure 4.37. Landmark Score (Santa Barbara H/L)

Figure 4.38 shows the box blot for the errors per CP attempted based on the subject's Santa Barbara results. The analysis of means shows a significant difference between the two classifications, F(1,35) = 19.240, P = 0.0001. Looking at the results of these two plots shows that those classified as high ability by the Santa Barbara averaged half the number of errors of the low ability group. Because they made fewer errors, they appeared less inclined to lose their way, and in turn, this helped them find more controls. Also shown in Figure 4.38 is the total error score. While these results are not statistically different (F = 2.333, P = 0.264), direct observation does suggest that the high Santa Barbara group traveled less distance per error before recovering.

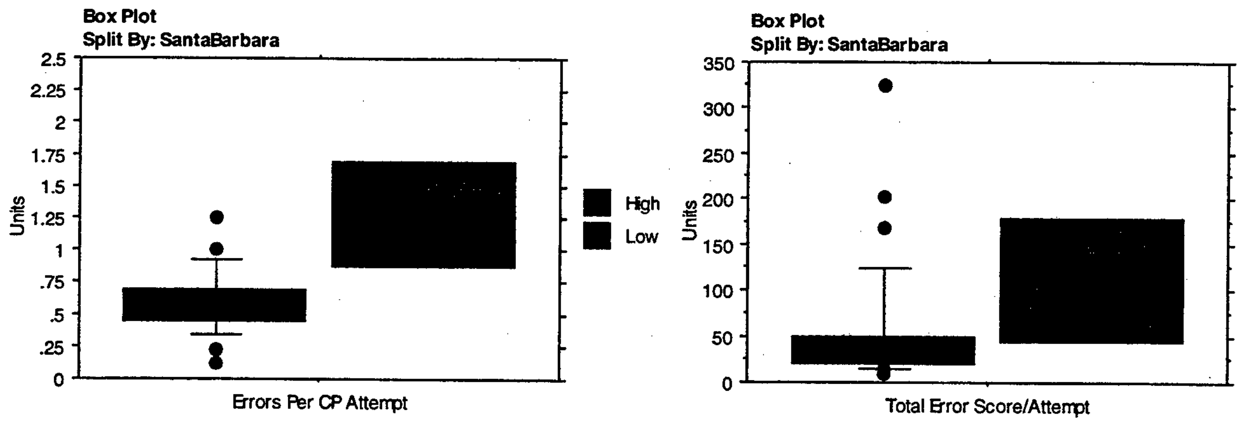

Figure 4.38. Errors per CP Attempt and Total Error Score /Attempt (Santa Barbara)

The data showed no statistically significant difference between the Santa Barbara levels and the normalized map check scores or the number of maintenance checks the subject made. However, there was a significant difference between the means in the level of route difficulty between the groups (Banker F = 4.513, P = 0.0412, Lisp F = 5.84, P = 0.0243). This result is shown in Figure 4.39 with the lower score being the easier route. Observation of these results indicate that low Santa Barbara subjects tended to choose more difficult routes. This choice in turn may have caused them to make more errors. These subjects may have lacked intermittent landmarks to help them confirm they were on track, allowing them to travel further before they recovered from errors.

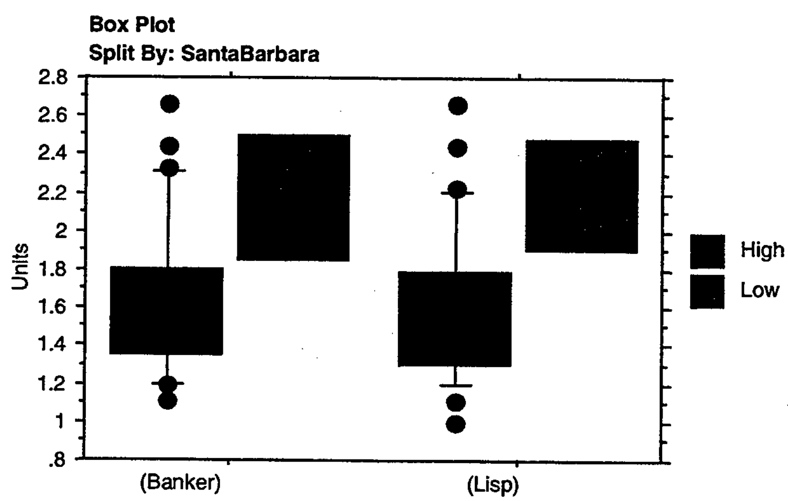

Figure 4.39. Banker and Lisp Route Difficulty (Santa Barbara)

There were no differences between the groups for the wheel test survey tasks. Neither the high nor the low group performed better on the whiteboard. Only one low ability subject completed the course, but that subject was able to complete the unplanned route task to standard so no conclusions can be drawn there as well. There appears to be no relation between a subject's survey knowledge and their Santa Barbara rating.

6. Simulator Sickness

Goerger had commented on user's having simulator sickness during the conduct of the experiments [GOER 98b]. Of the ten subjects who used the VE in this experiment, only one complained of simulator sickness. That individual described feeling sick but said he attributed it to a lack of food prior to beginning the experiment. The subject had found he had to take frequent breaks until it became quite uncomfortable. The subject, who was part of the train-to-standard group, was given 20 minutes to go eat. Upon returning, all symptoms of simulator sickness disappeared and he was able to successfully continue the experiment without hindrance. No other VE subjects experienced any symptoms, though many spent considerable time training (one subject trained almost three hours). Remember that all of the train-to-standard subjects had to complete the straight run through of the course in the VE as part of the pre-course test prior to being allowed on the course. This would tend to suggest that simulator sickness is largely due to individual differences and the physical condition of the subjects at the time of the experiment.

7. Distinguishing Benefits Between Groups.

The analysis of the data so far has shown that there are both differences between the spatial knowledge gained based on training group and based on spatial ability. The question that is often asked is whether one training method is better for training a particular type of spatial ability individual? In other words, is it better to train a low spatial ability person using a map or by the VE? In order to answer this question the results of the error per CP attempt and total error score were examined broken down by group and GZ ability. Table 1 shows the means of the errors per CP results. No significant statistical results can be concluded from the data. However direct observation of the data does suggest that there was a smaller difference between the results of the low ability and high ability subjects who used the VE than those who used the map or were real world subjects. Table 1 shows that the low spatial ability map-only groups averaged 0.3 errors more per CP than the high ability GZ subjects in the same training group. The real world had an even larger difference, with the low ability averaging 0.6 errors more per CP than high ability subjects. In contrast, the low GZ VE subjects averaged only 0.1 to 0.2 errors more than their high GZ counterparts. This suggests that low spatial ability subjects perform closer to their high ability counterparts when trained using the VE at least as far as the number of errors committed. This may be because of the advantages high spatial ability subjects have in mentally rotating the map to envision what the terrain will look like, which low GZ subjects may lack. In the VE, subjects did not have to do this mental translation and thus all performed to roughly the same level.

Descriptive Statistics
Split By: Group, Ability Group

	Mean	Std. Dev.	Std. Error	Count
Errors Per CP Attempt, Total	.660	.331	.056	35
Errors Per CP Attempt, MAP, High	.556	0.000	0.000	3
Errors Per CP Attempt, MAP, Low	.857	.202	.143	2
Errors Per CP Attempt, MAP1, High	.778	.157	.111	2
Errors Per CP Attempt, MAP1, Low	.481	.170	.098	3
Errors Per CP Attempt, MAP2, High	.583	.056	.028	4
Errors Per CP Attempt, MAP2, Low	.889	•	•	1
Errors Per CP Attempt, RW, High	.444	.157	.111	2
Errors Per CP Attempt, RW, Low	1.014	.638	.368	3
Errors Per CP Attempt, VE, High	.929	.101	.071	2
Errors Per CP Attempt, VE, Low	1.102	.489	.283	3
Errors Per CP Attempt, VE1, High	.333	.192	.111	3
Errors Per CP Attempt, VE1, Low	.500	.079	.056	2
Errors Per CP Attempt, VE2, High	.460	.246	.142	3
Errors Per CP Attempt, VE2, Low	.508	.090	.063	2

Table 1. Errors per CP Attempted by Group and GZ Ability

Table 2 shows the descriptive statistics concerning the total error score per CP attempted. Again, no significant differences can be inferred. In this case, it is not readily apparent if any one style of training technique minimizes the differences between high and low GZ ability. The largest percentage difference is in the real world group, suggesting that while direct exploration for a limited period may be effective for high GZ subjects, low ability subjects would best avoid this technique. The subjects in the Goerger study had the largest differences between the ability levels. The extended study time may explain the closer performance levels for the train-to-standard groups (VE1, MAP1), and the poor map and resulting easier route selection may do the same for the low fidelity map groups (MAP2, VE2). In these groups, there seemed little difference in how quickly the high and low spatial ability subjects realized they had made an error. Considering only the Goerger groups, while as a whole the map group realized their errors quicker, the difference between the spatial ability groups as a percentage was the smallest in the VE group.

Descriptive Statistics
Split By: Group, Ability Group

	Mean	Std. Dev.	Std. Error	Count
Total Error Score/Attempt, Total	58.327	68.549	11.587	35
Total Error Score/Attempt, MAP, High	35.815	31.896	18.415	3
Total Error Score/Attempt, MAP, Low	153.871	68.507	48.442	2
Total Error Score/Attempt, MAP1, High	25.558	15.972	11.294	2
Total Error Score/Attempt, MAP1, Low	26.602	13.449	7.765	3
Total Error Score/Attempt, MAP2, High	26.200	8.084	4.042	4
Total Error Score/Attempt, MAP2, Low	17.097	•	•	1
Total Error Score/Attempt, RW, High	17.352	1.074	.759	2
Total Error Score/Attempt, RW, Low	121.842	60.342	34.839	3
Total Error Score/Attempt, VE, High	59.066	29.893	21.138	2
Total Error Score/Attempt, VE, Low	180.597	148.275	85.606	3
Total Error Score/Attempt, VE1, High	23.935	12.752	7.363	3
Total Error Score/Attempt, VE1, Low	30.081	8.717	6.164	2
Total Error Score/Attempt, VE2, High	36.325	8.575	4.951	3
Total Error Score/Attempt, VE2, Low	36.181	29.443	20.819	2

Table 2. Total Error Score/Attempt by Group and GZ Ability

Overall, the results in this section suggest that it may be beneficial for low spatial ability subjects to train using the VE, as this may help to visualize the map in a way that they have difficulty doing on their own. Further research into this area is needed to determine if low ability subjects really would be better training by one particular method.

8. Non-Error Map Checks

During the course of the orienteering experiment, individuals would sometimes conduct map checks even if they were still on their planned path or at a known point. These non-error map checks are referred to as maintenance checks. Some of the individuals may have been disoriented at the time of the check (even if not yet in error). Most, however, used these checks to confirm their memory of their planned route or to refresh themselves as to the features they planned to use to assist them in finding the next control. Some subjects had planned to request the compass at certain locations to conduct dead reckoning from a known attack point. As this style of map check is completely different from those caused by errors, the data was analyzed by considering only the maintenance map checks to see what effect, if any, the training group, user's spatial ability, user's navigational ability, etc., had on their requesting maintenance checks. Figure 4.40 shows the box plot results for the training groups.

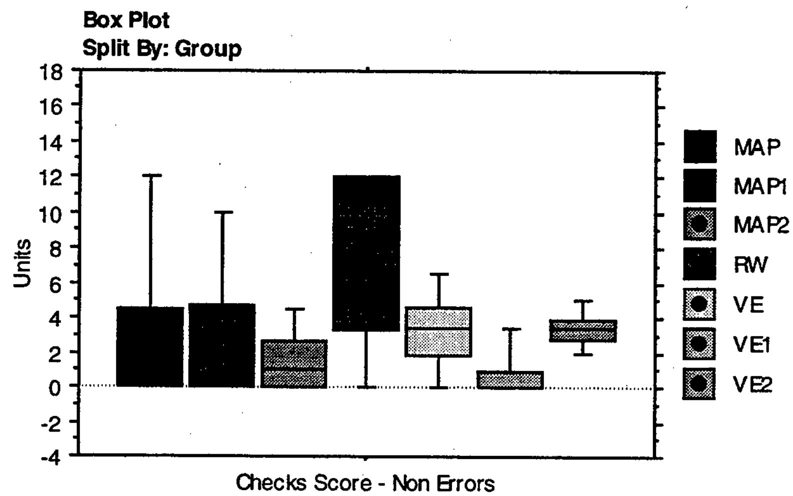

Figure 4.40. Box Plot of Maintenance Checks (Group)

The analysis of means is not statistically significant, $F(6,35) = 2.038$, $P = 0.937$ Most groups averaged around three points worth of maintenance map checks. Direct observation of the results suggests that the train-to-standard VE group (VE1) averaged the least number of maintenance checks (0.7). This suggests that extended exploration of the environment in the VE allowed them to better internalize their route so that they needed fewer reminders during the course. The low fidelity map-only group also scored below the average. It is likely that the lack of information on the map persuaded subjects not to consult it.

Examining the results based on ability group, there is no discernable differences between the number of maintenance map checks and either GZ ability level, Santa Barbara level, or the user's experience. Furthermore, regression analysis showed no association between the number of maintenance checks and the subject's resulting landmark score (F(1,35) = 0.550, P = 0.4637). Figure 4.41 shows this regression analysis.

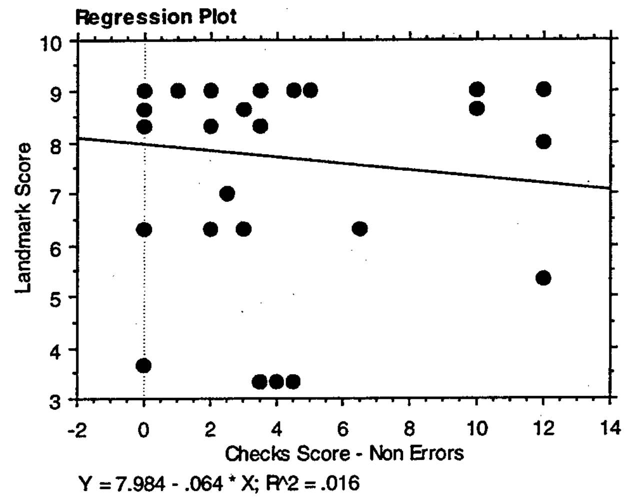

Figure 4.41. Regression Plot of Maintenance Checks vs. Landmark Score

Figure 4.42 shows the same analysis this time comparing maintenance checks and the errors per control attempted. Again, there is no correlation between the number of maintenance checks and the subject's performance.

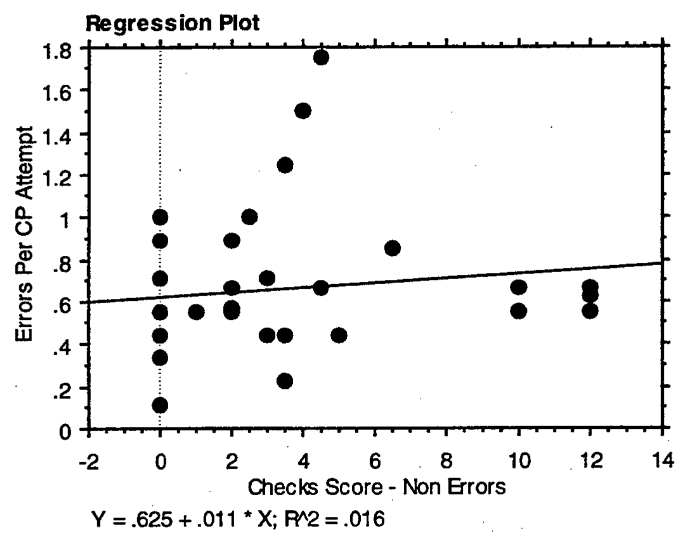

Figure 4.42. Regression Plot of Maintenance Checks vs. Errors per CP Attempted

From the above, we can conclude that while the training group may have an effect on the number of maintenance checks a subject takes, the number of maintenance checks a subject takes does not appear to affect their actual performance. The number of maintenance checks appears totally independent from the subject's ability level.

9. Correlation Between Disorientation in Virtual Environment and Disorientation in Real World

In his 1998 study, Goerger noticed a possible correlation between subject's disorientation in the VE and in the same location in the real world [GOER 98b]. The same general effect was noticed on several occasions in this experiment as well. Subject VE2-1 had trouble in the VE looking for CP3. The subject in fact bypassed it on the left and continued into the depression near CP4 before realizing the error. Despite resolving this in the VE, the subject made the exact same error while running the course, even remarking "Shoot, I did the same thing in the computer". No concrete conclusion can be drawn, however, because of the limited number of participants who demonstrated this effect.

Generally, subjects were asked which point they found to be the hardest to find in the VE and which they felt would be the toughest in the real world. Some of the subject's difficulties came from the limitations in the VE model (cannot see through/under brush). Many subjects assumed CP5 would be difficult to find based on their model experience. Several subjects also were very up front about their planned usage of trail intersections for navigation. Many commented that if they could not discern those intersections on the actual course, they would be in trouble.

Several subjects got into trouble by planning cross-country movements using the VE. During the course of the VE training, they relied heavily on the compass to cut direct movement while "beating brush." The ease of this method in the VE disarmed the subjects to the actual difficulty of their planned route, and the subjects had difficulty replicating these routes on the actual course.

10. Resolving Ambiguities in Mental Maps

One of the biggest difficulties facing the subjects was resolving differences in their mental maps upon arrival on the ground. These difficulties were noted by Goerger in his experiment, and similar effects were observed during this experiment. Goerger felt that each group (map-only, VE and real-world) faced it's own specialized challenges in this regard. These differences are partly due to the way the information bout the environment was acquired.

VE (and real-world) subjects gathered much of their information from *dynamic imagery*. Many VE subjects described it as playing back a movie in their heads. They would try to match the imagery their eyes were seeing to this mental movie in their heads to determine if they were on course. The potential pitfall in this, as discussed by Goerger [GOER 98b], is when this mental movie is incomplete or inaccurate. Then users, as opposed to confirming their location, merely become confused and disoriented.

Map-only subjects tended to store their information as a list of objects or actions referred to as static imagery or symbolic imagery. This gave them knowledge about particular points of interest but fuzzier information about indistinct areas. This in turn lends the map-only groups more slack when conducting the course, as they are only looking for a few key points of interest. Map-only subjects became confused only when they encountered key structures out of turn or encountered areas that appeared similar to their focus area (see Chapter III Errors). Many map-only subjects discarded distance estimation entirely, relying solely upon their mental checklist. While this may not have assisted them, it did not hinder their completion of the course unless they later tried to apply distance estimation to their mental model. Subjects who stuck to a poor strategy performed better than those who tried to change tactics "in the middle." This later group usually only further confused themselves and ended up becoming totally disoriented.

For all of the groups, it was critical that they quickly adjust their mental models to the terrain. This meant transferring the picture/movie in their minds into actual distances covered on the ground. Once subjects established the distance/scale relationships, they usually had little difficulties later. The caveat is that subjects with imprecise mental models often radically change their entire model, not just the bad portions. One map subject who did not memorize distances, underestimated the distance between the SP and CP1, as well as CP1 and CP2. Having discovered that these points were much closer than he expected, he radically shorted his mental map image of the area. This resulted in his stopping two hundred meters short of CP4 when he first initiated his search. Because the first two controls had been closer than he thought, he guessed that the whole course was that way.

The VE group in particular had the most trouble in quickly resolving differences between the real world and their mental model. The first movement in the course, from the SP to CP1, was where VE1 subjects averaged their greatest amount of error distance. Figure 4.43 shows the distance per error for leg one for all groups. The lack of an effective means of discerning scale and distance traveled in the VE likely contributed to this early difficulty.

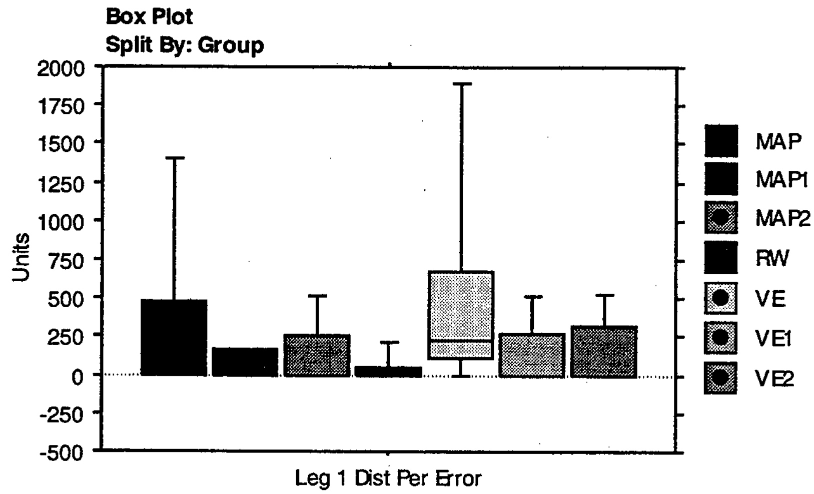

Figure 4.43. Distance per Error SP to CP1 (Group)

While no statistical significance can be drawn, direct observations show that the real-world group made the least error distance on this movement. Also, disregarding one Goerger VE subject who circled the course area looking for CP1, all of the VE groups on this leg performed about the same regardless of training method. Once the mental ambiguities were resolved, however, the train-to-standard VE group was able to perform better on the rest of the course.

11. Map Reading

Goerger did not determine any difference in performance based on map reading ability. The results in this experiment did find some noticeable effects on performance based on map reading ability. For a subject's landmark scores, the map reading score showed a significant effect, with $F(1,34) = 7.143$, $P = 0.0116$. Figure 4.44 show the regression plot.

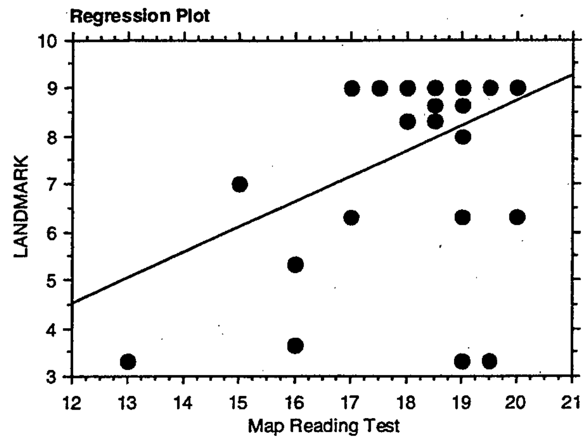

Figure 4.44. Regression Plot of Landmark Score vs. Map Reading Score

Observation of the data suggests that while a high map reading score is not a good predictor of success, a low map reading score is a good predictor of failure. Those subjects who had difficulty with basic map reading skills in turn had difficulty in locating the control points.

Direct observation of the data suggested that subjects with poorer map reading skills also tended to make more errors per CP attempted and traveled more distance per error. This may be because they cannot identify viable routes, or the necessary features to help keep them on their route. Neither regression was significant statistically however (for the errors per CP attempted F= 3.916, P = 0.0562, distance per error F = 2.701, P = 0.1098). The regressions for both are shown in Figure 4.45 below.

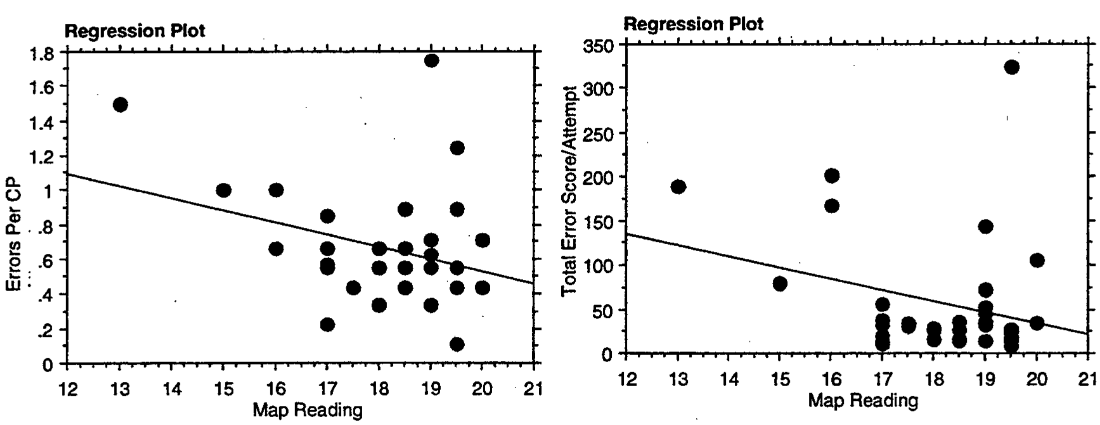

Figure 4.45. Regression Plots of Map Reading vs. Total Error Score/Attempt and Map Reading vs. Errors per CP Attempt

A subject's map reading skills also may have had an effect on the difficulty of the route they chose. While no statistically valid difference exists, direct observation (see Figure 4.46) of the regression comparison suggests that subjects with higher map reading skills choose less difficult routes.

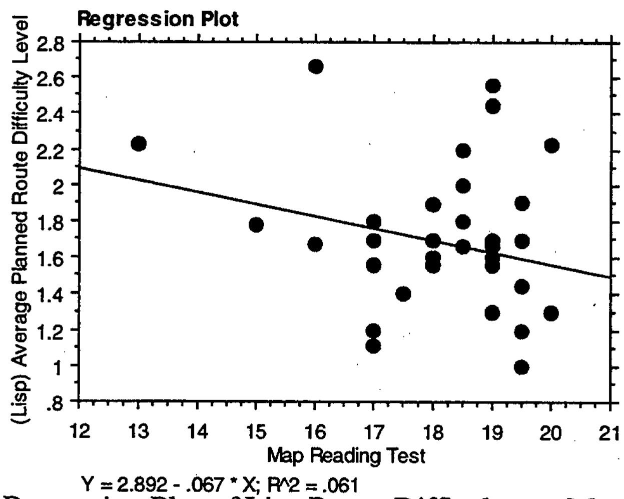

Figure 4.46. Regression Plot of Lisp Route Difficulty vs. Map Reading Score

The map reading scores were examined to see how much they were influenced by the subject's individual differences. There were no significant differences between the map reading scores of high and low GZ ability subjects. This is shown in Figure 4.47.

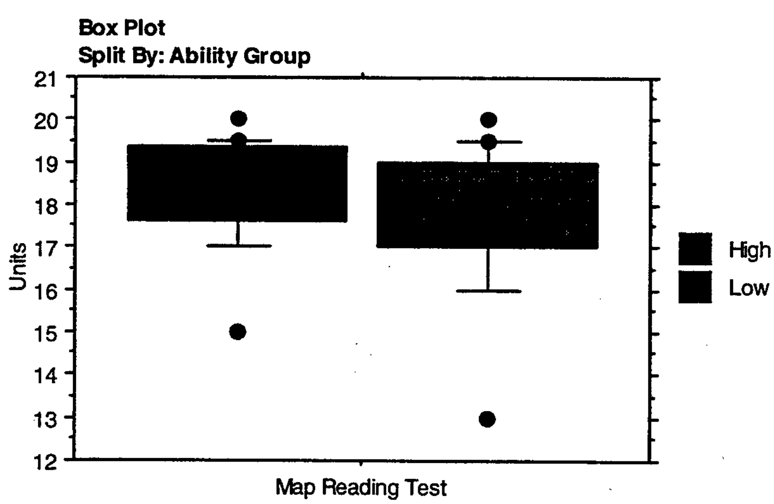

Figure 4.47. Map Reading Score (GZ Ability Group)

There was also no difference between the Santa Barbara ability groups. There was an observed difference based on the bar-line evaluation. While those classified as experts did not outperform the others, those classified as beginners did demonstrate weaker map reading skills. Since map reading is largely a learned skill, this is to be expected. The data is shown in Figure 4.48.

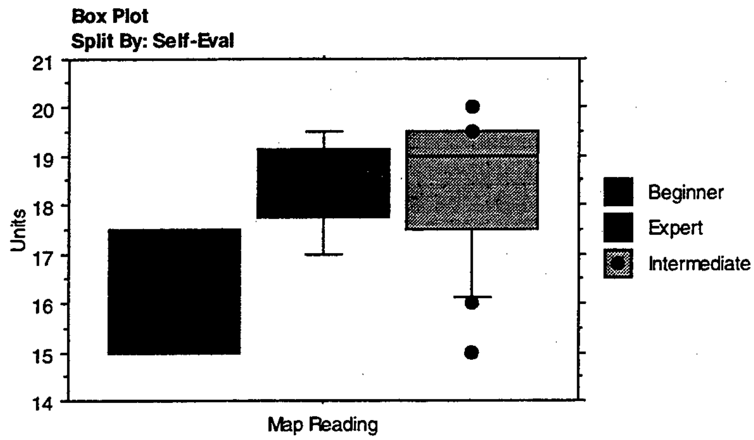

Figure 4.48. Map Reading Score (Self-Eval)

Examining the distribution of map-reading scores across the groups, we find that the lowest scoring map-readers were in the original VE group. See Figure 4.49. This brings up an interesting question of whether or not the subject scored low because he could not read a map, or because of the training tool he used? The data may have to be analyzed using MANOVAs to answer which criteria had the strongest effect on performance.

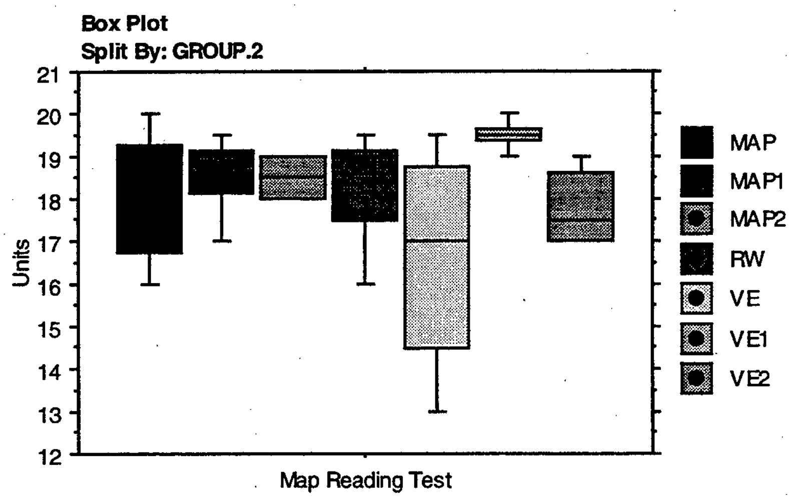

Figure 4.49. Map Reading Score (Group).

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. General Conclusions

The thesis experiments studied the effects of various training methods on the transfer of spatial knowledge to a real world environment. The first experiment used a high-resolution 1:5,000 scale map and the high fidelity real time VE. The subjects either trained only using the map or with the map and VE together. Subjects had to meet a set standard before continuing on to the actual testing phase. The second experiment used a lower fidelity 1:24,000 scale map but the same high fidelity VE. Subjects were again either map-only or VE and map together. Training time was limited to exactly one hour. The results of the experiments were then analyzed against each other and the original Goerger results [GOER 98b]. The following conclusions are drawn from both the quantitative and qualitative results previously presented:

a. Subjects who trained to standard with a high fidelity VE demonstrated superior route and landmark knowledge to any other training group (Chapter IV, Sections A.4 and A.5).

b. Spatial Ability (including Santa Barbara level or self-assessment of spatial ability) plays a significant role in an individual's ability to obtain and demonstrate spatial knowledge (Chapter IV, Sections B.4 and B.5). High spatial ability subjects perform better on route and landmark tasks than do low spatial ability subjects.

c. Subjects with poor map reading skills are likely to have difficulty in navigational tasks and demonstrate significantly poorer spatial knowledge than any other subjects (Chapter IV, Section B.11).

d. The difficulty of the planned route has an effect on its successful completion, and a significant effect of the amount of spatial knowledge gained (Chapter IV, Section B.2). The easier the route, the better the overall perfromance.

e. Adjusting the fidelity of the map causes subjects to adjust their planned routes to the information that is provided (Chapter IV, Section B.1). The accuracy of the map in representing terrain can have a dramatic effect on errors at specific locations (Chapter IV, Section B.1).

2. Performance by Study Group

Based on the outcomes of the three experiments, the results suggest that those who trained to a standard and not to time, gained more spatial knowledge about a one km square piece of terrain than those who trained to a one-hour time limit. VE subjects who trained to standard had the best overall landmark and route knowledge performance. Subjects who were given only one hour to train and a high fidelity map performed better than those with only an hour, the high fidelity map, and the high fidelity VE [GOER 98b]. Results suggest that with only one hour of training and a less detailed map (but with one critical area being more accurate), the subjects would adjust their routes to the detail provided. They then performed better in following these simple routes than those who planned their routes on the more detailed map.

3. Performance by Spatial Ability

The results suggest that regardless of training group, individuals with above average spatial ability scores (as determined by the Guilford-Zimmerman test) demonstrated more spatial knowledge than individuals with low spatial ability scores. Subjects with high Santa Barbara ability scores also outperformed those with low Santa Barbara ability scores. Higher ability level individuals selected easier routes and executed them better. The results suggest that high ability individuals had better egocentric knowledge than their counterparts. High spatial ability individuals demonstrated slightly better exocentric knowledge (survey knowledge) than low ability individuals. Using the train-to-standard VE seemed to minimize the differences between spatial ability users (Chapter IV, Section B.7).

4. Performance by User Experience/Map Reading Skills

Users who classified themselves as expert navigators made fewer errors than intermediate or beginner level subjects did. They also conducted fewer map checks. While they did find slightly more controls, this was not significant. There was no significant difference between ability levels in how fast subjects recognized their errors. Nor did subjects demonstrate differences in survey knowledge based on their experience classification. Beginners were much less likely to make map checks, because they did not realize they needed them or were uncertain as to their benefit. Beginners also had much lower map reading skills on average.

While a high map reading score was not a good predictor of success, a low map reading score was an excellent predictor of failure. Subjects with poor map reading skills had difficulty planning executable routes, had problems locating the controls, were more apt to make errors, and were less likely to recover quickly from those errors.

5. Route Selection

Subjects who planned simpler routes made fewer errors and found more controls than those who planned harder routes. These simpler routes included more key features that could be used as reference points or navigational aids. This helped them recover from errors they did make faster than other subjects. They avoided areas where parallel errors were likely.

6. Map Fidelity

Subjects who were given the low fidelity map adjusted by planning much simpler routes in general and by sticking to the boundary roads whenever possible. The importance of accuracy in the map was highlighted in the improved results in finding CP4. The original Banker map, however detailed, was not clear in showing this depression, which caused more errors for those who relied on that map. Subjects who had access to highly detailed maps and had time constraints gained more spatial knowledge than their VE counterparts [GOER 98b].

B. SIGNIFICANCE

1. Study Group

If mission constraints include limited preparation time and highly detailed maps, individuals who only use maps will gain more information about the mission area than those who also use the VE. If time is not a constraint, individuals who use the VE will gain more information than those who only study the map. Individuals should tailor their learning method based on the time available. If there is not enough time to thoroughly explore the VE and make multiple iterations, then stay with the map. This basic rule will help individuals focus their efforts where they will make the most gain. If time is limited and only poor maps are available, using the VE may also prove valuable as long as there is information in the VE that is not included on the map.

2. Spatial Ability

High spatial ability individuals are better suited as navigators than low spatial ability individuals. These individuals should be identified if possible and be assigned in positions requiring navigational skill. If it is possible to improve an individual's spatial ability, it should be done. Low spatial ability individuals may have an easier time using the VE in training than just the map alone. This may be due to their difficulty in mentally orientating and visualizing a map.

3. User Experience

Experienced navigators make less errors and are more confident, if not actually better, at navigational tasks. The only way to become experienced is to practice. Individuals must conduct regular navigational practice across a variety of terrain types and using all navigational techniques to stay proficient. Navigation is best learned by doing. Individuals may also get involved in recreational activities that utilize navigational skills (Sport Orienteering, Scouting) to practice and have fun at the same time.

Map reading is a critical and perishable skill. Individuals who cannot read a map will have difficulty performing even the most basic of navigational tasks. It is for this reason that basic map reading is the first navigational skill taught to soldiers. Individuals should plan to refresh their skill in this area prior to missions.

4. Route Selection

Good route selection is critical to navigational performance. Individuals who plan routes with numerous easy-to-remember reference points or simplified paths are much more likely to execute them. Mission constraints may prohibit the use of the most direct or the easiest route. Individuals should try to tailor their route difficulty to the mission. Difficulty for difficulty's sake is not desirable. A good route should include many of the navigational aids described in Appendix P.

5. Map Fidelity

Maps, regardless of how detailed, must accurately show the terrain in a clear manner. A map with too much detail clutter may actually induce error at certain locations. An accurate high fidelity map can be relied upon for success if time is limited. A low fidelity map will force subjects to simplify their planned movements to use the information provided by the map. A high fidelity map may offer users more freedom as they can have multiple reference points to choose from when planning their route.

Ideally, a high fidelity VE has the same information as a high fidelity map. The VE takes longer to build and is not as easy to reproduce nor can it be carried with you. Thus regardless of the time allowed for preparation, a map should always be included in the program.

C. FUTURE WORK

While this thesis may have validated the utility of using a VE to transfer spatial knowledge about a natural area, there remain significant areas for future work and exploration.

1. Immersive vs. NonImmersive

Ruddle, Randle, Payne, and Jones [RUDD 96] concluded that there was no significant difference between immersive and non-immersive VEs with regards to performance results. However, their experiment was conducted in an indoor environment that was relatively small in scale. Will the same conclusion hold to a large outdoor environment? Most VE subjects, judging by their survey answers, felt comfortable with the three screen wide FOV display. However, this may not be the most immersive, nor the best way to display the VE. Future experiments can compare the current VE results to those obtained using a more immersive interface. The MOVES curriculum at NPS is currently building their own VE CAVE that could be used in the experiment in addition to head mounted displays. The effect of downsizing the wide screen TVs to a more affordable and space friendly three monitor configuration should also be studied.

2. Incorporating Sense of Scale into the VE

One comment heard repeatedly from the VE subjects was how they lacked a real sense of scale in the VE model. They complained of being unable to accurately estimate distance and often felt uncomfortable when first introduced into the real world until they were able to focus their mental map. This result backs up the findings of Witmer and Kline [WITM 98] in that judging distance in a VE is difficult, and usually underestimated. Goerger had originally added two HMMWVs to the model at the start point in order to give a sense of scale [GOER 98b], but most subjects didn't find this particularly useful. There are several possible options for introducing a sense of scale and distance traveled into the model. It would be possible to incorporate some sort of sound cue that could beep after a set distance of travel. A visual pace count or pedometer could also be displayed. Users should be able to reset this counter easily as they maneuver through the environment. Another option would be to change the interface into one that actually requires locomotion by the subject, whether by treadmill or cycle. While these last two methods may negate the advantage of being able to explore faster than humanly possible, it would allow users a more realistic sense of traveling and to acquire a sense of distance traveled.

3. Fidelity Levels

The current model is classified as high fidelity (see Chapter III, Section C Model). Now that the transfer of spatial knowledge from VE to natural terrain is a proven concept, new experiments could adjust the fidelity level of the model to determine what is both the optimal level of fidelity for transfer, and what is the minimum level of fidelity to achieve this transfer. Hopefully, reducing the fidelity would enable the model to be run on a less powerful machine. By determining the optimal levels, we can ensure we develop models that reach this but do not go past the point of diminishing returns. The model currently uses digital photographs to create photo-realistic bushes, trees, and buildings. However, all this comes at the expense of processing power. What if the same training effect can be achieved by substituting green cones for trees? Is it really an advantage to exactly replicate the buildings with detailed textured photographs or would a simple black square be enough? Obviously the idea of just incorporating symbolic representation (as is done with a map) may make the model appear less "realistic", but would that necessarily lessen the training impact?

4. Transfer to a Desk-Top Model

The current model requires a high-end multi-processor machine to run. This machine is both expensive and takes up considerable space. It would be of tremendous interest to the Army to determine if the model could be ported to a smaller desktop machine. Obviously, this would result in changes to both the display and to the model fidelity. However, these reductions would be accompanied by a cost and space savings. If such a transfer were proven feasible, it would be a boon to the military and would allow for a more widespread distribution of a VR training system.

5. Design a MOUT Environment

It has been shown that participants can gain spatial knowledge of indoor man-made environments, and in natural outdoor areas. The next logical step is to explore the knowledge transfer in a combination of these environments, namely urban areas. The perfect setting for this is available locally with the old MOUT site (Military Operations in Urban Terrain) on Fort Ord. This site consists of a several mock city blocks with multiple story cinderblock buildings with rooms, windows, staircases, and sewers. The area has streets and parks as well. The military used the site to practice fighting in cities and other built up areas. The area is currently used almost daily by local and national law enforcement agencies to train quick reaction forces or SWAT teams [BELC 99]. The military uses a standard design for its MOUT training areas, so detailed blueprints should be readily available to facilitate accurate model construction. Given the high usage of the area by local law enforcement, a large pool of test subjects is potentially available. It should be possible to arrange for test subjects and develop the standards for evaluating the models' effectiveness to everyone's satisfaction.

6. Make the Model More 3D/ More Realistic

At a recent virtual reality conference held at NPS, many psychologists complained about the use of billboard photos for trees or other non-flat objects. They said this technique robs the environment of its three-dimensional feel and makes it seem less real. Coupled with the fidelity research above, future work could focus on making the trees and other objects seem less flat and more solid. Another problem that presented itself in the model was the lack of the ability to raise or lower the avatar's viewpoint from the set 5'8" height. While the 15-meter pop-up view was provided, this still did not allow the user the flexibility that they possess in the real world. Often when searching for a point in the VE, subjects desired to look under branches but could not lower themselves down without just backing up. But, in dense areas, backing up would usually put a new tree in front of them further obscuring the view. The ability to lower the avatar's viewpoint might allow for more "realistic" training. A third area for work is in collision detection. The current model has no collision detection and allows users to walk unimpeded through the trees and buildings. One potential problem with this, seen in a couple of VE subjects, was the selection of routes based on this "easy" movement. Upon arrival into the real world, these subjects regretted choosing a cross-country route through dense brush that was easy in the model but difficult and time-consuming in the real world (see Figure 5.1 Tight Squeeze). Adding some code to the model to slow movement through difficult terrain (whether dense woods, swamps, etc.) would make exploration in the model more realistic. It would also make it possible to allow weather effects to be incorporated into the model later (such as slowed movement from mud or snow).

Figure 5.1. Tight Squeeze

7. Cooperative Learning

Within the educational community, many groups are reporting that computer trainers work best when cooperative learning is incorporated into the learning program. The optimal size seems to be two to three students [ROSE 95]. Rose concludes that "...virtual reality technology that fosters collaboration will yield even greater educational benefits"[Rose 95]. The effect of cooperative learning could be done so two subjects could conduct the training phase together but then be tested in the environment separately or together. The results would be to see if they performed better as individuals than those who trained alone. This would also be more realistic because in the active military most navigation is done by a group, not an individual. Individuals would pool knowledge to arrive at a more informed decision. Obviously, introducing cooperative learning would also introduce a host of other factors, not the least of which include individual personality, compatibility, and cooperation.

8. Training Navigation as a Secondary Task

Land navigation is never the end goal of any military navigation other than in training courses. However, it is an essential skill to the successful completion of most missions. Given its critical, but secondary, nature, it would be interesting to see if spatial knowledge could be obtained while ostensibly not training navigation but another task. An ideal experiment could use a popular 3D-shooter type game such as Quake or Doom. Subjects would be told they are conducting research in virtual environments, not in land navigation in particular. They would be presented with the game environment built to replicate the outdoor Fort Ord area. The players would be given limited ammunition and have the goal of killing all the enemies. At each control point, additional ammo is found, as well as one or more enemies. However, to encourage the players to visit the controls in order, the program spawns additional enemies at the controls based on a time factor, with more enemies being produced at the lower number controls quicker than at the higher number. Once a control is captured however, it stops producing enemies. In this manner players would optimally clear the lower controls. Otherwise they may be swamped with enemies and be unable to "win". After several sessions, the players would be taken to the outdoor environment and tested on the navigational tasks to see what knowledge was transferred during the course of their gaming.

9. Evaluating Navigation as a Secondary Task

As with Section 8 above, land navigation rarely stands alone. To provide validity of the model's effectiveness, the evaluation phase should incorporate some secondary task that requires constant thinking, but is not totally overwhelming. A possible solution is the introduction of a hunter. As with most military mission, there is an enemy to be avoided. This person is armed with a paintball gun and is actively searching for the subject. Our subject is told that person has a map of the area but does not have the location of the control points. Our subject is not forced to follow a route, but is given an empty gun with ammunition being at the controls. He is also required to punch the stamp at each control point (to confirm he visits there). If he shoots the hunter the hunter must return to the start point (or so he is told). The goal is to reach every control point in the fastest time, while minimizing the number of times you are shot.

10. Focus More on Survey Knowledge

The research into VEs has shown it to be most effective in attaining route and landmark knowledge (see Chapter II). This is not to say that survey knowledge cannot be derived from a VE, just that it is not transferred as readily as the other forms. In this thesis' experiments, survey knowledge was not tested until after exposure to the environment, which may have produced additional learning and corrupted the results. To more accurately test the ability of the VE to transfer survey knowledge we must test survey knowledge more extensively during the experiments. One avenue to explore is to force the subject to change their route during the course of the experiment. By informing the subject of a chemical spill/forest fire and making them adjust their route without looking at a map, their survey knowledge could be tested earlier than the unplanned route test in the current model. Goerger suggested that another way of doing the same task would be to reduce the number of points but upon arrival at the test site force the subjects to run their route backwards [GOER 98b]. Either method would be more preferable to the current tests which were not done by all subjects, and certainly weren't done prior to extensive exposure to the area itself for an extend period of time (at least 30 minutes).

11. Introduce Competition into Training

As mentioned above in Section seven, people often learn best when they do not learn alone. In this case, however, they will not be learning as much as in competition during their training. Using a networked virtual environment, two subjects would be run through simultaneously. Both subjects would start at the start point and race each other for the controls. Each would get a point for each control they "captured" first. Each control could be captured only once and must be captured in order. This would put pressure on the subjects to quickly decide upon a route and not get lost en-route. The game could be run several times. The subjects may or may not be given a familiarization phase with the area first. This experiment would not only examine the effects of competition, but would also make the navigation a secondary goal of the training.

12. More Guided Instruction

Another lesson in the learning community is that "Concrete teaching is necessary before students attain basic knowledge and skills to make free exploration"[FENG 95]. Feng notes that when students are given a "sea of resources" and told to sink or swim, many will sink. Without experience to guide them, many students will not learn efficiently as they do not know how to learn. With VEs, most, if not all, of the subjects had little experience with 3D models and environments. With a map, most subjects allowed for minor variances between what the map showed and they saw in the real world. Some subjects did not give the VE the same leeway. More than one VE subject fully expected all the trails in the real world to look like the "yellow brick roads" of the VE. Other subjects ignored potential reference points shown in the VE because they were not on the map and were uncertain how much they could "trust" the VE. Until people become more familiar with VEs, it may be necessary to guide subjects through the instruction of this unfamiliar medium more than the simple 15-minute orientation that was conducted in the experiments so far.

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APPENDIX A. EXPERIMENT OUTLINE

1) In Brief/Consent Form

    a) Time – 5 Min
    b) Location – CS Student Conf. Room
    c) OIC – CPT Quay B. Jones
    d) Materials – Consent Form, Privacy Act Statement, Minimal Risk Consent Form, Subject Roster, pencils, Fort Ord Map (confirm the subject has not been on the course terrain before), In Briefing Script

2) Color Blindness Test/Self Evaluation Questionnaires/Map Reading Test

    a) Time – 15 Min
    b) Location – CS Student Conf Room
    c) OIC – CPT Quay B. Jones
    d) Materials – Color Charts (1 min), Self Ability Evaluation Sheet (1 min), Santa Barbara Sense of Direction Scale Questionnaire (3 min), Map Reading Test (5 min), pencil
    e) Grading (5 min)

3) Spatial Orientation

    a) Time – 15 Min
    b) Location – CS Student Conf Room
    c) OIC – CPT Quay B. Jones
    d) Materials – Guilford-Zimmerman Aptitude Tests (10 min), pencils, answer sheets,
    e) Grading and Grouping (5 min)
    f) Groups

        i) Group A - Upper 50 percentile
        ii) Group B - Lower 50 percentile

4) Interface Familiarization (VE Only)

    a) Time – 15 Min minimum
    b) Location – Graphics Lab
    c) OIC – CPT Quay B. Jones
    d) Materials –SGI machine, Performer Town Model, Flybox instructions, Virtual Environment Briefing Script, Interface Familiarization Checklist
    e) Movement (15 min minimum)

5) Training

a) Map Group (Low Fidelity Map)
   (1) Time – 60 Min
   (2) Location – CS Student Conf Room
   (3) OIC – CPT Quay B. Jones
   (4) Materials – 1:24,000 Scale Fort Ord Map, Aerial Photograph, Participant Task List, Map Marking Instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Low Fidelity Map Group Briefing Script, Training Evaluation Sheet

b) Map Group (Train-to-Standard)
   (1) Time – Varies
   (2) Location – CS Student Conf Room
   (3) OIC – CPT Quay B. Jones
   (4) Materials – Fort Ord Orienteering Map, Participant Task List, Map Marking Instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Train-to-Standard Map Group Briefing Script, Training Evaluation Sheet

c) Virtual Environment Group (Low Fidelity Map)
   (1) Time – 60 Min
   (2) Location – Graphics Lab CPT Quay B. Jones
   (3) OIC – CPT Quay B. Jones
   (4) Materials – Elvis (SGI) w/ flybox and 21"/40" screen configuration or projector, Fort Ord Model, 1:24,000 Scale Fort Ord Map, Aerial Photograph, Participant Task List, Map Marking Instructions, Flybox instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Low Fidelity Map Virtual Environment Briefing Script, Training Evaluation Sheet

d) Virtual Environment Group (Train-to-Standard)
   (1) Time – Varies
   (2) Location – Graphics Lab CPT Quay B. Jones
   (3) OIC – CPT Quay B. Jones
   (5) Materials – Elvis (SGI) w/ flybox and 21"/40" screen configuration or projector, Fort Ord Model, Fort Ord Orienteering Map, Participant Task List, Map Marking Instructions, Flybox instructions, red alcohol marker, alcohol marker eraser, pencil, scratch paper, orienteering clue sheet, Train-to-Standard, Virtual Environment Briefing Script, Training Evaluation Sheet

6) Testing (est Time 120 Minutes – travel to Fort Ord Orienteering Course, run the course, and return).

a) Time – Travel Time 30 Min (total); Run Course 90 Min; Total Time (120 min)
b) Location – Fort Ord Orienteering Course
c) OIC – CPT Quay B. Jones
d) Materials – Clipboard with subject's map & designated route, compass, Think Out Loud Instructions, Data Collection Sheet, red pen to record data, blue alcohol pen, stop watch/timer, Color Wheel for Tasks 3.1. & 5.1, White Board with ten magnets, rucksack frame w/GPS system, helmet & camera, water, first aid kit (cellular phone), Course Briefing Script, blind fold (for movement to course), spare clue sheet & color wheel arrows, Tecnu (for poison oak)
e) Tasks:

i) Task 1. (*Path Knowledge*) Move from the starting point to Checkpoint #1 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
ii) Task 2. (*Path Knowledge*) Move from Checkpoint #1 to Checkpoint #2 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
iii) Task 3.1. (*Survey Knowledge*) Take bearings to SP, CP #5, and CP #9 at the south side of CP #4)
iv) Task 3.2. (*Path Knowledge*) Move from Checkpoint #2 to Checkpoint #3 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
v) Task 4. (*Path Knowledge*) Move from Checkpoint #3 to Checkpoint #4 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
vi) Task 5.1. (*Survey Knowledge*) Take bearings to CP #1, CP #6, and CP #8 at the south side of CP #4)
vii) Task 5.2. (*Path Knowledge*) Move from Checkpoint #4 to Checkpoint #5 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
viii) Task6. (*Path Knowledge*) Move from Checkpoint #5 to Checkpoint #6 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
ix) Task 7. (*Path Knowledge*) Move from Checkpoint #6 to Checkpoint #7 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
x) Task 8. (*Path Knowledge*) Move from Checkpoint #7 to Checkpoint #8 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)
xi) Task 9. (*Path Knowledge*) Move from Checkpoint #8 to Checkpoint #9 along designated route. (measure elapsed time and number of errors; mark deviation from route on map)

xii) Task 10. (*Survey Knowledge*) Have subject indicate bearing and route he must traverse to make it to Checkpoint #4. Have subject return to Checkpoint #4. Mark route and any turn which leads the subject away from Checkpoint #4. Allow a maximum of ten minutes to return to Checkpoint #4)

xiii) Task 11. (*Survey Knowledge*) Have subject arrange magnets on the white board indicating the location of the starting point and nine checkpoints. Measure time and note method of magnet placement (i.e. in order of visit, outside-in, or inside-out). Take picture of final results (allow 5 minutes maximum).

g) Error (Definition)

Subject strays from designated route (5 meters from designated route on a path/trail/road; 15 meters from cross country designated route). (record one error)

7) Debriefing.

a) Time – 30 Min
b) Location – Graphics Lab
c) OIC – CPT Quay B. Jones
d) Materials – Clipboard with subject's map & designated route, Data Collection Sheet, red pen to record data, GPS system, Troop (PC) w/ Arcview and Fort Ord Maps, digital camera, Participant Questionnaire(s), Researcher's Script
e) Administer questionnaire(s); down load GPS datum and display on aerial photo using Arcview.
f) Discuss route.

i) Have the subject complete the Debriefing Questionnaire. Read their answers and ask for any clarification.
ii) Walk the subject through his route using the subjects planned route and the GPS data down loaded from the Message Pad and plotted on the aerial photo in Arcview.

(a) Have the subject to explain why they deviated from their route at those locations where the two differ.
(b) Have the subject explain when & how they determined they were off course.
(c) Have the subject explain how they recovered.

iii) Ask the subject if he would have done anything different in the training phase now that has completed the experiment.
iv) How much time does the subject spend playing computer games or working with computer graphics (more than an hour a day, a couple hours a week, once or twice a month, rarely, never)?

APPENDIX B. TASK LISTING

Task 1. (*Path Knowledge*) Move from starting point to Checkpoint #1 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 2. (*Path Knowledge*) Move from Checkpoint #1 to Checkpoint #2 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 3.1. (*Survey Knowledge*) Take bearings to SP, CP #5, and CP #9 at the south side of CP #4).

Task 3.2. (*Path Knowledge*) Move from Checkpoint #2 to Checkpoint #3 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 4. (*Path Knowledge*) Move from Checkpoint #3 to Checkpoint #4 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 5.1. (*Survey Knowledge*) Take bearings to CP #1, CP #6, and CP #8 at the south side of CP #4).

Task 5.2. (*Path Knowledge*) Move from Checkpoint #4 to Checkpoint #5 along designated route (measure elapsed time and # errors; mark deviation from route on map).

Task 6. (*Path Knowledge*) Move from Checkpoint #5 to Checkpoint #6 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 7. (*Path Knowledge*) Move from Checkpoint #6 to Checkpoint #7 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 8. (*Path Knowledge*) Move from Checkpoint #7 to Checkpoint #8 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 9. (*Path Knowledge*) Move from Checkpoint #8 to Checkpoint #9 along designated route (measure elapsed time and number of errors; mark deviation from route on map).

Task 10. (*Survey Knowledge*) Have subject indicate bearing and route he must traverse to make it to Checkpoint #4. Have subject return to Checkpoint #4 (mark route and any turn which leads the subject away from Checkpoint #4. Allow a maximum of ten minutes to return to Checkpoint #4).

Task 11. (*Survey Knowledge*) Have subject arrange magnets on the white board indicating the location of the starting point and nine checkpoints. Measure time and note method of magnet placement (i.e. in order of visit, outside in, or inside out). Take picture of final results (allow 5 minutes maximum).

APPENDIX C. BRIEFING SCRIPTS

1. GENERAL

The scripts in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of five briefing scripts: In Briefing, Low Fidelity Map Group Briefing, Train-To Standard Map Group Briefing, Low Fidelity VE Briefing, Train-to-Standard VE Briefing, and the Course Briefing. Each participant receives the In Briefing and Course Briefing. The participants are exposed to either the Control Group Briefing, Map Group Briefing, or Virtual Environment Briefing depending on which group they are assigned. This appendix also contains the Debriefing hand out.

2. IN BRIEFING

Welcome to the Naval Postgraduate School's Computer Science Department. My name is CPT Quay B. Jones. Thank you for your assistance with today's experiment. Today's experiment deals with dismounted navigation in natural terrain.

This experiment is not a test of your intelligence or performance. Rather, it is an evaluation of navigational tools. ***(For Military Personnel)*** *Your performance will not be recorded in your personnel records but is intended for research purposes only.* All information collected is for academic research only. Prior to starting the experiment you will be asked to read and sign a series of consent forms. Upon signing the consent forms, you will take self-evaluation, map reading, and spatial orientation exams. After the tests, you will under go a sixty-minute train-up period prior to moving to the navigation course. Upon completing the course, you will be brought back to Spanagel Hall for a short debriefing.

If there are no questions, please read and sign this consent form.

3. LOW FIDELITY MAP GROUP BRIEFING

In front of you is a 1:24,000 scale map of an orienteering course. On the flip side of the map is the same map enlarged to 1:5,000 scale but with no additional information. You have an aerial photograph or the area. You also have a clue sheet describing the location of the control points as well as photos of the control points. The map and photos are for your use to study and plan the route you will be using to navigate the course.

You have sixty minutes to study the map. Your planned route must navigate you through the nine checkpoints in order. ***(Show the participant the checkpoints in order then point out each checkpoint in the photo.)*** Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. Before the end of the sixty-minute study phase, you will mark your planned route on the aerial photograph using a red alcohol marker.

After completing the study phase, you will be taken to the navigation course to run the route you designated on your aerial photograph. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a one-minute map or a 30-second compass check; or a ninety-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

4. TRAIN-TO-STANDARD MAP GROUP BRIEFING

In front of you is a map of an orienteering course. You also have a clue sheet describing the location of the control points as well as photos and screen capture images of the control points. The map, photos, and clue sheet are for your use to study and plan the route you will be using to navigate the course.

You will now study the map and photos to plan and memorize your route. Your planned route must navigate you through the nine checkpoints in order. (Show the subject the checkpoints in order.) Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. You will mark your planned route on the map using a red alcohol marker.

Once you have finished planning your route, you should study it in order to memorize it. When you feel you have memorized it, (previous subjects have taken up to an hour to plan and study their route) you will be tested prior to departing for the course. If you do not adequately pass the test, you will again be given time to study your route. You must pass the pre-course test to standard before being allowed on the course.

The pre-course test will consist of you verbally explaining your route from memory using only the clue sheet provided. You will explain how you are moving between the control points, and what clues you plan to use to assist you. During this test you will be allowed to view the map twice in order to refresh your memory but only for 30 seconds each. Be as detailed and descriptive as possible.

After completing the study phase, you will run the route you designated on your laminated map. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a thirty seconds map or compass check; or a sixty-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

5. TRAIN-TO-STANDARD VE GROUP BRIEFING

Prior to beginning the study phase you will under go a fifteen-minute model familiarization phase. This is to help you become accounted with the model controls prior to starting the experiment. The model you will be using for this phase bares no resemblance to the actual model to be used during the training phase. You will be required to show proficiency with the interface prior to moving on to the terrain model.

In front of you is the 3-screen configuration, a joystick interface, and a list of instruction for the use of the interface ***(demo controls)***. Please feel free to explore the environment and control for the next few minutes. When you feel confident with the controls, I will walk you through a serious of questions to demonstrate your expertise. If you feel you need more time then please say so.

(Conduct Familiarization Phase; after demonstrating their proficiency with the interface, load up the terrain model and begin the training phase)

In front of you is a map of an orienteering course as well as a high fidelity 3-D model of the terrain depicted on the map. You also have a clue sheet describing the location of the control points as well as photos and screen capture images of the control points. The map, photos, and VE are for your use to study and plan the route you will be using to navigate the course.

You will now study the map and VE to plan and memorize your route. Your planned route must navigate you through the nine checkpoints in order. (Show the subject the checkpoints in order, paging through each page as you go to each checkpoint.) Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. You should utilize both the map and VE in your planning. Once you have decided upon a route, you will mark your planned route on the map using a red alcohol marker.

Once you have finished planning your route, you should use the map and VE to assist you in memorizing it. Once you feel you have memorized your route (previous subjects have taken up to an hour or more to plan and study their route) you will be tested prior to going to the course. If you do not pass the pre-course test, you will not be taken to the course, but will instead be given more time to study your route. You must pass the pre-course test to standard before being allowed on the real course.

The pre-course test will consist of you being placed at the start point in the VE and running the course while following your planned route. You will not be allowed to utilize the 15 meter "pop-up" view during this test. You will not be allowed to utilize the "you are here" map during this test. You are allowed to take up to two map checks using the actual laminated map of the area. You are allowed to make compass checks as needed, but cannot run the course with the compass "always on". If you become lost, leave your planned route for 5 minutes, leave the boundaries or encounter a check point out of order I will stop you, perform a mandatory map check, record a mistake, and allow you to continue. On the third mistake I will conclude the test and give you more time to study. Note that conducting a search for a nearby point does not count as being lost.

After completing the pre-course test, you will be taken to the navigation course to run the route you designated on your laminated map. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a thirty seconds map or compass check; or a sixty-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

6. LOW FIDELITY MAP VE GROUP BRIEFING

Prior to beginning the study phase you will under go a fifteen-minute model familiarization phase. This is to help you become comfortable with the model controls prior to starting the experiment. The model you will be using for this phase bears no resemblance to the actual model to be used during the training phase. You will be required to show proficiency with the interface prior to moving on to the terrain model.

In front of you are the 3-screen configuration, a joystick interface, and a list of instructions for the use of the interface ***(demo controls)***. Please feel free to explore the environment and controls for the next few minutes. When you feel confident with the controls, I will walk you through a serious of questions to demonstrate your expertise.

(Conduct Familiarization Phase; after the participant demonstrates proficiency with the interface, load up the terrain model and begin the training phase)

In front of you is a 1:24,000 scale map of an orienteering course as well as a high fidelity 3-D model of the terrain depicted on the map. On the flip side of the map is the same map enlarged to 1:5,000 scale. No additional information is included on the enlarged map. Along with the map, you have an aerial photograph of the region. You also have a clue sheet describing the location of the control points as well as photos and screen capture images of the control points. The maps, photos, and VE are for your use to study and plan the route you will be using to navigate the course.

You have sixty minutes to study the map and VE. Your planned route must navigate you through the nine checkpoints in order. ***(Show the participant the checkpoints in order then point out each checkpoint in the photo.)*** Beginning at the designated starting point, you will go to CP1, then to CP2, then to CP3, ... and finally to CP9. The checkpoints are described in the clue sheet provided. You may take the clue sheet with you when you go on the course. Before the end of the sixty-minute study phase, you will mark your planned route on the aerial photograph using a red alcohol marker.

After completing the training phase, you will be taken to the navigation course to run the route you designated on your aerial photograph. While navigating the course, you will not have the map nor will you be allowed to use a compass. During the execution of the course, you may request a one-minute map or a 30-second compass check; or a 90-second map and compass check. You can request as many map or compass checks as you wish, but each check will be recorded. If you decide to deviate from your previously planned route, you may request the map to mark your newly planned route.

Do you have any questions before we begin?

7. COURSE BRIEFING

Pick-up participant from the Graphics Lab.

Move participant to the Fort Ord orienteering course.

Move participant to start point:

Brief the participant on animals and ammunition

"You are at the start point of the Navigation Course. During the experiment, I may stop you and ask you to answer questions. You must navigate the nine checkpoints in order. Each control point will be identified by a control point marker ***(show participant a control marker)*** which you must touch prior to moving to the next control point. Once you touch a control marker, I will tell you which marker it is. If it is the correct marker, I will give you further instructions. If it is the incorrect marker, I will not say anything other then the marker's number. I will not stop you unless you attempt to cross the course boundaries ***(show participant the boundaries)***. You may request the compass for a thirty second compass check; the map/maps for a (30/60) second map check; or the map and compass for a (60/90) second compass and map check. These checks will be recorded and timed by me. If you determine that you would like to change your route, you may request the map and a blue marker to mark changes to your proposed route. You will have sixty seconds to mark your new route. You may request an additional sixty seconds if you deem it necessary. You have sixty minutes to make it as far as you can along your planned route. From now until completion of the navigation course do not interact with **anyone**. Before you begin, do you have any questions?"

TASK 1: START POINT TO CHECKPOINT ONE.

Task: "Your first task is to move from the start point to checkpoint one along your designated route."

Condition: "Without a map or interaction with anyone move from start point to checkpoint one along your preplanned route. If you deviate from the designated route you will be allowed to continue your movement unless you attempt to go outside the course boundaries. You may deviate 5m from your route, if you are on a trail, or 15m, if you are conducting cross-country movement before you are assessed an error. You can move back and forth along your route without being assessed an error. If you deviate from your path for more then 15 continues minutes and are not make progress towards the intended control point, I will stop you, show you your location on the map, and give you sixty seconds to mark a new route to the appropriate control point."

Standard: "Do the best you can."

"Ready,... Begin."

TASK 2: CHECKPOINT ONE TO CHECKPOINT TWO.

Task: "Checkpoint one. Your next task is to move from the checkpoint one to checkpoint two along your planned route. Conditions and standards are unchanged."

TASK 3.1.A, B, C: SPATIAL AWARENESS TEST I.

Stop timer

Stop participant at spatial awareness test area.

"Checkpoint two. Stop, I am going to have you identify the direction to three checkpoints."

Place the color wheel platform in its base on the south side of checkpoint.

Task: "Identify the direction to the start point, checkpoint five, and checkpoint nine."

Show participant arrows as you state their names.

Condition: "Given a color coded, 360-degree wheel and three arrows, identify the direction to the start point, checkpoint five, and checkpoint nine by placing the appropriate arrow in the direction of its checkpoint."

Standard: "Unchanged."

Record the time it takes the participant to perform the Wheel task and the orientation of the participant (looking north, south, east, rotates in the direction of the arrows, etc). Once done, photo graph the wheel, remove wheel platform from its stand, and have participant continue to checkpoint three.

TASK 3.2: CHECKPOINT TWO TO CHECKPOINT THREE.

Task: "Your next task is to move from the checkpoint two to checkpoint three along your planned route. Conditions and standards are unchanged. Ready,... Begin."

Start timer

TASK 4: CHECKPOINT FOUR TO CHECKPOINT FIVE.

Task: "Checkpoint three. Your next task is to move from the checkpoint three to checkpoint four along your planned route. Conditions and standards are unchanged."

TASK 5.1.A, B, C: SPATIAL AWARENESS TEST I.

Stop timer

Stop participant at spatial awareness test area.

"Checkpoint four. Stop, I am going to have you identify the direction to three checkpoints."

Place the color wheel platform in its base on the south side of checkpoint.

Task: "Identify the direction to checkpoint one, checkpoint six, and checkpoint eight."

Show participant arrows as you state their names.

Condition: "Given a color coded, 360-degree wheel and three arrows, identify the direction to checkpoints one, six, and eight by placing the appropriate arrow in the direction of its checkpoint."

Standard: "Unchanged."

Record the time it takes the participant to perform the Wheel task and the orientation of the participant (looking north, south, east, rotates in the direction of the arrows, etc). Once done, photo graph the wheel, remove wheel platform from its stand, and have participant continue to checkpoint five.

TASK 5.2: CHECKPOINT TWO TO CHECKPOINT THREE.

Task: "Your next task is to move from the checkpoint four to checkpoint five along your planned route. Conditions and standards are unchanged. Ready,... Begin."

Start timer

TASK 6: CHECKPOINT FIVE TO CHECKPOINT SIX.

Task: "Checkpoint five. Your next task is to move from the checkpoint five to checkpoint six along your planned route. Conditions and standards are unchanged."

TASK 7: CHECKPOINT SIX TO CHECKPOINT SEVEN.

Task: "Checkpoint six. Your next task is to move from the checkpoint six to checkpoint seven along your planned route. Conditions and standards are unchanged."

TASK 8: CHECKPOINT SEVEN TO CHECKPOINT EIGHT.

Task: "Checkpoint seven. Your next task is to move from the checkpoint seven to checkpoint eight along your planned route. Conditions and standards are unchanged."

TASK 9: CHECKPOINT EIGHT TO CHECKPOINT NINE.

Task: "Checkpoint eight. Your next task is to move from the checkpoint eight to checkpoint nine along your planned route. Conditions and standards are unchanged."

TASK 10.1: CHECKPOINT 4 IDENTIFICATION.

While standing at checkpoint nine:

Stop timer

Task: "Checkpoint nine, finish point. Your next task is to identify the location of checkpoint four from where you are."

Condition: "Point to checkpoint four and tell me where checkpoint four is from here. (i.e., twenty meters and in this direction)."

Standard: "Unchanged."

TASK 10.2: DESCRIBE ROUTE FROM CHECKPOINT NINE TO START POINT

Task: "Your next task is to describe what you consider the easiest route you would take to move from here to checkpoint four."

Condition: "Without a map, describe the route you would take to move from checkpoint nine to checkpoint four."

Standard: "Unchanged."

TASK 10.3: CHECKPOINT NINE TO START POINT (if described route would take them in the general location of the start point)

Task: "Your next task is to move from checkpoint nine to checkpoint four using the route you just described."

Condition: "Again, do not interact with anyone to include the researcher. You may not request a map or a compass check."

Standard: "You have ten minutes, otherwise standards are unchanged."

"Ready,... Begin"

Start timer

Reach checkpoint #4 or ten minutes has elapsed.

FINISH

Stop timer

"Stop. Congratulations you have completed the navigation portion of this experiment. We will now return to the vehicle for one final test before returning to the laboratory."

TASK 11: WHITE BOARD TEST.

Task: "Your final task is to create a top down representation of the start point and nine control points."

Condition: "Without a map or interaction with anyone take the ten magnets labeled with the start point and nine checkpoints ***(show the participant the magnets)*** and place them on a clean white board in proper perspective to each other. You are attempting to create a top down view of the checkpoints, actual distance between points does not matter, however, relative locations to each checkpoint does. Until you feel you are finished or five minutes has elapsed, you may place and move the magnets as you wish.

Standard: "Do the best you can."

"Any questions,... Ready,... Begin."

Start timer

Stop the timer when the participant indicates he has finished or ten minutes has elapsed, which ever occurs first. Observe the participant and note his method for placing the magnets (i.e. in order of visit, outside in, or inside out). Take a picture of the final results (allow participant 5 minutes maximum to perform the task).

Stop timer

"Stop. Congratulations on completing the final task for this experiment. We will now return to NPS for a final debriefing session."

Move participant back to the Graphics Lab for debriefing.

8. DEBRIEFING

The use of virtual environments in training and education has been an expanding field for the last two decades. With recent developments in computer systems, virtual reality models are now able to display much higher fidelity. In order to insure we are providing a positive training transfer and properly replicating real world environments, research is being conducted in the levels of detail required in models.

The study you have just completed is concerned with gathering information on how individuals navigate through complex virtual environments. You spent a session planning and studying a route demonstrating route knowledge Finally, you demonstrated spatial knowledge of the terrain through estimating bearings to known points and movement to an unplanned location.

Four separate groups were examined in order to determine performance levels. All four groups were given a map on which they designated their routes prior to running the navigation course. The first group was only allowed to study a 1:24,000 map for 60 minutes. The second group was given the 1:24,000 map and allowed to maneuver through a real time, high fidelity virtual representation of the terrain for 60 minutes. The third group had only a 1:5,000 scale map but had to train to a set standard before being allowed on the actual outdoor course. The fourth group had the 1:5,000 scale map and the VE and also had to complete the training to a standard before running the course.

The research personnel observed and recorded information based on the experience and behavior of the participants in order to gather the information equipped for the redesign and implementation of a more useful virtual model. The notes and observations collected will be used for the purpose of establishing standards for model development.

Your assistance in this project will contribute to the production of more useful virtual environments that provide users with spatial knowledge and better navigational skills. With the information gathered from your experience and the experience of other participants, we are discovering what people generally use as navigational cues in the virtual and real world environments. This information will assist in the design of future virtual reality models that will be adaptive to a variety of individual needs.

If you have any questions about the study, please ask your research assistant. *Until 30 August 1999, please do not discuss this experiment with anyone except our research personnel to prevent influencing any future participants*. Thank you for your participation in this study.

The research supervisor, CPT Quay B. Jones, for this study can be contacted at (408) 656 – 4077 or Email: jones@cs.nps.navy.mil.

APPENDIX D. CONSENT FORMS

1. GENERAL

The forms in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of three documents: Consent Form, Minimal Risk Consent Statement, and the Privacy Act Statement. Each participant is required to read and sign these documents before he is allowed to participate in the study. A research monitor observes and verifies the signing of each document. The format and content of these documents is based on the forms used in MAJ William Banker's land navigation experiment [BANK 97] and MAJ Simon R. Goerger's land navigation experiment [GOER 98b].

2. CONSENT FORM

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study of spatial awareness of natural and virtual environments. With information gathered from you and other participants, we hope to discover insight on navigational aids used to move through virtual environments during dismounted navigation of natural terrain. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.

2. **Background Information.** The Naval Postgraduate School NPSNET Research Group is conducting this study.

3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be two sessions: a) 30 pretest phase and 2) training and execution phases lasting approximately five hours in duration, during which you will be expected to accomplish a number of tasks related to navigating natural terrain.

4. **Risks and Benefits.** This research involves no risks or discomforts greater then those encountered in ordinary hike through rolling, wooded terrain. The benefits to the participants are gaining techniques for enhancing spatial knowledge of unfamiliar environments and contributing to current research in human-computer interaction.

5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which will possibly identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, CPT Quay B. Jones, at (408) 656 – 4077 (Email: jones@cs.nps.navy.mil).

9. **Statement of Consent.** I have read the above information. I have asked all question and have had my questions answered. I agree to participate in this study.

-- ------------------------

Participant's Signature Date

-- ------------------------

Researcher's Signature Date

3. MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: Virtual Environments and Navigation in Natural Environments

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary, refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Rudy Darken, Ph.D., Principal Investigator, and about my rights as a research participant or concerning a research related injury is the Modeling Virtual Environments and Simulations Chairman. A full and responsive discussion of the elements of this project and my consent has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

____

Signature of Principal Investigator Date

____

Signature of Volunteer Date

____

Signature of Witness Date

4. PRIVACY ACT STATMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: Spatial Cognition information will be collected to enhance knowledge, or to develop tests, procedures, and equipment to improve the development of Virtual Environments.

3. Use: Spatial Cognition information will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

4. Disclosure/Confidentiality:

   a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

   b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

   c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____

Signature of Volunteer   Name, Grade/Rank (if applicable)   DOB   SSN   Date

____

Signature of Witness   Date

APPENDIX E. QUESTIONNAIRES AND TESTS

1. GENERAL

The items in the appendix appear in the same format utilized for the experiment and thus do not follow the standard thesis format utilized in the chapters of this document. This appendix consists of eight documents: Land Navigation Questionnaire, Self Ability Evaluation, Santa Barbara Sense-of-Direction Scale, Map Reading Test, Guilford-Zimmerman Aptitude Survey (cover only), Practice Model Test, and two Debriefing Questionnaires. This tests and questionnaires are the same as in Goerger's thesis [GOER 98b].

The Land Navigation Questionnaire (Appendix E.2) gathers general navigational background of the participant. The participant completes this prior to beginning the experiment.

The Self Ability Evaluation (Appendix E.3) is a qualitative self analysis of an individual's navigational ability. It provides a participant with general limits from which to appraise his perceived navigation aptitude. The left end of the scale is valued at 0.00 and the right end of the bar line is valued at 1.00. Values measured from 0.00 to 0.33 are assessed as beginning navigators. From 0.33 to 0.66 is ranked as an intermediate navigator. Values of 0.66 to 1.00 are evaluated as experts. This test was included to negate any bias inherent in the word "beginner" from the Land Navigation Questionnaire.

The Santa Barbara Sense-of-Direction Scale (Appendix E.4) is a quantitative self-evaluation of navigational ability. The University of California at Santa Barbara developed the scale. An individual's score is calculated by reversing the values of questions 2, 6, 8, 10, 11, 12, 13, and 15. For example, if the participant answered question number two as "3", the question is given a numerical value of "5". Once the values for the above questions are reversed, sum the value of each question and divide the total by the number of questions answered. The lower the resulting score the more confidant an individual is in their navigational abilities. The test scale has a mean score of 3.54 with a standard deviation of 1.03. For this experiment, most individuals expressed high confidence in their navigational abilities.

The Map Reading Test (Appendix E.5) consists of twenty questions dealing with terrain identification. The test is designed to determine an individual's proficiency in reading the terrain features on a map and associating them to real world terrain features. The first fifteen questions concern properly identifying terrain features from 1:50,000 scale military maps. The final five questions dealt with matching images of terrain features to map depictions of terrain features. The answers for the test are listed in Table E.1. Each question is worth one point. If a participant misidentifies a linear terrain feature they receive 0.5 points for the question. For example, if the terrain feature is a stream and the participant classifies it as a road, they receive 0.5 points for the question. However, if the participant describes a stream as a draw, they receive no credit. Participants must score 65% (13 out of 20) or better to be allowed to participate in the study.

Question	***Answer***	***Feature***
1.1	B	Draw
1.2	I	Spur/Finger
1.3	H	Saddle
1.4	A	Depression
1.5	C	Hill Top
2.1	F	Road/Trail
2.2	B	Draw
2.3	E	Ridge Line
2.4	L	Valley
2.5	I	Spur/Finger
3.1	I	Spur/Finger
3.2	C	Hill Top
3.3	G	Road/Trail Intersection
3.4	J	Stream/River
3.5	B	Draw
4.1	F	Road/Trail
4.2	D	Hill Top
4.3	A	Road
4.4	E	Saddle
4.5	C	Spur/Finger

Table E.1 Map Test Answer Key

The Guilford-Zimmerman Aptitude Survey (Appendix E.6) evaluates an individual's spatial orientation ability. The results of this test are compared to a pool of national test scores to determine if a participant is above or below the national average for spatial orientation. Those above the national average are describe as having a "high" GZ score, or high spatial ability. Those scoring below the average are classified as "low". The experiment groups were set up to evenly distribute high and low ability subjects evenly between the groups.

The Practice Model Test (Appendix E.7) is administered to each VE participant prior to moving onto the actual course model. It is used to provide the participant with familiarity with the interface functions. Each virtual environment participant was required to complete each task of the Practice Model Test. After completing the test, a participant is retested on any functions they failed to properly employ until he is able to do so.

The Debriefing Questionnaires (Appendices E.8 and E.9) are administered upon return from running the course and prior to the final review of the participant's route. Participants in the Map Only Groups received the questionnaire in Appendix E.8. Virtual Environment participants receive the questionnaire in Appendix E.9 that has an additional page containing questions related to the VE and its interface. The questions are designed to provide a qualitative analysis of the training materials and course [GOER 98b]. A five point scale (1-5) is used for the questionnaire. The last page of the questionnaire is used to determine what details subjects think are necessary for inclusion in a useful VE. Goerger deliberately left stream/rivers off of the list to see how much attention subjects were paying.

The raw scores from these tests and questionnaires are listed in Appendix O.

2. LAND NAVIGATION QUESTIONNAIRE

Name:____________________________ Age:_____ Sex:_____

Branch of Service: __________________ Rank: _____________

1) Where did you first learn to navigate?

a) Scouting, Boys/Girls Club
b) Parents
c) Friend
d) ROTC/Academy
e) Basic Training
f) Officer Candidate School
g) Officers Basic Course
h) Other: ____________

2) How many years have you been Orienteering/Navigating?

a) less then a year
b) one year or more
c) two years or more
d) five years or more
e) ten years or more

3) At what level would you classify your navigating abilities?

a) Novice/Beginner
b) Intermediate/Average
c) Expert/Advanced

4) How many Land navigation or Orienteering courses have you done in the last year?

5) The land navigation course runs through varying degrees of vegetation and over rolling terrain. It will require you to negotiate a distance of no more than three miles in one hour. Do you have any physical disabilities that would prevent you from executing this task? Yes/No

3. SELF ABILITY EVALUATION

Participant ID: _______

The following bar line depicts the navigation ability evaluation of an average infantry officer with five years experience. The "X" indicates his ability level.

X

Knows how to read a map — Navigates with no errors; Rarely looks at map

Place an "X" on the line below were you feel your navigational abilities are at this time.

Knows how to read a map — Navigates with no errors; Rarely looks at map

4. SANTA BARBARA SENSE-OF-DIRECTION SCALE

Participant ID: __________ Date: ___________ SEX: F M AGE:____

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

1. I am very good at directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for were I left things.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W)

   strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

   strongly agree 1 2 3 4 5 6 7 strongly disagree

(turn over and continue)

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

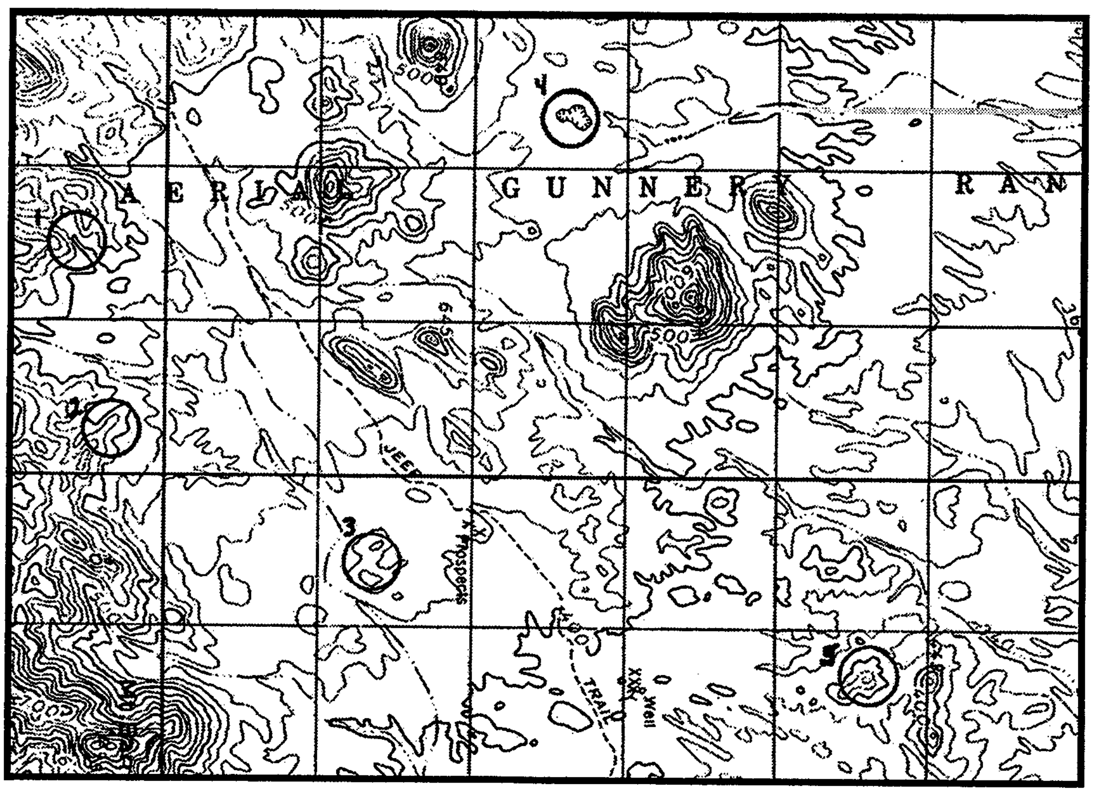
15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. MAP READING TEST

The following is a list of terrain features commonly found on military and/or orienteering maps. Using the list of terrain features, identify the most predominate terrain feature within each circle and place your answer in the space provided. Each terrain feature from the list may be used more than once or not at all.

A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

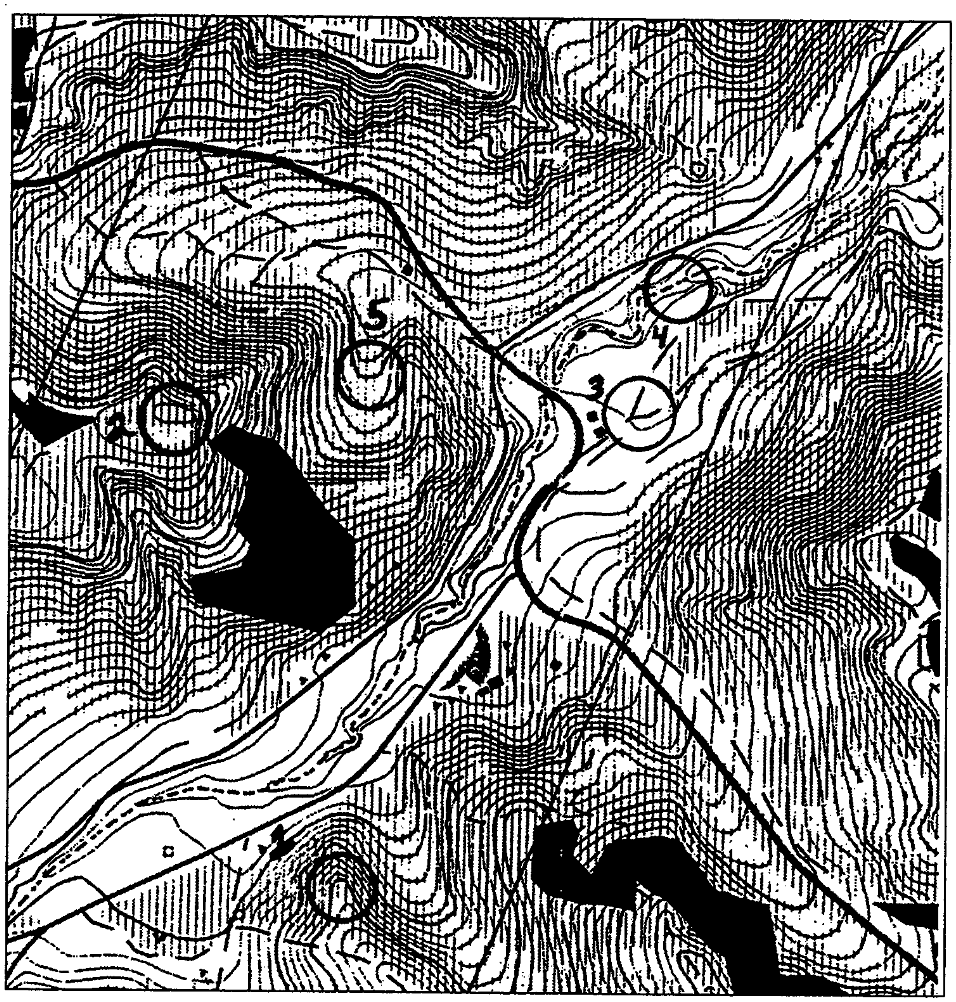


1. _____ 2. _____ 3. _____ 4. _____ 5. _____

A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

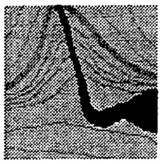
1. _____ 2. _____ 3. _____ 4. _____ 5. _____

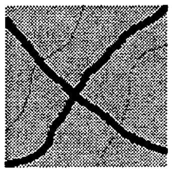
A. Depression
B. Draw
C. Hill Top
D. Lake/Pond
E. Ridge Line
F. Road/Trail
G. Road/Trail Intersection
H. Saddle
I. Spur/Finger
J. Stream/River
K. Stream/River Intersection
L. Valley

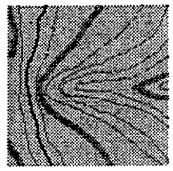


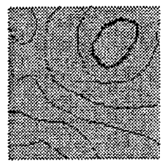
1. _____ 2. _____ 3. _____ 4. _____ 5. _____

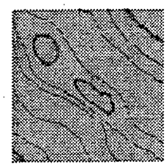
Using the following map representations, choose the best representation for each picture displayed below. The map representations are a facsimile of the terrain shown in the photos. Some map representations may be used more than once or not at all.

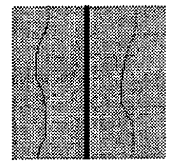

A

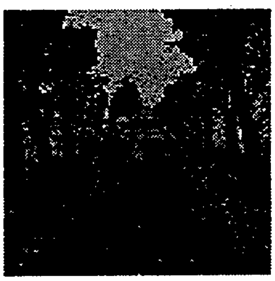

B

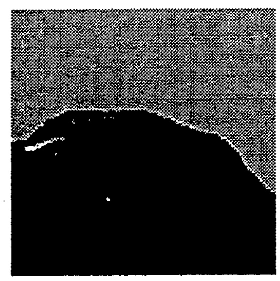

C

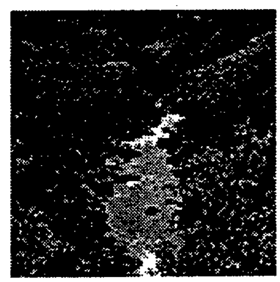

D

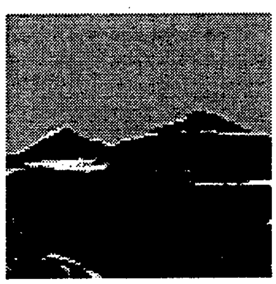

E


F


1. _____


2. _____


3. _____


4. _____


5. _____

6. GUILFORD-ZIMMERMAN APTITUDE SURVEY

The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

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Name ______________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.
This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

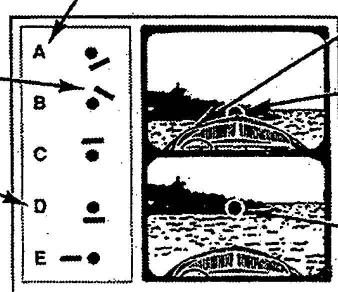
Here is Sample Item 1.

These bars represent the boat's prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)

These are the five possible answers to the item.



Sample Item 1

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

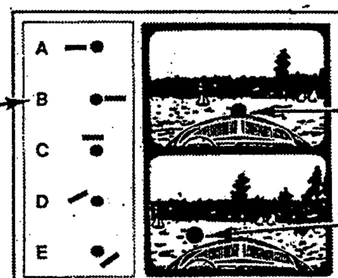
This is the same aiming point shown above. Note that the prow has dropped below it.

To work each item: **First**, look at the top picture and see where the motor boat is headed. **Second**, look at the bottom picture and note the CHANGE in the boat's heading. **Third**, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)



Sample Item 2

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

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98 97 96 95 94 8 7 6 5 4

Figure E.1 Guilford-Zimmerman Aptitude Survey Cover Page

7. PRACTICE MODEL TEST

a. Turn to a heading of 360 degrees and begin movement.

b. Switch to a top down view

c. Switch to a 15-meter view

d. Change to run mode

e. Change to walk mode

f. Move to the road and take a right

g. While following the road:

   i) Look-up
   ii) Look down
   iii) Look left
   iv) Look Right

h. Head into town

i. Stop

j. What is your heading?

k. Begin movement.

l. Run

m. Slow down and stop at the road sign

n. Look to your right. What do you see?

o. Using the quick view keys, see what is at CP6

p. Using the hot keys, return to the start point

8. DEBRIEFING QUESTIONNAIRES

a. Map Group Debriefing Questionnaire

MAP						
	Hard to Read				Easy to Read	
Was the map easy to read?	1	2	3	4	5	N/A
	Hard to Understand				Easy to Understand	
Was the map easy to understand?	1	2	3	4	5	N/A
Were the trails & roads adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Were the man made structures	Definitely Not				Definitely Yes	
Adequately shown on the map?	1	2	3	4	5	N/A
Were the obstacles adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Was the vegetation adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Using the map, how difficult was it	Easy				Very Difficult	
to plan your route?	1	2	3	4	5	N/A
Comments:						

COURSE						
	Easy				Very Challenging	
How difficult was the course?	1	2	3	4	5	N/A
	Definitely Not				Definitely Yes	
Were the control points well marked?	1	2	3	4	5	N/A
Were the control points located	Definitely Not				Definitely Yes	
where you expected them?	1	2	3	4	5	N/A
Had routes been trampled down	Definitely Not				Definitely Yes	
leading to the control points?	1	2	3	4	5	N/A
Did you have difficulties remembering	Definitely Not				Definitely Yes	
your planned route?	1	2	3	4	5	N/A
Comments:						

MISC						
	Definitely Not				Definitely Yes	
Did you enjoy this experiment?	1	2	3	4	5	N/A
Did you feel the training phase	Definitely Not				Definitely Yes	
was long enough?	1	2	3	4	5	N/A
Did you feel the training phase	Definitely Not				Definitely Yes	
was too short?	1	2	3	4	5	N/A
Do you feel the training familiarized	Definitely Not				Definitely Yes	
you learn the environment?	1	2	3	4	5	N/A
Did you feel confident in navigating	Definitely Not				Definitely Yes	
the terrain without a map or compass?	1	2	3	4	5	N/A
Comments:						

1. Place an "X" next to the items you feel must be replicated in a model that prepares you to navigate an actual piece of terrain.

Buildings	factory	________	roads	dirt roads	________
Buildings	houses	________	roads	foot paths	________
Buildings	public buildings	________	roads	paved roads	________
Buildings	shacks	________	roads	trails	________
Buildings	other	________	roads	other	________

Misc	compass	________	obstacles	electric lines	________
Misc	road signs	________	obstacles	pits/fox holes	________
Misc	rock piles	________	obstacles	shallow ditches	________
Misc	sand bags	________	obstacles	telephone poles	________
Misc	street signs	________	obstacles	towers	________
Misc	the sun	________	obstacles	trenches	________
Misc	people	________	obstacles	other	________
Misc	animals	________			
Misc	sound	________			
Misc	other	________	vegetation	bushes	________
Misc	other	________	vegetation	flowers	________
			vegetation	grass/weeds	________
Terrain	clearings	________	vegetation	trees	________
Terrain	depressions	________	vegetation	other	________
Terrain	hills	________			
Terrain	knolls	________			
Terrain	ridgelines	________	water	lakes	________
Terrain	spurs/fingers	________	water	marsh lands	________
Terrain	other	________	water	ponds	________
			water	puddles	________
			water	swamps	________
			water	other	________

2. From the list of items in question # 1, choose and rank the six items you feel are the most important for a computer model which will be used to prepare an individual to navigate an actual piece of terrain.

1 ________
2 ________
3 ________
4 ________
5 ________
6 ________

b. Virtual Environment Group Debriefing Questionnaire

MAP						
	Hard to Read				Easy to Read	
Was the map easy to read?	1	2	3	4	5	N/A
	Hard to Understand				Easy to Understand	
Was the map easy to understand?	1	2	3	4	5	N/A
Were the trails & roads adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Were the man made structures	Definitely Not				Definitely Yes	
Adequately shown on the map?	1	2	3	4	5	N/A
Were the obstacles adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Was the vegetation adequately	Definitely Not				Definitely Yes	
shown on the map?	1	2	3	4	5	N/A
Using the map, how difficult was it	Easy				Very Difficult	
to plan your route?	1	2	3	4	5	N/A
Comments:						

COURSE						
	Easy				Very Challenging	
How difficult was the course?	1	2	3	4	5	N/A
	Definitely Not				Definitely Yes	
Were the control points well marked?	1	2	3	4	5	N/A
Were the control points located	Definitely Not				Definitely Yes	
where you expected them?	1	2	3	4	5	N/A
Had routes been trampled down	Definitely Not				Definitely Yes	
leading to the control points?	1	2	3	4	5	N/A
Did you have difficulties remembering	Definitely Not				Definitely Yes	
your planned route?	1	2	3	4	5	N/A
Comments:						

MISC						
	Definitely Not				Definitely Yes	
Did you enjoy this experiment?	1	2	3	4	5	N/A
Did you feel the training phase	Definitely Not				Definitely Yes	
was long enough?	1	2	3	4	5	N/A
Did you feel the training phase	Definitely Not				Definitely Yes	
was too short?	1	2	3	4	5	N/A
Do you feel the training familiarized	Definitely Not				Definitely Yes	
you learn the environment?	1	2	3	4	5	N/A
Did you feel confident in navigating	Definitely Not				Definitely Yes	
the terrain without a map or compass?	1	2	3	4	5	N/A
Comments:						

MODEL	Definitely Not				Definitely Yes	
Was the model clear and viewable?	1	2	3	4	5	N/A
	Definitely Not				Definitely Yes	
Did the model coincide with the map?	1	2	3	4	5	N/A
Were the trails & roads adequately	Definitely Not				Definitely Yes	
represented in the model?	1	2	3	4	5	N/A
Were the man made structures	Definitely Not				Definitely Yes	
adequately represented in the model?	1	2	3	4	5	N/A
Were the obstacles adequately	Definitely Not				Definitely Yes	
represented in the model?	1	2	3	4	5	N/A
Was the vegetation adequately	Definitely Not				Definitely Yes	
represented in the model?	1	2	3	4	5	N/A
Were changes in elevation adequately	Definitely Not				Definitely Yes	
represented in the model?	1	2	3	4	5	N/A
Did the model help you identify the	Definitely Not				Definitely Yes	
control points within the last 50m?	1	2	3	4	5	N/A
Did the model help you identify the	Definitely Not				Definitely Yes	
general area of the control points?	1	2	3	4	5	N/A
Using the model, how difficult was it	Easy				Very Difficult	
to plan your route?	1	2	3	4	5	N/A
Do you feel the model gave you an	Definitely Not				Definitely Yes	
advantage you normally wouldn't have had?	1	2	3	4	5	N/A
Would you use this tool if it were	Definitely Not				Definitely Yes	
available for mission planning?	1	2	3	4	5	N/A
Would you use this tool if it were	Definitely Not				Definitely Yes	
available for mission rehearsal?	1	2	3	4	5	N/A
Would you use this tool if it were	Definitely Not				Definitely Yes	
available for navigation training?	1	2	3	4	5	N/A
Comments:						

MODEL INTERFACE	Confusing				User Friendly	
Were you able to easily move through the model?	1	2	3	4	5	N/A
	Confusing				User Friendly	
Was the joystick easy to use?	1	2	3	4	5	N/A
	Confusing				User Friendly	
Was the acceleration lever easy to use?	1	2	3	4	5	N/A
	Confusing				User Friendly	
Were the toggle buttons easy to use?	1	2	3	4	5	N/A
	Confusing				User Friendly	
Your overall felling about the interface?	1	2	3	4	5	N/A
Was the 15-minute train-up on the	Definitely Not				Definitely Yes	
initial model useful?	1	2	3	4	5	N/A
Was the 15-minute train-up on the	Definitely Not				Definitely Yes	
initial model enough time to become familiar with the interface?	1	2	3	4	5	N/A
Did the use of three screens cause	Definitely Not				Definitely Yes	
any confusion when maneuvering?	1	2	3	4	5	N/A
Comments:						

1. Place an "X" next to the items you feel must be replicated in a model that prepares you to navigate an actual piece of terrain.

Buildings	factory ________	roads	dirt roads ________
Buildings	houses ________	roads	foot paths ________
Buildings	public buildings ________	roads	paved roads ________
Buildings	shacks ________	roads	trails ________
Buildings	other ________	roads	other ________
Misc	compass ________	obstacles	electric lines ________
Misc	road signs ________	obstacles	pits/fox holes ________
Misc	rock piles ________	obstacles	shallow ditches ________
Misc	sand bags ________	obstacles	telephone poles ________
Misc	street signs ________	obstacles	towers ________
Misc	the sun ________	obstacles	trenches ________
Misc	people ________	obstacles	other ________
Misc	animals ________		
Misc	sound ________		
Misc	other ________	vegetation	bushes ________
Misc	other ________	vegetation	flowers ________
		vegetation	grass/weeds ________
Terrain	clearings ________	vegetation	trees ________
Terrain	depressions ________	vegetation	other ________
Terrain	hills ________		
Terrain	knolls ________		
Terrain	ridgelines ________	water	lakes ________
Terrain	spurs/fingers ________	water	marsh lands ________
Terrain	other ________	water	ponds ________
		water	puddles ________
		water	swamps ________
		water	other ________

2. From the list of items in question # 1, choose and rank the six items you feel are the most important for a computer model which will be used to prepare an individual to navigate an actual piece of terrain.

1 ________
2 ________
3 ________
4 ________
5 ________
6 ________

APPENDIX F. COURSE

1. GENERAL

This appendix consists of six items: the 1:24,000 scale map enlarged to 1:5,000 scale, an aerial photo of the course, an aerial photo with an example participant debriefing route, 1:5,000 course orienteering map, and an explanation of the map legend [BANK 97]. The 1:50,000 and 1:24,000 maps are the standard scales used by most US ground forces for military operations. The difference in detail between the 1:5,000 scale map and the 1:24,000 map are obvious upon comparison. The aerial photo is the same given to the low fidelity map subjects. The 1:5,000 scale orienteering map was created by Banker [BANK 97] and modified by Goerger [GOER 98b]. The map legend explanation is taken directly from Appendix D of MAJ Banker's 1997 Masters Thesis.

2. 1:24,000MAP EXCERPT OF COURSE AREA

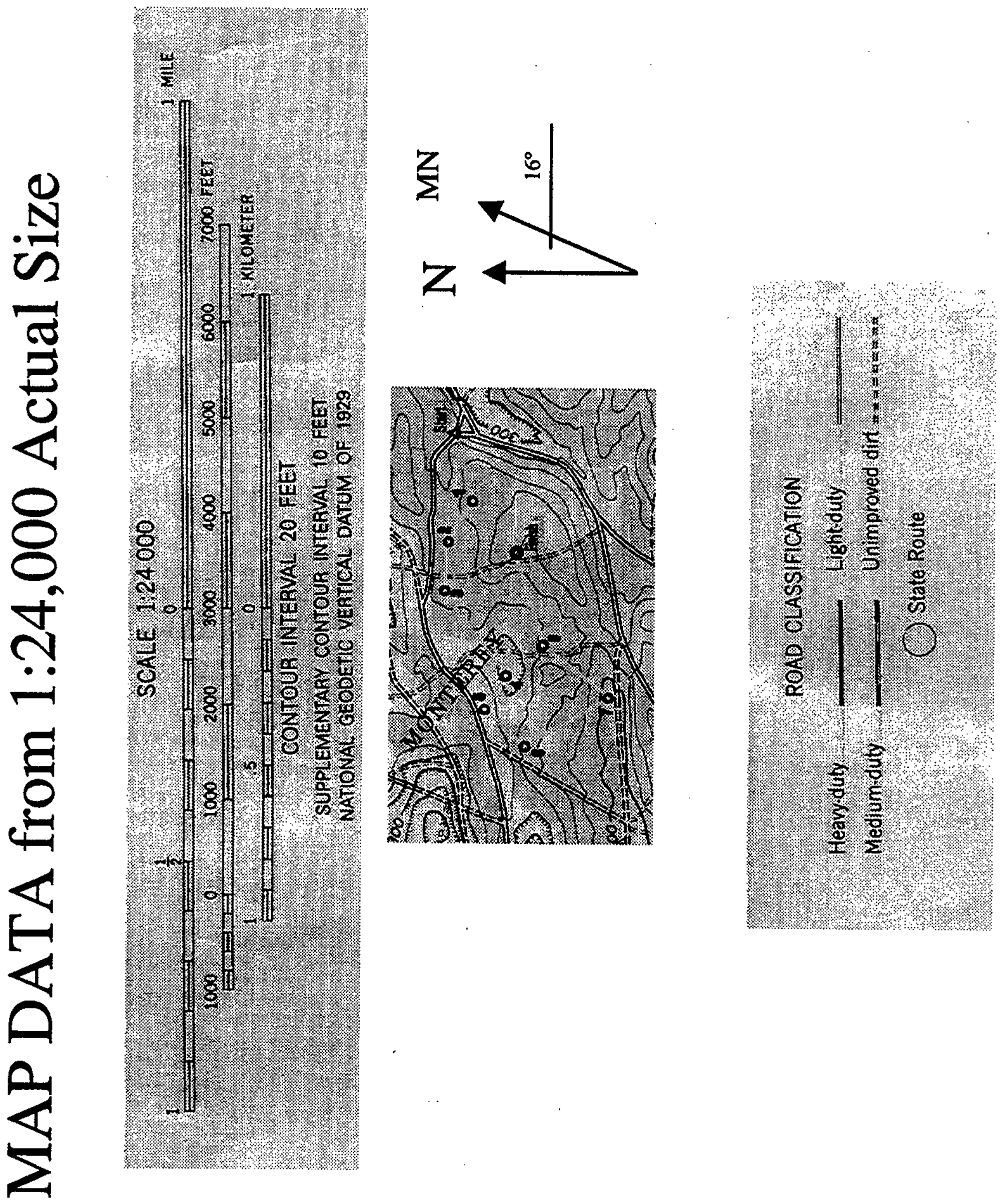


Figure F.2. 1:24,000 Map Excerpt of Course Area

3. 1:24,000MAP ENLARGED TO 1:5,000

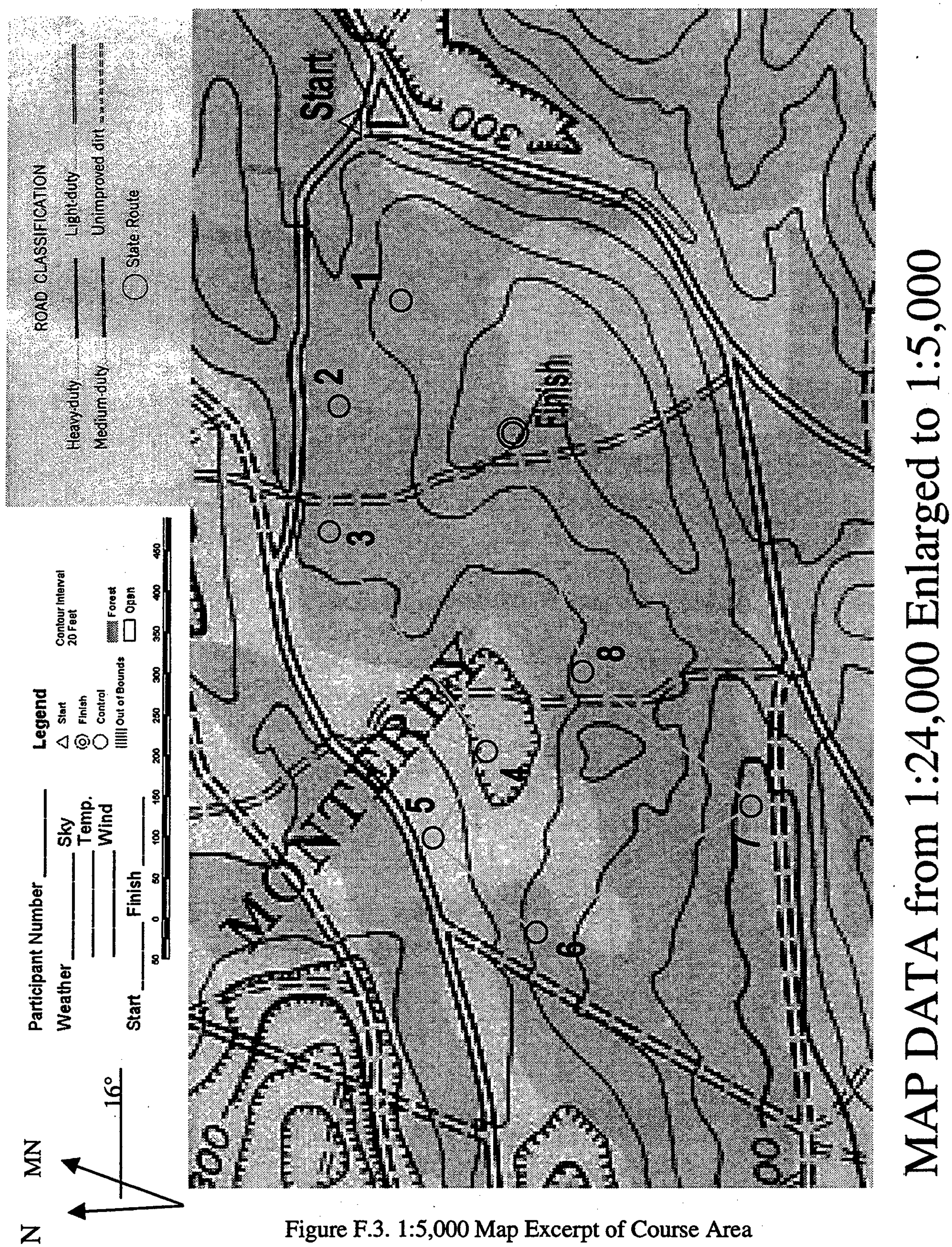


Figure F.3. 1:5,000 Map Excerpt of Course Area

4. AERIAL PHOTO

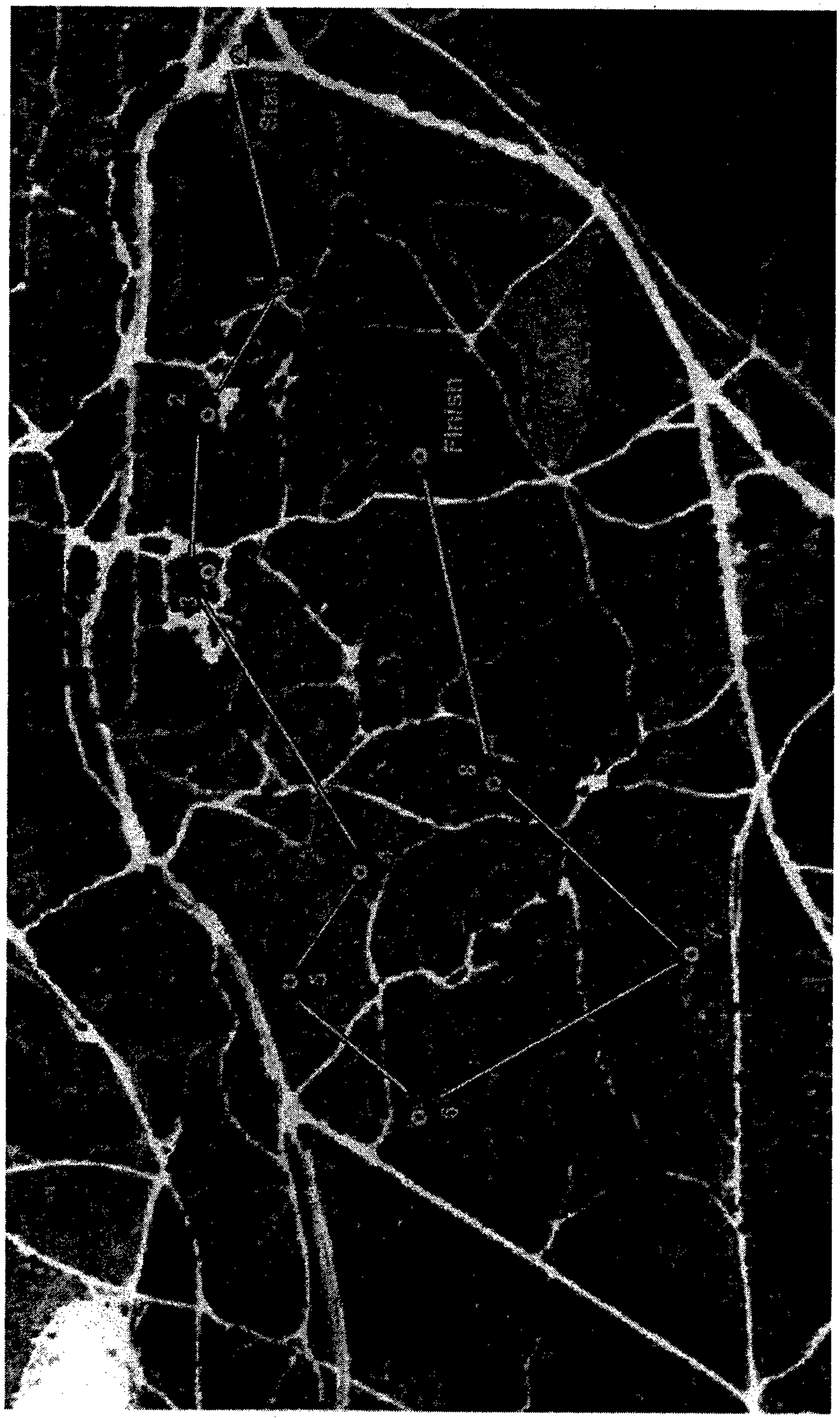


Figure F.4. Aerial Photo

5. AERIAL PHOTO WITH PARTICIPANT ROUTE

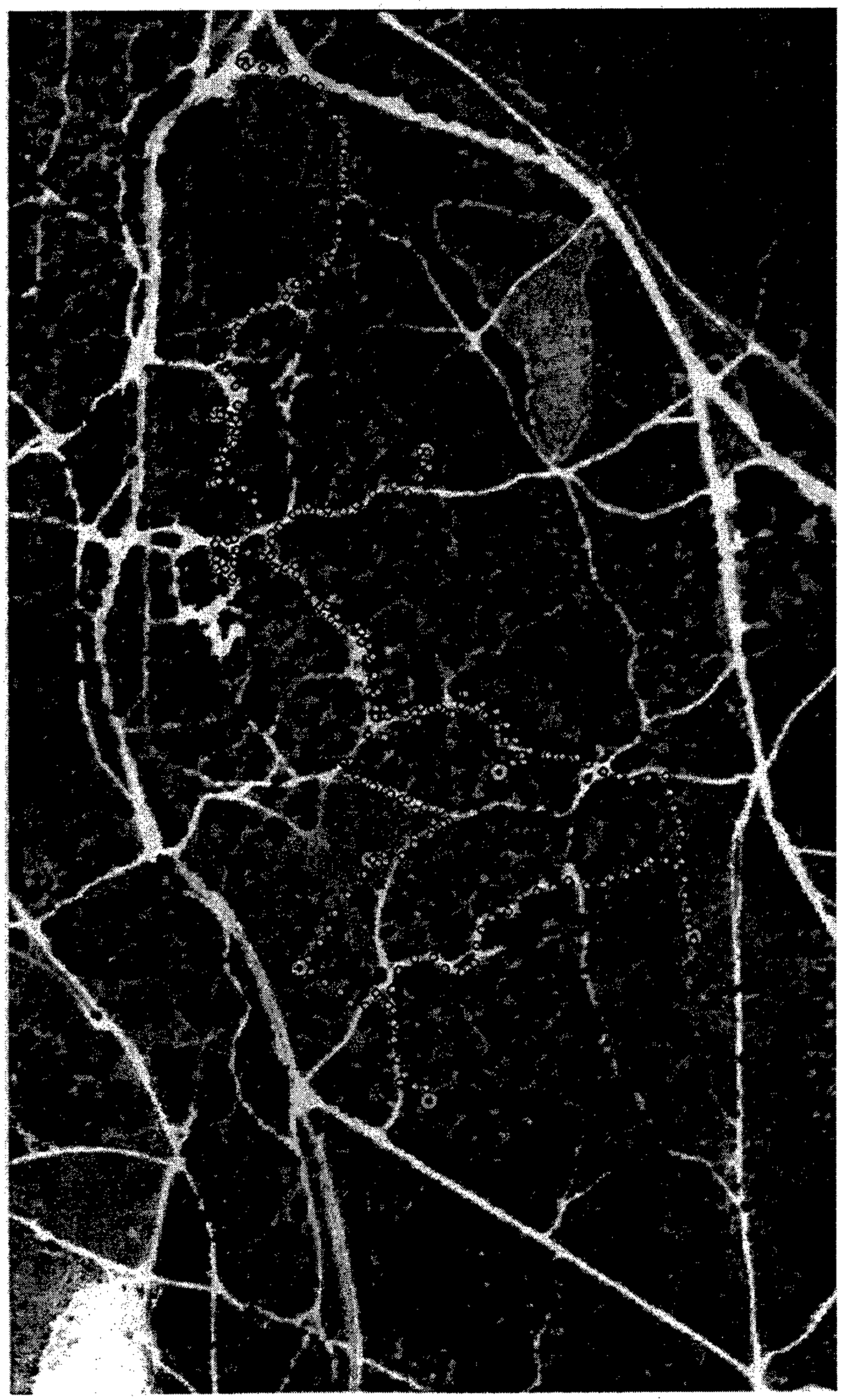


Figure F.5. Aerial Photo With Subject Route

6. 1:5,000 SCALE ORIENTEERING MAP

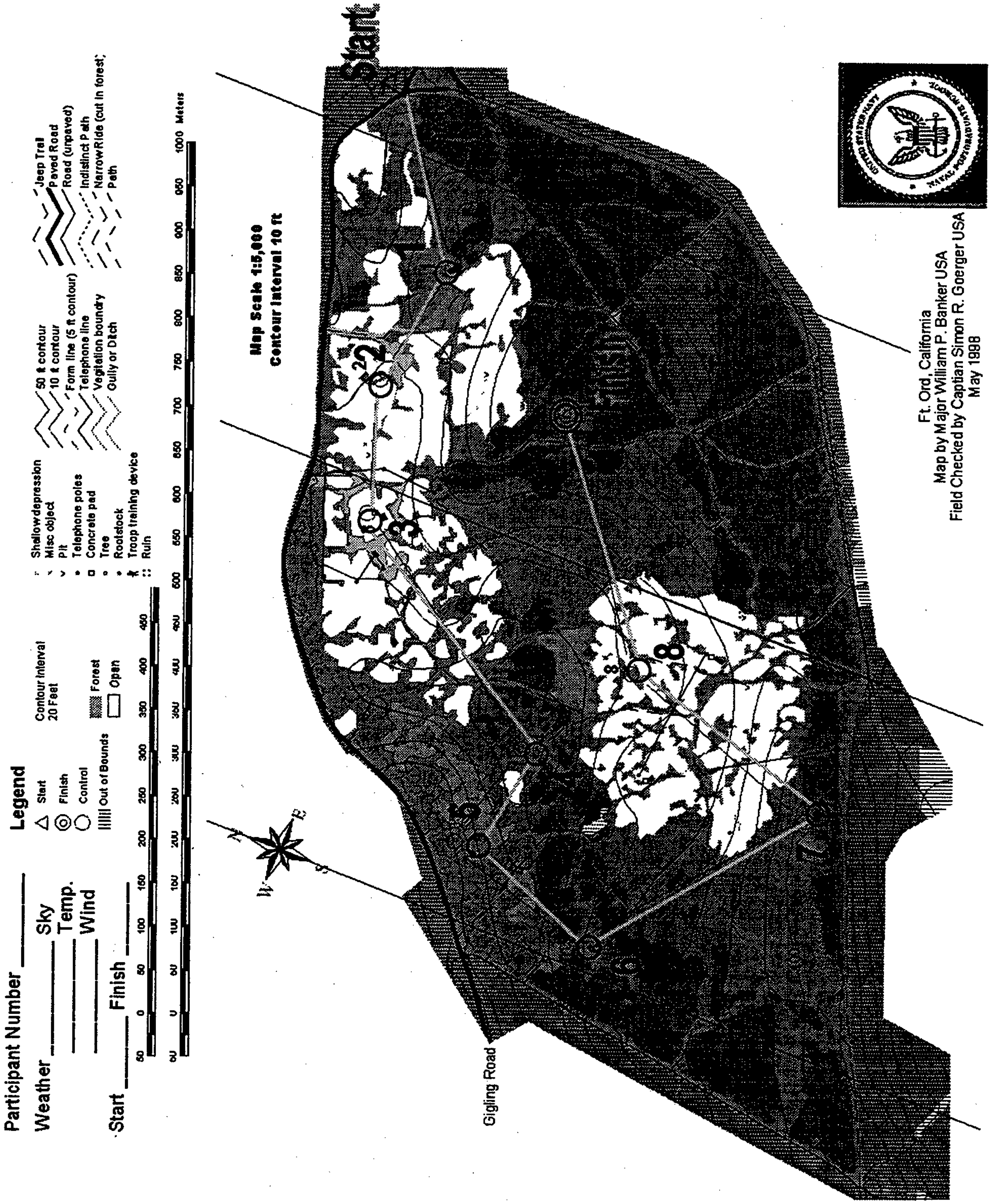


Figure F.6. 1:5,000 Scale Orienteering Map

7. COURSE MAP LEGEND EXPLANATION

All maps are generalizations. They use symbols to portray actual features on the earth's surface. Not all features are represented with the same precision. Discrete non-vegetation items are plotted on the map in the exact location they are in the actual environment, whereas vegetation boundaries (unless indicated with a distinctive dotted line) are not meant to represent a clean break from one type of vegetation to another. Rather, this line separating one vegetation area from another is a generalization of where one type more or less ends and another more or less begins. The line separating the two can best be thought of as a blurry line where the two types of vegetation intermingle. The below guide will help to determine the specific limitations of each symbol on the orienteering map.

Building - Buildings in the area are of several types:

a. Latrines - most common building, tan in color, approx. size 3 x 8 meters

b. Shelters - second most common building, green wood, roofed, no walls, approx. size 3 x 8 meters

c. Admin. - field office and shack, black with gold trim, 8 x 8 meters and 2 x 2 meters respectively

Open Sandy Ground - a significant patch of sand that will slow running

Open ground - dirt, hard pack, free of grass and other vegetation.

Undergrowth walk - immature chaparral or oak, dense stands of bushes, incomplete overlap of two distinct areas of fight which allow restricted passage along that overlap, other plants that prevent running.

Fight - mature chaparral or immature oak in such density that passage through is very difficult, running impossible

Forest walk - oak forest with patchy undergrowth, low lying tree limbs or tree density that prevents running from being sustained

Forest slow run - oak forest fairly free of undergrowth, but with low lying limbs or tree density that makes sustained running difficult.

Rough open ground - grass covered ground, possibly with scattered (avoidable) undergrowth. Note that there are a few locations that have what appears to be old jeep trails but are portrayed as rough open ground. Sometimes the distinction between one or the other blurs. If in doubt refer to other more distinctive features (contour lines, etc.) to determine your location.

Shallow depression - most likely an old decaying foxhole position or other man made excavation where the banks have eroded to create a bowl-like depression of 1 to 3 feet below surrounding ground.

Misc. object - a manmade feature, rubble, derelict military equipment, or other item whose exact description is only provided if it is the location of a control

Pit - an old foxhole or likely other man made pit that has steep vertical walls and may be reinforced with wood, depth from 2 to 5 feet. Note that there will be many pits in the area that are not depicted on the map. The pits that are depicted are accurate.

Telephone poles - wood poles (if bearing wire it will be noted on map) approx. 25 to 30 feet in height

Concrete pad - old concrete tent pad extending from 2 to 5 inches above ground level

Tree - a tree or large bush (could be two or more trees growing close together – forming an unbroken single canopy -- if the trees are small)

Rootstock - a dead or overturned tree

Troop training device - a bunker or other man made item built for training soldiers

Vegetation boundary - the edge of a vegetation type

Gully or Ditch - ranging from a shallow 1-foot deep gully to 5-foot deep military trench

Jeep Trail - a road more suitable for 4 x 4 vehicles due to width restriction and/or ruts. May be distinctive and worn or in some places overgrown with grass but still containing ruts.

Paved Road - a surfaced all weather road

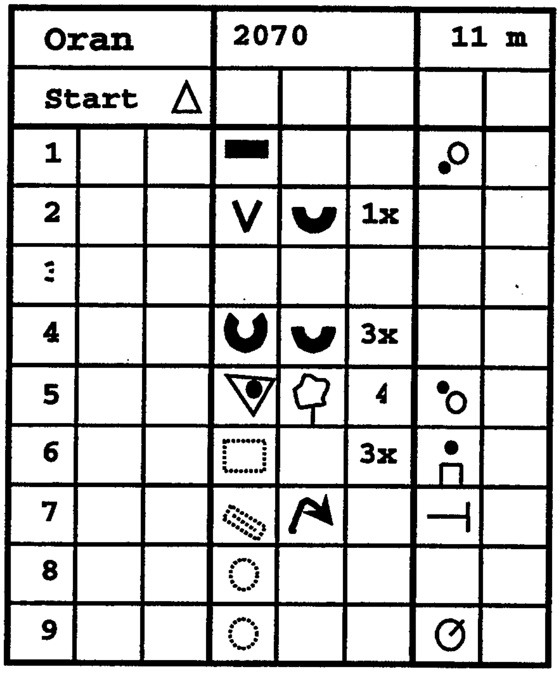
Road - a sandy or dirt road wide and level enough for 2 wheel drive vehicles

Indistinct Path - a path that is in the process of being overgrown with only intermittent marks on the ground that indicate that it was once a well traveled path

Narrow Ride - a linear break in the forest that may have once been a jeep trail but now is overgrown with grass and lacks telltale wheel ruts

Path - a foot or bike path.

8. CLUE SHEET



Course Orange Length 2070 meters

Building

Pit Shallow

Small depression Shallow

Single tree Deciduous Height 4 m

Ruin Size 3x7

Dry ditch Ruined

Clearing

APPENDIX G. PARTICIPANT TASK LIST[1]

Thank-you for participating in this study. You will do an Orienteering course today. However, there are some important differences to note:

1. You will be wearing a light pack with DGPS and Newton MSG Pad 130. Its purpose is to log your route and act as a data capture device for other actions you may perform.

2. Before you run the course you will carefully plan your route through the entire course (see Important Information on Marking Your Map)

3. Use this training time to commit the route and course to memory. You are expected to do the following on the actual course run:

   a. Navigate without aid of map and compass, utilizing only your memory
   b. Attempt to find all the controls utilizing your planned route

Summary of objectives
<u>All Objectives are equally important!!</u>

1. Choose the most efficient route based on your abilities
2. Minimize the number of map checks you request from the administrator
3. Minimize the number of compass checks you request from the administrator
4. Minimize the number of map with compass checks you request from the administrator
5. Stay on your planned route
6. Find all the controls in order (you have 60 minutes to conduct this task)

- If you need to make a map check then say so and the administrator will give you the map for (30/60) seconds. Additional time can be requested in (30/60) second increments at the additional cost of a map check each.
- If you need to make a compass check then say so and the administrator will give you the compass for 30 seconds. Additional time can be requested in 30-second increments at the additional cost of a compass check each.
- If you need both map and compass then say so and the administrator will give you both for (60/90) seconds. Additional time can be requested in increments of (60/90) seconds.
- If you want to change your route announce to the administrator that you are changing your route plan. At that point the administrator will hand you the map, compass, and blue pen. From the time that he gives you the materials you will have 60 seconds to plot the new route. If you need more time then tell him you need more time and you will get another 60 seconds. Request additional time as needed but remember that one of your objectives is to make as few map checks as necessary. **Every (30/60) seconds**

[1] This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

that you are looking at the map beyond the original 60 seconds for the route change counts as a map check.

Note that when two times are given (30/60) the larger time applies to low fidelity map subjects since they had both the map and the aerial photograph to consult.

APPENDIX H. MAP MARKING INSTRUCTIONS[1]

Pay close attention to how you mark your route, be as precise as the map and pen allow. Before your actual run you are expected to preview your map within your group's prescribed context. Mark your **planned route using the RED pen.** You may correct any mistakes you make while planning with the white eraser. Once the planning period is up or you elect to finish you will not be allowed to erase any of the red route marks you have made. **SO BE PRECISE** in marking your map, detail does matter. Later during the actual course run anytime that you are going to deviate from your planned route you must stop:

1. Announce to the administrator that you are changing your route plan. At that point the administrator will hand you the map. From the time that he gives you the map you will have 60 seconds to plot the new route. If you need more time than tell him you need more time and you will get another (30/60) seconds. Request additional time as needed but remember that one of your objectives is to make as few map checks as necessary. **Every (30/60) seconds that you are looking at the map beyond the original 60 seconds for the route change counts as a map check.**

2. Take the blue pen and draw in your new route with the same attention to detail that you applied or the original route planning in red.

3. Leave your original route on the map. The eraser is provided so that you may make corrections to a route as you draw it. Once you finish drawing and begin navigating you are not allowed to erase routes, or corrections to planned routes (blue penned routes).

4. You may make as many corrections to your route(s) as necessary while navigating the course.

Importance of detail in map marking and navigation

You are allowed to deviate from your planned route within the following tolerances while still being considered on that route:

Jeep Trails, Paved Roads, Unpaved Roads, Indistinct Paths, Narrow Rides and Paths -- If your marked route is on any of these features you are allowed **5 meters either side** of the feature and you are still considered as being "on your route".

All other features -- On all other types of non road/trail terrain you may travel **15 meters to either side** of your marked route and you are still considered as being "on your route"

[1]This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

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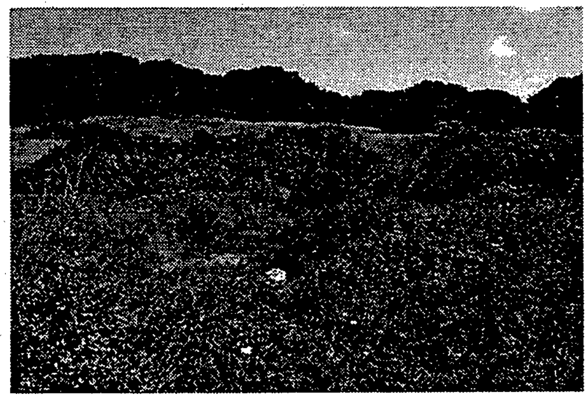
APPENDIX I. DIGITAL PHOTOS

1. GENERAL

As part of their training aids, subjects are provided with a series of digital images of the control points. Map-only subjects received the photos displayed in Appendix I.2 while Virtual Environment subjects receive the Appendix I.3 photo sets. The VE subjects also received screen shot images from the VE of what the control looks like in the model. This is so the subject can compare the model to the real world. The photos are furnished in color. Having the corresponding VE screen shot helps VE subjects overcome some model deficiencies, such as lack of accurate ground cover, and lack of negative spot elevations (i.e., pits and ditches) in the model. The photographs provide a useful tool for the subject in fixing exactly what the target control point looks like, and perhaps some of what the surrounding terrain looks like. Having this type of information is not entirely unreasonable for a military mission. The photos help to outfit the subject with a stronger grasp of the defining landmarks they are searching for.

2. MAP AND REAL WORLD GROUP PHOTOS

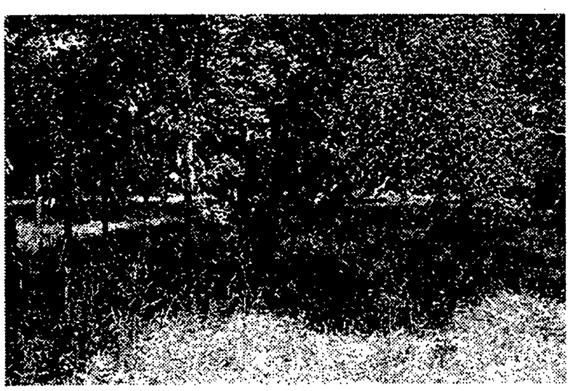
Control Point 1



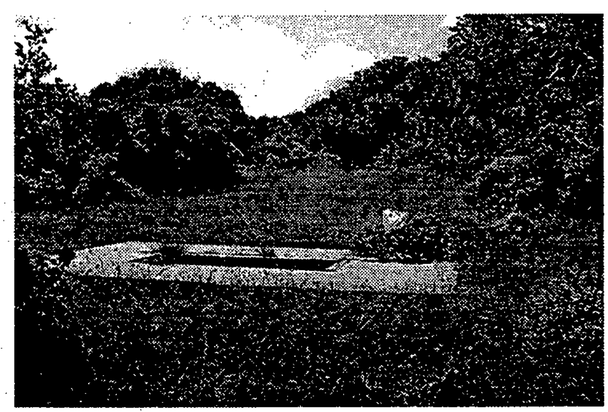
Control Point 4

Control Point 2

Control Point 5



Control Point 3



Control Point 6

Control Point 7

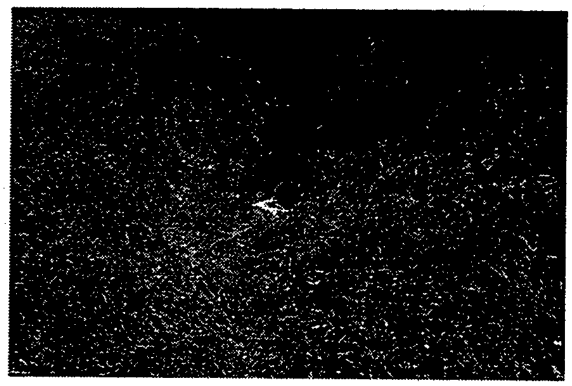
Control Point 8

Control Point 9

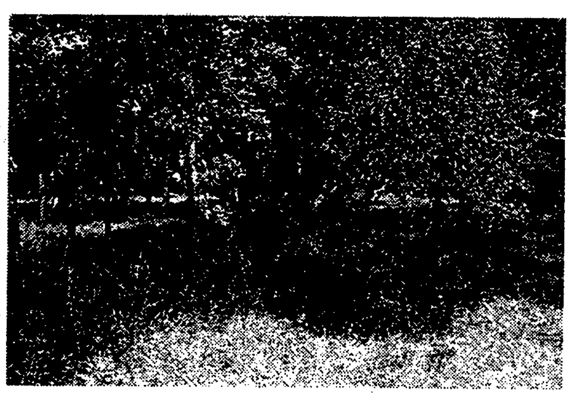
3. VIRTUAL ENVIRONMENT GROUP PHOTOS

Real World

Control Point 1



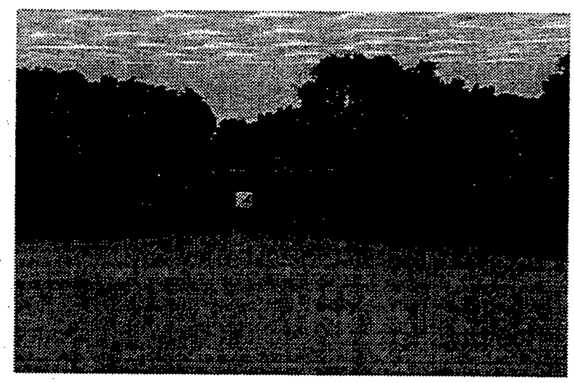
Control Point 2



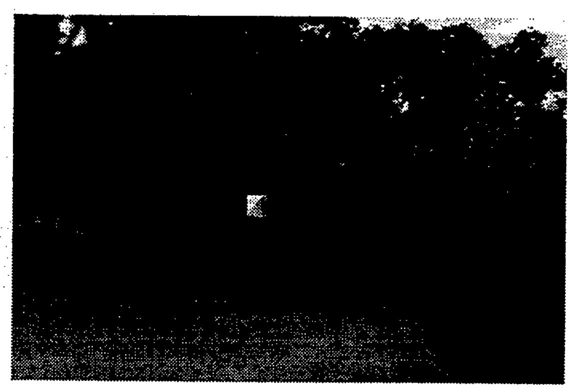
Control Point 3

Model

Control Point 1



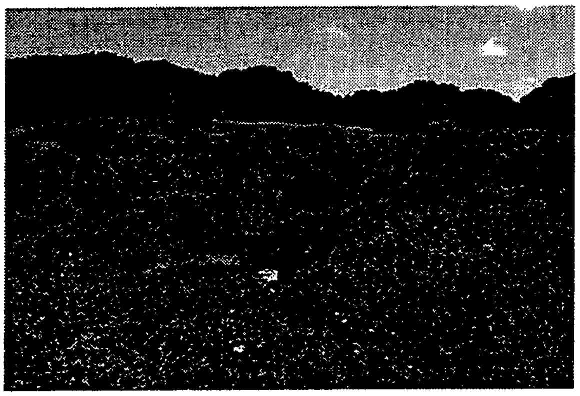
Control Point 2



Control Point 3

Real World

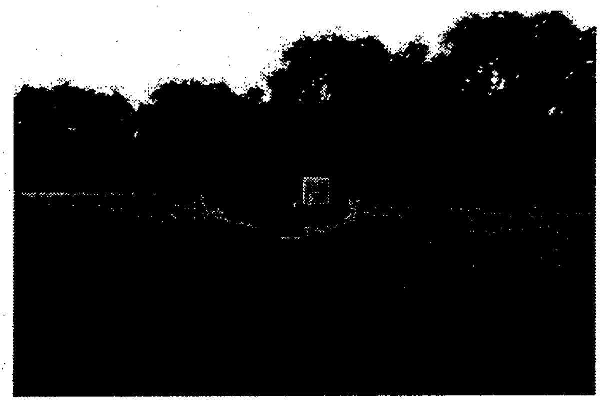
Model



Control Point 4

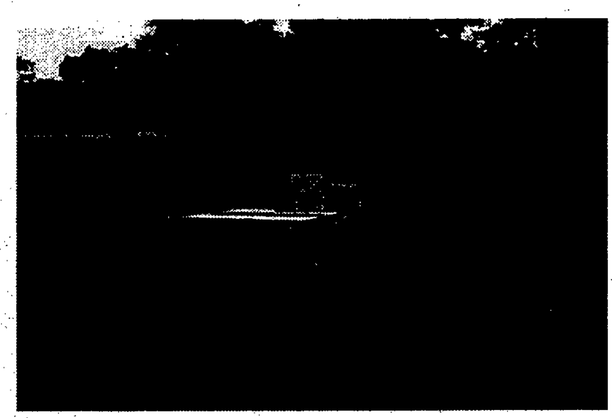
Control Point 4

Control Point 5



Control Point 5

Control Point 6



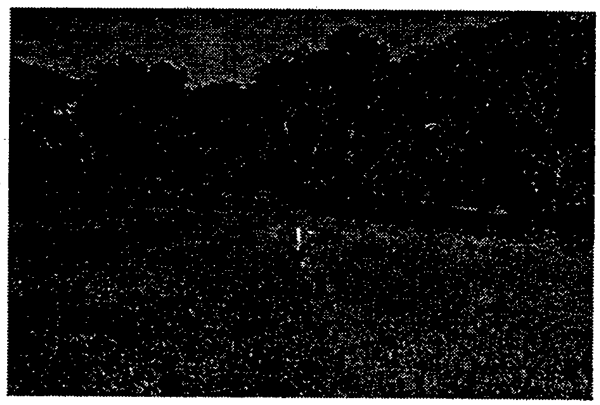
Control Point 6

Real World

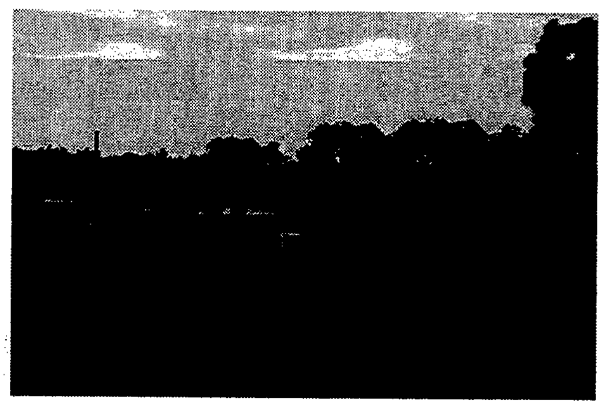
Model

Control Point 7

Control Point 7

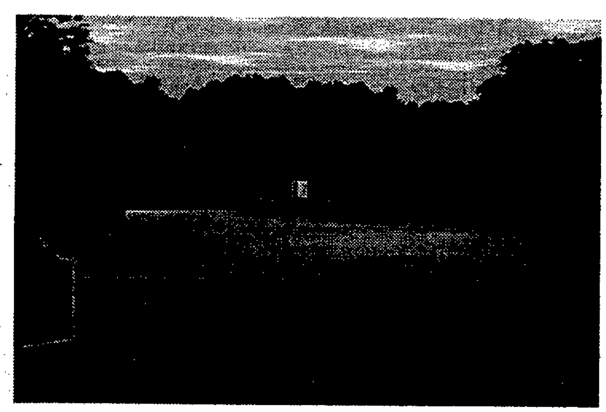


Control Point 8



Control Point 8

Control Point 9



Control Point 9

APPENDIX J. COURSE EQUIPMENT CHECKLIST

Binder Containing:

_____ Subject's map & designated route

_____ Think Out Loud Instructions

_____ Data Collection Sheet

_____ Researcher's Script

Data Recording:

_____ blue alcohol pen to record route deviations

_____ red pen to record data

_____ digital camera

_____ helmet & 8mm camera

_____ rucksack frame w/GPS system

_____ stop watch/timer

Misc:

_____ extra battery (8mm camera)

_____ extra cassette (8mm camera)

_____ extra Color Wheels for Tasks 3.1. & 5.1

_____ extra arrows (color wheels)

_____ extra clue sheet (incase subject looses his/hers)

_____ blindfold (for movement to course)

_____ cellular phone (*optional*)

_____ compass

_____ first aid kit

_____ Tecnu (for poison oak)

_____ water

Prepositioned:

_____ Color Wheel Platform for Tasks 3.1. & 5.1

_____ Control flags

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APPENDIX K. THINK OUT LOUD INSTRUCTIONS[1]

Your thoughts are important to this research. As you navigate the course, you should be "thinking out loud".

As you move through the environment and experience it directly, express what you are thinking. The mental preconception you had of this environment before you stepped into it will now be evaluated by you as you experience the course directly. As this image is confronted with direct experience your expectations and plan may be confirmed, modified, or refuted. Be sure to talk "out loud" these thoughts.

The process of talking "out loud" and paying close attention to your route will slow you down. This is expected and why you are given an hour to finish the course.

PLEASE SPEAK LOUDLY SO THAT YOUR VOICE WILL BE PICKED UP BY THE MONITOR AND HE CAN RECORD WHAT YOU SAY.

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[1] This document is adapted and modified from MAJ Banker's Masters Thesis [BANK 98]

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APPENDIX L. ROUTE CLASSIFICATIONS

1. GENERAL

This appendix consists of five items: route analysis, an explanation of route classifications for each leg of the course [BANK 97], and route classifications based on a Goerger's LISP Program [GOER 98b]. The explanation of route classifications for each leg of the course is taken directly from Appendix F of MAJ Banker's 1997 Masters Thesis. The explanation of the LISP routes is taken directly from MAJ Goerger's 1998 Master Thesis. Route classifications were utilized to categorize the difficulty of an individual's planned routes for comparison to their navigational ability. Routes were classified using MAJ Banker's route classification listing and again utilizing the results of Goerger's LISP route planning program.

2. ROUTE ANALYSIS

Participant routes were analyzed for difficulty level and performance. Participants' Leg Error Scores were correlated with their Leg Difficulty Rating and ability level. The relationship between a subject's route difficulty and their overall performance is discussed in Chapter IV, Section B.3.

Goerger felt that if participants planned routes which were beyond their ability level (a novice planning expert routes), the chances they will fail to successfully execute the planned routes increases. Advanced routes, while being faster and perhaps more direct, required true expertise in navigational skills to successfully implement them. In fact, most "expert" navigators did not plan "expert" routes. The poorest routes were planned by novices who failed to realize what exactly they were attempting.

3. BANKER'S ROUTE CLASSIFICATIONS

What follows is MAJ Banker's classification of some of the most probable routes to a given control and is based on the International Specification for Orienteering Maps [INTE 90]. They do not represent the only ways of getting to a control but the most likely routes chosen by participants based upon MAJ Banker's orienteering experience and knowledge of the terrain. The classifications are used as a basis for comparison with the routes selected by Goerger's LISP Route Selection Program. Note that all controls possess at least one beginner's route. If a participant did not exactly follow the route described by Banker, the route was examined. If it had numerous handrails, it was considered intermediate. If it had more catching features, it was considerd advanced. A lack of any navigational features, or a direct line azimuth between any but the closest points earned an advanced rating [GOER 98b].

a. Control 1.

1. Beginner

a) Gigling Road west to jeep trail
b) Jeep Trail south by east by south to building
c) Control on NW corner of building

2. Beginner

a) Watkin's Gate Cutoff to indistinct path.
b) Indistinct path southwest up hill to jeep trail
c) Jeep Trail west to building
d) Control on NW corner of building

3. Intermediate

a) West through plotted individual trees (catching features)
b) Handrail rough open ground south to junction indistinct path and jeep trail
c) Jeep Trail west to building (catching feature)
d) Control on NW corner of building

4. Advanced

a) West through plotted individual trees
b) Follow runnable forest southwest
c) Try to hit small rough open gap by keeping walkable forest to left shoulder
d) Use forest fight to west as catching feature if needed
e) Control on NW corner of building
f) Use jeep trail for catching feature if control is missed

5. Advanced

a) Go straight at control from start

b. Control 2.

1. Beginner

   a) Jeep trail northwest to building
   b) Follow open ground to west and look for rough open clearing going northwest (handrail)
   c) Follow rough open clearing northwest looking for pit
   d) Control in pit

2. Intermediate
   a) Jeep trail northwest to building
   b) Go straight at control (WSW) from building

3. Advanced
   a) Set out on straight line directly for control
   b) Hit open ground and look for building on the right and rough open break on the left. (Catching feature)
   c) Follow rough open clearing northwest looking for pit
   d) Control in pit

c. Control 3.

1. Beginner

   a) Head northwest and get out onto Gigling Road
   b) Take Gigling Road west to jeep trail junction with telephone pole
   c) Take jeep trail southeast to convergence of two jeep trails
   d) Head southwest into tree grove looking for control

      (1) Use building as catching feature
      (2) Use open ground to west as backup catching feature

   e) Control hanging from tree limb

2. Advanced

   a) Head straight at control; use jeep trail prior to control as catching feature
   b) Head southwest into tree grove looking for control

      (1) Use building as catching feature
      (2) Use open ground to west as backup catching feature

   c) Control hanging from tree limb

d. Control 4.

1. Beginner

   a) Head southwesterly and try to get on jeep trail headed in same direction
   b) Take jeep trail to junction
   c) Take jeep trail southeast to junction
   d) Take southerly fork to next junction
   e) Take fork to northwest
   f) Once beyond patches of fight leave trail and start looking for control
   g) Control is in pit

2. Beginner

   a) Turn around and go back to jeep trail to the east
   b) Take jeep trail southwest to junction
   c) Take fork to the south to another junction
   d) Take fork to the west to next junction
   e) Take southerly fork to next junction
   f) Take fork to northwest
   g) Once beyond patches of fight leave trail and start looking for control
   h) Control is in pit

3. Intermediate

   a) Go south towards road junction
   b) Get on road and take to junction
   c) Take road west to other road junction
   d) Handrail around fight to west coming down through small patch of fight into control

4. Advanced

   a) Head straight at control expect to hit jeep trail that runs NW to SE (catching feature)
   b) Hit trail and then thread way through scattered fight
   c) Emerge into center of depression and rough open ground, (catching feature) look for pit
   d) Control is in pit

e. Control 5.

1. Beginner

a) Move back out onto jeep trail
b) Take trail west to trail junction
c) Take trail WNW up to misc object
d) From misc. object go straight at control

2. Intermediate

a) Move directly at control
b) Use Gigling Road as catching feature if miss on control
c) Control is in center of clearing

3. Advanced

a) Move directly at control
b) Use southwesterly linear clearing as catching feature
c) Follow clearing NW right into control
d) Use Runnable forest along Gigling as catching feature in case of miss

f. Control 6.

1. Beginner

a) Move out onto Gigling Road and take it westerly to junction with dirt road
b) Move down dirt road (south) to junction with jeep trail
c) Take jeep trail to east look for concrete rubble
d) Move southeast through runnable forest
e) Look for control on concrete pad

2. Beginner

a) Move straight at control and hit jeep trail
b) Go southwest on Jeep trail to junction with another jeep trail
c) Take jeep trail westerly and look for concrete rubble
d) Move southeast through runnable forest
e) Look for control on concrete pad

3. Intermediate

a) Move south to junction of two jeep trails (catching feature)
b) Handrail jeep trail southeasterly to clearing (catching feature)
c) Handrail clearing to the west
d) Hit fight going west (catching feature) and move south

e) Handrail fight (keeping it on right shoulder) into control
f) Look for control on concrete pad

4. Advanced

a) Move straight at concrete rubble (aiming off technique) use jeep trail as catching feature and handrail
b) Move southeast through runnable forest
c) Look for control on concrete pad

g. Control 7.

1. Beginner

a) Move back out onto east west jeep trail
b) Go west to junction of jeep trail and dirt road
c) Take dirt road south to junction with four jeep trails
d) Take jeep trail east by northeast
e) Look for second linear break in vegetation (indistinct path)
f) Take indistinct path (handrail) to ditch
g) Follow ditch to its end
h) Control at east end of ditch

2. Intermediate

a) Move through rough open ground easterly to jeep trail (catching feature)
b) Follow jeep trail (handrail) to junction with other jeep trail by building
c) Locate telephone poles and follow wire (handrail) south easterly
d) Hit fight and turn west and follow fight boundary into ditch (handrail)
e) Control at east end of ditch

3. Advanced

a) Move through rough open ground easterly to jeep trail (catching feature)
b) Take jeep trail to curve where it turns east (hand rail)
c) Leave jeep trail and head straight for control use east west jeep trail as checkpoint (catching feature)
d) Aim off to east side of ditch and go southeast (telephone wires to east as catching feature to prevent drifting too far east)
e) Use fight as catching feature

f) Hit fight and turn west and follow fight boundary into ditch
g) Control at east end of ditch

4. Advanced

a) Move straight at control
b) Use jeep trail junction as attack point
c) From attack point take offset route to west part of ditch
d) Follow ditch to east and find control at end of ditch

h. Control 8.

1. Beginner

a) Handrail fight to the east till hitting the jeep trail
b) Follow jeep trail northerly through intersection to sharp curve to the east
c) Once at sharp curve to east turn off trail to west and look for control in clearing
d) Control located in clearing

2. Intermediate

a) Handrail fight to telephone poles
b) Take telephone poles NW back to jeep trail junction
c) Follow jeep trails east to next junction
d) Take jeep trail north
e) Leave jeep trail and move directly at control

3. Advanced

a) Move directly at control (avoiding forest walk) use jeep trail junction as catching feature
b) From jeep trail junction aim off to east of control at sharp curve to east of jeep trail keeping eyes open for control in clearings
c) Use same trail as Beginner route as catching feature (for drift)

i. Control 9 (Finish)

1. Beginner

a) Move back out to jeep trail just to east of control 8
b) Take trail south to four way junction with other trails (handrail)

c) Take southeasterly running trail to trail fork
d) Take northeasterly running fork to five way junction (handrail)
e) Take northwesterly running trail keeping eyes open for small break in fight to the east (catching feature)
f) Take indistinct path into clearing and hook to north
g) Control on east edge of clearing

2. Intermediate
    a) Move back out to jeep trail just to east of control 8
    b) Move off trail using rough open to move closer to control
    c) Take rough open out onto jeep trail which runs NE to SW
    d) Take trail to junction with North South jeep trail
    e) follow jeep trail looking for indistinct path
    f) Take indistinct path into clearing and hook to north
    g) Control on east edge of clearing

3. Advanced

    a) Move straight at control on east by northeast azimuth
    b) Use trail as catching feature
    c) Fight to north and south of route used as catching features
    d) Locate opening in fight
    e) Take indistinct path into clearing and hook to north
    f) Control on east edge of clearing

4. LISP PROGRAM ROUTE CLASSIFICATION

This section is taken directly from MAJ Goerger's thesis [GOER 98b]. This LISP program plans a route through a specified piece of terrain based on identifiable decision points and terrain characteristics. The information is manipulated by a branch and bound search, pruning heuristics, and terrain classification.

The program is designed to locate three optimal paths through the course. One Beginner (Figure L.1), one Intermediate (Figure L.2), and one Advanced Course (Figure L.3) are calculated and displayed on maps for comparison with participant maps. The program also produces a sequential list of decision points or waypoints to traverse in order to complete the course. Each leg of a participant's route is compared to the LISP program route legs. If two LISP routes have legs that are the same, the leg is classified as the easier of the two routes. If a participant's planned route between control points is not the same as any of the computer program's planned routes, the participant's route is assigned a classification which is most closely associated with the participant's route with respect to the program algorithm's defining characteristics.

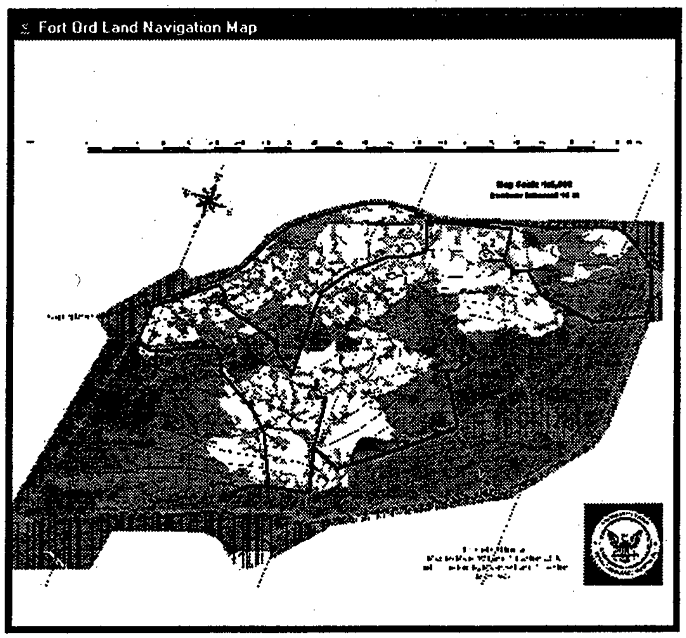


Figure L.1. LISP Beginner Route

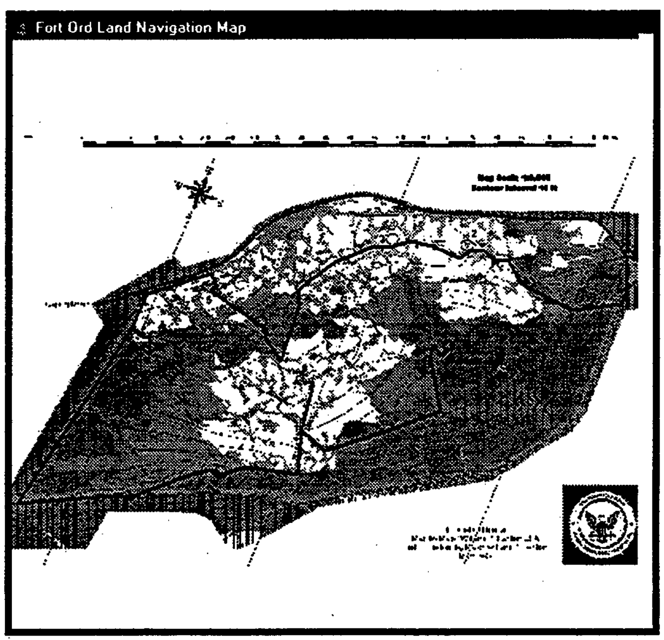


Figure L.2. LISP Intermediate Route

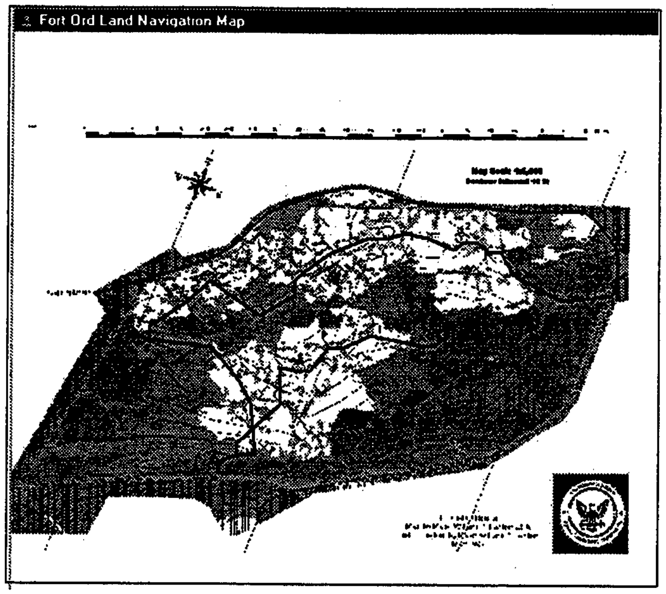


Figure L.3. LISP Advanced Route

APPENDIX M. DATA COLLECTION WORKSHEETS

1. TRAINING PHASE DATA COLLECTION SHEET

PARTICIPANT ID:	**Session Date:**			
	Session Start Time:			
RECORDER:	**Session End Time:**			
Initial Subject Study Method:	**a) Study Map**	**b) Read Map and Start Mvt**	**c) Explore Terrain**	
Number Compass Checks:				**NA**
Number Map Checks:				**NA**
Number of times subject became "lost":				**NA**
Number of times subject went out of bounds or fell off the edge of the model:				**NA**
Did the subject have difficulty reading the compass?		**Yes**	**No**	**NA**
Did the subject have difficulty reading the map?		**Yes**	**No**	**NA**
Did the subject have difficulty with the model interface?		**Yes**	**No**	**NA**
Comments/Observations:				

2. EVALUATION PHASE DATA COLLECTION SHEET

PARTICIPANT ID:	Session Date:
	Session Start Time:
RECORDER:	Session End Time:

Task #	Task Description	Tape Counter	Elapsed Time	Num of Errors	New Route	Participant's Actions And Comments	Evaluator's Observations
1	Move to CP #1						
2	Move to CP #2						
3.1.a	Indicate Location SP	N/A	Direction:	Color:	Bearing:		Time:
3.1.b	Indicate Location CP #5	N/A	Direction:	Color:	Bearing:		Orientation:
3.1.c	Indicate Location CP #9	N/A	Direction:	Color:	Bearing:		
3.2	Move to CP #3						
4	Move to CP #4						
5.1.a	Indicate Location CP #1	N/A	Direction:	Color:	Bearing:		Time:
5.1.b	Indicate Location CP #6	N/A	Direction:	Color:	Bearing:		Orientation:
5.1.c	Indicate Location CP #8	N/A	Direction:	Color:	Bearing:		
5.2	Move to CP #5						
6	Move to CP #6						
7	Move to CP #7						
8	Move to CP #8						
9	Move to CP #9						
10.1	Direction and Distance to CP#4 from CP#9	N/A	N/A	N/A	N/A	GO / NGO	
10.2	Directions from CP#9 to CP#4 (Verbal)	N/A	N/A	N/A	N/A	GO / NGO	
10.3	Move to CP#4						
11	White Board Test	N/A		N/A			Order:

Remarks:

APPENDIX N. PARTICIPANT DATA

1. GENERAL

Subject data consists of two items: map with planned route, and the map with executed route. For subjects who had the low fidelity map, their planned and executed routes are shown on the overhead photo. The errors for deviation from the planned route are located in Appendix O. The angle and distance measurements for the Wheel and White Board Tests can be found in Appendix O.2 and O.3 respectively.

2. PARTICIPANT NUMBER M1-1

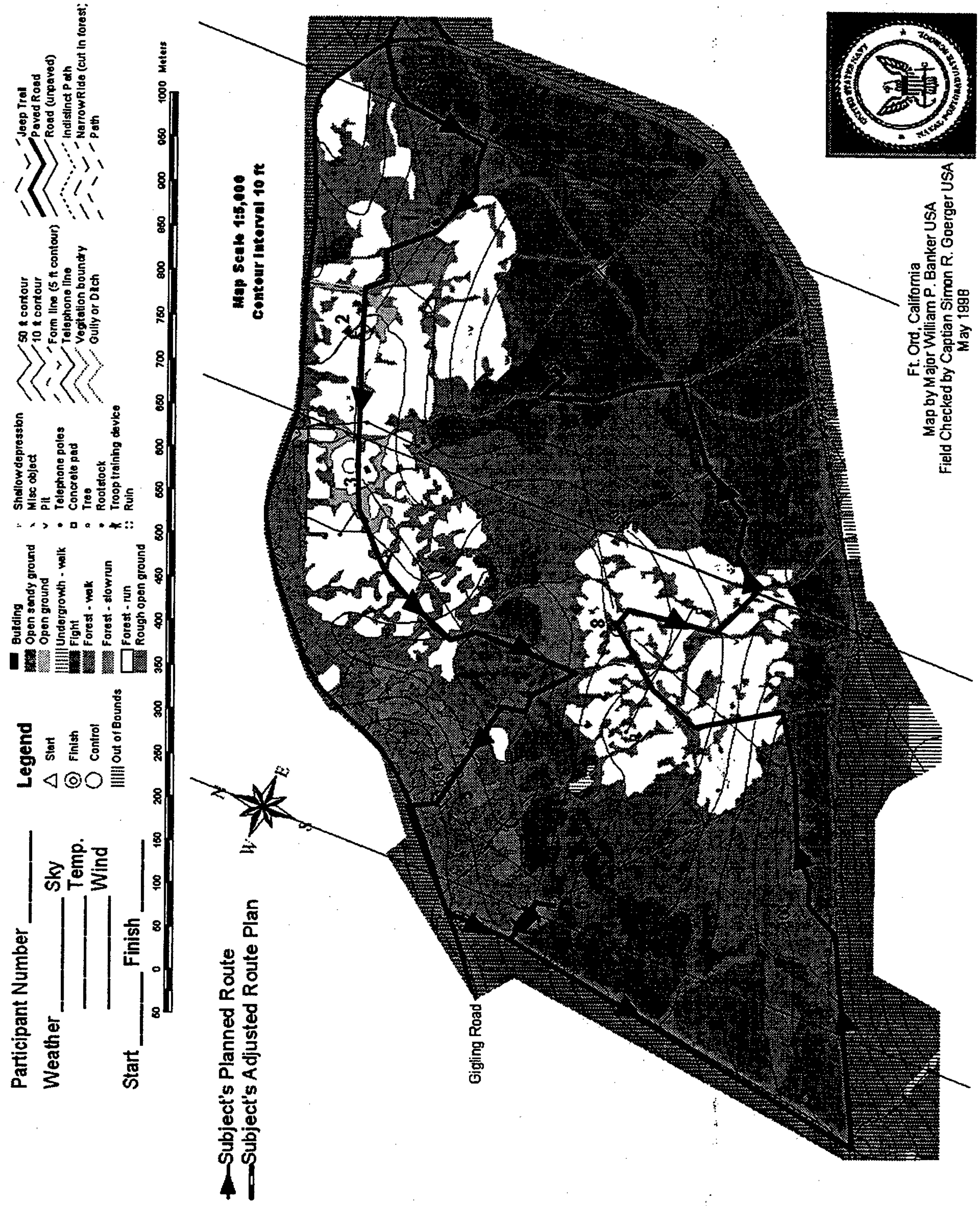


Figure N.1. M1-1 Planned Route

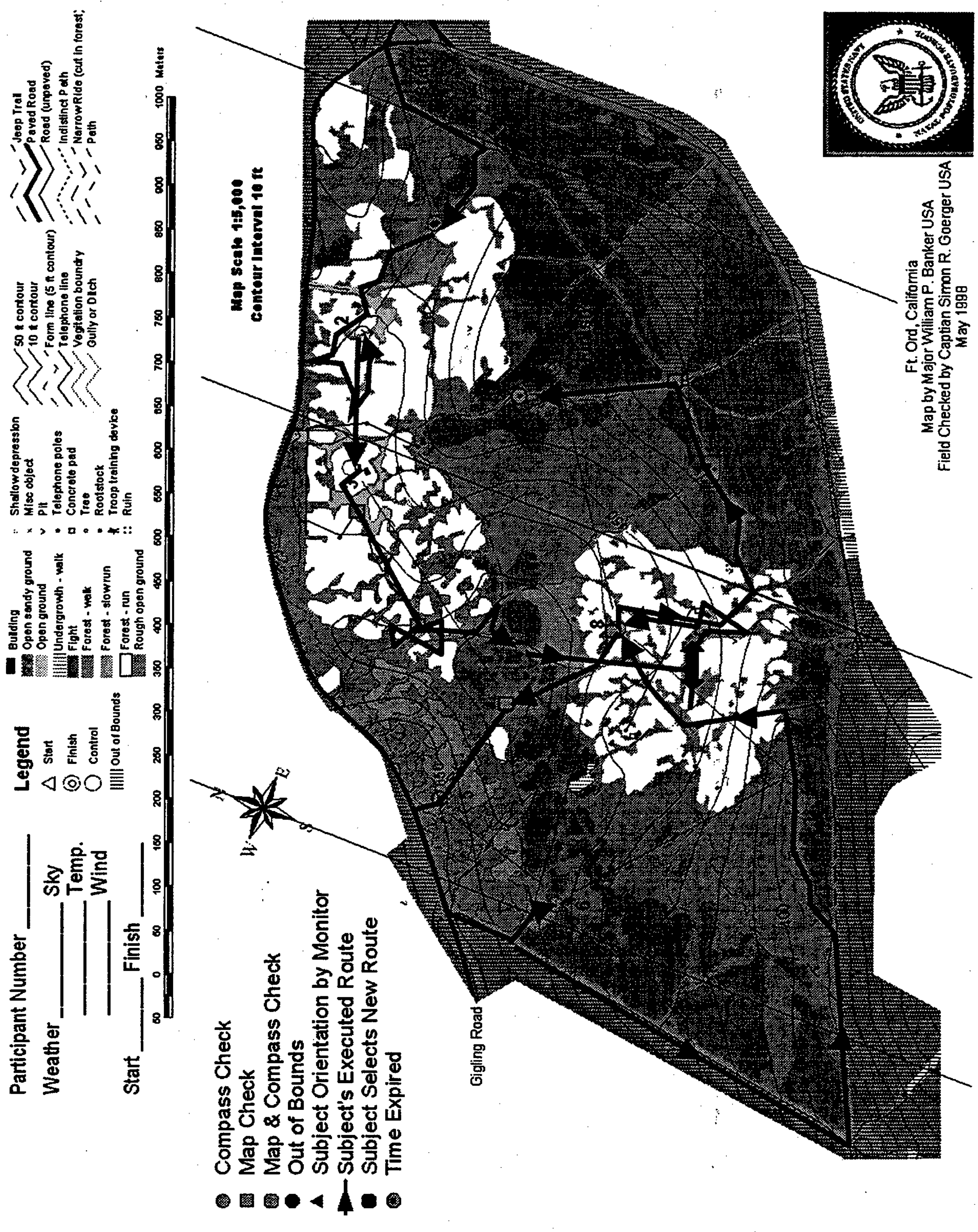


Figure N.2. M1-1 Executed Route

3. PARTICIPANT NUMBER M1-2

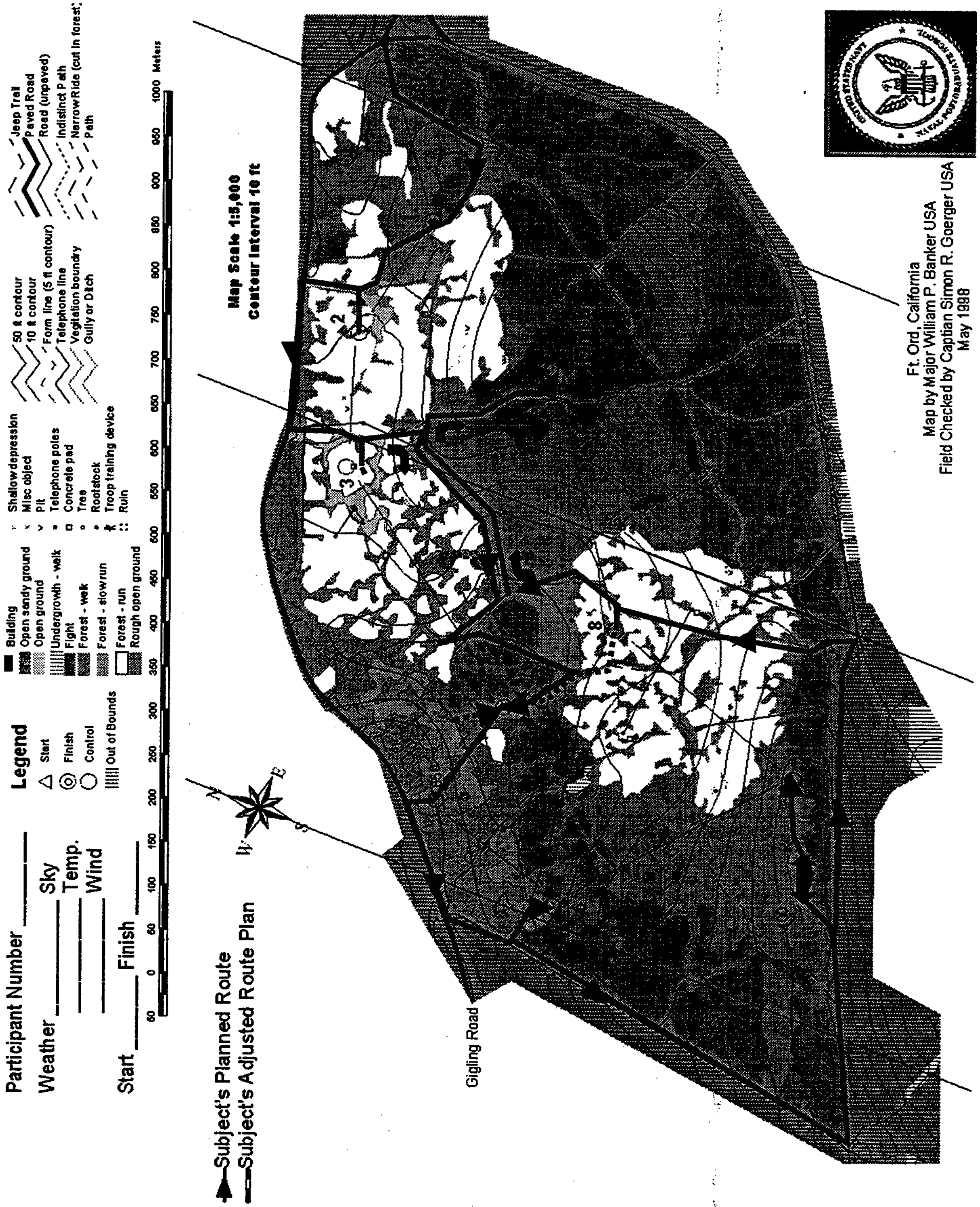


Figure N.3. M1-2 Planned Route

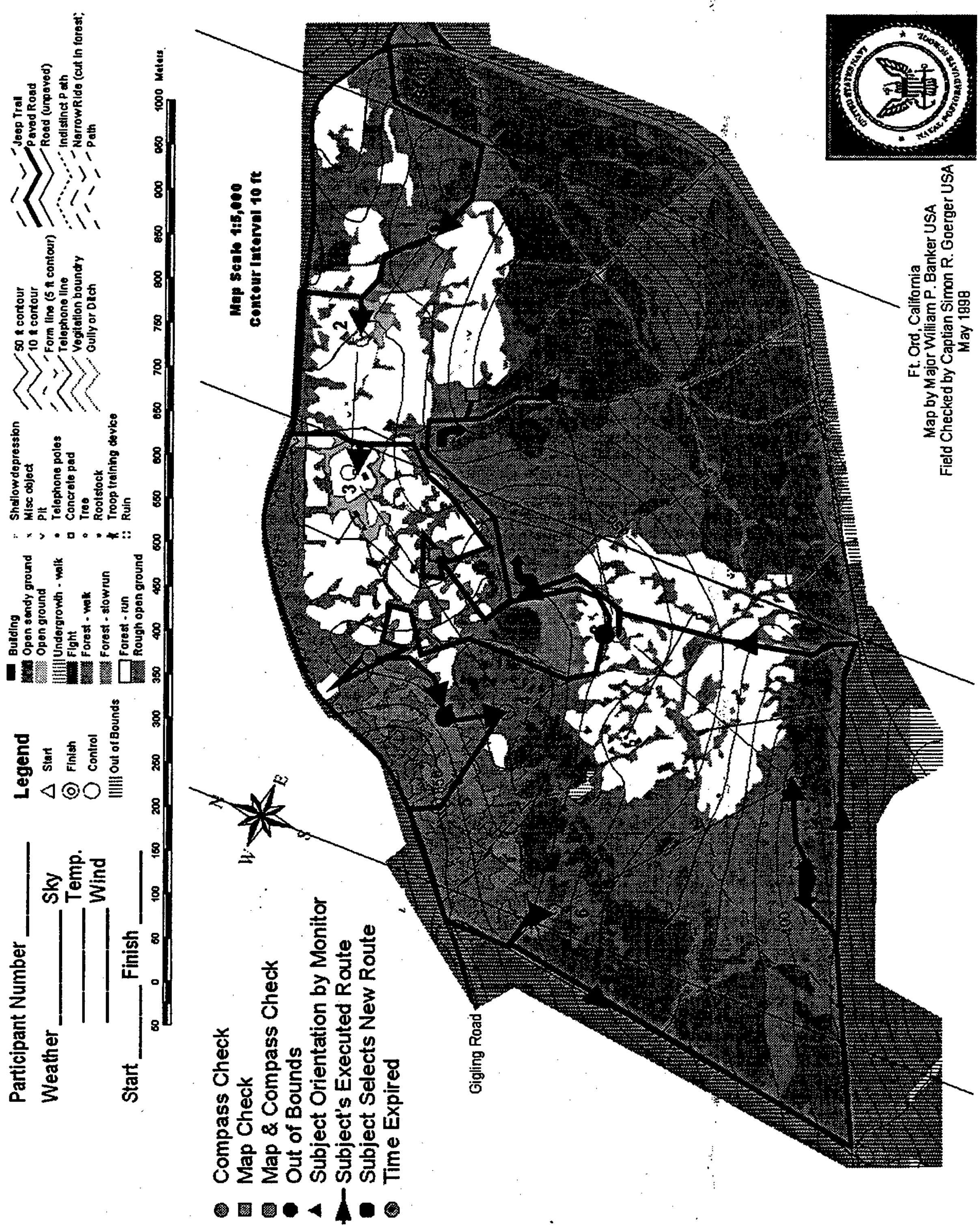


Figure N.4. M1-2 Executed Route

4. PARTICIPANT NUMBER M1-3

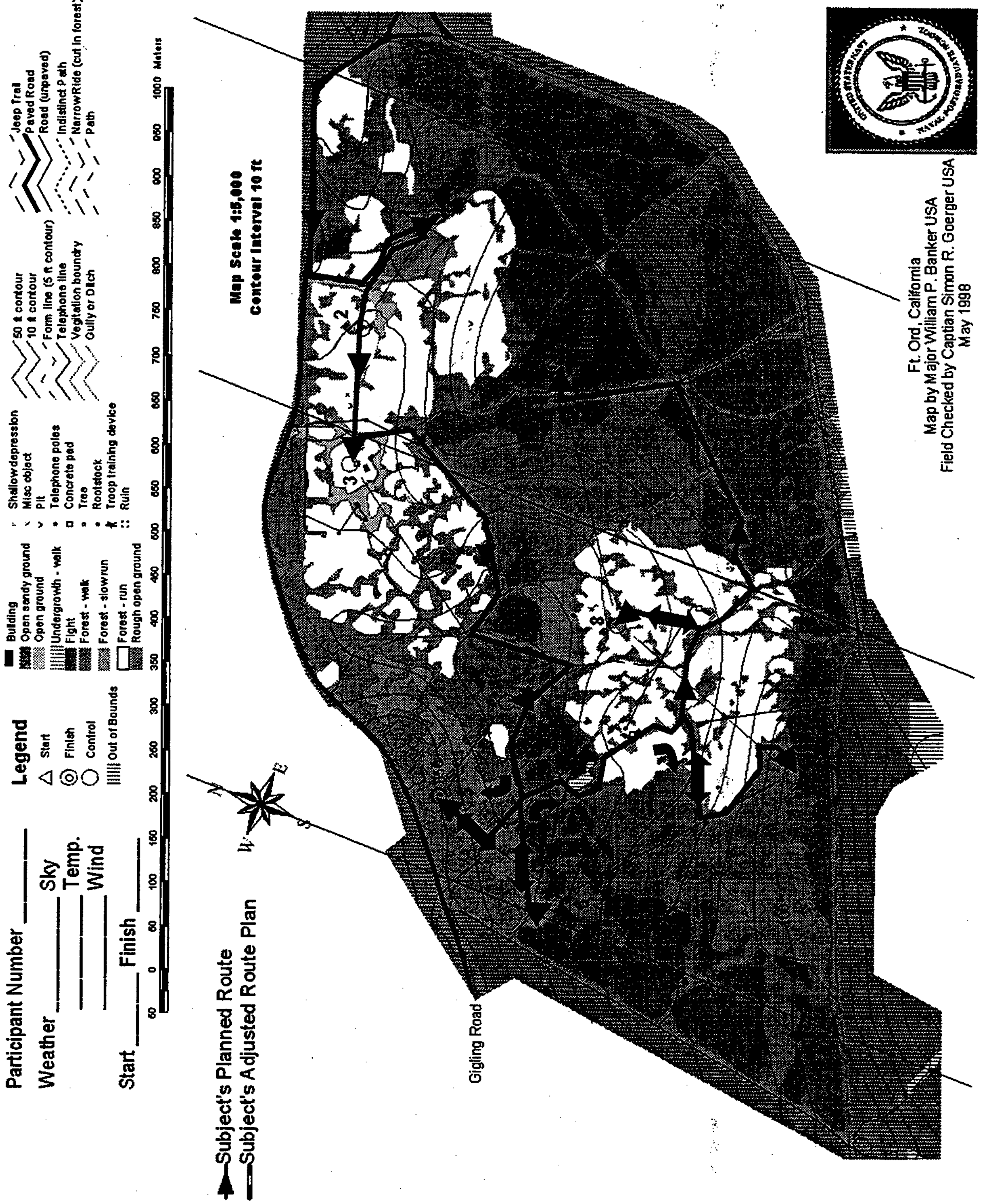


Figure N.5. M1-3 Planned Route

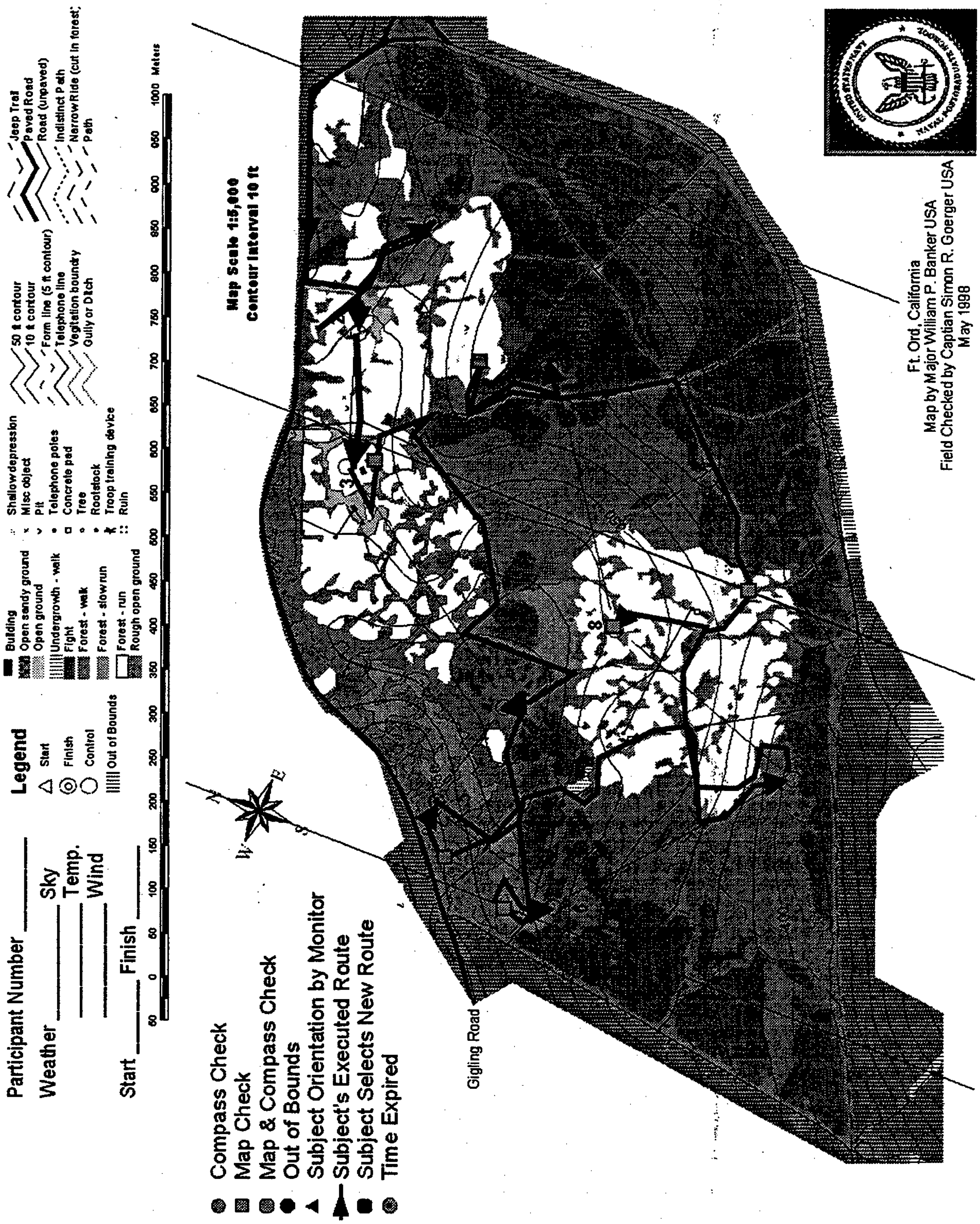


Figure N.6. M1-3 Executed Route

5. PARTICIPANT NUMBER M1-4

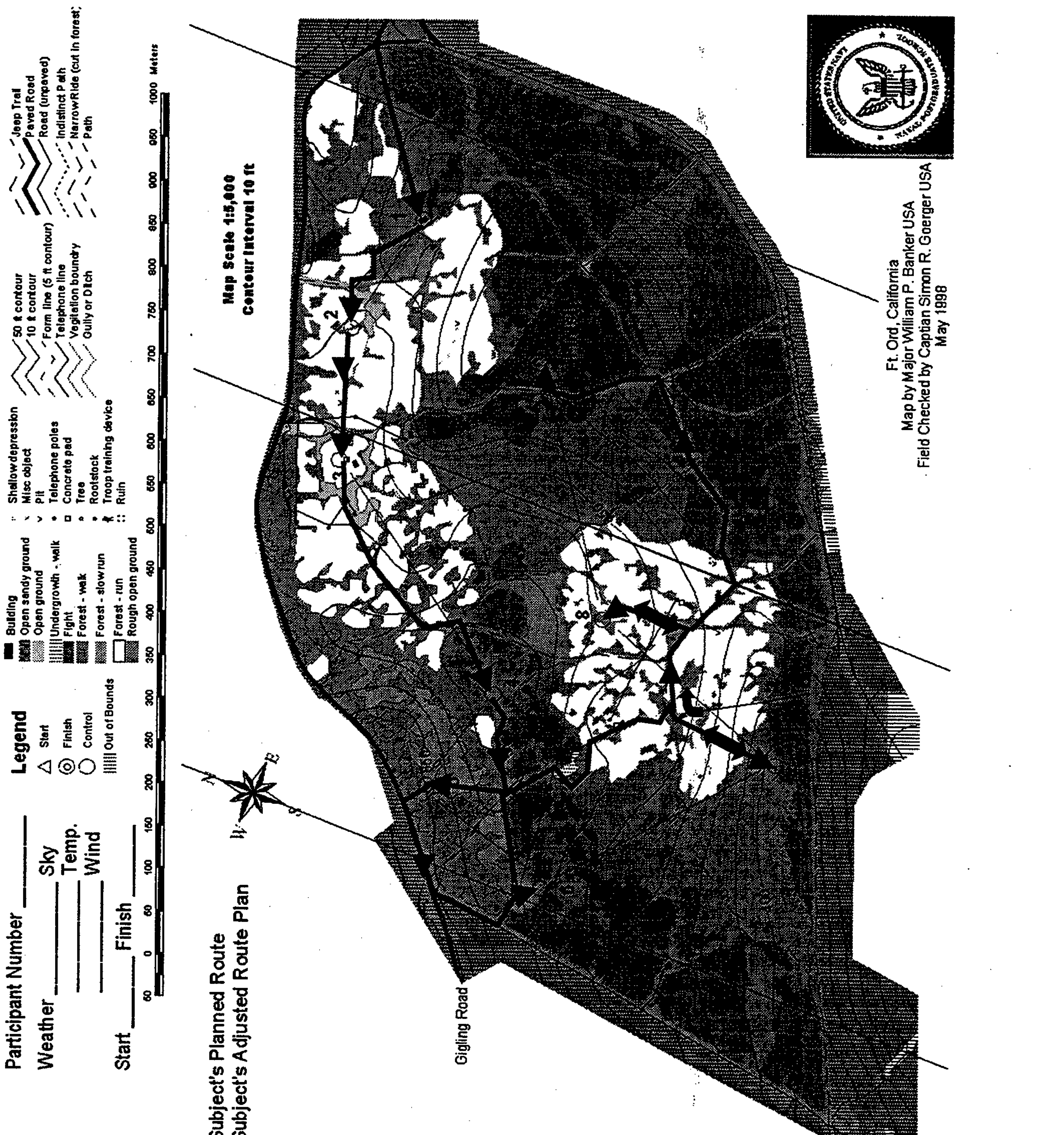


Figure N.7. M1-4 Planned Route

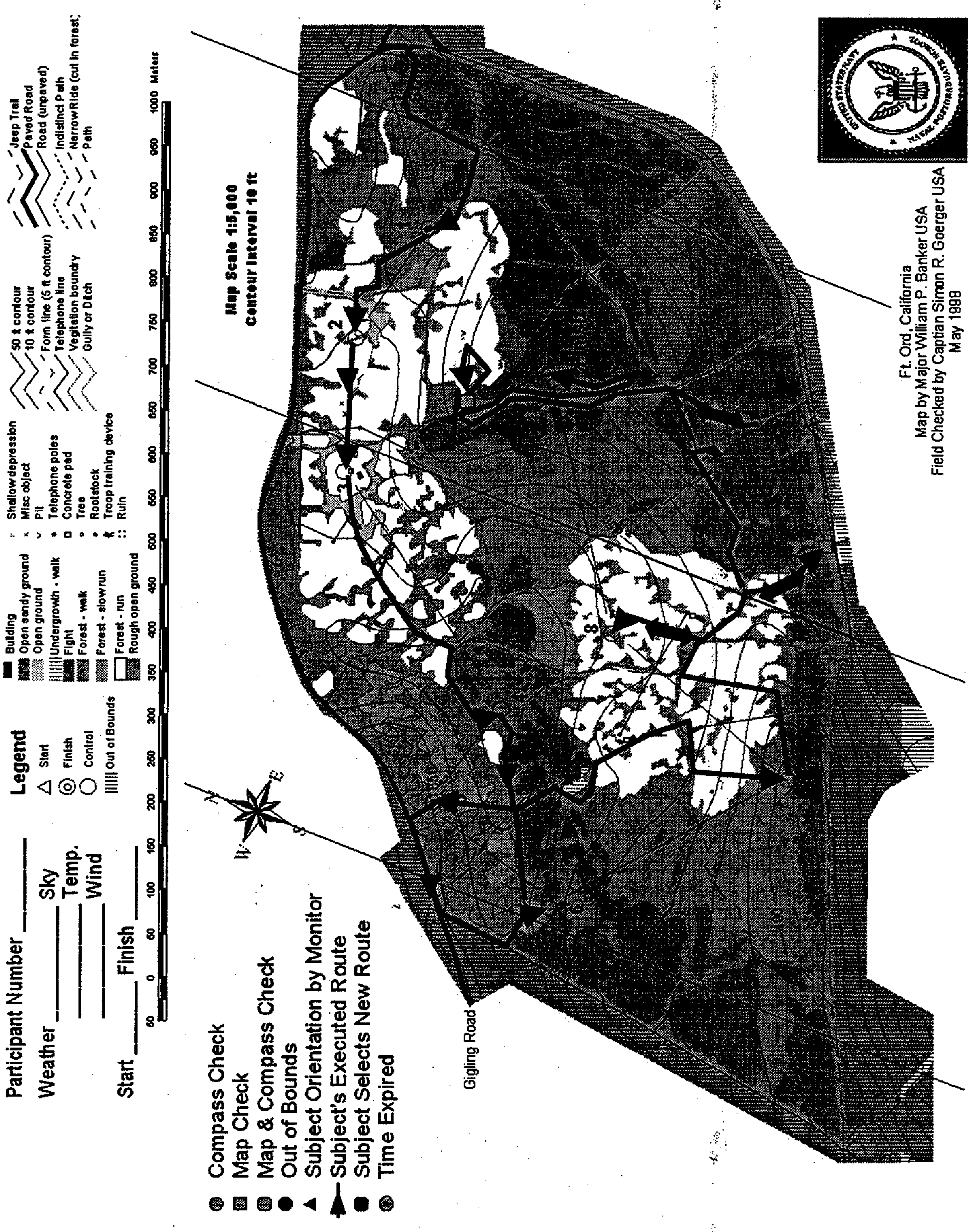


Figure N.8. M1-4 Executed Route

6. PARTICIPANT NUMBER M1-5

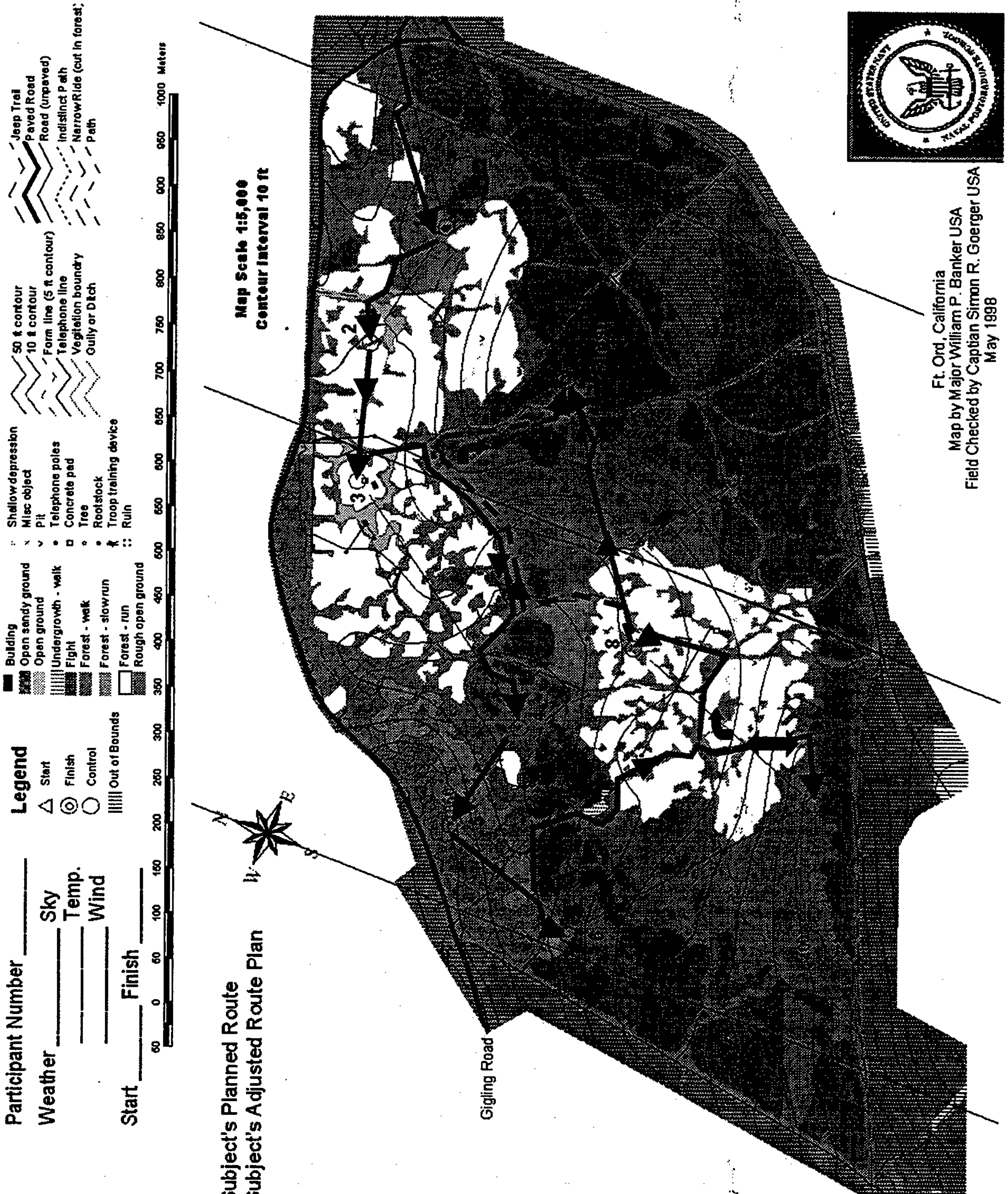


Figure N.9. M1-5 Planned Route

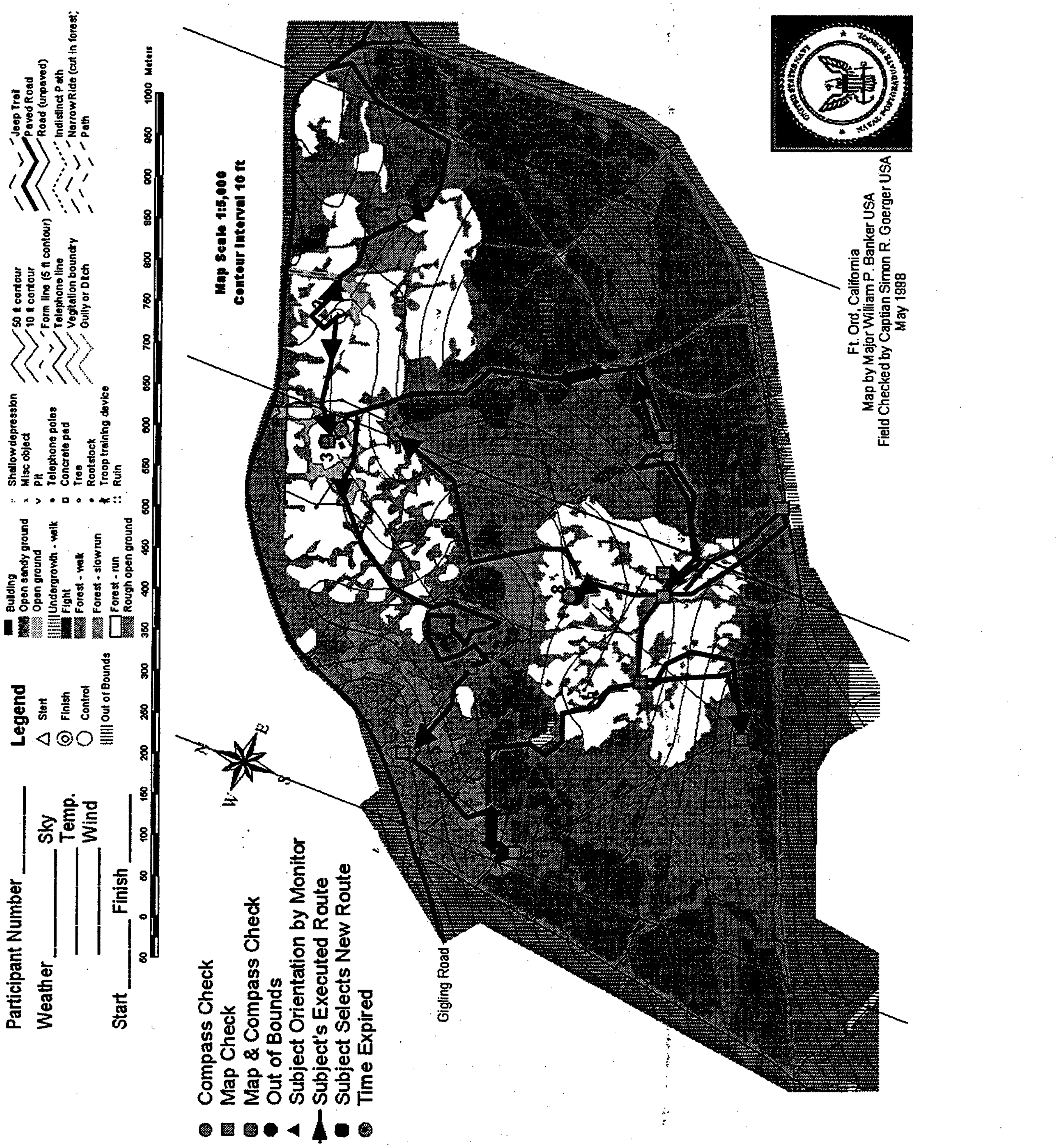


Figure N.10. M1-5 Executed Route

7. PARTICIPANT NUMBER M2-1

Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.10. M2-1 Planned Route

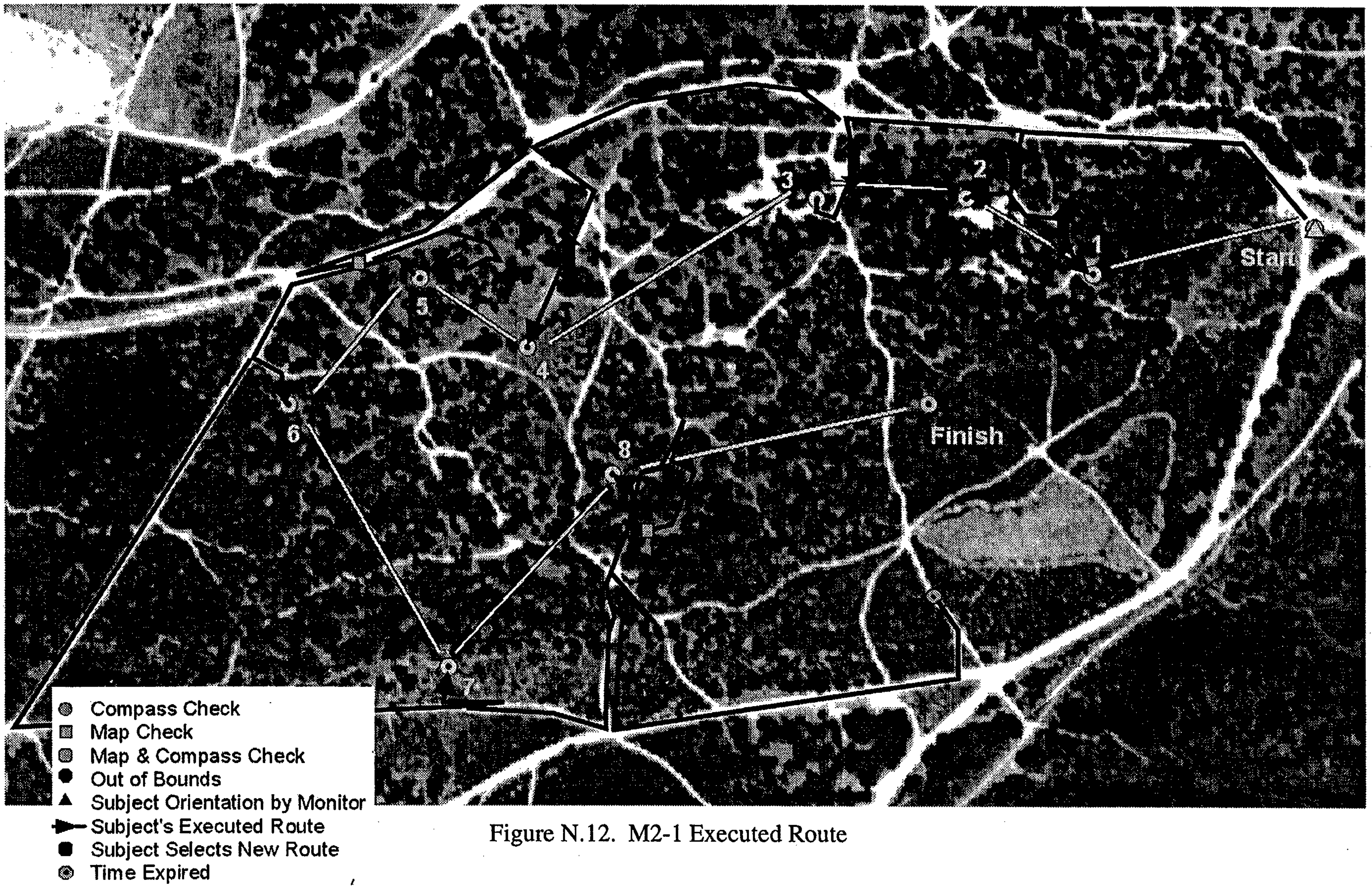


Figure N.12. M2-1 Executed Route

8. PARTICIPANT NUMBER M2-2

Figure N.13. M2-2 Planned Route

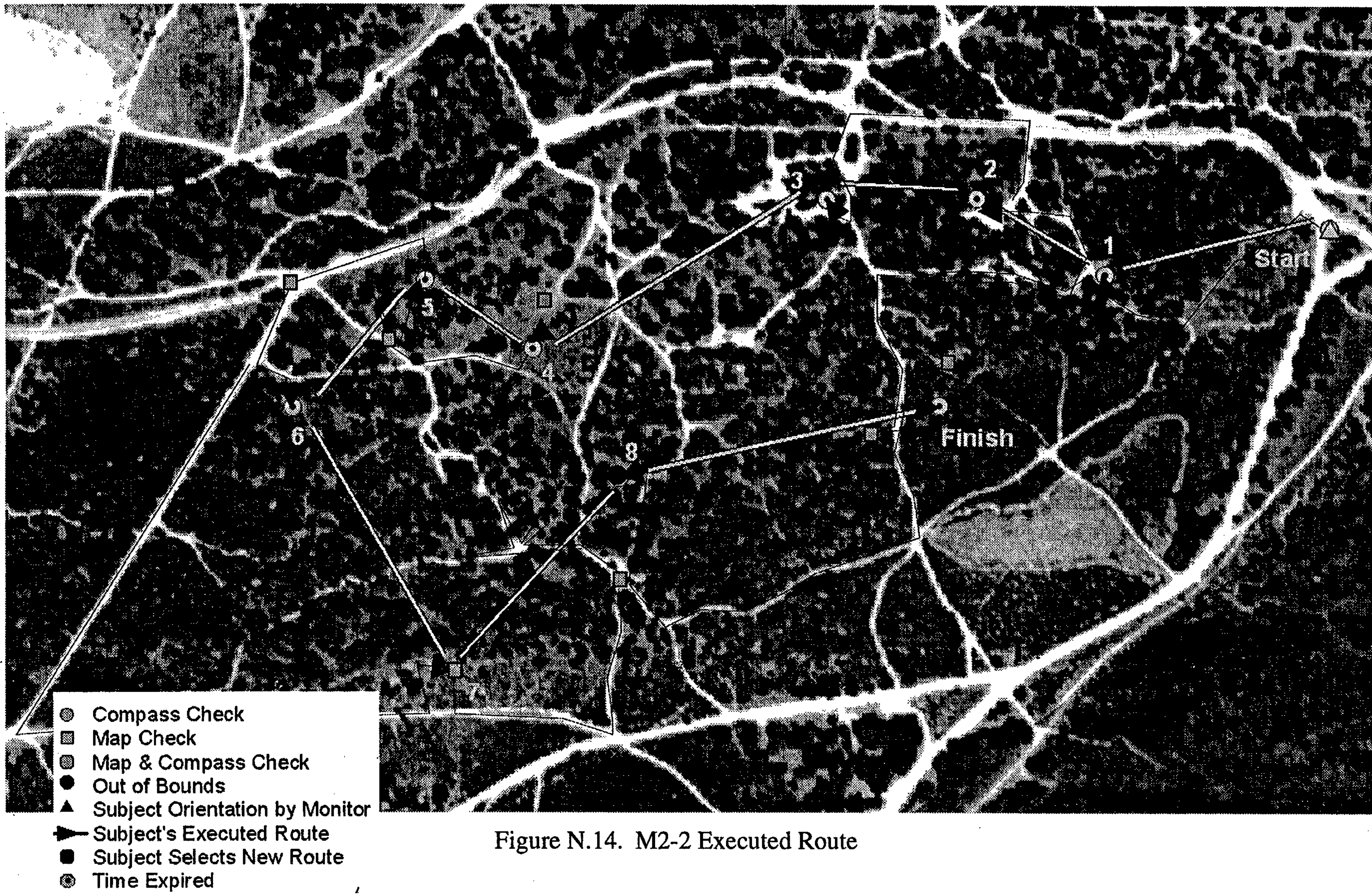
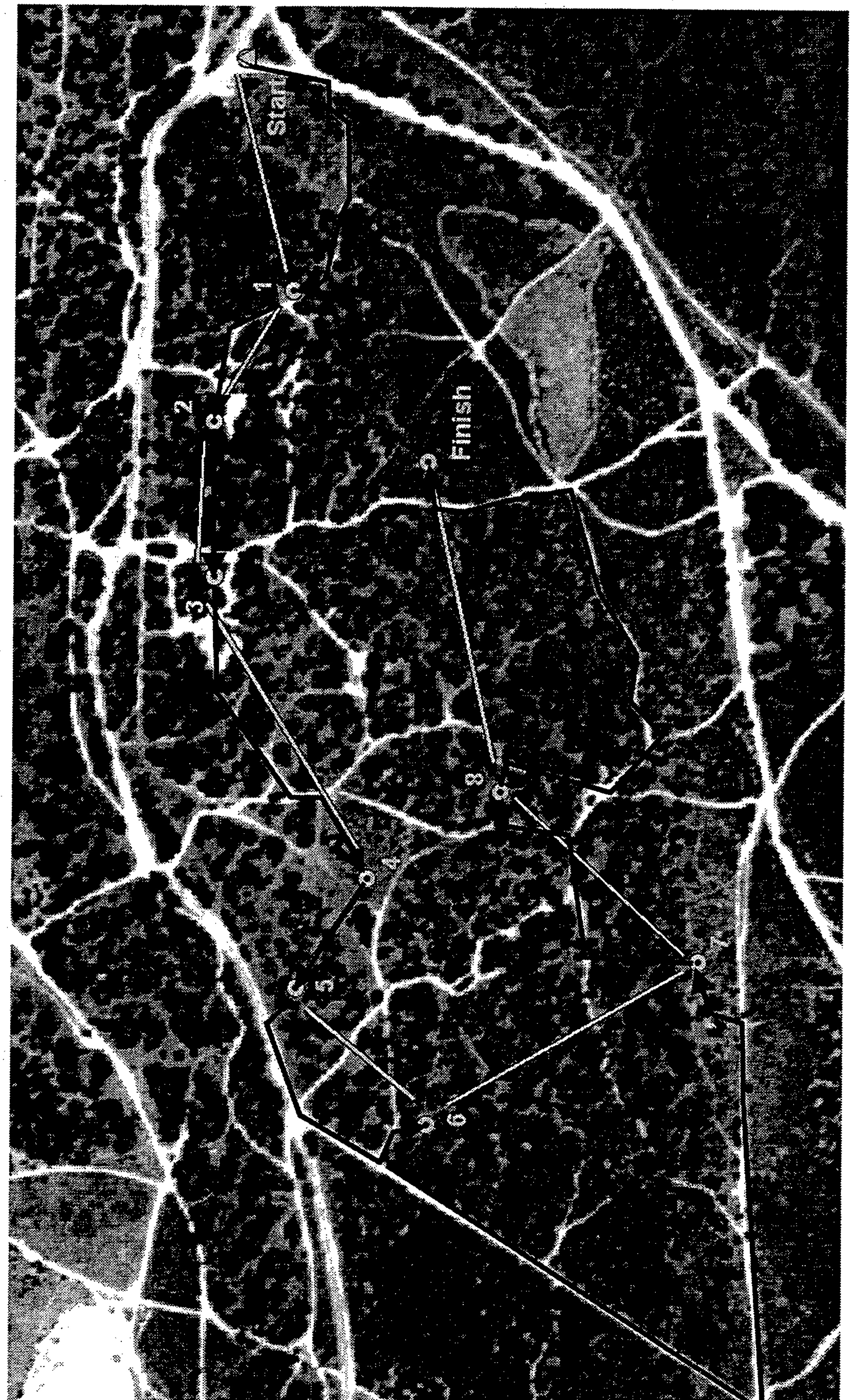


Figure N.14. M2-2 Executed Route

9. PARTICIPANT NUMBER M2-3



Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.15. M2-3 Planned Route

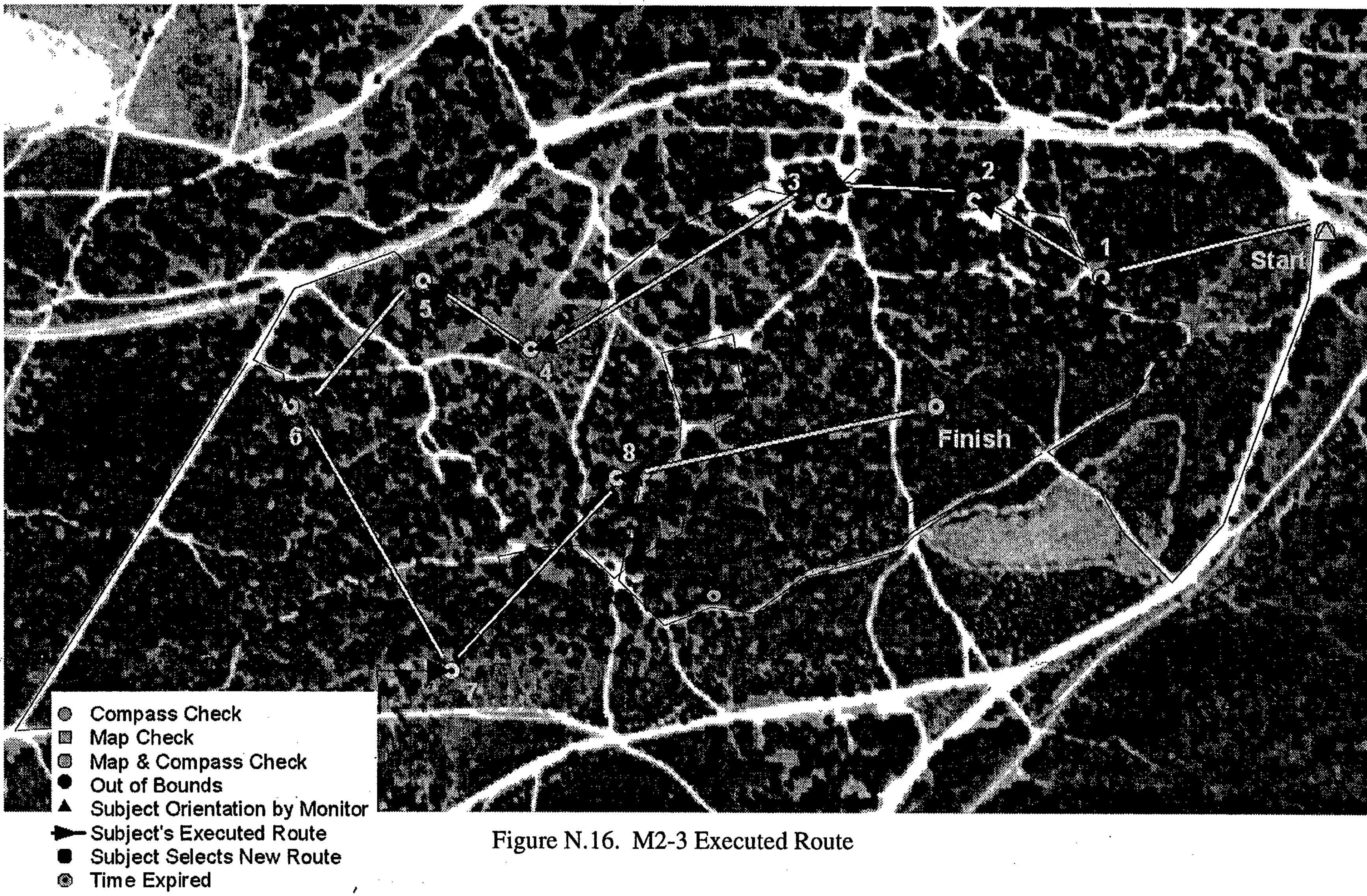


Figure N.16. M2-3 Executed Route

10. PARTICIPANT NUMBER M2-4

Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.17. M2-4 Planned Route

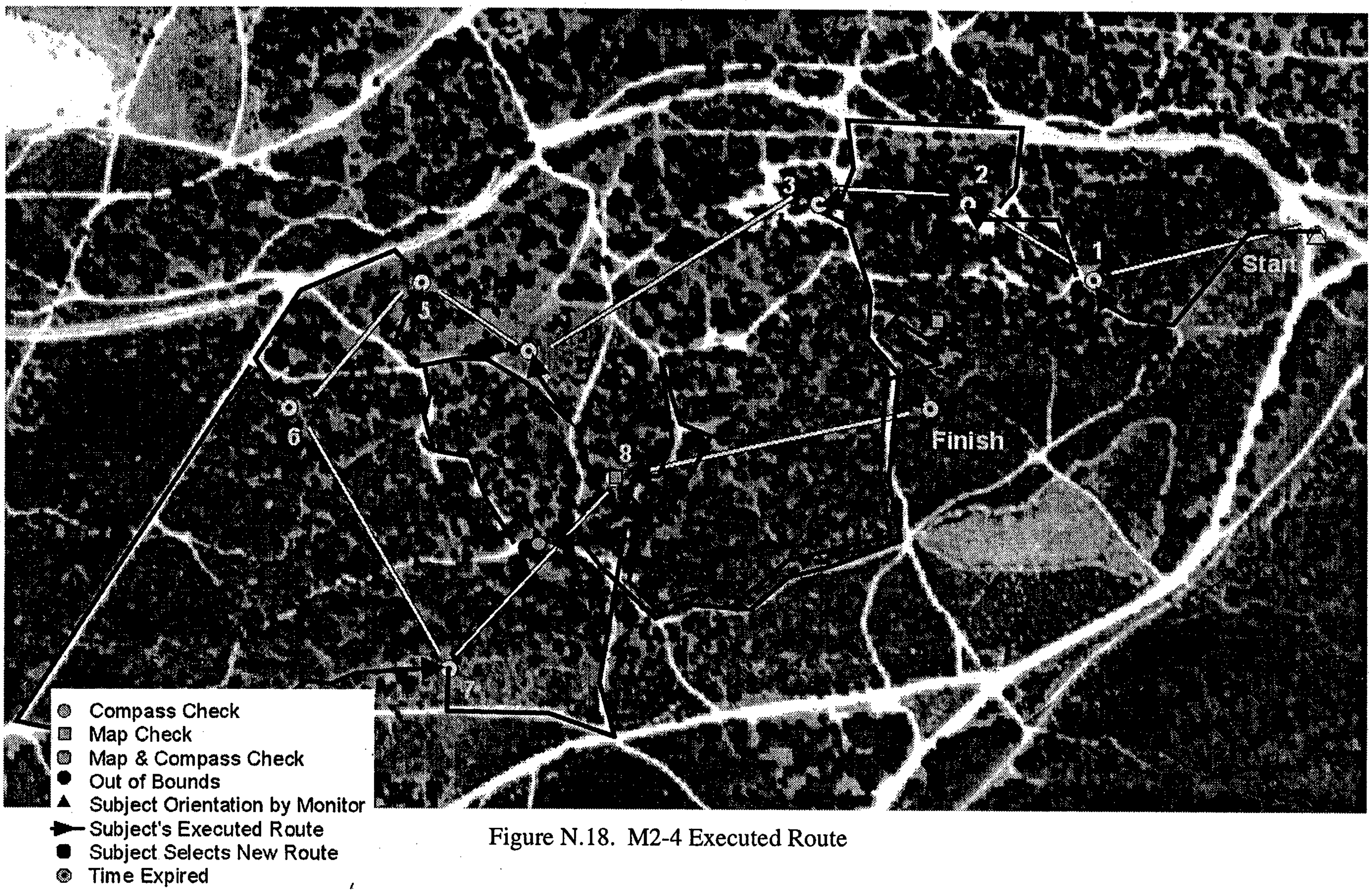


Figure N.18. M2-4 Executed Route

11. PARTICIPANT NUMBER M2-5

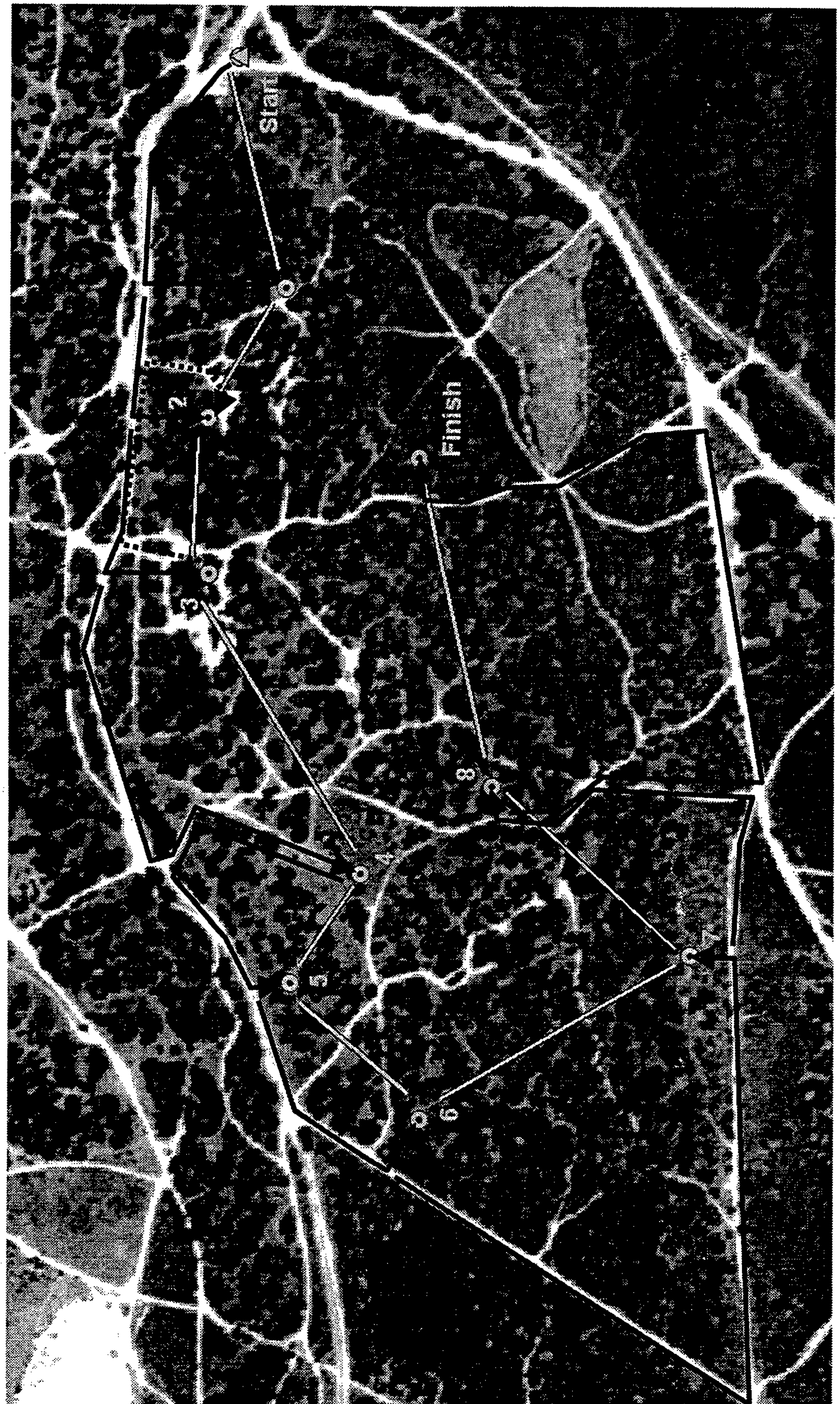


Figure N.19. M2-5 Planned Route

Subject's Planned Route
Subject's Adjusted Route Plan

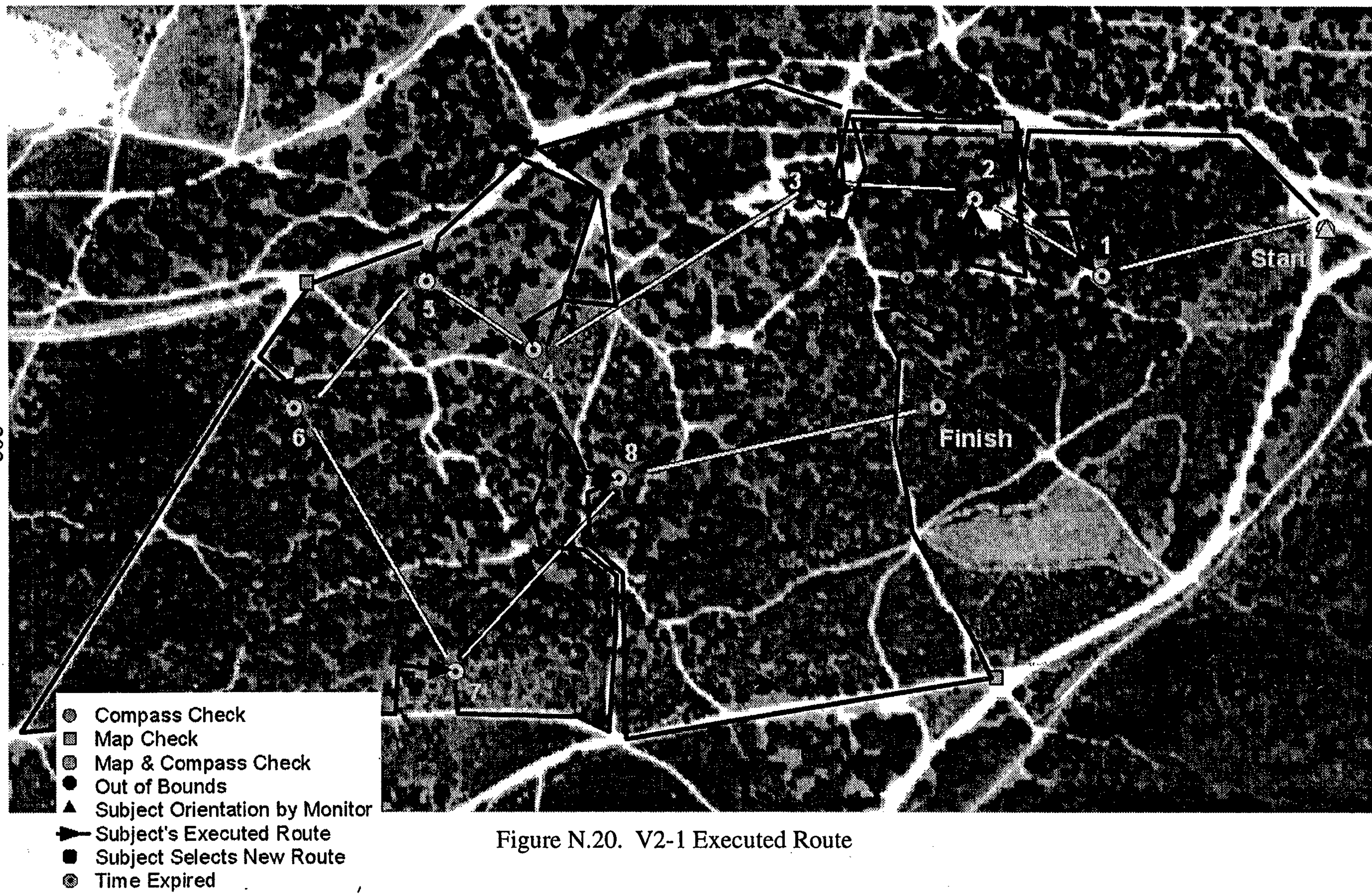


Figure N.20. V2-1 Executed Route

12. PARTICIPANT NUMBER V1-1

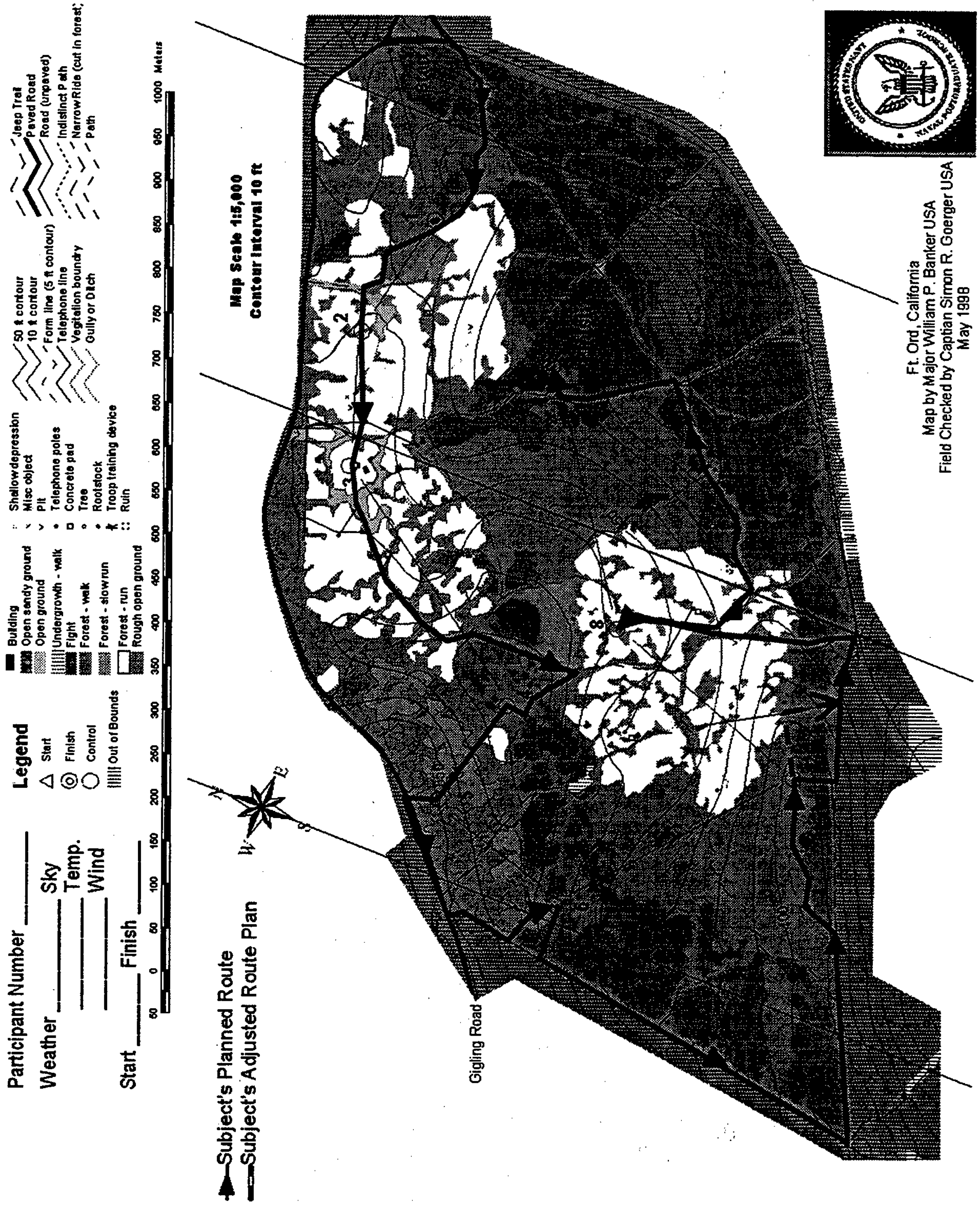


Figure N.21. V1-1 Planned Route

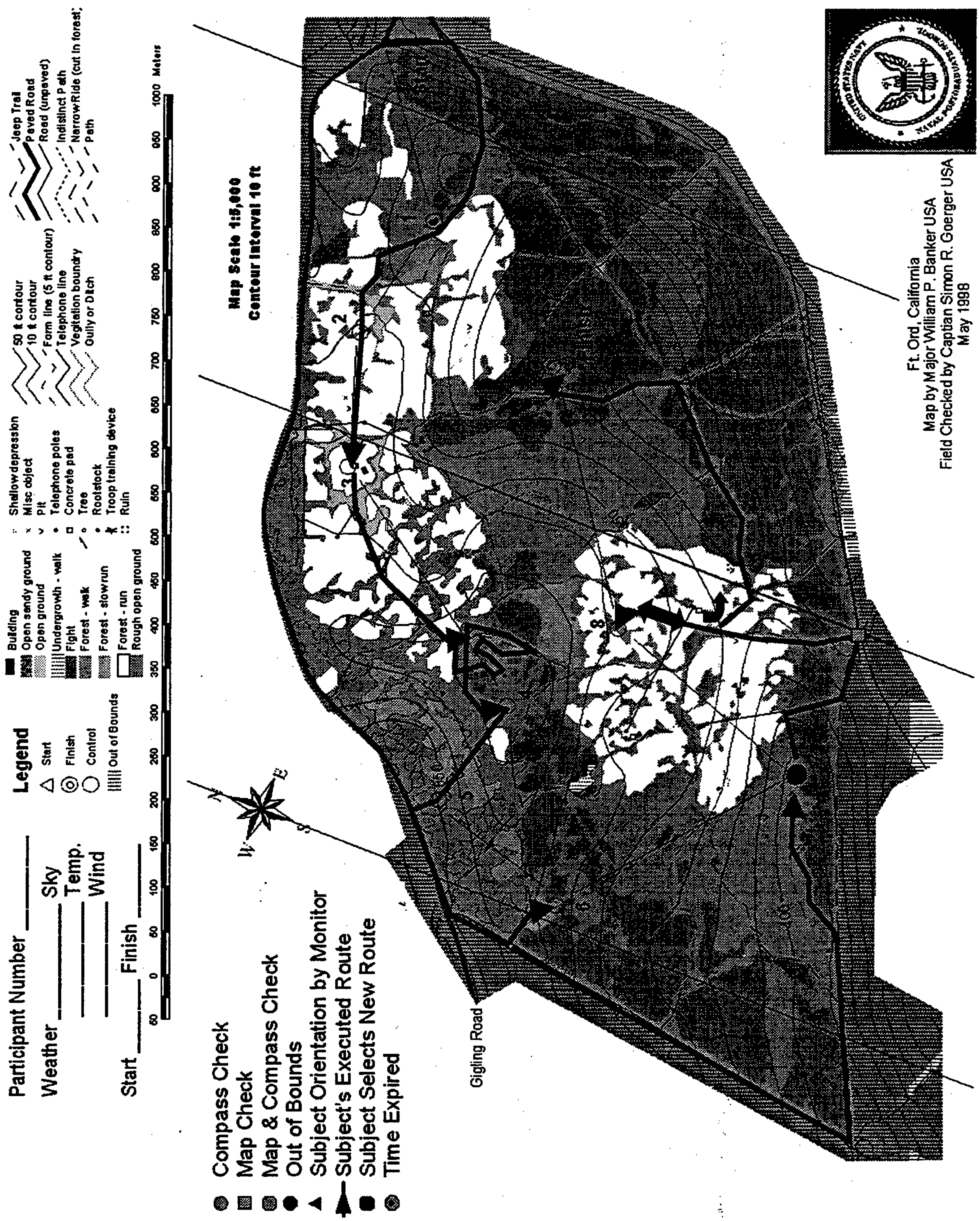


Figure N.22. V1-1 Executed Route

13. PARTICIPANT NUMBER V1-2

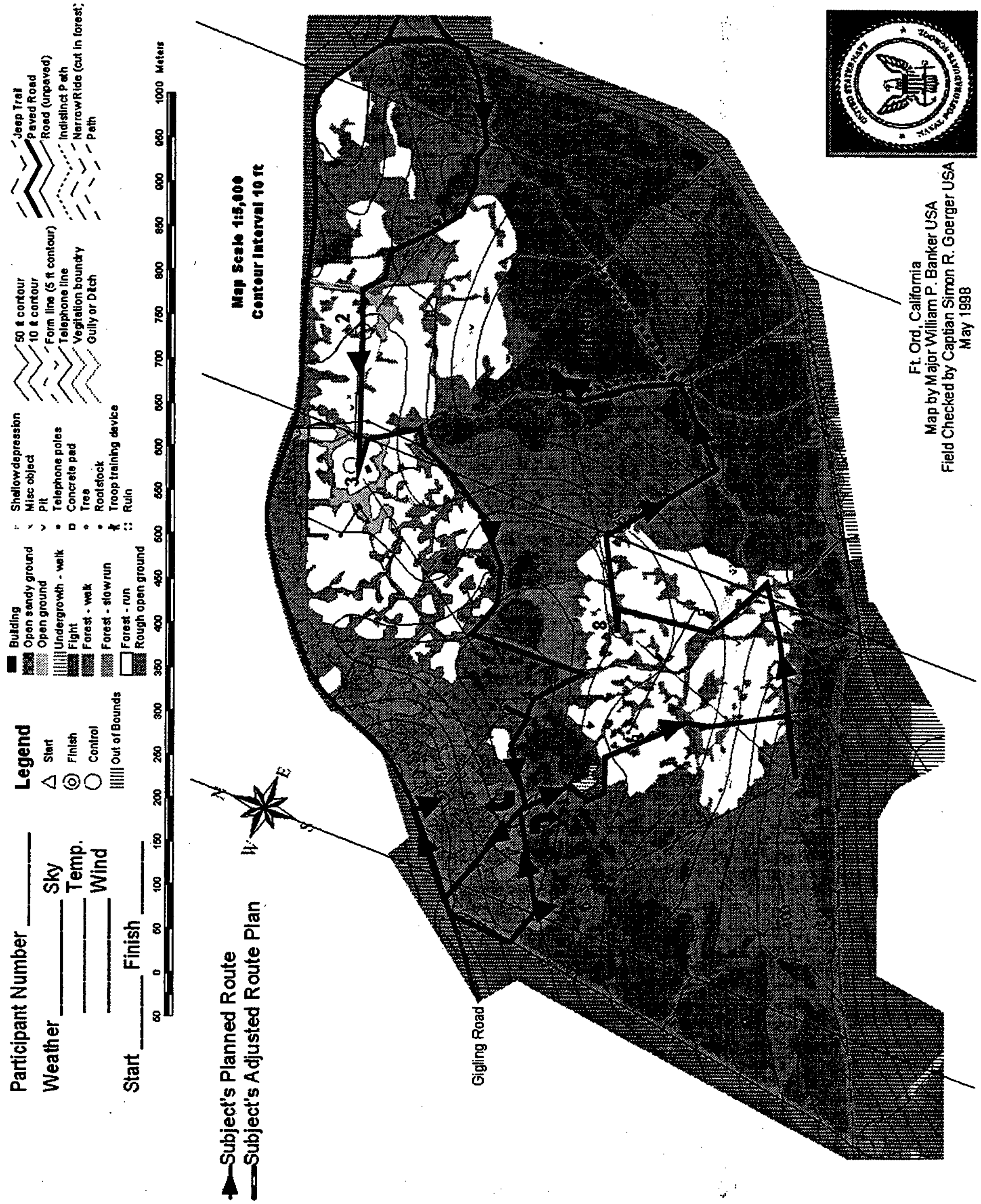


Figure N.23. V1-2 Planned Route

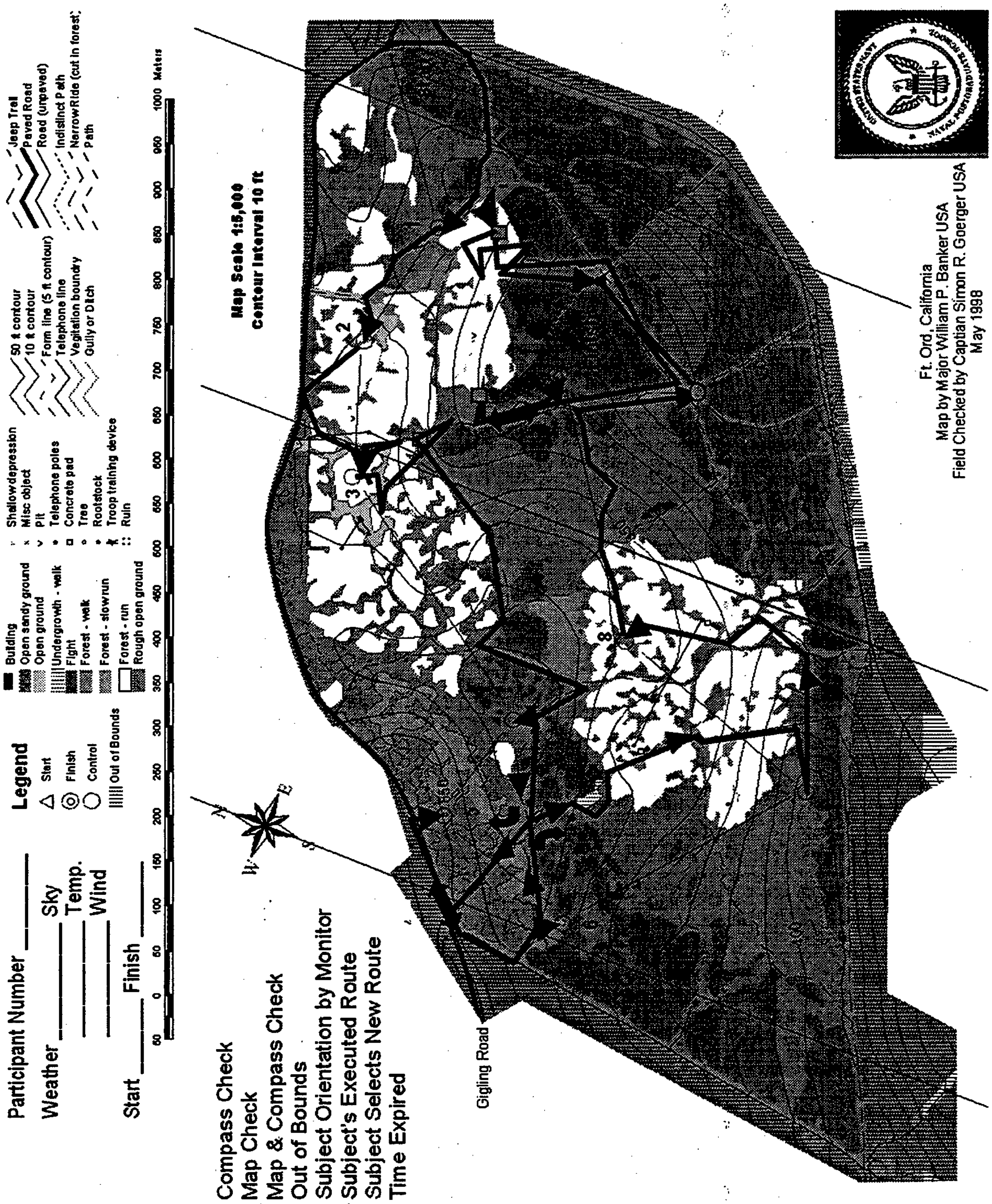


Figure N.24. V1-2 Executed Route

14. PARTICIPANT NUMBER V1-3

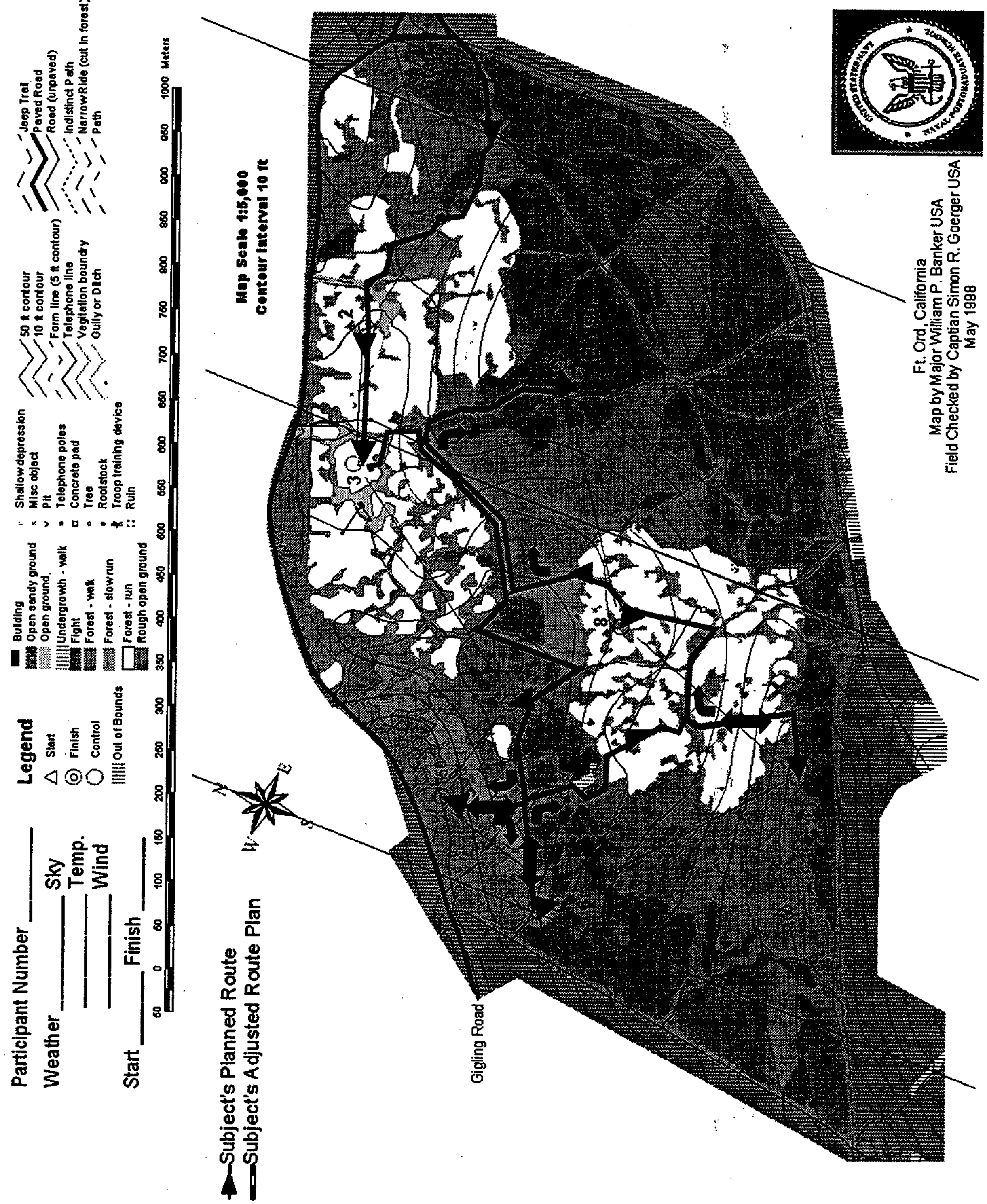


Figure N.25. V1-3 Planned Route

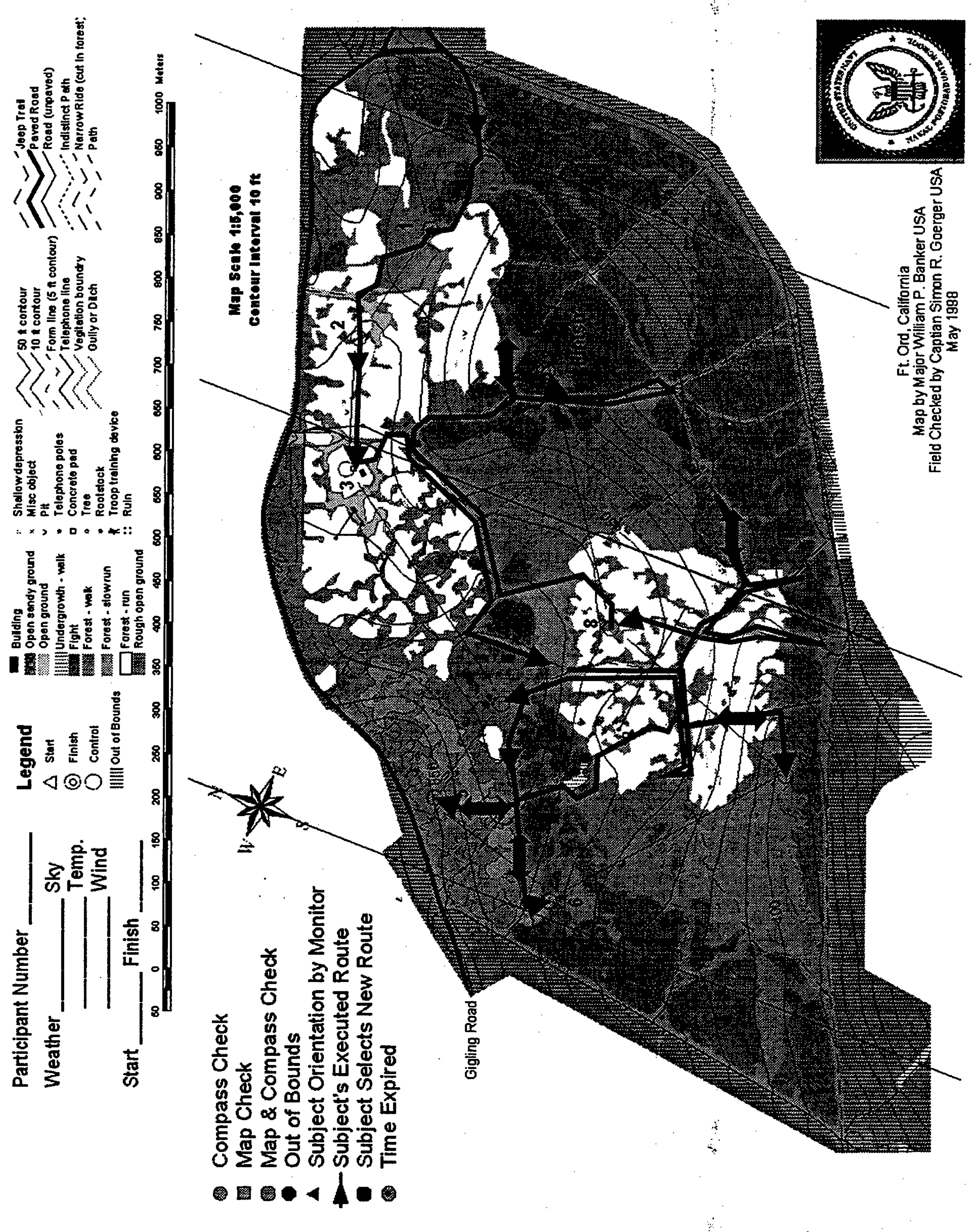


Figure N.26. V1-3 Executed Route

15. PARTICIPANT NUMBER V1-4

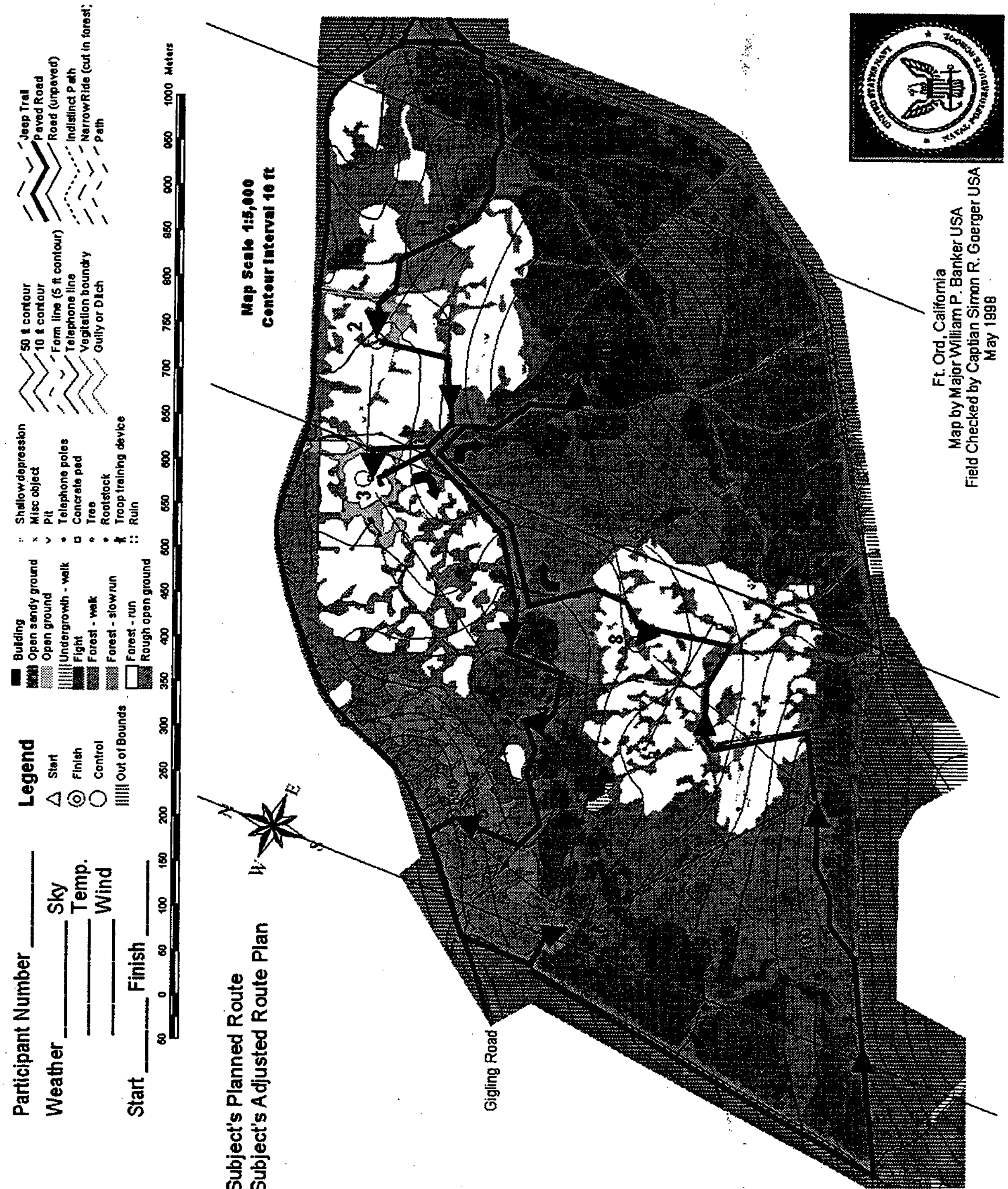


Figure N.27. V1-4 Planned Route

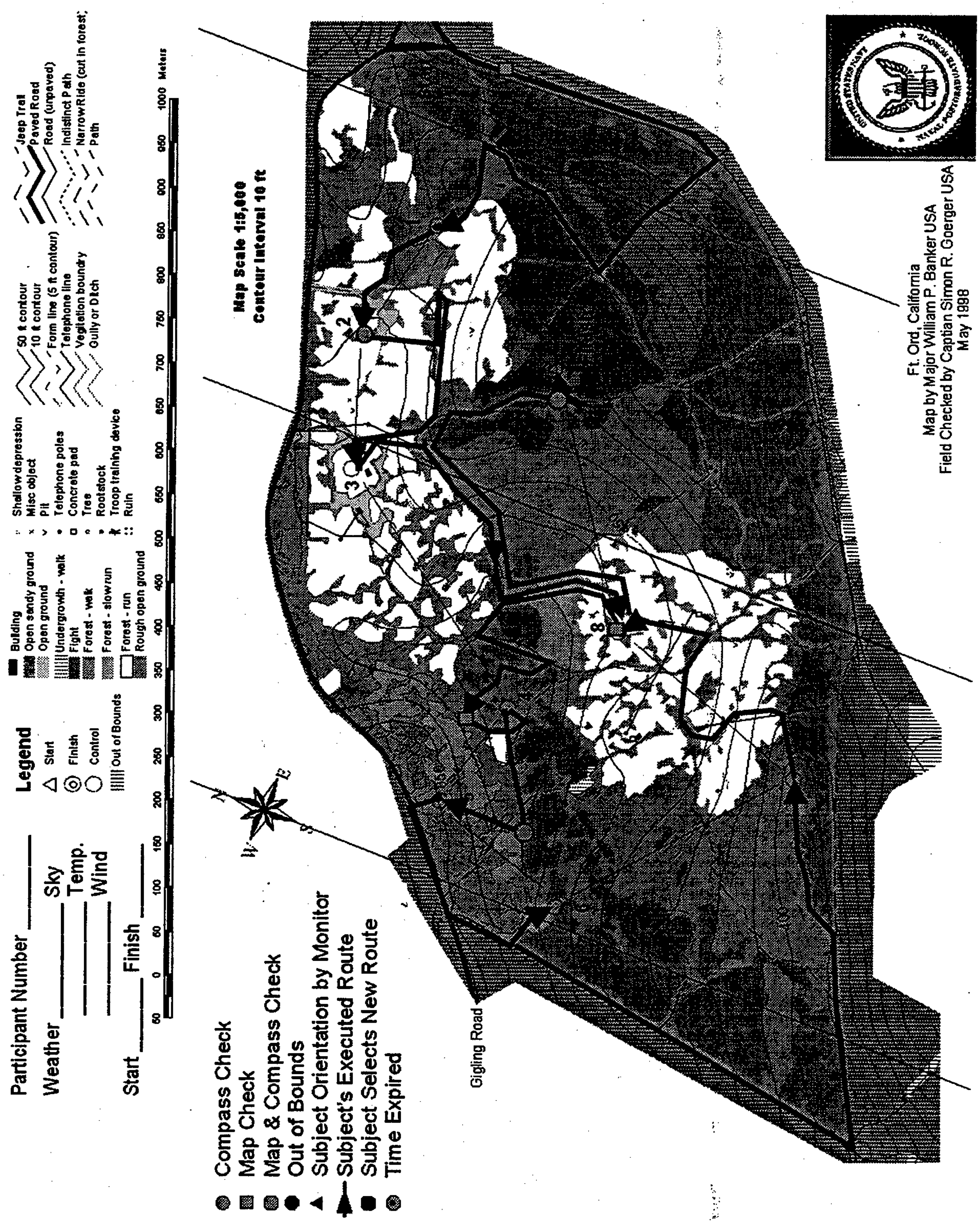


Figure N.28. V1-4 Executed Route

16. PARTICIPANT NUMBER V1-5

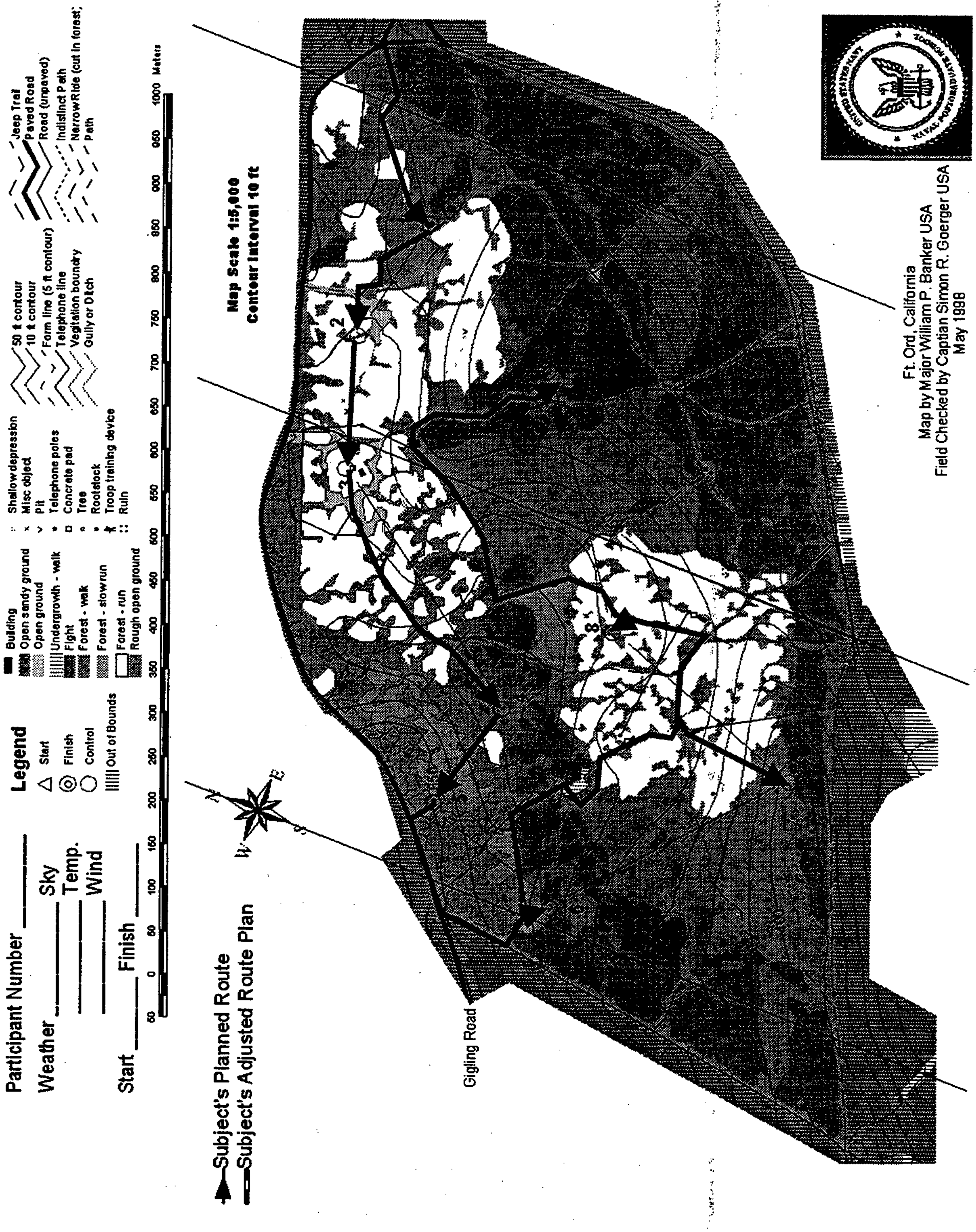


Figure N.29. V1-5 Planned Route

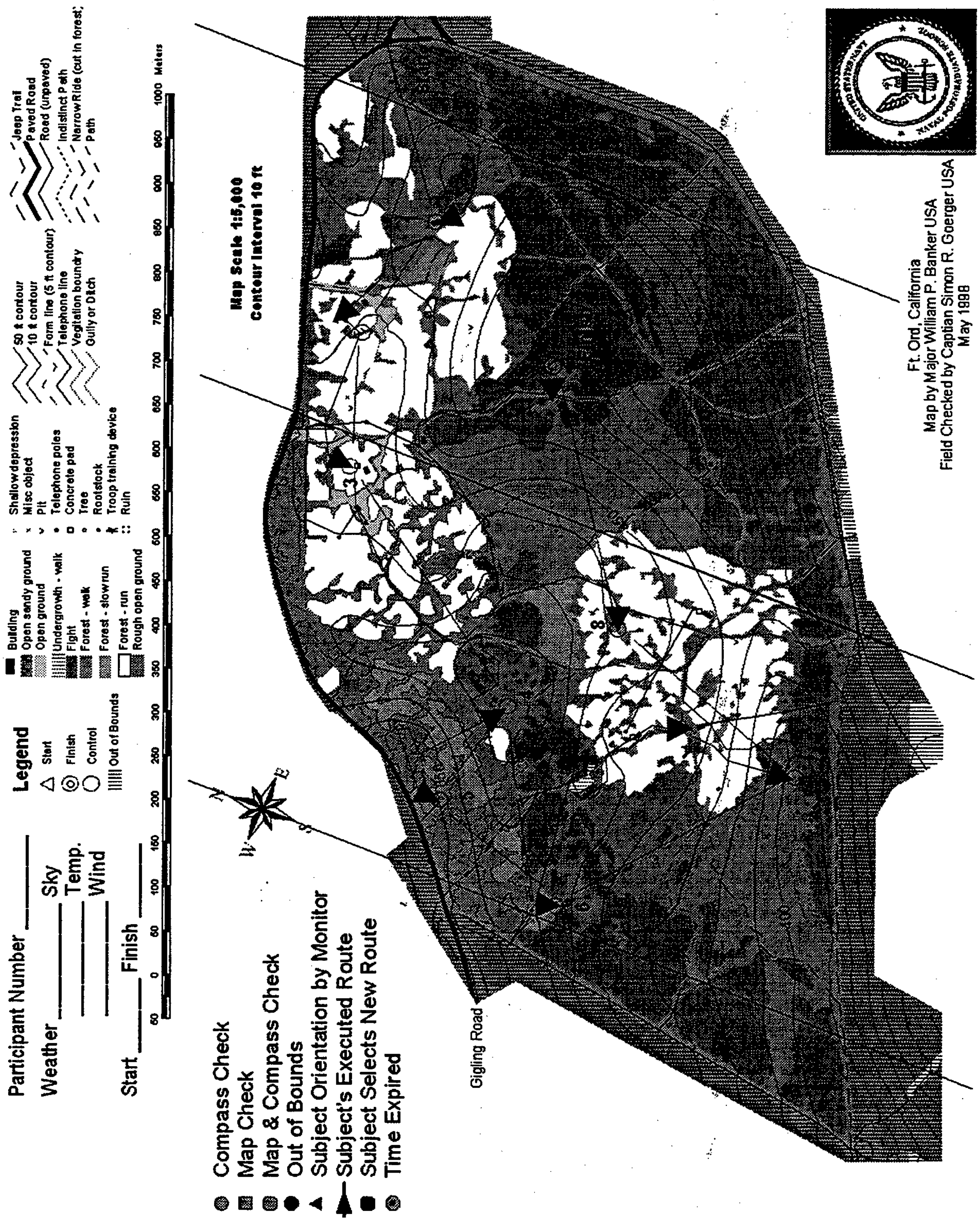


Figure N.30. V1-5 Executed Route

17. PARTICIPANT NUMBER V2-1

Figure N.31. V2-1 Planned Route

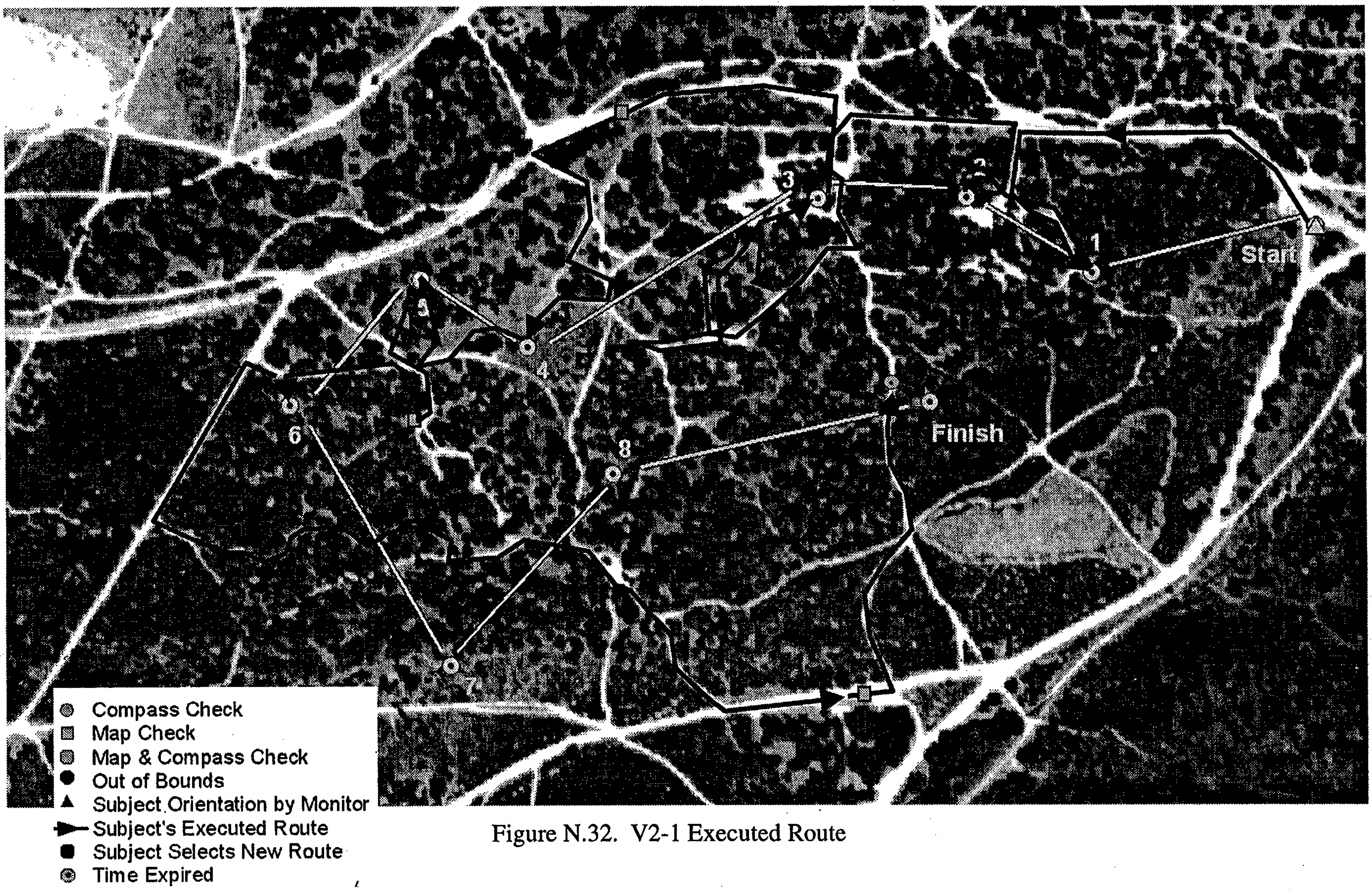


Figure N.32. V2-1 Executed Route

18. PARTICIPANT NUMBER V2-2

Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.33. V2-2 Planned Route (NOTE Subject's detour/new route due to construction crew)

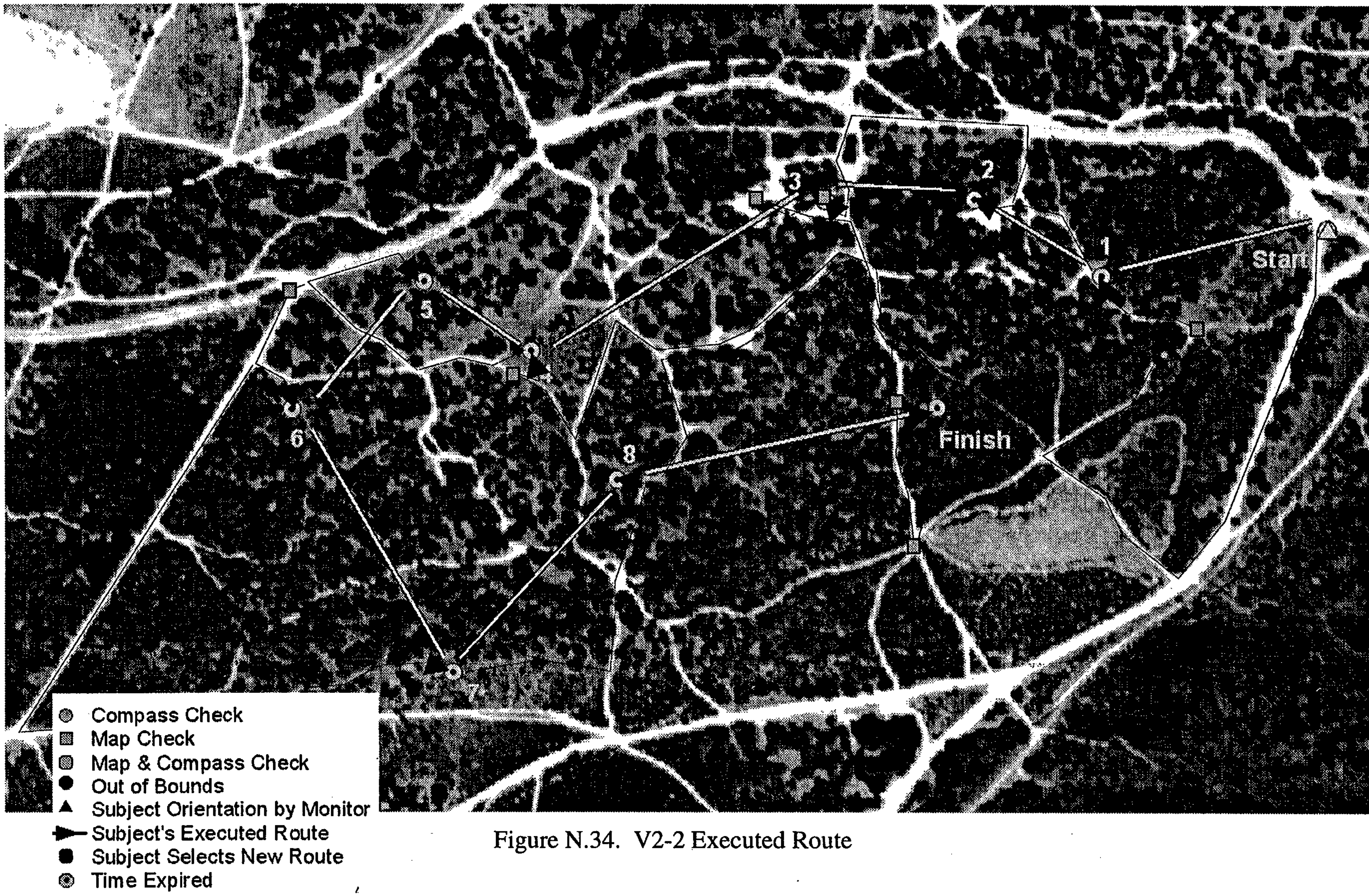


Figure N.34. V2-2 Executed Route

19. PARTICIPANT NUMBER V2-3

Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.35. V2-3 Planned Route

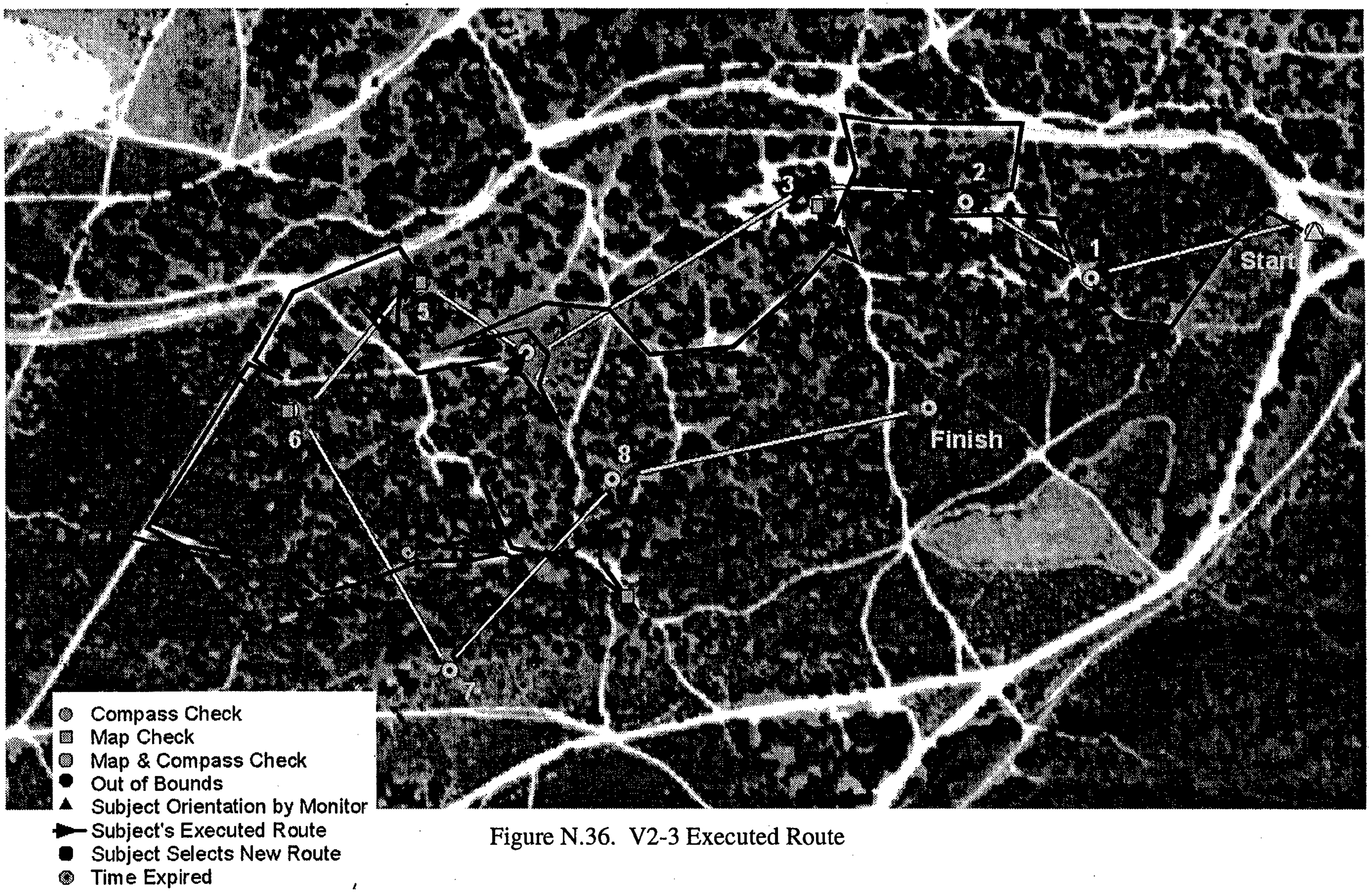


Figure N.36. V2-3 Executed Route

20. PARTICIPANT NUMBER V2-4

Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.37. V2-4 Planned Route

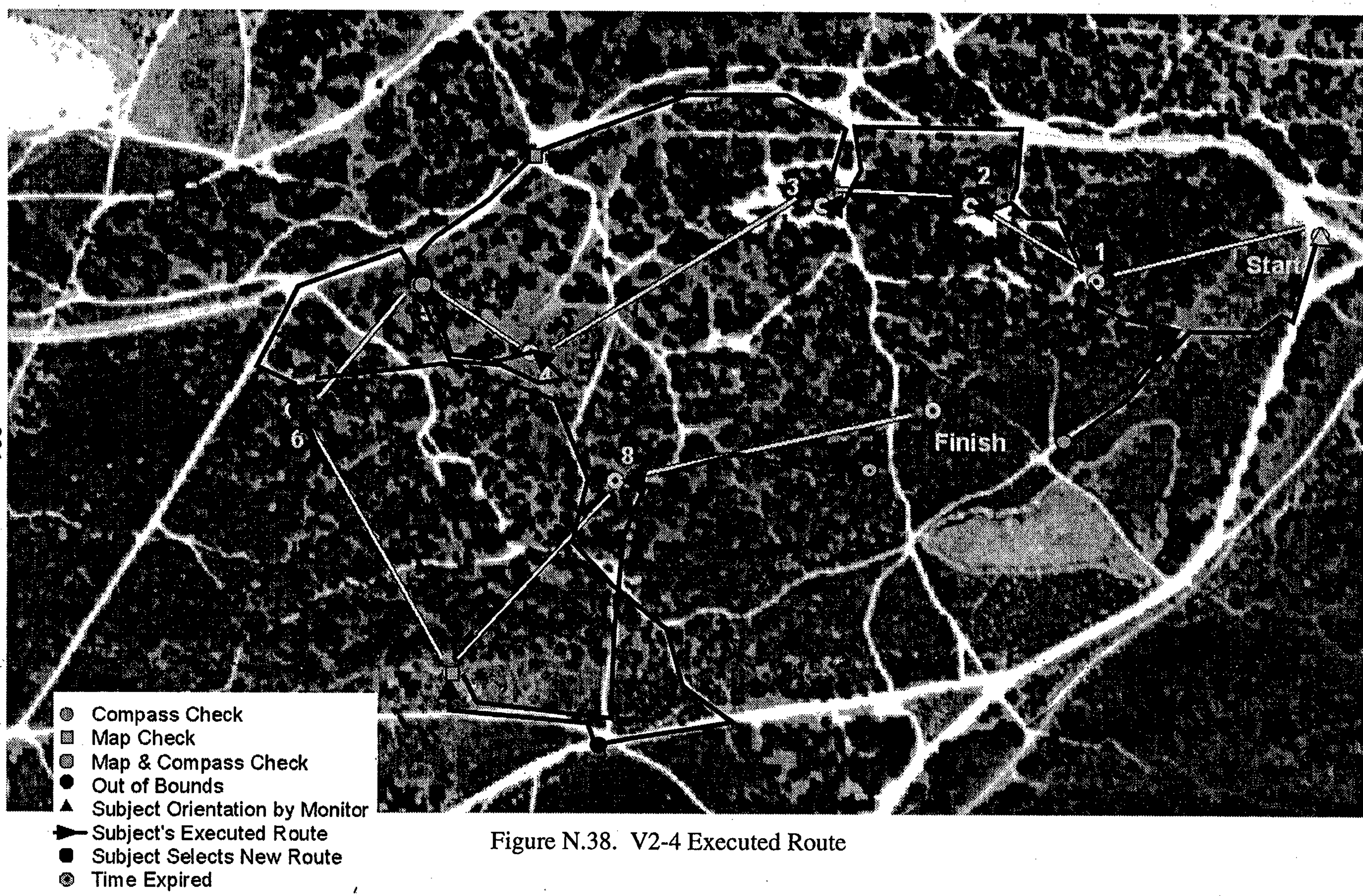
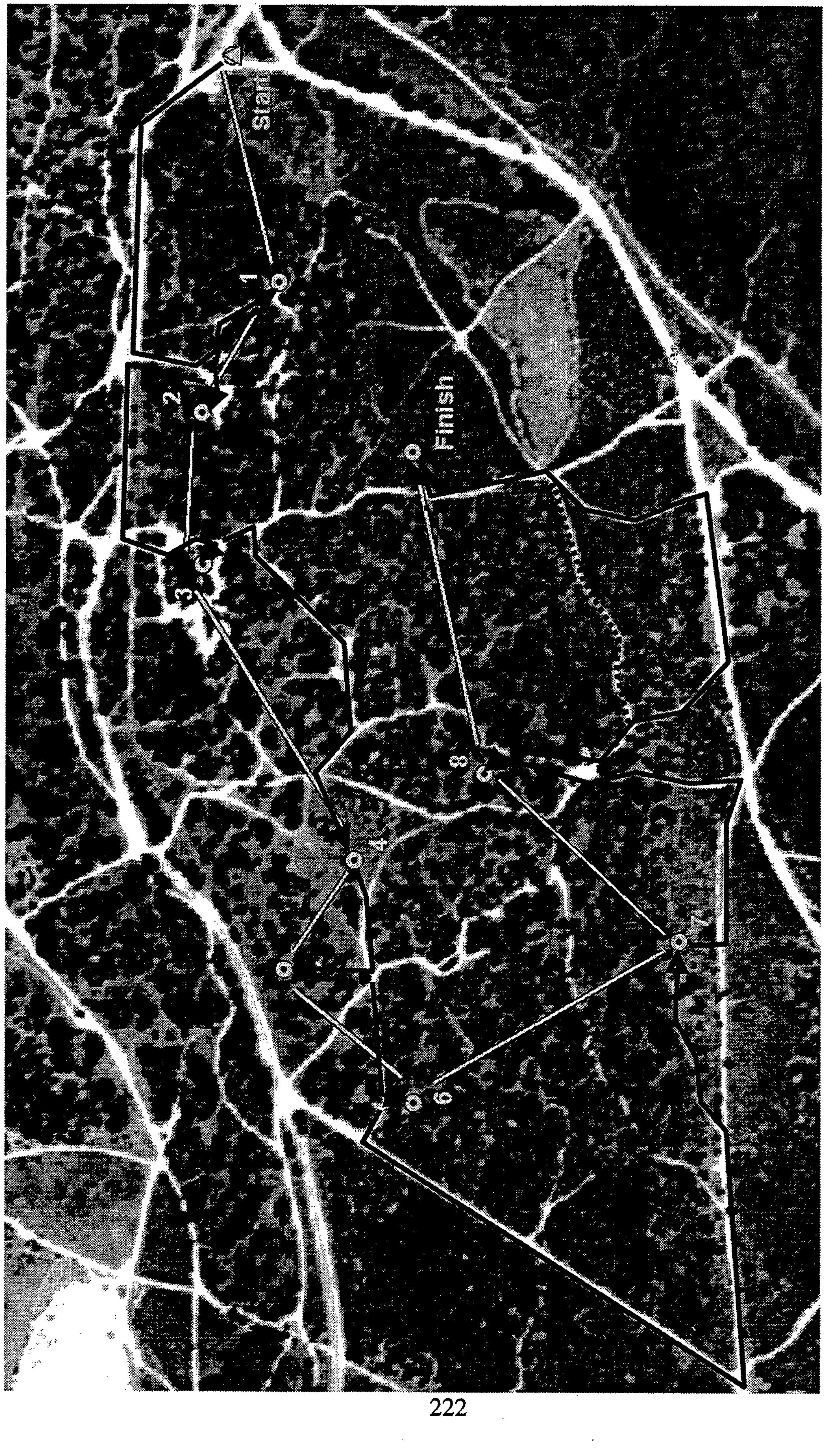


Figure N.38. V2-4 Executed Route

21. PARTICIPANT NUMBER V2-5



Subject's Planned Route
Subject's Adjusted Route Plan

Figure N.39. V2-5 Planned Route

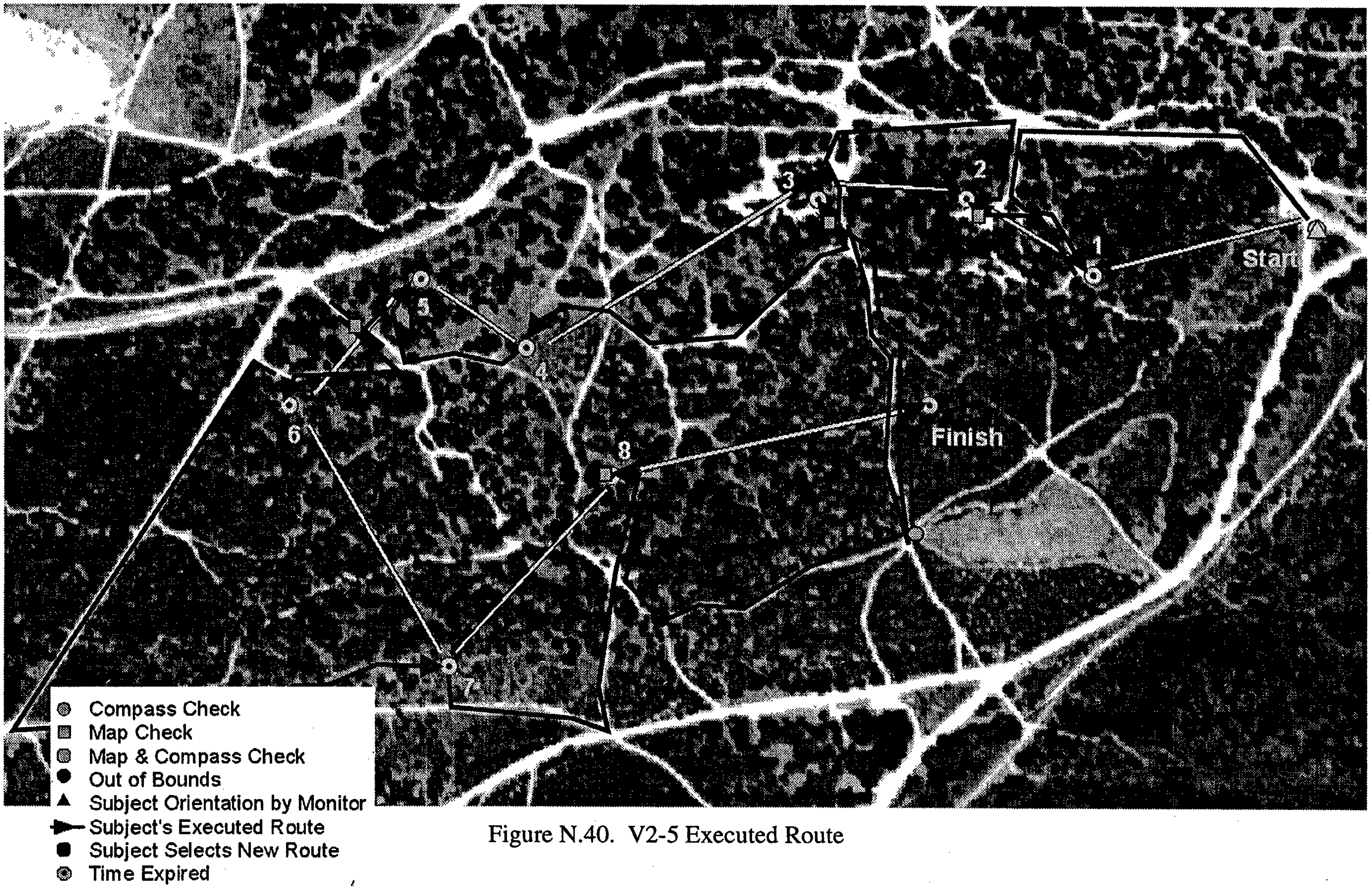


Figure N.40. V2-5 Executed Route

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APPENDIX O. RAW DATA

1. GENERAL INFORMATION

Participant data is referenced by the participant identification (ID) label (M1 – Train-to-Standard Map-Only Group, M2 – Low Fidelity Map Map-Only Group, VE1 – Train-to-Standard VE, VE2 – Low Fidelity Map VE). The number corresponds to the participant's internal group label. Data fields that are left blank represent information not recorded because a participant did not undergo the test or failed to reach that point in the course.

Subject ID	Group	Test Date	Test Time	Age	Sex	Rank	Service	Branch	Self Assessed Ability
V1-1	VE1	22-Apr-99	11:57	32	M	O3	Army	AR	Intermediate
V1-2	VE1	29-Apr-99	11:48	31	M	O3	Army	AV	Intermediate
M1-1	MAP1	23-Apr-99	9:22	32	M	O3	Marine	SC	Intermediate
M1-2	MAP1	30-Apr-99	9:30	31	M	O3	Army	INF	Expert
V1-3	VE1	7-May-99	10:00	32	M	O4	Army	AR	Intermediate
M1-3	MAP1	13-May-99	12:00	36	M	O4	Army	ADA	Expert
V1-4	VE1	14-May-99	13:00	32	M	O3	Marine	SC	Intermediate
V1-5	VE1	15-May-99	10:00	30	M	O3	Army	SC	Intermediate
M1-4	MAP1	21-May-99	9:00	32	F	O3	Army	SC	Intermediate
M1-5	MAP1	5-Jun-99	8:00	36	M	O3	Marine	SC	Expert
V2-1	VE2	11-Jun-99	9:00	30	F	O3	Marine	SC	Intermediate
M2-1	MAP2	3-Jul-99	6:30	32	M	O3	Marine	INF/FIN	Intermediate
V2-2	VE2	13-Jul-99	8:00	29	M	O3	Marine	SC	Intermediate
M2-2	MAP2	15-Jul-99	13:30	31	M	O3	Army	ADA	Intermediate
V2-3	VE2	16-Jul-99	7:00	40	M	O4	Marine	SC	Intermediate
M2-3	MAP2	16-Jul-99	12:00	34	M	O3	Marine	SC	Expert
V2-4	VE2	17-Jul-99	11:00	30	M	O3	Army	AR	Intermediate
M2-4	MAP2	19-Jul-99	13:00	32	M	O3	Army	AV	Expert
V2-5	VE2	21-Jul-99	12:00	35	M	O3	Marine	SC	Intermediate
M2-5	MAP2	23-Jul-99	8:00	33	M	O3	Army	MI	Expert

2. INITIAL TESTES AND QUESTIONNAIRE RESULTS

The initial tests and questionnaires are in Appendix E. Answers for the Map Test are located in Appendix E.1.

Subject ID Nº	GZ Score	Ability Group	Map Test Score	Bar Eval	Santa Barbara	Santa Barbara
M1-1	18.75	Low	17.5	Intermediate	2.80	High
M1-2	15.5	Low	19	Expert	1.93	High
M1-3	8.25	Low	17	Intermediate	2.80	High
M1-4	24.25	High	19.5	Intermediate	1.73	High
M1-5	21.5	High	18.5	Expert	1.80	High
M2-1	27	High	19	Intermediate	2.87	High
M2-2	42.25	High	18	Expert	2.33	High
M2-3	56.25	High	18	Beginner	3.20	High
M2-4	20.75	High	19	Intermediate	1.47	High
M2-5	14.5	Low	18.5	Intermediate	2.33	High
V1-1	23	High	19.5	Intermediate	1.67	High
V1-2	42.25	High	20	Intermediate	2.80	High
V1-3	10.5	Low	19	Intermediate	4.33	Low
V1-4	19.5	Low	19.5	Intermediate	2.80	High
V1-5	35	High	19.5	Intermediate	3.47	High
V2-1	10.75	Low	17	Beginner	3.13	High
V2-2	29.25	High	17.5	Intermediate	2.93	High
V2-3	31.25	High	19	Intermediate	2.27	High
V2-4	14.25	Low	18.5	Intermediate	2.87	High
V2-5	23	High	17	Intermediate	2.93	High

3. ROUTE ERRORS

The data provided in this section consists of the map checks, errors, error distances, and route leg classifications. The data appears in its raw form, summations, and normalized form for each of the experiment's twenty participants. The abbreviations utilized are listed in Table O.1.

Abbreviation	*Category*
C - #	Compass Check – Leg Number
M - #	Map Check – Leg Number
MC - #	Map and Compass Check – Leg Number
MCL - #	Map and Compass Check, Location Provided by Monitor – Leg Number
OB - #	Out of Bounds – Leg Number
New Rt - #	New Route Planned – Leg Number

Table O.1. Route Errors Abbreviation Table

a. Route Data Summation

Subject ID	(Banker) Average Planned Route Difficulty Level	(Lisp) Average Planned Route Difficulty Level	Controls Attempted	Controls Found
M1-1	1.60	1.60	9	8
M1-2	1.56	1.56	9	9
M1-3	1.80	1.80	9	9
M1-4	1.80	1.70	9	9
M1-5	2.30	2.00	9	8
M2-1	1.30	1.30	9	8
M2-2	1.40	1.70	9	9
M2-3	1.70	1.60	9	8
M2-4	1.30	1.30	9	9
M2-5	2.20	2.20	9	8
V1-1	1.20	1.20	9	9
V1-2	1.60	1.30	9	9
V1-3	1.60	1.30	9	9
V1-4	1.20	1.20	9	9
V1-5	1.90	1.90	9	9
V2-1	1.70	1.70	7	6
V2-2	1.30	1.40	9	9
V2-3	1.80	1.70	7	6
V2-4	1.90	1.80	9	8
V2-5	1.20	1.20	9	9

Subject ID	Errors-Tot	Dist-Tot	Errors Per CP Attempt	Distance Per Error(Total Error)	Total Error Score/Attempt	Total Error Score/Found (All)	Total Error Score/Found (Only)
M1-1	4.00	1245.00	0.44	311.25	34.58	38.91	49.92
M1-2	3.00	922.00	0.33	307.33	34.15	34.15	34.15
M1-3	6.00	598.00	0.67	99.67	11.07	11.07	14.18
M1-4	8.00	1027.00	0.89	128.38	14.26	14.26	14.26
M1-5	6.00	1990.00	0.67	331.67	36.85	41.46	46.40
M2-1	5.00	661.00	0.56	132.20	14.69	16.53	18.56
M2-2	6.00	1464.00	0.67	244.00	27.11	27.11	27.11
M2-3	5.00	1336.00	0.56	267.20	29.69	33.40	34.59
M2-4	5.00	1499.00	0.56	299.80	33.31	33.31	33.31
M2-5	8.00	1231.00	0.89	153.88	17.10	19.23	19.45
V1-1	1.00	245.00	0.11	245.00	27.22	27.22	27.22
V1-2	4.00	1250.00	0.44	312.50	34.72	34.72	34.72
V1-3	5.00	1631.00	0.56	326.20	36.24	36.24	36.24
V1-4	4.00	861.00	0.44	215.25	23.92	23.92	23.92
V1-5	4.00	355.00	0.44	88.75	9.86	9.86	9.86
V2-1	4.00	1596.00	0.57	399.00	57.00	66.50	44.28
V2-2	4.00	1085.00	0.44	271.25	30.14	30.14	30.14
V2-3	5.00	1614.00	0.71	322.80	46.11	53.80	34.08
V2-4	4.00	553.00	0.44	138.25	15.36	17.28	16.03
V2-5	2.00	589.00	0.22	294.50	32.72	32.72	32.72

Subject ID	Total Map Check Score	Normalized Map Check Score (Attempted)	Normalized Map Check Score (Found - All)	Normalized Map Check Score (Found-Only)	Controls Attempted	Controls Found	Landmark Score
M1-1	6.00	0.67	0.75	0.63	9.00	8.00	8.66
M1-2	7.00	0.78	0.78	0.78	9.00	9.00	9.00
M1-3	6.00	0.67	0.67	0.67	9.00	9.00	9.00
M1-4	2.00	0.22	0.22	0.22	9.00	9.00	9.00
M1-5	15.50	1.72	1.94	1.63	9.00	8.00	8.66
M2-1	2.50	0.28	0.31	0.31	9.00	8.00	8.66
M2-2	7.50	0.83	0.83	0.83	9.00	9.00	9.00
M2-3	0.00	0.00	0.00	0.00	9.00	8.00	8.33
M2-4	4.00	0.44	0.44	0.44	9.00	9.00	9.00
M2-5	3.50	0.39	0.44	0.31	9.00	8.00	8.33
V1-1	0.00	0.00	0.00	0.00	9.00	9.00	9.00
V1-2	7.50	0.83	0.83	0.83	9.00	9.00	9.00
V1-3	0.00	0.00	0.00	0.00	9.00	9.00	9.00
V1-4	6.50	0.72	0.72	0.72	9.00	9.00	9.00
V1-5	0.00	0.00	0.00	0.00	9.00	9.00	9.00
V2-1	3.00	0.43	0.50	0.33	7.00	6.00	6.33
V2-2	8.00	0.89	0.89	0.89	9.00	9.00	9.00
V2-3	4.00	0.57	0.67	0.50	7.00	6.00	6.33
V2-4	7.00	0.78	0.88	0.88	9.00	8.00	8.33
V2-5	7.00	0.78	0.78	0.78	9.00	9.00	9.00

b. Route Data Leg SP to CP1

Subject ID	Errors SP-1	Dist-1	C-1	M-1	MC-1	MCL-1	OB-1	New Rt-1	Checks Score SP-1	Control Found SP-1
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	0	0	0	0	0	0	0	0	0.00	1
M1-4	1	163	0	0	0	0	0	0	0.00	1
M1-5	1	158	0	0	0	0	0	0	0.00	1
M2-1	0	0	0	0	0	0	0	0	0.00	1
M2-2	0	0	0	0	0	0	0	0	0.00	1
M2-3	1	518	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	1	168	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	0	0	0	0	0	0	0	0	0.00	1
V1-4	1	511	0	1	0	0	0	0	1.00	1
V1-5	1	189	0	0	0	0	0	0	0.00	1
V2-1	0	0	0	0	0	0	0	0	0.00	1
V2-2	1	534	0	1	0	0	0	0	1.00	1
V2-3	0	0	0	0	0	0	0	0	0.00	1
V2-4	1	246	[illegible]	[illegible]	1	0	0	0	1.50	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

c. Route Data Leg CP1 to CP2

Subject ID	Errors 1-2	Dist-2	C-2	M-2	MC-2	MCL-2	OB-2	New Rt-2	Checks Score 1-2	Control Found 1-2
M1-1	1	253	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	1	93	0	0	0	0	0	0	0.00	1
M1-4	0	0	0	0	0	0	0	0	0.00	1
M1-5	1	129	0	0	0	0	0	0	0.00	1
M2-1	0	0	0	0	0	0	0	0	0.00	1
M2-2	1	632	0	1	0	0	0	0	1.00	1
M2-3	0	0	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	3	593	0	1	0	0	0	1	1.50	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	0	0	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	1	34	0	0	0	0	0	0	0.00	1
V2-1	0	0	0	0	0	0	0	0	0.00	1
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3	1	113	0	0	0	0	0	0	0.00	1
V2-4	0	0	0	0	0	0	0	0	0.00	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

d. Route Data Leg CP2 to CP3

Subject ID	Errors 2-3	Dist-3	C-3	M-3	MC-3	MCL-3	OB-3	New Rt-3	Checks Score 2-3	Control Found 2-3
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	0	0	0	0	0	0	0	0	0.00	1
M1-4	1	49	0	0	0	0	0	0	0.00	1
M1-5	0	0	0	0	0	0	0	0	0.00	1
M2-1	0	0	0	0	0	0	0	0	0.00	1
M2-2	0	0	0	0	0	0	0	0	0.00	1
M2-3	[illegible]	46	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	0	0	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	1	110	0	0	0	0	0	0	0.00	1
V1-3	1	119	0	0	0	0	0	0	0.00	1
V1-4	1	74	0	0	0	0	0	0	0.00	1
V1-5	1	43	0	0	0	0	0	0	0.00	1
V2-1	1	621	0	0	0	0	0	0	0.00	1
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3	0	0	0	0	0	0	0	0	0.00	1
V2-4	0	0	0	0	0	0	0	0	0.00	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

e. Route Data Leg CP3 to CP4

Subject ID	Errors 3-4	Dist-4	C-4	M-4	MC-4	MCL-4	OB-4	New Rt-4	Checks Score 3-4	Control Found 3-4
M1-1	2	711	0	3	0	0	0	0	3.00	1
M1-2	2	852	1	1	0	1	0	2	6.00	1
M1-3	1	126	0	1	0	0	0	0	1.00	1
M1-4	1	147	0	0	0	0	0	0	0.00	1
M1-5	1	913	0	1	1	0	0	0	2.50	1
M2-1	0	0	0	0	0	0	0	0	0.00	1
M2-2	1	107	0	0	0	0	0	0	0.00	1
M2-3	0	0	0	0	0	0	0	0	0.00	1
M2-4	2	815	0	0	1	0	0	1	2.00	1
M2-5	1	78	0	0	0	0	0	0	0.00	1
V1-1	1	245	0	1	0	0	0	0	1.00	1
V1-2	1	131	0	1	0	0	0	0	1.00	1
V1-3	1	434	0	0	0	0	0	0	0.00	1
V1-4	2	276	0	2	0	0	0	0	2.00	1
V1-5	0	0	0	0	0	0	0	0	0.00	1
V2-1	1	95	0	0	0	0	0	0	0.00	1
V2-2	2	220	0	1	0	0	0	0	1.00	1
V2-3	1	270	0	0	0	0	0	0	0.00	1
V2-4	1	48	0	0	0	0	0	0	0.00	1
V2-5	1	490	0	1	1	0	0	0	2.50	1

f. Route Data Leg CP4 to CP5

Subject ID	Errors 4-5	Dist-5	C-5	M-5	MC-5	MCL-5	OB-5	New Rt-5	Checks Score 4-5	Control Found 4-5
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	1	120	0	1	0	0	0	0	1.00	1
M1-4	0	0	0	0	0	0	0	0	0.00	1
M1-5	0	0	0	0	0	0	0	0	0.00	1
M2-1	2	309	0	1	0	0	0	0	1.00	1
M2-2	1	102	0	0	0	0	0	0	0.00	1
M2-3	0	0	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	0	0	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	0	0	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	1	89	0	0	0	0	0	0	0.00	1
V2-1	0	0	0	0	0	0	0	0	0.00	1
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3	1	135	0	0	0	0	0	0	0.00	1
V2-4	0	0	0	0	0	0	0	0	0.00	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

g. Route Data Leg CP5 to CP6

Subject ID	Errors 5-6	Dist-6	C-6	M-6	MC-6	MCL-6	OB-6	New Rt-6	Checks Score 5-6	Control Found 5-6
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	1	69	0	1	0	0	0	0	1.00	1
M1-4	0	0	0	0	0	0	0	0	0.00	1
M1-5	0	0	0	0	0	0	0	0	0.00	1
M2-1	0	0	0	0	0	0	0	0	0.00	1
M2-2	0	0	0	0	0	0	0	0	0.00	1
M2-3	0	0	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	0	0	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	0	0	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	0	0	0	0	0	0	0	0	0.00	1
V2-1	1	81	0	1	0	0	0	0	1.00	1
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3	1	300	0	0	0	0	0	0	0.00	1
V2-4	0	0	0	0	0	0	0	0	0.00	1
V2-5	1	99	0	1	0	0	0	0	1.00	1

h. Route Data Leg CP6 to CP7

Subject ID	Errors 6-7	Dist-7	C-7	M-7	MC-7	MCL-7	OB-7	New Rt-7	Checks Score 6-7	Control Found 6-7
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	1	45	0	0	0	0	0	0	0.00	1
M1-4	1	103	0	0	0	0	0	0	0.00	1
M1-5	1	123	0	0	0	0	0	0	0.00	1
M2-1	1	50	0	0	0	0	0	0	0.00	1
M2-2	1	26	0	0	0	0	0	0	0.00	1
M2-3	1	66	0	0	0	0	0	0	0.00	1
M2-4	0	0	0	0	0	0	0	0	0.00	1
M2-5	1	62	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	0	0	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	0	0	0	0	0	0	0	0	0.00	1
V2-1	1	799	0	1	0	0	0	0	1.00	0
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3	1	796	0	1	0	0	0	0	1.00	0
V2-4	1	219	0	0	0	0	1	0	2.00	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

i. Route Data Leg CP7 to CP8

Subject ID	Errors 7-8	Dist-8	C-8	M-8	MC-8	MCL-8	OB-8	New Rt-8	Checks Score 7-8	Control Found 7-8
M1-1	0	0	0	0	0	0	0	0	0.00	1
M1-2	0	0	0	0	0	0	0	0	0.00	1
M1-3	0	0	0	0	0	0	0	0	0.00	1
M1-4	0	0	0	0	0	0	0	0	0.00	1
M1-5	1	553	0	4	0	0	0	0	4.00	1
M2-1	1	235	0	1	0	0	0	1	1.50	1
M2-2	1	398	0	1	0	0	0	0	1.00	1
M2-3	1	477	0	0	0	0	0	0	0.00	1
M2-4	1	329	0	0	0	0	0	0	0.00	1
M2-5	1	188	0	0	0	0	0	0	0.00	1
V1-1	0	0	0	0	0	0	0	1	0.50	1
V1-2	0	0	0	0	0	0	0	0	0.00	1
V1-3	1	787	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	0	0	0	0	0	0	0	0	0.00	1
V2-1									0.00	0
V2-2	0	0	0	0	0	0	0	0	0.00	1
V2-3									0.00	0
V2-4	0	0	0	0	0	0	0	0	0.00	1
V2-5	0	0	0	0	0	0	0	0	0.00	1

j. Route Data Leg CP8 to CP9

Subject ID	Errors 8-9	Dist-9	C-9	M-9	MC-9	MCL-9	OB-9	New Rt-9	Checks Score 8-9	Control Found 8-9
M1-1	1	47	0	0	0	0	0	0	0.00	0
M1-2	1	70	0	1	0	0	0	0	1.00	1
M1-3	1	145	0	1	0	0	0	0	1.00	1
M1-4	4	565	0	2	0	0	0	0	2.00	1
M1-5	1	134	0	0	0	0	0	0	0.00	0
M2-1	1	67	0	0	0	0	0	0	0.00	0
M2-2	1	199	0	1	0	0	0	0	1.00	1
M2-3	1	229	0	0	0	0	0	0	0.00	0
M2-4	2	355	0	1	0	0	0	0	1.00	1
M2-5	1	142	0	0	0	0	0	0	0.00	0
V1-1	0	0	0	0	0	0	0	0	0.00	1
V1-2	2	1009	1	2	0	1	0	1	6.50	1
V1-3	2	291	0	0	0	0	0	0	0.00	1
V1-4	0	0	0	0	0	0	0	0	0.00	1
V1-5	0	0	0	0	0	0	0	0	0.00	1
V2-1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0
V2-2	1	331	0	1	0	0	0	0	1.00	1
V2-3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0
V2-4	1	40	0	0	0	0	0	0	0.00	0
V2-5	0	10	0	0	0	0	0	0	0.00	1

k. Route Data Non Error Checks

Subject ID	C-Non Errors	M-Non Errors	MC-Non Errors	MCL-Non Errors	OB-Non Errors	New Rt-Non Errors	Checks Score - Non Errors
M1-1	0	3	0	0	0	0	3.00
M1-2	0	0	0	0	0	0	0.00
M1-3	0	2	0	0	0	0	2.00
M1-4	0	0	0	0	0	0	0.00
M1-5	1	7	1	0	0	1	10.00
M2-1	0	0	0	0	0	0	0.00
M2-2	0	4	0	0	0	1	4.50
M2-3	0	0	0	0	0	0	0.00
M2-4	0	1	0	0	0	0	1.00
M2-5	0	2	0	0	0	0	2.00
V1-1	0	1	0	0	0	0	1.00
V1-2	0	0	0	0	0	0	0.00
V1-3	0	0	0	0	0	0	0.00
V1-4	2	0	1	0	0	0	3.50
V1-5	0	0	0	0	0	0	0.00
V2-1	0	1	0	0	0	0	1.00
V2-2	0	5	0	0	0	0	5.00
V2-3	0	3	0	0	0	0	3.00
V2-4	1	2	0	0	0	1	3.50
V2-5	0	3	0	0	0	1	3.50

l. Route Data Totals

Subject ID	Errors-Tot	Dist-Tot	Dist Per Error	C-Tot	M-Tot	MC-Tot	MCL-Tot	OB-Tot	New Rt-Tot
M1-1	4	1245	311.25	0	6	0	0	0	0
M1-2	3	922	307.33	1	2	0	1	0	2
M1-3	6	598	99.67	0	6	0	0	0	0
M1-4	8	1027	128.38	0	2	0	0	0	0
M1-5	6	2010	335.00	1	11	2	0	0	1
M2-1	5	661	132.20	0	2	0	0	0	1
M2-2	6	1464	244.00	0	[illegible]	0	0	0	[illegible]
M2-3	5	1336	267.20	0	0	0	0	0	0
M2-4	5	1499	299.80	0	2	1	0	0	1
M2-5	8	1231	153.88	0	3	0	0	0	1
V1-1	1	245	245.00	0	2	0	0	0	1
V1-2	4	1250	312.50	1	3	0	1	0	1
V1-3	5	1631	326.20	0	0	0	0	0	0
V1-4	4	861	215.25	2	3	1	0	0	0
V1-5	4	355	88.75	0	0	0	0	0	0
V2-1	4	1596	399.00	0	3	0	0	0	0
V2-2	4	1085	271.25	0	8	0	0	0	0
V2-3	5	1614	322.80	0	4	0	0	0	0
V2-4	4	553	138.25	1	2	1	[illegible]	1	1
V2-5	2	589	294.50	0	5	1	0	0	1

m. Leg Difficulty Evaluation Banker

Each leg is evaluated utilizing MAJ Banker's Route Classification (Appendix L.2). "B" stands for Beginner, "I" stands or Intermediate, and "A" stands for Advanced. The total is based on a point value system of B = 1, I = 2, and A = 3. The Average is the total divided by the number of legs. 0-1.50 is an average course difficulty of Beginner, 1.51-2.5 is Intermediate, and 2.51-3.0 is Advanced. The same criteria apply to the Lisp leg difficulty evaluation.

Subject	leg1	leg2	leg3	leg4	leg5	leg6	leg7	leg8	leg9	Banker (Tot)	Banker (Ave)
M1-1	I	I	I	B	B	B	B	A	B	14	1.6
M1-2	B	I	B	B	I	B	B	B	B	11	1.2
M1-3	B	I	I	B	I	I	A	I	B	16	1.8
M1-4	A	I	I	A	B	B	I	B	B	16	1.8
M1-5	A	I	I	A	I	A	I	B	A	21	2.3
M2-1	B	I	B	I	I	B	B	B	B	12	1.3
M2-2	I	I	B	I	B	B	B	I	B	13	1.4
M2-3	B	I	I	I	I	B	I	I	B	15	1.7
M2-4	B	I	B	I	B	B	B	I	B	12	1.3
M2-5	A	A	A	I	I	B	I	I	I	20	2.2
V1-1	B	B	I	B	I	B	B	B	B	11	1.2
V1-2	B	I	I	B	B	B	I	B	A	14	1.6
V1-3	B	I	I	B	B	I	I	I	B	14	1.6
V1-4	B	I	B	B	B	B	B	I	B	11	1.2
V1-5	A	I	I	I	I	B	I	I	B	17	1.9
V2-1	B	B	B	I	B	B	A	I	A	15	1.7
V2-2	B	I	B	I	B	B	B	B	I	12	1.3
V2-3	B	I	B	A	I	B	A	I	B	16	1.8
V2-4	B	I	B	A	I	B	A	B	A	17	1.9
V2-5	B	I	B	I	B	B	B	B	B	11	1.2

n. Leg Difficulty Evaluation LISP

Subject	leg1	leg2	leg3	leg4	leg5	leg6	leg8	leg9	LISP (Total)	LISP (Ave)
M1-1	I	B	I	B	B	B	A	B	14	1.6
M1-2	B	B	B	B	B	B	B	I	11	1.2
M1-3	B	B	I	B	I	A	I	B	16	1.8
M1-4	A	B	I	A	B	B	B	B	15	1.7
M1-5	A	B	I	A	B	A	B	A	18	2
M2-1	B	B	B	I	I	B	B	B	12	1.3
M2-2	A	B	B	I	I	B	I	B	15	1.7
M2-3	B	B	I	I	I	B	I	B	14	1.6
M2-4	B	B	B	I	B	B	I	B	12	1.3
M2-5	A	A	A	I	I	B	I	I	20	2.2
V1-1	B	B	I	B	B	B	B	B	11	1.2
V1-2	B	B	I	B	B	B	B	A	12	1.3
V1-3	B	B	I	B	B	I	B	I	12	1.3
V1-4	B	B	I	B	B	B	B	B	11	1.2
V1-5	A	B	I	A	B	B	I	B	17	1.9
V2-1	B	B	B	I	B	B	I	A	15	1.7
V2-2	B	B	B	B	I	B	I	I	13	1.4
V2-3	B	B	B	A	I	B	I	B	15	1.7
V2-4	B	B	B	A	I	B	B	A	16	1.8
V2-5	B	B	B	I	B	B	B	B	11	1.2

4. WHEEL TEST RESULTS

a. Wheel Test Results for Control Point 2

Subject ID	Wheel CP2 SP	Wheel CP2 CP5	Wheel CP2 CP9	Difference Wheel CP2 CP1	Difference Wheel CP2 CP6	Difference Wheel CP2 CP8	Ave Ang Diff CP2	CP2 Orient	CP2 Time (sec)
M1-1	90	260	180	-20	-20	-10	16.67	South	60
M1-2	60	270	120	10	-30	50	30.00	NW	90
M1-3	90	260	160	-20	-20	10	16.67	West	30
M1-4	150	270	180	-80	-30	-10	40.00	SW	28
M1-5	70	250	180	0	-10	-10	6.67	NW	30
M2-1	95	270	215	-25	-30	-45	33.33	N	85
M2-2	75	240	165	-5	0	5	3.33	N	85
M2-3	82	240	163	-12	0	7	6.33	N	37
M2-4	76	270	182	-6	-30	-12	16.00	S	37
M2-5	30	200	110	40	40	60	46.67	North	17
V1-1	122	259	180	-52	-19	-10	27.00	North	52
V1-2	100	310	165	-30	-70	5	35.00	NW	140
V1-3	90	210	130	-20	30	40	30.00	SW	58
V1-4	60	223	120	10	17	50	25.67	South	60
V1-5	90	250	140	-20	-10	30	20.00	West	58
V2-1	80	195	130	10	45	40	31.67	NW	66
V2-2	160	370	230	-90	-130	-60	93.33	East/SE	15
V2-3	130	255	210	-60	-15	-40	38.33	N	15
V2-4	80	240	210	-10	0	-40	16.67	N	36
V2-5	135	285	200	-65	-45	-30	46.67	NW	28

b. Wheel Test Results for Control Point 4 and Total Wheel Test Angular Difference

Subject ID	Wheel CP4 CP1	Wheel CP4 CP6	Wheel CP4 CP8	Difference Wheel CP4 CP1	Difference Wheel CP4 CP6	Difference Wheel CP4 CP8	Ave Ang Diff CP4	CP4 Orient	CP4 Time (sec)	Total Wheel Test Angular Diff
M1-1	97	275	180	-39	-40	-64	47.67	West	45	32.167
M1-2	20	200	60	38	35	56	43.00	NW	45	36.500
M1-3	90	270	150	-32	-35	-34	33.67	NW	45	25.167
M1-4	100	255	180	-42	-20	-64	42.00	S	31	41.000
M1-5	80	170	120	-22	65	-4	30.33	S	48	18.500
M2-1	83	220	125	-25	15	-9	16.33	N	59	24.833
M2-2	45	260	140	13	-25	-24	20.67	N	65	12.000
M2-3	58	240	138	0	-5	-22	9.00	NW	48	7.667
M2-4	72	265	178	-14	-30	-62	35.33	N	76	25.667
M2-5	48	250	150	10	-15	-34	19.67	N	28	33.167
V1-1	97	290	200	-39	-55	-84	59.33	SW	78	43.167
V1-2	80	205	120	-22	30	-4	18.67	SW/240	90	26.833
V1-3	20	230	90	38	5	26	23.00	N	30	26.500
V1-4	100	230	150	-42	5	-34	27.00	South	20	26.333
V1-5	55	185	105	3	50	11	21.33	NW	52	20.667
V2-1	40	225	125	18	10	-9	12.33	West	72	22.000
V2-2	30	240	170	28	-5	-54	29.00	East	20	61.167
V2-3	65	223	100	-7	12	16	11.67	N	25	25.000
V2-4	50	224	97	8	11	19	12.67	NW	44	14.667
V2-5	80	263	162	-22	-28	-46	32.00	S	35	39.333

5. WHITE BOARD RESULTS

a. White Board Normalized Distance Differences from Actual Normalized Distances

Subject ID	SP to CP1	CP1 to CP2	CP2 to CP3	CP3 to CP4	CP4 to CP5	CP5 to CP6	CP6 to CP7	CP7 to CP8	CP8 to CP9	CP9 to SP	Total	Avg
M1-1	-0.0177	0.0575	-0.0083	-0.0246	0.0227	0.0358	0.0044	-0.0338	-0.0217	-0.0143	0.24	0.024
M1-2	-0.0090	0.0271	0.0085	-0.0093	0.0121	0.0335	-0.0078	-0.0020	-0.0518	-0.0014	0.16	0.016
M1-3	-0.0144	-0.0017	0.0060	0.0341	0.0085	0.0239	-0.0255	0.0085	-0.0515	0.0123	0.19	0.019
M1-4	-0.0176	0.0363	0.0242	-0.0332	0.0186	0.0321	-0.0028	0.0116	-0.0334	-0.0358	0.25	0.025
M1-5	0.0171	0.0138	0.0135	-0.0210	0.0346	0.0338	0.0124	0.0131	-0.0142	-0.1030	0.28	0.028
M2-1	-0.0027	-0.0130	0.0036	-0.0148	0.0225	0.0195	0.0465	0.0081	-0.0298	-0.0400	0.20	0.020
M2-2	-0.0204	-0.0066	0.0115	-0.0217	0.0063	0.0162	0.0469	-0.0246	-0.0289	0.0215	0.20	0.020
M2-3	0.0093	0.0193	-0.0003	-0.0095	0.0209	-0.0059	0.0179	-0.0008	-0.0528	0.0018	0.14	0.014
M2-4	-0.0112	-0.0039	0.0432	-0.0115	0.0112	0.0414	-0.0092	-0.0052	-0.0521	-0.0027	0.19	0.019
M2-5	0.0078	0.0075	0.0067	-0.0130	0.0191	-0.0026	0.0168	0.0100	-0.0089	-0.0434	0.14	0.014
V1-1	-0.0179	0.0229	-0.0108	-0.0327	0.0516	0.0339	0.0690	0.0338	-0.0734	-0.0763	0.42	0.042
V1-2	0.0118	0.0136	0.0127	-0.0176	-0.0007	0.0472	-0.0449	0.0058	-0.0564	0.0286	0.24	0.024
V1-3	-0.0170	0.0784	-0.0687	-0.0189	0.0263	0.0229	-0.0635	0.0681	-0.0292	0.0017	0.39	0.039
V1-4	-0.0357	-0.0044	-0.0107	-0.0017	0.0356	0.0309	0.0814	-0.0326	0.0165	-0.0794	0.33	0.033
V1-5	-0.0119	0.0052	-0.0013	-0.0273	0.0001	0.0283	0.0094	0.0006	-0.0297	0.0264	0.14	0.014
V2-1	0.1236	0.0435	0.0742	0.1038	0.0577	0.0732	0.1809	0.0998	0.1056	0.1378	1.00	0.100
V2-2	0.0895	0.0578	0.0304	0.0616	0.0619	0.1204	0.1491	0.0851	0.1048	0.2393	1.00	0.100
V2-3	0.0856	0.1024	0.0883	0.0883	0.0750	0.1358	0.0803	0.1061	0.0656	0.1726	1.00	0.100
V2-4	0.0478	0.0629	0.0862	0.1418	0.0738	0.0909	0.1635	0.1121	0.0649	0.1561	1.00	0.100
V2-5	0.1119	0.0533	0.0802	0.1026	0.0820	0.0862	0.1052	0.0785	0.1012	0.1988	1.00	0.100

b. White Board Angles

Subject ID	SP,1,2	1,2,3	2,3,4	3,4,5	4,5,6	5,6,7	6,7,8	7,8,9	8,9,SP	9,SP,1
M1-1	105.009	115.017	139.800	92.679	90.533	98.783	89.427	162.563	169.641	3.668
M1-2	106.519	172.635	94.635	85.007	78.781	100.180	95.210	121.392	128.242	3.226
M1-3	172.102	156.228	136.950	75.170	50.747	119.143	79.205	150.097	179.395	34.491
M1-4	180.153	142.200	143.533	86.710	46.631	131.596	91.723	144.857	146.021	30.015
M1-5	136.884	159.665	102.932	78.740	57.920	112.238	112.066	139.131	126.863	88.632
M2-1	176.650	160.253	166.578	130.049	84.190	112.333	91.814	157.760	167.907	48.083
M2-2	119.015	134.748	178.233	120.332	106.344	86.744	86.204	163.751	161.395	6.297
M2-3	132.568	148.016	147.159	116.137	81.199	111.245	110.756	178.648	174.579	14.398
M2-4	103.857	133.874	147.316	103.670	69.583	88.876	116.684	146.751	159.304	1.359
M2-5	170.056	158.441	156.936	174.022	158.883	79.344	128.063	171.870	155.495	50.740
V1-1	169.329	124.542	94.488	78.148	50.864	171.973	34.147	85.011	124.730	91.745
V1-2	169.695	131.035	180.000	72.255	9.484	156.585	51.759	149.718	160.156	22.960
V1-3	106.565	59.636	40.601	100.222	86.993	108.452	116.370	149.832	140.987	16.812
V1-4	178.832	145.200	168.174	128.452	94.074	84.835	64.013	103.739	161.528	55.531
V1-5	138.006	147.304	157.220	105.349	96.936	105.565	73.288	161.168	173.229	10.981
V2-1	169.051	154.432	161.411	104.700	74.940	110.319	69.296	134.013	171.529	47.735
V2-2	150.672	178.199	161.661	71.538	25.454	131.842	63.252	148.317	109.700	23.742
V2-3	102.772	115.176	165.573	101.133	44.965	126.676	119.055	177.274	168.288	6.899
V2-4	117.289	159.931	131.637	122.871	89.983	95.674	88.652	152.556	160.316	12.845
V2-5	169.522	132.673	164.489	123.135	84.315	112.809	89.283	158.737	159.041	26.866

c. White Board Angles Differences from Actual Angles and Totals

Subject ID	SP,1,2	1,2,3	2,3,4	3,4,5	4,5,6	5,6,7	6,7,8	7,8,9	8,9,SP	9,SP,1	Total	Avg
M1-1	-28.58	-7.65	-31.01	-35.56	-8.06	-7.64	16.87	15.94	1.67	-7.38	160.36	16.04
M1-2	-27.02	49.97	-76.18	-43.23	-19.81	-6.24	22.66	25.23	-39.73	-7.82	317.94	31.79
M1-3	38.52	33.56	-33.86	-53.07	-47.85	12.72	6.65	3.48	11.42	23.44	264.57	26.46
M1-4	6.57	19.53	-27.28	-41.53	-51.96	25.18	19.17	-1.76	-21.95	18.97	233.90	23.39
M1-5	3.30	37.00	-67.88	-49.50	-40.67	5.82	39.51	-7.49	-41.11	77.59	369.86	36.99
M2-1	43.07	37.58	-4.23	1.81	-14.40	5.91	19.26	11.14	-0.07	37.04	174.52	17.45
M2-2	-14.57	12.08	-7.42	-7.51	7.75	19.67	13.65	17.13	-6.58	4.75	111.12	11.11
M2-3	-1.02	25.35	-23.65	-12.10	-17.39	4.83	38.20	32.03	6.60	3.35	164.53	16.45
M2-4	-29.73	11.20	-23.49	-24.57	-29.01	-17.54	44.13	0.13	-8.67	9.69	198.17	19.82
M2-5	36.47	35.77	-13.87	45.78	60.29	-27.07	55.51	25.25	-12.48	39.69	352.20	35.22
V1-1	35.75	1.87	-76.32	-50.09	-47.73	65.55	-38.41	-61.61	-43.25	80.70	501.27	50.13
V1-2	36.11	8.37	-9.19	-55.98	-89.11	50.17	-20.79	3.10	-7.82	11.91	292.55	29.26
V1-3	-27.02	-63.03	-130.21	-28.02	-11.60	2.03	43.82	3.21	-26.99	5.77	341.70	34.17
V1-4	45.25	22.51	-2.63	-0.21	-4.52	-21.58	-8.54	-42.88	-6.45	44.49	199.08	19.91
V1-5	4.42	24.63	-13.59	-22.89	-1.66	-0.85	0.74	14.55	5.25	-0.07	88.65	8.87
V2-1	35.47	31.76	-9.40	-23.54	-23.65	3.90	-3.26	-12.61	3.55	36.69	183.83	18.38
V2-2	17.09	55.53	9.15	-56.70	-73.14	23.42	-9.30	4.70	-58.28	12.70	319.00	31.90
V2-3	-30.81	-7.49	-5.24	-27.11	-53.63	20.26	46.50	30.65	0.31	-4.15	226.15	22.62
V2-4	-16.30	37.26	39.17	-5.37	-8.61	-10.74	-16.10	5.94	-7.66	1.80	148.95	14.89
V2-5	35.94	10.00	-6.32	-5.10	-14.28	6.39	16.73	12.12	-8.93	15.82	131.64	13.16

APPENDIX P. NAVIGATION TERMS

The following navigational terms are used in this thesis. This appendix is included to explain the terms in more detail than is allowed in the thesis body.

HANDRAILS – A linear feature that runs parallel to the route the subject is following. This can be used to provide directional cues. For example, a subject may choose a route which handrails a creek. As long as the subject can see the creek to his side, he knows he is on course.

CONTROL POINT – This is the marker which is what orienteerer/student has to find when taking part in a land navigation course. This marker may be a flag, post, sign, or other device which marks the target location.

CHECKPOINTS – A prominent point that you can be sure to identify, both on the ground and on the map. These are sometimes known as reference points. Military navigators using dead reckoning are advised to dead reckon between interim checkpoints as opposed to trying to do it in one step.

CATCHING FEATURES – A linear feature behind or beyond your intended destination. Much like a backstop in baseball, this is meant to stop you and let you know that you have gone too far.

NAVIGATIONAL CORRIDORS – This is having a handrail to either side, preventing you from straying too far to the left or right. Combined with a catching feature, this "boxes in" the destination.

ATTACK POINT – This is used when the desired objective is small or may be difficult to locate. The attack point is an easily recognizable checkpoint near the objective. You first locate the attack point, then plan a precise movement to the objective. If you miss finding the objective, you merely return to the attack point and try again.

EXPANDED OBJECTIVE – Similar to an attack point, this is used when the objective is part of a larger terrain feature, say a hilltop. This simplifies the problem as you first locate the larger terrain feature (i.e., the hill), then continue on to the actual objective.

ROUGH COMPASS – This involves using a compass to establish a general direction of travel to the next destination area or checkpoint. This is useful if the next target area is a road or other linear feature.

BOX AROUND – This technique is used when following a dead reckoning azimuth and a significant obstacle is encountered. The subject would turn at 90 degrees to the direction of travel and proceed at a measured distance (the box pace count) until the obstacle was clear to his side. The subject then continues parallel to the line of original travel resuming the original pace count until the obstacle was cleared again. Now the subject turns 90 degrees in the opposite direction, repeats the original measured distance (the box pace count), and then returns to the original direction of travel at the pace count they had at the end of the parallel leg. Difficulties arise when the obstacle is not uniform in size. Having to maintain two different pace counts can also be difficult for some individuals.

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