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The Graduate School

College of Engineering

**ELECTRONIC NAVIGATION DISPLAYS FOR
TELEOPERATED VEHICLES**

A Thesis in

Industrial Engineering

by

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ABSTRACT

The purpose of this study was to determine the cognitive processes employed by an experienced individual when a 3D forward field of view (FFOV) was matched with a 2D topographic contour map. It was assumed that when the viewed landsurface and the map were at different azimuth orientations, comparisons between these two displays could not proceed without some preliminary cognitive adjustive manipulations. The findings of this experiment concluded that these manipulations appeared to be a combination of feature selection and mental rotation processing skills. It was discovered that for azimuth orientation, Reaction Time (RT) and Location Accuracy (LA) were more sensitive to the distinctiveness or salience of the terrain features in the FFOV than the angular disparities between the two displays. As a consequence, more accurate responses were accompanied by significantly faster RTs ($p < .001$) as azimuth orientations were manipulated. Additionally, the results of this study showed that as the complexity level (the number of visually presented terrain features) of the 2D map increased, RTs also increased and LAs were closer to the actual locations as participants had to process and compare that extra information. It was determined that these findings again indicated that map representations are encoded as individual landmarks and spatially organized together in a scene. Participants in this experiment also completed subjective ratings using a seven-point Likert scale. These results reflected participant's preferences for 3D views that contain distinctive terrain features and 2D maps with the highest complexity level.

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1. Background

Unmanned or teleoperated systems are rapidly becoming the technology of choice to replace soldiers and other personnel in hazardous environments since they can greatly increase operator safety and comfort. Teleoperated systems in the military have been developed for land, air, and sea, however, unmanned ground vehicles (UGVs) have the greatest number of application areas due to their relatively lower cost and technology requirements. UGVs can act as force multipliers with limited autonomy and reduce military manpower requirements. Key areas of UGV utilization include military reconnaissance, surveillance and target acquisition, nuclear, biological, and chemical environmental monitoring, mine detection and clearing, security, logistics, and resupply missions.

Initially, UGVs being developed for the U.S. Army will be used primarily in reconnaissance roles. These UGVs will contain two separate components. The first section is called the Mobile Base Unit and consists of a remotely driven vehicle via data links and sensors. The second and most important component in this operation is the Operator Control Unit (OCU). A human operator in the OCU uses typical driver controls

(i.e. steering wheel, brake and accelerator pedals, etc.) as well as several viewing monitors and touch screen controls to “pilot” the UGV. Although the U.S. Army Research Lab at Aberdeen Proving Grounds, MD, is manipulating issues such as forward field of view (FFOV), transmission bandwidth, auditory feedback levels, and the amount of haptic feedback on driver controls, this research focused on the problem of the integration of two electronic map displays simultaneously presented to the operator in order to enhance navigation abilities.

The paramount issue confronted by designers is how to configure electronic maps with available features so they can best serve the navigational operation of the UGV, considering both technological feasibility and human cognitive limitations. Designers may be tempted to integrate every available geographical feature so that the FFOV and the electronic map are close in physical identity. However, the potentially degrading effect of high complexity or “information overload” suggests the need for image simplification without sacrificing navigation performance (Hickox and Wickens, 1997). The two person operator teams that will pilot the UGV consist of less experienced soldiers (Military Occupational Specialties: 19D10, 11M10, and 0311[USMC]) who will be expected to accurately and rapidly navigate the UGV to specific named areas of interest for information gathering and reconnaissance tasks. These soldiers will receive task related training on the operation of the UGV, but the overall process needs to be as simple as possible in order to reduce the chance of miscues, especially during conflict.

1.2. Terrain Association

The Army's Field Manual (FM) 21-26 states that the soldier who can rapidly identify and discriminate amongst the differing terrain features of the battlefield and knows how these features are mapped, is the one who will be at the right place to help defeat the enemy on the battlefield. Operators must be able to quickly visualize the terrain they will be navigating through from their contour maps, and likewise be able to convert their three-dimensional surroundings into the contour patterns depicted on their map in order to accurately and quickly identify their current location (Barsam and Simutis, 1984). Battlefield terrain recognition is generally limited by very short observation times and great time stress. Although situation dependent, soldiers conducting reconnaissance missions are trained not to expose themselves or their vehicles to possible enemy detection any longer than is absolutely necessary. As little as thirty seconds can compromise the success of an entire mission.

Navigation relies heavily upon the ability to recognize critical features and terrain as they are depicted on the maps used to navigate through the battlefield and the surrounding environment (Banks and Wickens, 1997). One method used by operators for conducting navigation terrain analysis is "terrain association" (FM 21-26). Terrain association involves matching features in the operator's forward view or environment with those features on a map. This association is based on a common identification and similar characterization of topographic structures in map and forward view.

The operator should always know where they are relative to their directional orientation and other landmarks and features. Possessing this knowledge and the ability to recognize prominent terrain features will in turn effect their ability to stay on the designated route (Banks and Wickens, 1997). Prominent terrain features can be divided into natural and man-made. Examples of natural terrain features are hilltops, valleys, streams, ridges, and saddles, and some examples of man-made features include distinctive buildings, roads, bridges, and intersections (FM 21-26).

1.3. Reference Frames

Research in the fields of aviation and air traffic control have been at the forefront in the development of electronic map displays in order to improve flight navigation and operator situational awareness. These studies investigated the issue of two and three-dimensional display formats supporting a variety of tasks, and the corresponding costs and benefits associated with them. Since little research exists regarding these issues for ground vehicle navigation, the present review also considered relevant studies in the design of displays in these fields. It can be assumed that they provide a basis for making predictions of display effectiveness and for understanding human perceptual limitations that can be applied to the cognitive processes used by the UGV operators to determine ground location (Banks and Wickens, 1997).

When an operator navigates using visual reference points rather than instrument navigation, a desired course is represented as a layout of navigational checkpoints on a map. Usually, visually salient man-made and natural terrain features are selected as checkpoints, and navigation consists of keeping the vehicle on course by matching those terrain features with the corresponding checkpoints on a map (Aretz, 1991). The term navigational awareness or navigational checking has been used to describe the cognitive elements of this task (Aretz, 1991; Hickox and Wickens, 1997).

The psychological foundations of navigational checking can be found in the vast literature on “same-different” judgment tasks (Posner, 1978; Krueger, 1978). Underlying many of these paradigms is the idea that “sameness” is not necessarily physical identity, but rather identity after the physical properties of the images are transformed into congruence (Hickox and Wickens, 1997). In the case of navigational checking, the “object” that is transformed between two images is actually a particular geographical area that is represented by two different renderings or “viewpoints”: a FFOV and a map (Aretz and Wickens, 1992).

Navigational checking is the maintenance of a cognitive coupling between two reference frames that correspond to the map and the forward view of the world (Aretz and Wickens, 1992). The ego-centered reference frame (ERF) is established by an operator’s forward view (or the view being transmitted by the vehicle) and directly corresponds to this three-dimensional perspective. The vehicle’s heading provides the ERF’s canonical axis and all navigational decisions are made relative to this axis. In contrast, the world-centered reference frame (WRF) is established by a visually presented two-dimensional

topographic map (Aretz, 1989). Since a map's standard canonical orientation is north up, all navigational decisions in the map's WRF are usually made relative to north (Evans and Pezdek, 1980).

Traditionally in the military a two-dimensional north up topographic map with grid lines and elevation contour lines is used to provide standardization among all the units. This allows for the coordination and integration of data, map overlays, and communication. Additionally, this map provides a top-down or global (WRF) viewpoint that depicts a broad area of terrain and ranges. However, two-dimensional contour maps do have several disadvantages. A considerable amount of mental workload or cognitive integration is required to transform the information provided in this 2D format into a coherent, three dimensional picture of the terrain (Wickens, 1992). A good deal of training and experience are required to accurately and rapidly decipher the contour map symbology and envision the various aspects of terrain (Barsam and Simutis, 1984).

According to Aretz (1991), in order to accurately navigate, an operator must be able to associate the current view of the world to its associated location on the map. The operator will identify salient landmarks within the map's WRF and attempt to locate the same landmarks in the forward view's ERF. In order to establish navigational awareness, these two distinct views must be brought into alignment with each other. If these two views are not properly related, then disorientation will result. For example, when an operator is driving towards a prominent terrain feature in a southerly direction, some form of mental rotation may be required to bring the computer-generated, world-referenced, north-up map into agreement with the forward view (similar to the physical rotation of a

paper map). Thus, left-right on the mentally rotated map would correspond to left-right in the ego-referenced forward view (Aretz, 1991). Olmos, Liang, and Wickens (1997) identified several types of mental rotation required to establish congruent views.

Envisioning is necessary to bring the more abstract two-dimensional (2D) features from a world-referenced map into a mental representation in which they can be compared with the 3D FFOV. Zooming is necessary to transform the reduced field of view of the ERF to the full-scale depiction provided by the WRF. Each of these mental transformations imposes costs to response time, error likelihood (accuracy), and mental workload (Wickens, 1995; Wickens and Prevett, 1995).

1.4. Mental Rotation

Shepard and Hurwitz (1984) determined that mental rotation could be a significant cognitive process used in navigation. Their data showed that subjects judge the direction of turns relative to movement in the forward direction. In other words, subjects had to mentally rotate a visually presented map in order for it to be similarly oriented as their direction of travel.

Shepard and Metzler (1971) published the first experiment demonstrating mental rotation and found that the time required for subjects to compare two visual images increased linearly with the angular disparity between the images. Several studies have replicated this linear function, and its robustness led Shepard and Cooper (1982) to

propose that the mental rotation of visual images is analogous to the corresponding physical rotation that would occur with the actual object. The extension of mental rotation from visual objects to visual scenes and maps has also received empirical support from several researchers (Aretz, 1988, 1989; Eley, 1988). The fundamental conclusions from these experiments is that there is a performance penalty when images differ in orientation from the upright (0°), and the performance penalty increases as a generally linear function of angle of discrepancies between the orientations of the two figures. This result works for both “match-mismatch” determinations from simultaneously presented stimuli, and for absolute identification of isolated stimulus presentations (Goldberg, Maceachran, and Korval, 1992). The literature also tends to support the assertion that, as complexity is increased, participants will require more time for judgments (Aretz and Wickens, 1992; Silverman, 1974). Also, there is an interaction between complexity and mental rotation, such that higher levels of complexity amplify the costs of mental rotation. To this effect, Hintzman, O’Dell, and Arndt (1981) obtained rates of rotation of 4.8ms/deg for simple stimuli and 9.2ms/deg for complex stimuli when subjects compared visual maps. However, the literature is not conclusive regarding this latter effect. Bethell-Fox and Shepard (1988) discovered that mental rotation times could be uniformly decreased with practice for individual subjects, regardless of the stimulus complexity. This could indicate that subjects constructed “templates” of the visual scene from which their decisions were based.

The robustness of this linear relationship suggests that mental rotation may be a fundamental cognitive process. If mental rotation is applicable to navigation, then the

time required to compare the information on an electronic map (WRF) to the forward view (ERF) should increase linearly with the angular difference between the orientation of the map and the real world view. The results from several studies of orientation misalignment have similarities to the mental rotation literature. Hooper and Coury (1994) compared judgments of orientation within two types of electronically displayed worldviews (north-up and track-up). Results indicated that a direct match between the forward worldview and the display produced significantly faster RTs (about 800 ms) than the display requiring some form of rotation. Accuracy was also higher with the matching displays than those requiring rotation. Aretz (1989) simultaneously presented a 3D world-view projection and a plan view map of a set of landmarks to establish aircraft locations. Subjects determined if any of the landmarks were deformed, based on either map. Task times steadily increased with greater orientation differences between the map and world views, much like a mental rotation task, and overall times increased from about 3.1 to 4.2 seconds between 0° and 180° orientation. Similarly, Holmes (1984) found subjects also using mental rotation strategies in rotating topographic maps about the azimuth axis, but not about elevation. Rotation functions about the azimuth were linear, increasing from about 5 seconds at 0° to 6.5 seconds at 180° . Shepard and Copper (1982) examined several factors in their experiments including the effects of axes of rotation, simultaneous or sequential presentation, and prior knowledge relevancy of stimuli. In all cases the same linear relationship was found between response times and angle of rotation with the maximum rate of rotation approximately 17.5ms/deg, or 57deg/s (Hooper and Coury, 1994).

However, there is an alternative explanation that has been explored in the literature, one that is possibly more compatible with views of spatial compatibility in reaction time tasks, for the cost of azimuth angle incongruity. Kornblum, Hasbroucq, and Osman (1990) suggested that the “cost” represents a symbolic transformation or reversal mapping. The reaction time cost was non-linear with azimuth rotation; small when rotation was less than 90°, and distinctly larger when it was greater than 90°, at which time mappings must be reversed. Similarly, when using north-up displays, Aretz (1991) discovered that for several subjects the mental rotation RT at 180° did not follow a linear function and actually decreased. According to Aretz, these decreases suggest the use of an alternative strategy, other than mental rotation, to perform the task. Since there were no increases in the number of errors to suggest that this decrease was attributable to a speed-accuracy trade-off, at 180° a response could be made using a “left = right” reversal strategy in which the two sides of the map are simply mentally reversed rather than rotated. Rossano and Warren (1989) also hypothesized that observed “mirror-image” errors at 180° could have been caused by the use of an alternative cognitive strategy such as left/right confusion rather than a mental flipping strategy. However, Rossano and Warren (1989) stated that mentally flipping a map, which is misaligned by any amount other than 180°, does not align any part of the map, and therefore subjects did not do it. Mental flipping produces partial alignment only when maps are misaligned by 180° and it is only in that condition that mirror-image errors occur to any significant degree.

Aretz (1991) concluded that the emergence of a reversal strategy could have been the result of the dual-nature of the flight control conditions. When a concurrent task such as flying an aircraft must also be performed in conjunction with navigation, the competition between these competing spatial tasks may make it more difficult for a subject to perform and therefore make a strategy switch at a difficult condition (180° misalignment) more likely. Aretz's (1991) data also imply that a reversal strategy is easier, or that it consumes fewer cognitive resources, than does mental rotation allowing more resources for control of the aircraft. Similarly, Rossano and Warren (1989) reported that if subjects spent a great deal of mental energy on visualizing the shape of the path and finding their proper location on it, than he or she may not have had the cognitive energy to engage in alignment (mental rotation) operations because most of the subject's cognitive resources were already used. It is known that tasks such as flight control (or driving a vehicle) require spatial resources (Wickens & Liu, 1988; Wickens, Sandry, & Vidulich, 1983). Therefore, it could be deducted that navigation also demands spatial resources.

Based on the numerous studies to date, it can be assumed that when faced with dynamic and realistic 3D views that change orientation, users must use some form of mental rotation or mental image transformation procedure to link their forward view to a standard 2D north-up map. Goldberg et al. (1992) state that mental rotation of a complex 3D surface is likely to be a difficult cognitive task that could interfere with other cognitive processes required when a map display is part of an environment in which the user must conduct parallel or subsidiary tasks (e.g. driving the UGV).

1.5. Stimulus Complexity

Eley (1988) investigated the cognitive processes employed by practiced individuals when a 2D topographic contour map (WRF) was sequentially matched against actual 3D landform shapes (ERF). Although subjects could have used some form of mental rotation, Eley concluded that when adjusting for an orientation misalignment between a studied map and a landsurface, subjects found it easier to move themselves mentally around an imaged landsurface than to rotate the image mentally. This was interpreted as suggesting that the image generated was “selectively encoded” as a collection of separable critical elements than as a single holistic entity. Mental representations of distinctive map features (i.e. hills, valleys, ridges, etc.) were encoded in a particular (specific) rather than a general fashion. That is, the image representation was generated by first detecting and discriminating these distinctive features and then arranging them in a spatially appropriate array. The resulting image was considered the criterion landscape and it was then compared to the viewed scene. The resulting imagery array might then have to be re-oriented or manipulated in some way using a combination of processing skills so that some sort of systematic comparison between the image and the criterion landscape could be made. And because all this takes time, as a map increased in complexity (the number of visually presented landmarks and/or features), response times for the matching task also increased as observers had to process and compare that information. Additionally, Eley (1988) determined that the adjustive

manipulations applied to the map user's mental representation of the landsurface shape were also sensitive to the absolute magnitude of orientation or azimuth misalignment.

Dror, Ivey, and Rogus' (1997) compared the visual mental rotation of possible and impossible objects. They noted that image representations are composed of parts that are spatially organized together. If the shapes were encoded globally, there would have been a change in the rotation rate when the impossible shapes were rotated; however, no such effect was found. Dror et al. (1997) also concluded that the complexity of objects would affect the rate of rotation. As such, if images are encoded locally by their parts and their spatial organization, then more complex images would be harder to rotate. Conversely, if images were encoded as a global image, then rotation rates would not be affected by the complexity of the image.

Aretz (1991) hypothesized that if subjects perceptually processed each landmark in a scene, then a serial relationship between scene content and RT would be expected. Aretz (1988, 1989) did, in fact, find an additive linear relationship between RT and the number of landmarks. Aretz's (1989) subjects RT increased by 450 msec per landmark. This additivity suggests that subjects cross-checked all landmarks before a response on their location was made. Aretz (1989) concluded that that there is probably a performance gain to be realized in keeping map complexity to a minimum. These results are similar to the complexity effects discovered by Bethell-Fox and Shepard (1988). The more complex patterns required more time for mental rotation under most conditions.

Apparently, once a map display has been encoded, it can be mentally rotated at the same rate regardless of the number of landmarks. Cooper and Podgorny (1976) found no

effects of complexity on the slope of the linear relationship between reaction time and angular difference. However, their subjects were highly practiced, and could form well-integrated internal representations of those familiar patterns and thus, be able to imagine them rotated holistically at the same rapid rate, regardless of complexity (Bethell-Fox & Shepard, 1988). Also, the random angular shapes used as stimuli by Cooper and Podgorny (1976) would be very difficult to encode as local representations; the shapes could not be easily described by their constituent parts or how they are spatially organized, as is evidenced by the low verbal association values of the shapes (Dror, Ivey, and Rogus, 1997).

A synopsis of these experiments indicates that while navigation tasks might vary in particular detail, the overall guiding strategy for map users is to perform as efficiently as possible. Map users tend to select a small number of discriminative features which optimally allow for the task's component decisions to be made. It is these selected features that are encoded into the map user's mental representation of a landsurface (Eley, 1991).

The use of a selective encoding strategy implies that some portion of the landscape information on a map might go unused. If the aim is to attend to, and encode, those features which are minimally sufficient to accurately and quickly complete the task, then some shape information could be treated as surplus to the requirements. Highly detailed or cluttered maps may bring about an "attentional filtering" transformation in which providing the map user with increasing amounts of topographic information will not lead to extra map processing or to increasingly precise mental representations. Only

when such supplementation actually provided information of task-determined usefulness would any extra processing be expected to result (Eley, 1991).

The rich array of visual information, often manifest in both a map and FFOV, must also force some selective allocation of resources, to process certain features and ignore others (Wickens, 1996). It has been determined that feature selection is based on both distinctiveness or uniqueness and salience of features (Garling, Book, and Lindberg, 1986; Schulte and Onken, 1995; Warren, 1994). When comparing the images of a 2D map with those of a corresponding 3D FFOV, Wickens and Hickox (1997) found that increased complexity yielded longer response times as well as an accuracy decrement. More importantly, it was also noted that map users tend to focus more on cultural or man-made features rather than natural features. In their study, Wickens and Hickox (1997) discovered that scenes containing a greater preponderance of man-made features were far less affected by disparity effects than were the natural feature scenes. Scenes that portrayed primarily man-made features were responded to approximately 0.7 seconds faster than scenes depicting primarily natural features and were also 4.9% more accurate. One explanation for these results is that man-made features contain a greater portion of straight line and rectangular elements, classified by Biederman (1987) and Biederman and Gerhardstein (1993) as “viewpoint invariant features”, which allows these features to be encoded more readily.

In summary, it can be assumed that map complexity would have a significant impact on navigation performance. At lower levels of complexity, the derived mental representation of landsurface tends to be minimal, and the subsequent location judgments

should tend to take longer and be more error prone. As further information is provided on the map, it is used to derive a more optimal or sufficient representation, which in turn should allow for faster, more accurate judgments. As map information is still further increased, the extra information can be regarded more as “noise” in that it is not needed for optimal task efficiency. Location judgments would “plateau” and not demonstrate any significant reduction in reaction times or error rates (Eley, 1991).

1.6. Individual Differences

A final point to consider is the strong influence of individual differences in navigational abilities. Some factors that produce these differences are prior training, specialized knowledge of a particular location (familiarity), or more inherent spatial ability parameters. Aretz (1988, 1989, 1991) revealed significant systematic differences among individuals’ cognitive processing abilities in terms of spatial awareness. Streeter, Vitello, and Wonsiewicz (1985) also reported significant individual differences in navigational skills. They determined that people who report themselves to be good navigators tend to make better use of critical landmarks whereas poor navigators do not use maps to their fullest and value all landmarks equally, regardless of their navigational value (Whitaker and Cuglock-Knopp, 1995).

When we mentally represent a geographical layout, our canonical axis appears to depend on how we have learned that knowledge (Wickens, 1992). When we have learned

by studying a map, the canonical orientation is north-up (Scholl, 1987). But when we learn by navigating through an environment, the canonical orientation is the same as the perspective garnered from our forward view.

1.7. Objective

In relation to electronically presented map displays, there is a need to understand how humans process and compare terrain information depicted from multiple perspectives. The electronic map displays in an Operator Control Unit (OCU) for the Army's UGV should be designed with the intent of providing an effective cognitive interface between the ERF and WRF. With the exception of azimuth orientation, the vehicle's forward 3D view can not realistically be manipulated since it's being produced by a real time video display. The electronically displayed 2D map, however, should be designed for optimal operator performance. Therefore, the goal of this study was to determine how a 3D FFOV and a 2D topographic contour map are integrated, and specifically if complexity level and azimuth orientation had an impact on that integration. It was hypothesized that participants would process the extra terrain information of the high complexity level in order to generate more accurate location decisions and that the additional information would also allow participants to make those decisions more quickly (faster Reaction Times). However, highly complex or cluttered maps may bring about a plateau or ceiling effect in which providing the participants with increasing

amounts of topographic information would not lead to quicker RTs or to increasingly precise location decisions. It was also expected that participants would demonstrate a generally linear increment in both RT and Location Accuracy (LA) with corresponding increases in orientation disparity between the two views. Lastly, it was anticipated that participant's subjective ratings using a seven-point Likert scale would reflect the objective results of the main effects. The practical implications of this study should benefit the designers of electronic navigation displays for any ground vehicle.

Chapter 2

METHODS

2.1. Participants

Ten Army ROTC undergraduate students from Penn State University were recruited for this study. Seven participants were MS4 (seniors) and the remaining three were MS3 (juniors). Eight of the participants were male and two were female. Additionally, all of the participants were right-handed. Each participant had his or her visual acuity tested on a Bausch & Lomb Ortho-Rater vision tester to assure corrected or uncorrected acuity was 20/30 or better. Ages of the participants ranged from 20 to 24 years with a mean of 22 years. The total session lasted approximately 1.5 hours and each participant was individually tested and paid \$5.00/hour.

As ROTC students, all participants had experience using traditional military-style paper topographic contour maps for navigation exercises. All participants had received formal military instruction on the recognition of various terrain features and on using terrain association techniques in order to locate a position. Additionally, it can be assumed that the MS4 level participants have the same navigational proficiency as that of a commissioned second lieutenant in the U.S. Army. None of the participants had ever used electronic map displays.

2.2. Apparatus

Each participant viewed stimuli on the screen of a PC and made responses by moving and clicking the left button of a two-button mouse. A Gateway 2000 Pentium PC (G6-200) with a 17" upgraded Vivitron SVGA monitor with 16 bit color and 1280×1024 screen resolution was used for this study. A Microsoft PC mouse was manipulated by the participants in order to respond to the presented stimuli. Multimedia software (Toolbook Multimedia version 3.0 by Asymmetrix) was used as the programming interface for the graphical representations which were derived from Janes Longbow II helicopter video game (Janes, Austin, TX). The 3D terrain and corresponding 2D topographic contour map used in the experiment was a depiction from an area in Western Azerbaijan that was not familiar to any of the participants. The quiet testing room was illuminated to 17 FC. Each participant sat comfortably with eyes located 24" from the screen. The visual angle subtended by the displays was 27° W $\times$ 18° H.

2.3. Electronic Map Displays

The 3D FFOV simulated a single perspective view that a video camera mounted approximately 8ft. from ground level would display. This FFOV was restricted to a 55° width and all eight scenes were depicted from a viewing distance of 1000m (1km) from

the center of the scene content as in Figure 2.1. The linear or distance scale used in the FFOV was the same as that for the 2D maps. The total scene content (combined number of man-made and natural terrain features) in the 3D view remained constant for all trials. Each scene contained seven pieces of terrain information (signals) that could be used for location identification, however, the types of individual features (i.e. barn vs. church or saddle vs. hilltop) in the scenes varied. Six of the scenes contained primarily man-made features while the other two scenes at 180°(South) and 225°(Southwest) contained primarily natural features.

The criteria used for the inclusion of specific terrain features in a scene were that the features were of moderate difficulty, and that they were reasonably discriminable from one another. This was necessary to ensure that less experienced participants (or operators) could easily identify each specific terrain feature and not confuse that feature with the other key features in the display.



FIGURE 2.1. Example of 3D Forward Field of View (FFOV) at 1km from the center of the scene. Seven distinctive features are shown in this view. From left to right: hill, warehouse, ranch, church, large and small barn, and a paved road that is nearest to the observer.

The scene orientation in the 3D view was altered such that the angular difference between forward in the view and up (north) on the topographic map was randomly varied from 0° to 315° in 45° increments. Thus, a 0° angle in 3D display would be the same view as the north-up topographic map. Appendix A depicts all eight of the 3D FFOVs used in this experiment. The 2D topographic map's orientation remained north-up (0°) throughout all conditions in the study

The 2D topographic maps shown in Figure 2.2. depicted the same geographical area as the 3D view except on a much more global scale. The 2D maps covered an area that was 9km by 6.7 km (longitude $\times$ latitude). This area was approximately the same as

a 1:24,000 scale topographic map. The amount of terrain information or content randomly varied among three complexity levels (high, medium, and low). The high complexity level (Figure 2.5) contained seven (7) prominent or distinctive terrain features. This level not only depicted enough terrain information to make a response, but it also contained an overabundance of clutter along with the salient information. The medium complexity level (Figure 2.6) contained enough terrain information to make accurate as well as quick decisions. This level had four (4) distinctive features that matched the corresponding FFOV. A low complexity level (Figure 2.7) contained barely enough terrain information to make an accurate decision. Since the low level contained only two (2) prominent terrain features that were concurrently displayed in the FFOV, some inferences would possibly have to be made in order for the participant to make an accurate response.

The man-made terrain features used in the 2D map included a church, ranch (large building surrounded by a fence), paved road, water tower, large and small barns, and an elongated warehouse, while the natural terrain features included four hilltops of varying elevations (as depicted by the contour lines), two saddles, and a lake. To reduce the possibility of a response bias or chance, additional terrain features or clutter were presented in the 2D map along with the target features. This “signal-to-noise” ratio remained constant at a 1:1 ratio across all conditions. As such, the 2D maps contained the same corresponding number of man-made and natural terrain features across all conditions. For example, the high complexity 2D map in Figure 2.2 depicts seven

features that could be identified in the corresponding FFOV from Figure 2.1, but it also includes seven additional features (clutter) that were not shown in the 3D forward view.

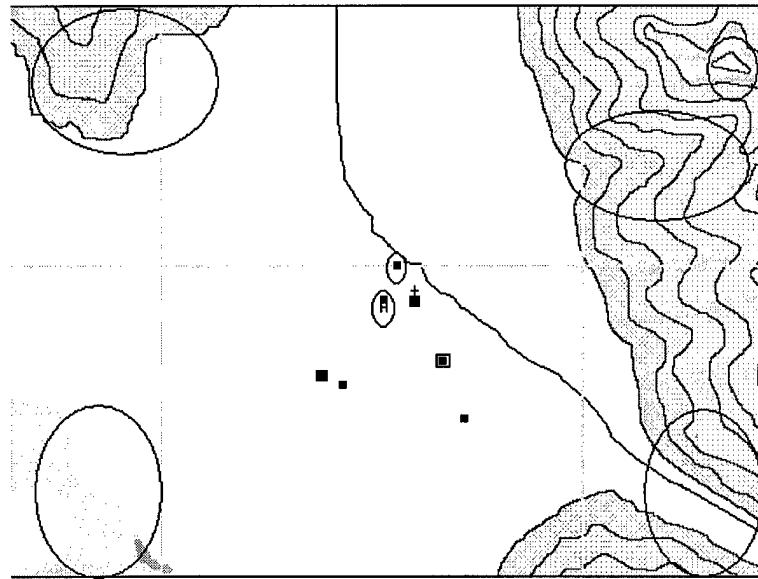


FIGURE 2.2. High Complexity 2D Topographic Contour Map with seven “clutter” features. Clockwise from the top left corner: hill, hilltop, draw, saddle, lake, non-descript building, and water tower.

Both the 3D FFOVs and the 2D maps were presented simultaneously on the PC screen as shown in Figure 2.3. The size of the FFOV on the screen was 710×568 pixels and subtended visual angles of 15° W $\times$ 10° H. The 2D topographic maps were 570×456 pixels and subtended visual angles of 12° W $\times$ 8° H. The 2D map also depicted longitudinal and latitudinal grid lines that were drawn every 5 kilometers.

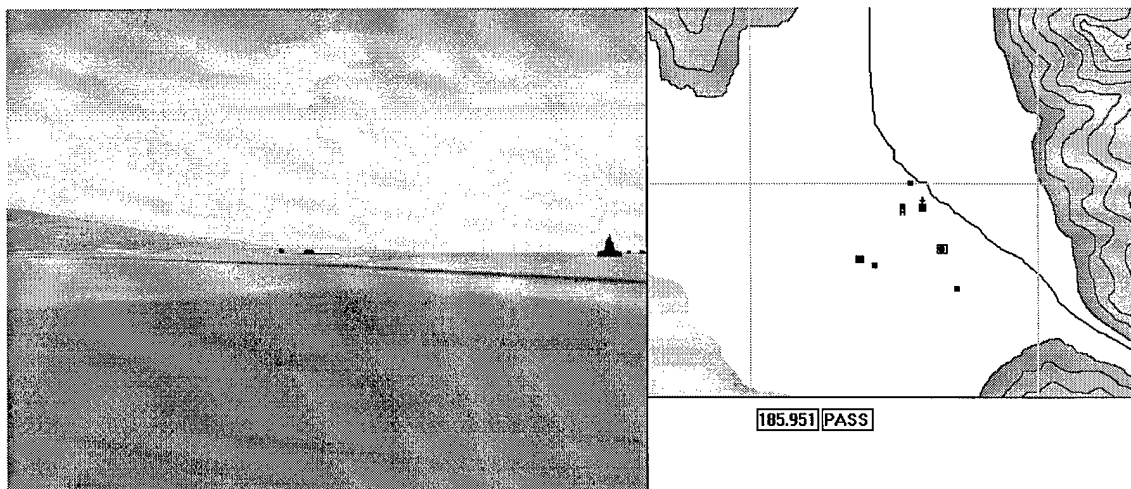


FIGURE 2.3. Simultaneous Presentation of 3D FFOV and 2D Topographic Contour Map with response feedback boxes under the 2D map.

2.4. Experimental Procedure

Each participant participated in a single session that lasted approximately 1.5 hours. The experimental portion of the session was started only after the participant had completed the training sufficiently and was confident in their ability to conduct the study. A blank screen that contained a rectangular box and a location (a white dot) where the participant placed the tip of the mouse pointer were the initial presentation for the study. This location remained the same for all conditions in the study and corresponded with the starting position for each map presentation display. After clicking the left mouse button, a forward three-dimensional (3D) view and a corresponding two-dimensional (2D) topographic contour map were simultaneously presented and a program controlled timer started. After examining the 3D FFOV, the participant's task was to quickly and

accurately move the tip of the mouse pointer to the corresponding location in the 2D map and click the left mouse button. As soon as a response was made, the timer stopped, and the participant was presented with a new screen (Figure 2.4) that asked them to subjectively rate the “usefulness” of the 2D map based on a seven-point Likert scale with one (1) being the lowest or least useful and seven (7) being the most useful. After selecting and clicking on one of the boxes, the initial mouse location display was re-presented for the start of the next trial.

Please rate the *usefulness* of the map in determining your location by selecting one of the following 7 choices.

After choosing, you will be automatically sent back to the next experimental trial.

1	2	3	4	5	6	7
Not Useful At All	Rather Not Useful	Somewhat Not Useful	Neutral	Somewhat Useful	Rather Useful	Extremely Useful

FIGURE 2.4. Likert (Subjective) Rating Scale

2.5. Experimental Design

The experimental design was a three-factor mixed analysis of variance (ANOVA) factorial model, with subjects (10 levels) treated as a random effect. Azimuth orientation (8 levels) was completely crossed with complexity (3 levels), both of which were fully randomized. The two independent variables manipulated were the FFOV azimuth orientations and the complexity levels used in the 2D map. The 3D FFOV orientation was varied such that the angular difference between the forward view and up on the 2D map varied from 0° to 315° in 45° increments. Therefore, the eight FFOV azimuth orientations used were 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The three levels of complexity in the 2D map were categorized as high, medium, and low, based on the number of man-made and natural features that were available for comparison. The three different levels of stimulus complexity used in this experiment are shown by Figures 2.5, 2.6, and 2.7 respectively. Each participant completed a total of 24 randomly presented trials. Only one observation per experimental cell was collected. As a result, no three-way interactions were observed and Subject $\times$ Azimuth $\times$ Complexity formed the denominator term for each F-test. The MSE was therefore derived from the three-factor interaction (Subject $\times$ Azimuth $\times$ Complexity).

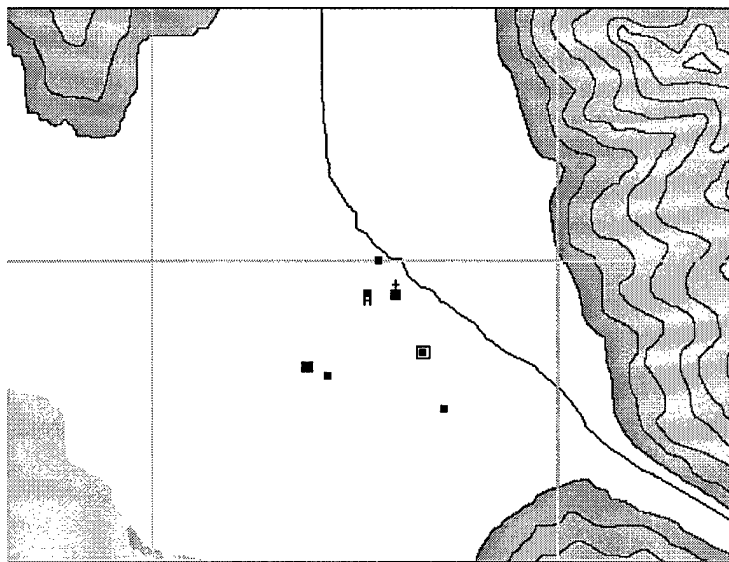


FIGURE 2.5. Example of a High Complexity Map

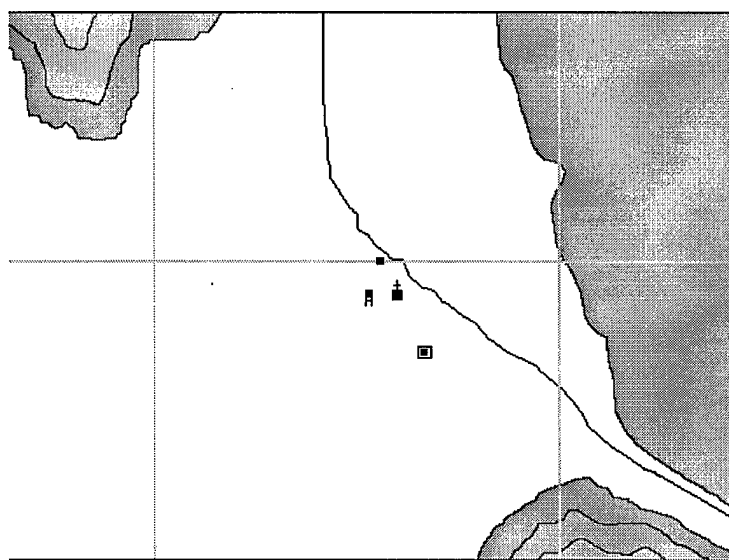


FIGURE 2.6. Example of a Medium Complexity Map

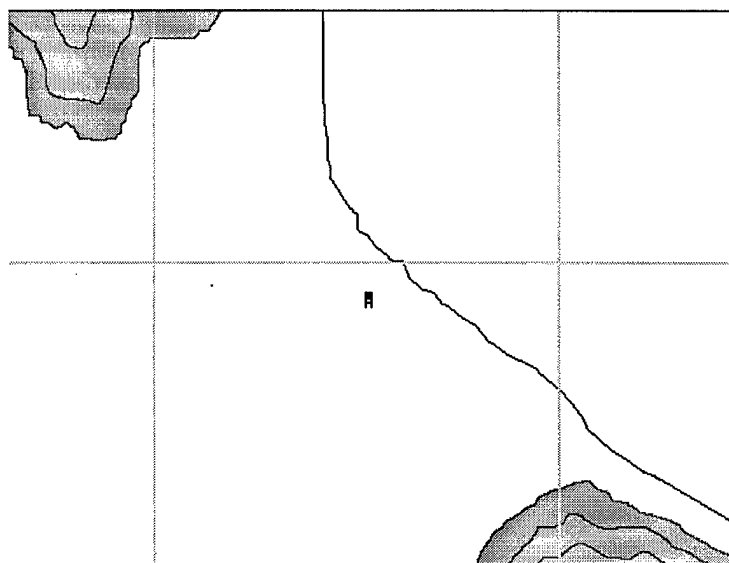


FIGURE 2.7. Example of a Low Complexity Map

The dependent measures included the participant's mean Reaction Time (RT) and Location Accuracy (LA) for each condition. RT was measured in seconds and LA was calculated as the number of pixels or "closeness" of the response to the actual location. The "hot spot" or cursor positioning accuracy for the mouse pointer was located at the tip of the pointer. No feedback was provided to the participant during the conduct of the study. Responses within 344 pixels (.29 in.) of the actual location were considered as high accuracy while responses that were greater than 344 pixels from the actual location were considered as low accuracy. A 344-pixel value corresponds with an actual ground distance of 500m. The mean values for the subjective rating of the 2D map's usefulness was also collected. All responses and data were recorded by the computer program.

2.6. Instructions and Training

After informing the participants as to the significance of the study and telling them the general testing procedure, the training session started with a PC mouse movement experiment. This quick experiment was conducted in order to record the participant's ability in moving the mouse to eight equidistant locations on the PC screen that varied in azimuth from 0° to 315° in 45° increments and clicking the left mouse button. The linear distance from the start location (a rectangular box with a white dot) to the end location (a single black dot) was exactly the same as the distance required to move from the starting point to the viewing location point on the 2D map used for the experimental data. Participants were encouraged to conduct this exercise as quickly and as accurately as possible. Participants completed a total of 24 randomly presented movement exercises and the mean Movement Time (MT) for each participant was recorded and then subtracted from the total response time for each corresponding trial in the study. The resultant measure was considered to be a Reaction Time (RT) since any variation between the participant's abilities to manipulate a PC mouse was eliminated.

The second portion of the training session started after an explanation about the electronic displays and their corresponding terrain features. Participants were repeatedly told that the object of this study was for them to determine their location on the two-dimensional topographic map as quickly and as accurately as possible. Response Time and accuracy were recorded for each trial. Responses would be made by moving and clicking a PC mouse on the appropriate location. Participants viewed a demonstration of

each portion of the training session before actually conducting the training. The display sequence for the training session was exactly the same as that for the experimental study except that feedback was provided to the participant after they selected their location by clicking the mouse. Two small boxes under the 2D map informed the participant how far (in pixels) their response was from the actual location and whether they “passed” or “failed” that trial (Figure 2.3). If the participant’s response was within 344 pixels of the actual location then they “passed” that trial. If their response, however, was greater than 344 pixels from the actual location, then they “failed” that trial. A 344-pixel length corresponded to an actual ground distance of 500 meters. In order to maintain a consistent accuracy rate, a minimum of 75% or, 18 out of the 24 trials needed to be passed. In addition to informing the participant how close their response was to the actual location, immediately after a response was made, a green blip was also displayed on the 2D map for two seconds that visually depicted the actual location to the participant. The participant repeated the practice trials until a success rate of at least 75% was achieved. This level of accuracy was necessary in order to eliminate any learning effect that could take place during the conduct of the study. Short breaks were provided as necessary throughout the training session.

Chapter 3

RESULTS

3.1. General

Table 3.1 contains the mean values for RT (seconds), Location Accuracy (pixels), rating (Likert subjective scale), and the Movement Time (seconds) across all experimental conditions. Mean RTs varied from 6.22 – 15.36 seconds, with an overall mean of 11.23 seconds. Although high, these values can be considered true RTs since the Movement Time (MT) was subtracted from the corresponding response times (see Section 2.6). It can also be inferred from this data that the task required a significant expenditure of cognitive resources at each level of complexity and azimuth orientation. The mean LAs varied from 141.8 – 353.1 pixels (.12 - .30 in. or 17 – 43 arc min), with an overall mean of 259.4 pixels (.22 in. or 32 arc min) from an exact location. The participant's overall actual mean ground distance was 377 m from an exact location. The mean subjective ratings for the usefulness of the 2D map in helping the participants determine their location was based on a seven-point Likert scale. The ratings varied from a low rating of 2.4 to the highest rating of 5.4, with an overall mean rating of 4.3.

Three factor analyses of variance (ANOVAs) for RT, Location Accuracy (LA), and subjective rating were investigated. The ANOVAs all agreed in the significance of

Subject. This was not surprising since it was assumed that each participant would differ in their ability to conduct the task. The significance of the other main effects (azimuth orientation and complexity) as well as their interactions differed for each measure.

Azimuth orientation and complexity were both significant for RT, but neither was significant for LA. Complexity was also highly significant for subjective rating. Where appropriate, post hoc multiple-range tests were computed to clarify significant effects.

Tukey's intervals were computed for both main effects and interactions at $\alpha = 0.05$ unless otherwise stated in these cases (Neter, Wasserman, and Kutner, 1985).

After plotting the main effects, it was noted that speed-accuracy trade-off occurred for the complexity condition but not for azimuth orientation. In other words, for complexity, more accurate responses were accompanied by correspondingly slower RTs while for azimuth orientation, more accurate responses were accompanied by faster RTs. The significance of these results will be explained in the following sections.

TABLE 3.1. Mean values for the Measured Variables for all Experimental Conditions

Conditions		Measured Variables			
Azimuth	Complexity	RT (sec)	LA*	Rating	MT (sec)
0° (N) 	H (High)	8.24	202.2	5.3	1.13
	M (Med)	9.73	171.0	4.6	
	L (Low)	7.80	242.4	3.4	
45° (NE) 	H	11.98	341.6	5.0	1.15
	M	8.70	353.1	4.2	
	L	7.73	324.3	4.1	
90° (E) 	H	11.72	283.6	4.5	1.19
	M	13.28	252.1	4.6	
	L	15.36	325.9	3.0	
135° (SE) 	H	6.22	179.3	5.4	1.20
	M	7.65	186.1	5.0	
	L	7.11	248.9	3.2	
180° (S) 	H	13.33	169.5	5.0	1.17
	M	9.98	255.4	4.6	
	L	8.87	212.9	3.6	
225° (SW) 	H	11.30	239.9	5.0	1.14
	M	11.88	306.9	4.5	
	L	12.84	334.8	3.2	
270° (W) 	H	14.50	141.8	5.3	1.16
	M	13.77	161.2	4.3	
	L	11.06	189.8	2.4	
315° (NW) 	H	9.54	270.8	5.2	1.19
	M	14.76	324.7	4.3	
	L	10.97	295.9	3.6	

* Smaller values indicate better performance

3.2. Reaction Time (RT)

The ANOVA for RT (Table 3.2) was highly significant for Subject ($F [9,126] = 13.16, p < .001$) and Azimuth ($F [7,126] = 5.59, p < .001$). Inspection of the main effects plot for RTs in Figure 3.2.1 indicated a generally increasing trend as the azimuth orientation of the FFOV was altered from that of the north-up (0°) 2D map. Minimum RT should have occurred at 0° with a corresponding increase in RT up to 180° when the RT should have shown a linear decrease until both views were the same orientation again. However, the lowest mean RT (7.17 sec) occurred at the 135° orientation. The highest mean RT (14.13 sec) was at 315° and not at 180° . This was a 6.96 sec difference between the highest and lowest measures. A post hoc analysis showed that the RTs for 0° (RT = 8.59 sec), 45° (RT = 9.47 sec), and 135° were significantly different than the RTs for 90° (RT = 13.94 sec), 270° (RT = 13.11 sec), and 315° . Additionally, RT at 135° was significantly different than the RT at 225° (RT = 12.00 sec). As a comparison, the group with less angular deviation ($0^\circ, 45^\circ, 135^\circ$) was an average of 4.13 sec faster than the group with a greater angular deviation ($225^\circ, 270^\circ, 315^\circ$). The average difference between these two groups was 44 deg/sec. The other comparisons were not significantly different. These results indicated that RT could be more dependent on the type(s) of distinctive terrain features in a view rather than its orientation.

TABLE 3.2. ANOVA for Reaction Time (RT)

SOURCE	DF	SS	MS	F	P
SUBJECT	9	1518613060	168734784	13.16	***
AZIMUTH	7	1362495299	194642186	5.59	***
COMPLEX	2	152608240	76304120	4.01	*
SUBJECT*AZIMUTH	63	2193353141	34815129	2.72	***
SUBJECT*COMPLEX	18	342731704	19040650	1.48	ns
AZIMUTH*COMPLEX	14	403730966	28837926	2.25	**
Error	126	1615691901	12822952		
Total	239	7589224310			

*** $p < .001$, ** $p < .01$, * $p < .05$, ns (not significant)

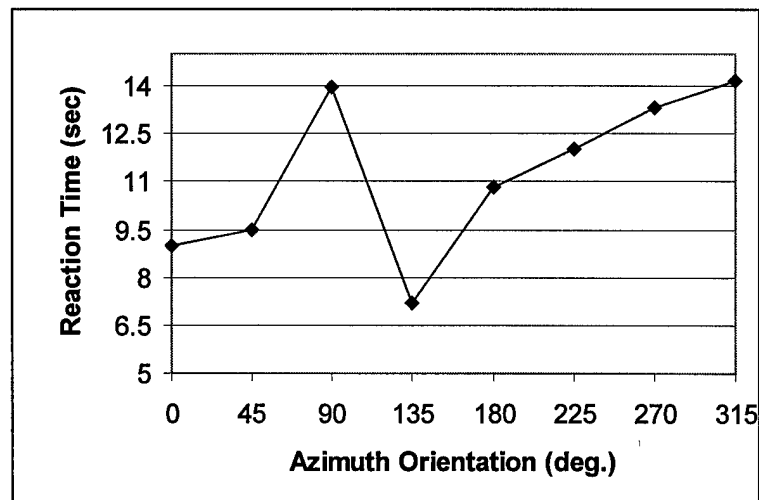


FIGURE 3.2.1. RT as a function of Angular Disparity

RT was marginally significant for Complexity ($F [2,126] = 4.01, p < .05$). Figure 3.2.2 demonstrated a 2.01 sec decrease in RT from the high complexity level (RT = 12.23 sec) to the low complexity level (RT = 10.22 sec). Longer RTs for the high complexity level could indicate that participants needed extra time in order to process the extra map information (clutter) and make a decision.

Given the results of the main effects, it was not surprising to find a significant two-way interaction between Subject $\times$ Azimuth ($F [63,126] = 2.72, p < .001$) and Azimuth $\times$ Complexity ($F [14,126] = 2.25, p < .01$). Subject $\times$ Complexity was not significant. Figure 3.2.3 shows the interaction plot for Azimuth $\times$ Complexity. Orientations at 135° and 0° still had the fastest RTs for all complexity levels while 315° generally had the slowest RTs. More interesting, however, was that for some angles (45°, 180°, 270°, 315°); the clutter associated with the high complexity level resulted in substantially slower RTs. Participants found it necessary to processing the extra map information even though it did not contribute to determining their location.

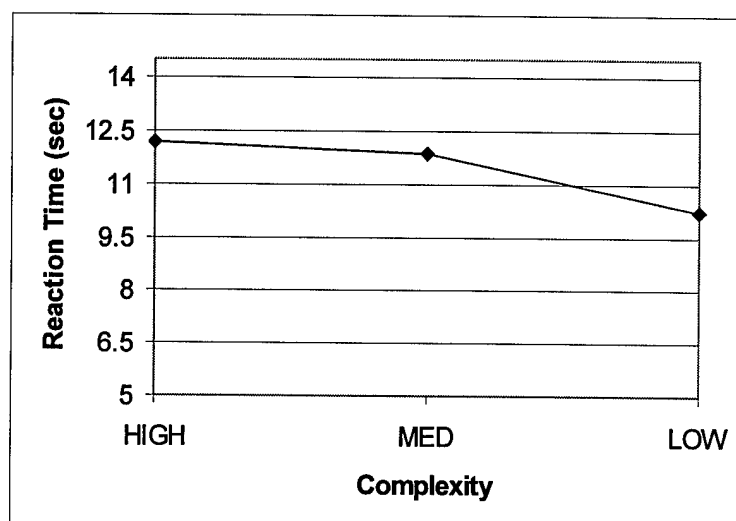
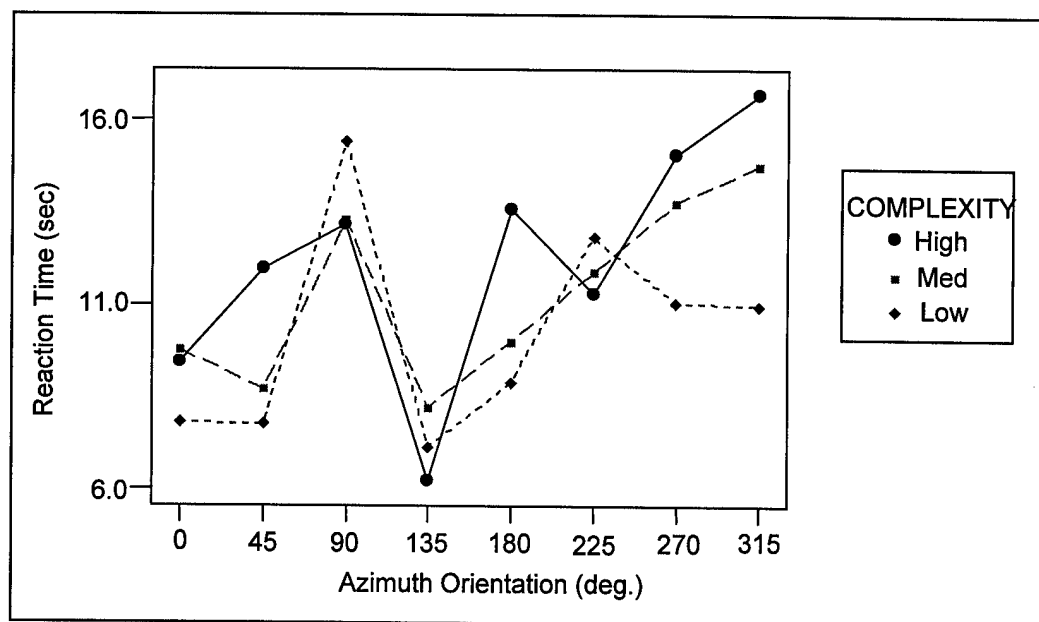


FIGURE 3.2.2. RT as a function of Complexity Level

FIGURE 3.2.3. Azimuth $\times$ Complexity two-way interaction plot for RT

3.3. Location Accuracy (LA)

The ANOVA in Table 3.3 demonstrated that the only significant main effect for Location Accuracy (LA) was Subject ($F [9,126] = 3.37, p < .01$). The two-way interaction between Subject $\times$ Azimuth ($F [63,126] = 4.38, p < .001$) was also highly significant. The other factors and interactions were not significantly affected by changes in the experimental conditions. Tukey's comparison at $\alpha = .001$ showed a significant difference between the mean LAs for 45° (339.7 pixels) and 270° (191.7 pixels).

TABLE 3.3. ANOVA for Location Accuracy (LA)

SOURCE	DF	SS	MS	F	P
SUBJECT	9	570840	63427	3.37	**
AZIMUTH	7	776643	110949	1.35	ns
COMPLEX	2	43414	21707	0.78	ns
SUBJECT*AZIMUTH	63	5189983	82381	4.38	***
SUBJECT*COMPLEX	18	502609	27923	1.48	ns
AZIMUTH*COMPLEX	14	261734	18695	0.99	ns
Error	126	2369628	18807		
Total	239	9714850			

*** $p < .001$, ** $p < .01$, * $p < .05$, ns (not significant)

These results were interesting because it was expected that LA would demonstrate a decrease in performance as the disparity between the FFOV and the 2D map increased up to 180° at which point performance would improve as the two views approached

congruity. Figure 3.3.1, however, depicts a non-linear response to changes in azimuth orientation. Again, these results can be attributed to the fact that several 3D views (0° , 135° , 270°) contained more relatively distinctive terrain features that allowed participants to determine their location on the 2D map more readily.

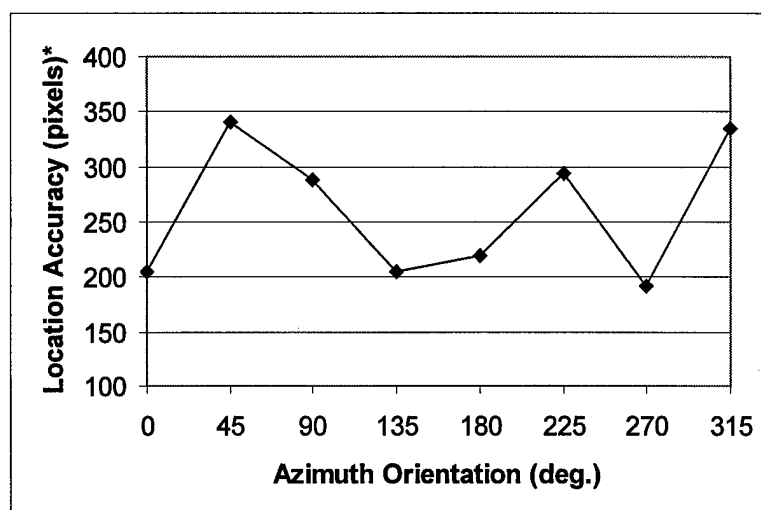


FIGURE 3.3.1. Location Accuracy (LA) as a function of Angular Disparity
 * Smaller values indicate better performance.

Changes in the complexity level as shown in Figure 3.3.2 did not significantly affect participant's ability to accurately determine their location on the 2D map. The high level, however, was 31.1 pixels better than the low level. The increased information in the high level translated into participants being 45meters closer to the exact location.

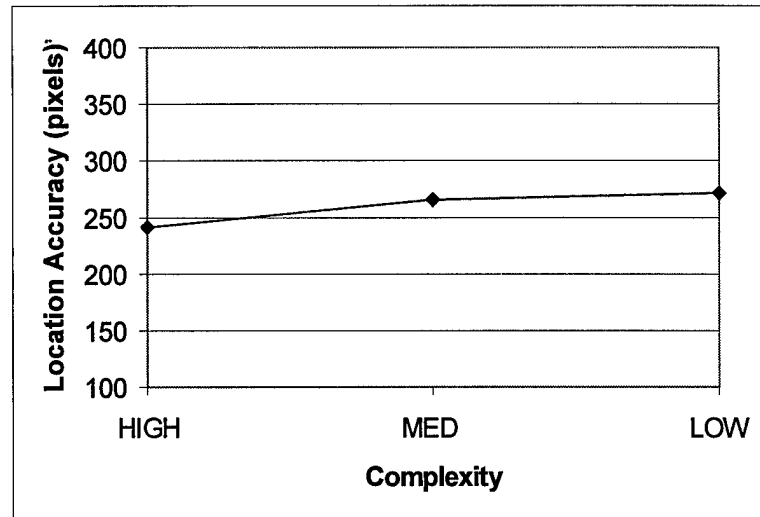


FIGURE 3.3.2. Location Accuracy (LA) as a function of Complexity Level
* Smaller values indicate better performance.

Figure 3.3.3 depicts the two-way interaction plot for Azimuth $\times$ Complexity as a function of LA. The high complexity level generally resulted in the most accurate responses. Participant's performance at the 270° orientation in this plot was significantly better than the corresponding two-way interaction results for RT (Figure 3.2.3). A possible reason for this contrast is that certain terrain features (i.e. paved road) could be processed in such a way that they better contribute to distance or location calculations but do not necessarily allow for faster RTs.

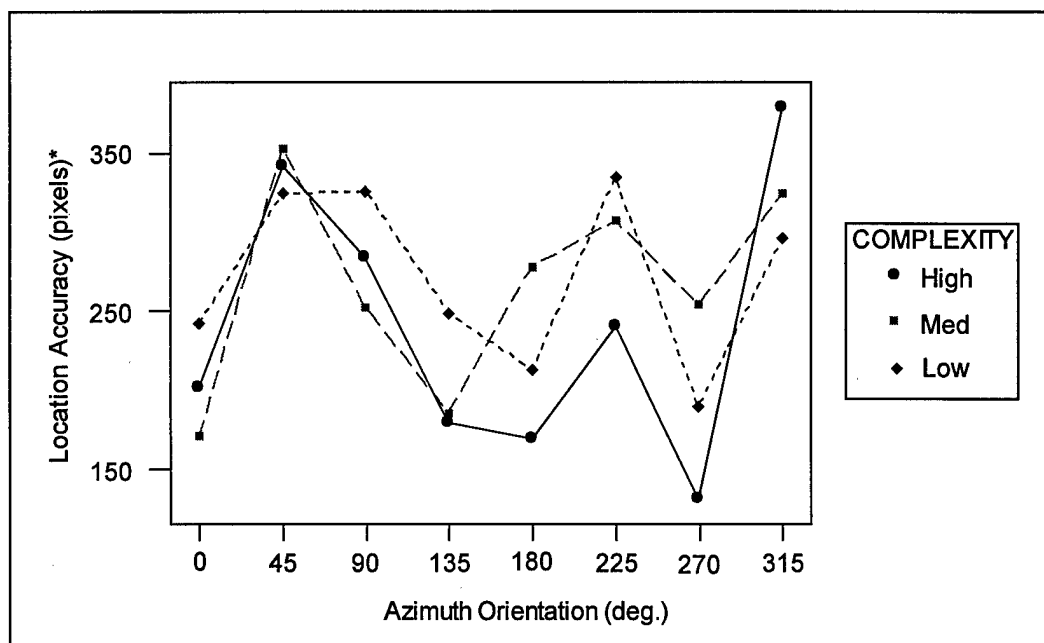


FIGURE 3.3.3. Azimuth $\times$ Complexity two-way interaction plot for LA
 * Smaller values indicate better performance.

3.4. Subjective Rating

A subjective analysis was conducted after every condition using a 7-point Likert scale. This scale was used by the participants to rate the usefulness of the presented 2D map in helping them determine their exact location. Table 3.4 contains the ANOVA for subjective rating. It demonstrated that both Subject ($F [9,126] = 28.81, p < .001$) and Complexity ($F [2,126] = 18.02, p < .001$) were highly significant factors. This was not surprising since the 2D map retained a north-up or 0° orientation, and differences in

azimuth orientation should not have had as significant an effect on participants performances as would changes in the complexity level.

TABLE 3.4. ANOVA for Subjective Rating

SOURCE	DF	SS	MS	F	P
SUBJECT	9	184.8167	20.5352	28.81	***
AZIMUTH	7	8.3333	1.1905	1.09	ns
COMPLEX	2	132.1000	66.0500	18.02	***
SUBJECT*AZIMUTH	63	68.5833	1.0886	1.53	*
SUBJECT*COMPLEX	18	65.9833	3.6657	5.14	***
AZIMUTH*COMPLEX	14	18.7667	1.3405	1.88	*
Error	126	89.8167	0.7128		
Total	239	568.4000			

*** $p < .001$, ** $p < .01$, * $p < .05$, ns (not significant)

Figure 3.4.1 depicts the rating differences between the complexity levels.

Participants clearly preferred the increased information content in the higher levels. The increased number of terrain features in this level contributed to a greater feeling of confidence in determining their location. Tukey's comparison yielded significant differences among all three levels. The high complexity level had a rating that was 1.8 points or 26% better than the low level. As mentioned previously, the results for azimuth orientation were not significant. Changes in the angular disparity had no effect on participant's perceived ability to determine location. Figure 3.4.2 shows the results for azimuth orientation.

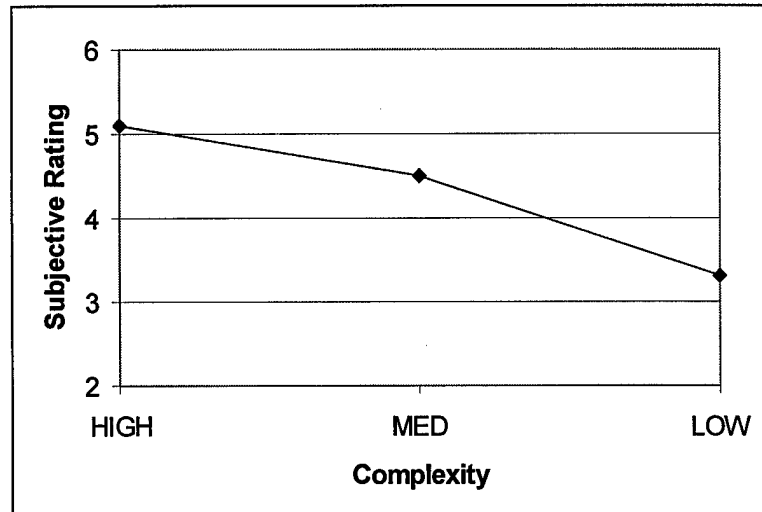


FIGURE 3.4.1. Subjective Rating as a function of Complexity Level

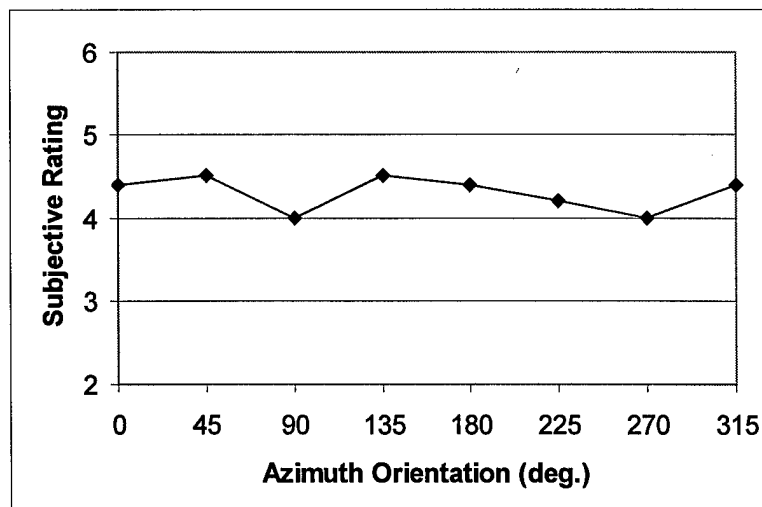


FIGURE 3.4.2. Subjective Rating as a function of Angular Disparity

The ANOVA analysis in Table 3.4 also resulted in significant two-way interactions. As expected, Subject $\times$ Complexity ($F [18, 126] = 5.14, p < .001$) was highly significant while Subject $\times$ Azimuth ($F [63, 126] = 1.53, p < .05$) and Azimuth $\times$ Complexity ($F [14, 126] = 1.88, p < .05$) were marginally significant. Tukey's comparisons generally resulted in a complex pattern of differences that generally demonstrated the overwhelming preference of the participants for the high complexity level (Figure 3.4.3).

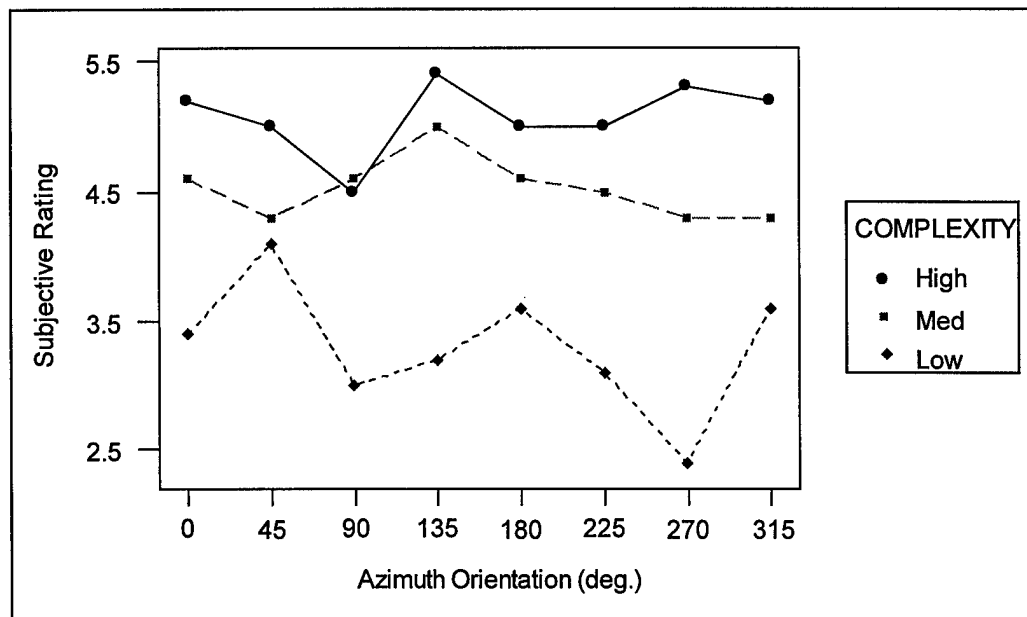


FIGURE 3.4.3. Azimuth $\times$ Complexity two-way interaction plot for Rating

3.5. Summary of Results

Each of the dependent measures was examined to determine if the data meet the assumptions of normality and homogeneity of variance between subjects. An analysis of the residual plots located in Appendix B showed that the experimental procedure did not significantly violate these assumptions. Any variance that was observed was the result of individual ability differences between the participants.

The RT, LA, and subjective rating ANOVAS generally agreed in the significance of the Subject factor and the interactions associated with that factor. Azimuth Orientation and Complexity were mixed in the significance of their effects. Table 3.5 lists the mean values for Azimuth Orientation across all conditions. As mean RTs increased, mean LAs performances almost always decreased, suggesting that a speed-accuracy trade-off was not problematic across subjects. An interesting result was the participant's performances at the 135° azimuth orientation. Not only did this orientation result in the highest mean subjective rating (4.5), but it also had the fastest associated RT and was one of the most accurate positions. These results illustrated that several views, particularly at 135°, contained more relatively distinctive terrain features that allowed participants to better determine their exact location. Figure 3.5.1 graphically depicts this comparison.

TABLE 3.5. Mean Values for Azimuth Orientation across all conditions

Measured Variables	Azimuth Orientation							
	0°	45°	90°	135°	180°	225°	270°	315°
RT	8.98	9.47	13.94	7.17	10.81	12.01	13.29	14.13
LA*	205.2	339.7	287.2	204.8	220.1	293.9	191.7	333.8
RATING	4.4	4.5	4.0	4.5	4.4	4.2	4.0	4.4

* Smaller values indicate better performance.

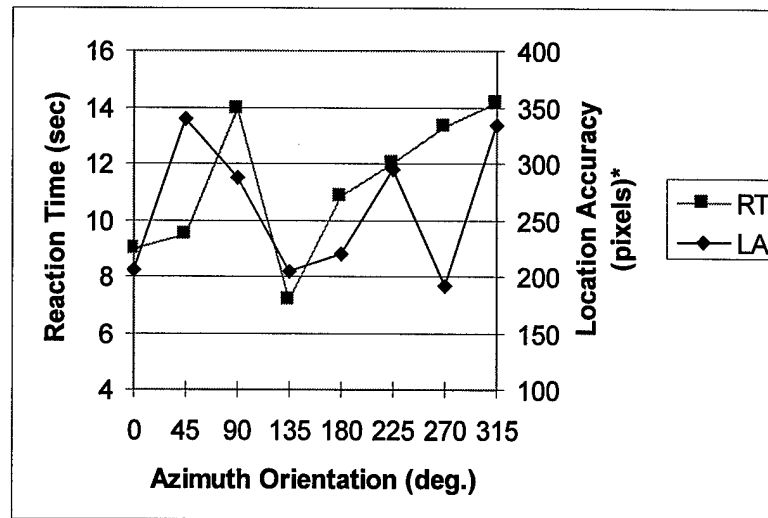


FIGURE 3.5.1. Mean values for Azimuth Orientation across experimental conditions

* Smaller values for LA indicates better performance

Table 3.6 lists the mean values for Complexity across all conditions. As mean RTs increased, mean LA performances almost always increased, suggesting that participants required extra processing time to make a decision when additional terrain information (higher complexity levels) was presented. Figure 3.5.2 graphically shows this comparison.

TABLE 3.6. Mean values for Complexity across all conditions

Measured Variable	Complexity		
	HIGH	MED	LOW
RT	12.23	11.22	10.22
LA*	228.59	251.31	271.86
RATING	5.09	4.51	3.31

* Smaller values indicate better performance.

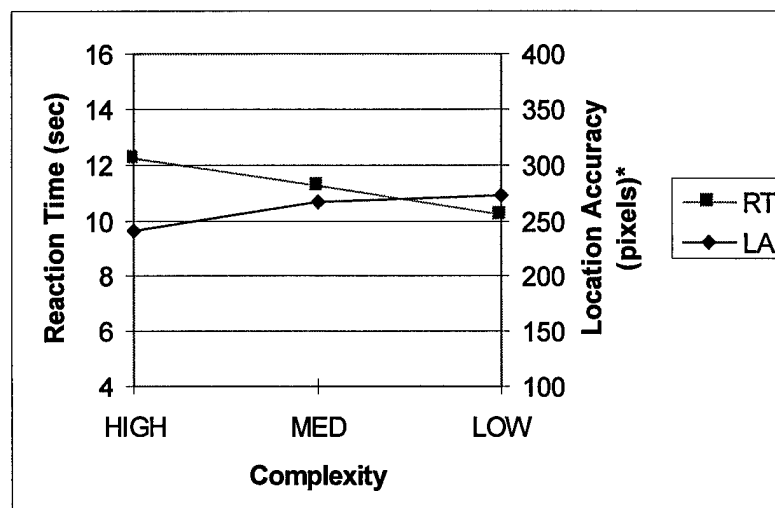


FIGURE 3.5.2. Mean values for Complexity across experimental conditions

*Smaller values for LA indicates better performance.

Chapter 4

DISCUSSION

4.1. General

The purpose of this study was to determine the cognitive processes employed by an experienced individual when a 3D FFOV was matched with a 2D topographic map. It was assumed that when the viewed landsurface and the map were at different azimuth orientations, comparisons between these two displays could not proceed without some preliminary cognitive adjustive manipulations. The findings of this experiment concluded that these manipulations appeared to be a combination of feature selection and mental rotation processing skills. For azimuth orientation, RT and LA were more sensitive to the distinctiveness or salience of the terrain features in the FFOV than the angular disparities between the two displays. As a result, more accurate responses were accompanied by faster RTs as azimuth orientation was manipulated.

As the complexity level (the number of visually presented terrain features) of the 2D map increased, RT for determining location also increased as participants had to process and compare that extra information. As RTs increased, LAs also improved suggesting the possibility of a speed-accuracy trade-off. However, these findings again indicated that map representations are encoded as individual landmarks and spatially

organized together in a scene. Interestingly, participant's subjective ratings also reflected their preferences for 3D views that contained distinctive terrain features and 2D maps with the most information.

4.2. Task Solution Strategy

The present task required participants to identify salient landmarks in the 3D FFOV and then attempt to locate those same landmarks in the 2D map in order to accurately determine their location. The transformation from the 3D to the 2D view was expected to impose a cost to RT, LA, and the subjective rating. Results indicated that there is some performance penalty, especially for RT, when the two views differed in orientation from the upright (0°) azimuth. Unlike previous experiments (Aretz and Wickens, 1992), the analysis did not initially indicate a linear increase in the performance penalty as a function of the angular differences between the 3D FFOV and the 2D map. However, a more detailed analysis of the results indicated that there was a generally linear increase in RT as the corresponding views increased in angular disparity. An ad hoc comparison of the group with less angular deviation (0° , 45° , 135°) was an average of 4.13 sec faster than the group with a greater angular deviation (225° , 270° , 315°). The average difference between these two groups was 44 deg/sec, which is only slightly less than the 57 deg/sec maximum rate of linear rotation observed by Hooper and Coury

(1994). Further comparisons of the interaction plots also suggested that participants preferred to conduct forward (+ direction) rotations as opposed to backward (- direction) rotations. Thus, the group with less angular deviation (+ direction) generally resulted in better RTs and LAs than the group with greater angular deviations (- direction).

The results for LA as a function of azimuth orientation were not as orderly as those for RT. One explanation for these findings could be that LA, as well as RT, were more sensitive to the relative distinctiveness of certain terrain features. These features greatly contributed to a participant's ability to accurately determine their location. When viewing a rich array of visual information, participants may have "selectively encoded" several distinctive or salient features as a collection of separable critical elements rather than as a single holistic entity. It seems logical to assume that after the participants selected this set of discriminative features (saddle, road, hills, ranch house, etc.), the features could then be mentally arranged into a spatially depictive array. This array of 3D terrain features would then be rotated, if necessary, to fit the north-up 2D topographic map. If the selected features are more distinctive than the surrounding "noise", then it can be expected that they would be encoded more quickly and subsequently be matched more readily with the corresponding 2D view. As such, both RT and LA would reflect better performance.

This concept of selective encoding has previously been reported to some extent by other experiments. Dror, Ivey, and Rogus' (1997) compared the visual mental rotation of possible and impossible objects. Their results indicated that image representations are composed of parts that are spatially organized together. If the shapes were encoded

globally, there would have been a change in the rotation rate when the impossible shapes were rotated; however, no such effect was found.

The findings of the current experiment also supported the concept of selective encoding. The 135° FFOV as shown in Figure A.4 contained a feature (saddle with road) that was clearly different than the surrounding terrain. This specific feature could be considered a templated object. Participants could have been more familiar with this “prototypical” view of a saddle and only had to recall a learned view from memory rather than process a new piece of information. No doubt that the effect of this distinctive feature contributed to the fastest RT and was one of the best LA performers. On the other hand, the 315° FFOV as depicted in Figure A.8 had the slowest associated RT and the second worst LA. This view contained general features (hill, buildings) that could have been in any one of the other 3D views. There was no major defining nature in that view to set it apart. An interesting note was that unlike previous studies (Wickens and Hickox, 1997), no significant difference in RT or LA was discovered between scenes that contained primarily man-made features versus those that were primarily natural features. The overriding importance of a prominent feature(s) was more significant than its type. Additionally, the results of the subjective rating generally coincided with those from the other factors. In other words, participants rated those views with more distinctive features as being more useful in helping them determine their exact locations on the 2D map.

4.3. Complexity Level

The results of this experiment indicated that as complexity of the 2D map was increased, participants required more time for judgments. These findings have also been supported by other experiments in the literature (Aretz and Wickens, 1992; Silverman, 1974). It has already been shown that participants selectively encode the salient features from the 3D views. Aretz (1991) hypothesized that if subjects perceptually processed each landmark in a scene, then a serial relationship between scene content and RT would be expected. Aretz's (1989) subjects RT increased by 450 msec per landmark. In this experiment, it was determined that RT increased by an average of 417 msec per landmark or terrain feature. Participants required more time to process and compare the additional information. This additivity or exhaustive search suggested that subjects crosschecked all landmarks, even clutter, before a response on their location was made.

It could be argued that the use of a selective encoding strategy for 2D maps implies that some portion of the landscape information on the map might go unprocessed. Eley (1991) stated the highly detailed or cluttered maps may bring about an "attentional filtering" transformation in which providing the map user with increasing amounts of topographic information will not lead to extra map processing or to increasingly precise mental representations. Only when such supplementation actually provided information of task-determined usefulness would any extra processing be expected to result. However, this argument would only be valid if a plateau or ceiling effect were attained. No such affect was discovered in this experiment. Future research should concentrate on

achieving this level because the potentially degrading effect of high complexity or “information overload” suggests the need for image simplification without sacrificing navigation performance.

It was also discovered that as RTs increased with a corresponding increase in the complexity level, LAs improved. These results were contradictory to those of Wickens and Hickox (1997) who found that increased complexity yielded longer response times but also an accuracy decrement. One possible explanation is that the participants could have been overly concerned with making an accurate decision rather than one that was quick as well as accurate. It should be noted that participant’s subjective ratings endorsed the higher complexity level. Apparently, these 2D maps provided more information that perceptually was used in helping determine locations.

4.4. Conclusions

A summary of this study as well as previous experiments in the literature indicate that while navigation tasks might vary in particular detail, the overall guiding strategy for map users is to perform as efficiently as possible. Map users tend to select a small number of discriminative features which optimally contribute to decisions. It is these selected features that are encoded into the map user’s mental representation of a landsurface and that allow him to determine his location. These selected features, however, may only be distinctive for that relative location.

It can be assumed that when faced with dynamic and realistic 3D views that change orientation, users must use some form of a selective encoding and mental rotation combination in order to link their forward view to a standard 2D north-up map. Goldberg et al. (1992) state that mental rotation of a complex 3D surface is likely to be a difficult cognitive task that could interfere with other cognitive processes required when a map display is part of an environment in which the user must conduct parallel or subsidiary tasks (e.g. driving the UGV).

It is known that tasks such as flight control (or driving a vehicle) requires spatial resources (Wickens & Liu, 1988; Wickens, Sandry, & Vidulich, 1983), but it has not yet been established that navigation demands spatial resources. It would be desirable to predict the cognitive resources utilized in navigation so that an operator's abilities can be matched to his performance capability.

Seeking information from electronically generated topographic displays of 3D views is a complex and poorly understood task whose prevalence is increasing daily. Future considerations into integrated designs of these displays should always be accompanied by careful consideration for the users and their capabilities.

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Appendix A

FFOVs for the 3D DISPLAY

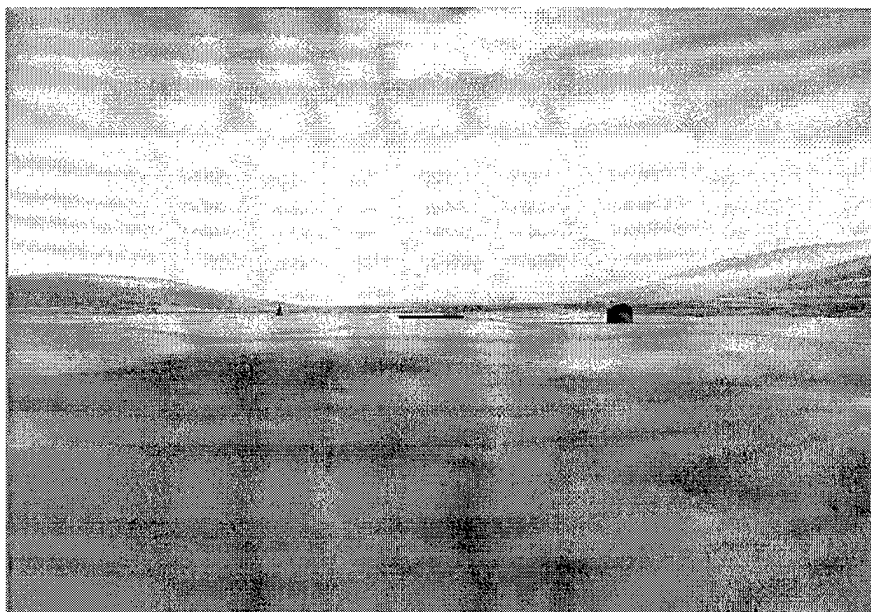


FIGURE A.1. FFOV from a location in the South looking North (0°)



FIGURE A.2. FFOV from a location in the Southwest looking Northeast (45°)



FIGURE A.3. FFOV from a location in the West looking East (90°)

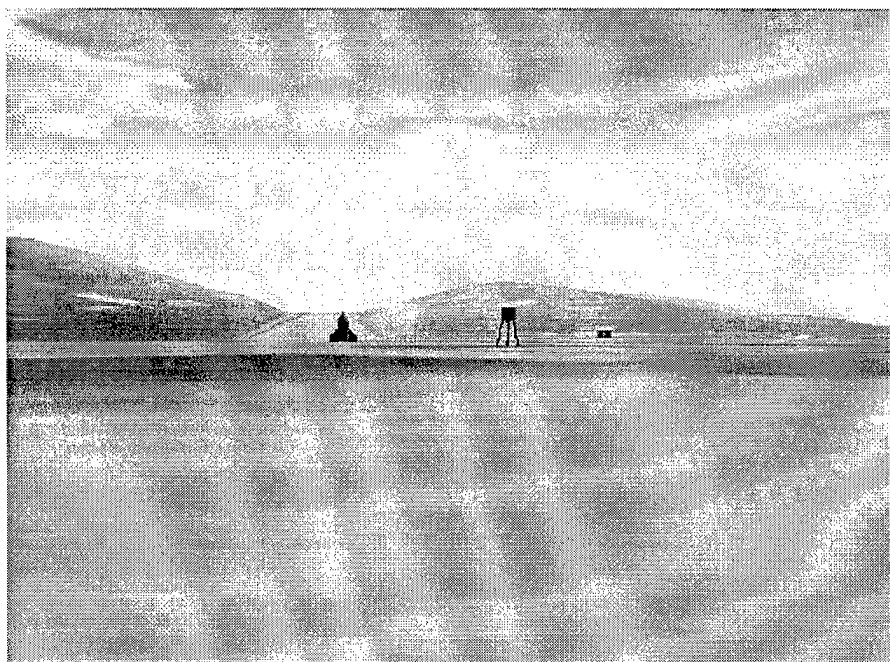


FIGURE A.4. FFOV from a location in the Northwest looking Southeast (135°)



FIGURE A.5. FFOV from a location in the North looking South (180°)

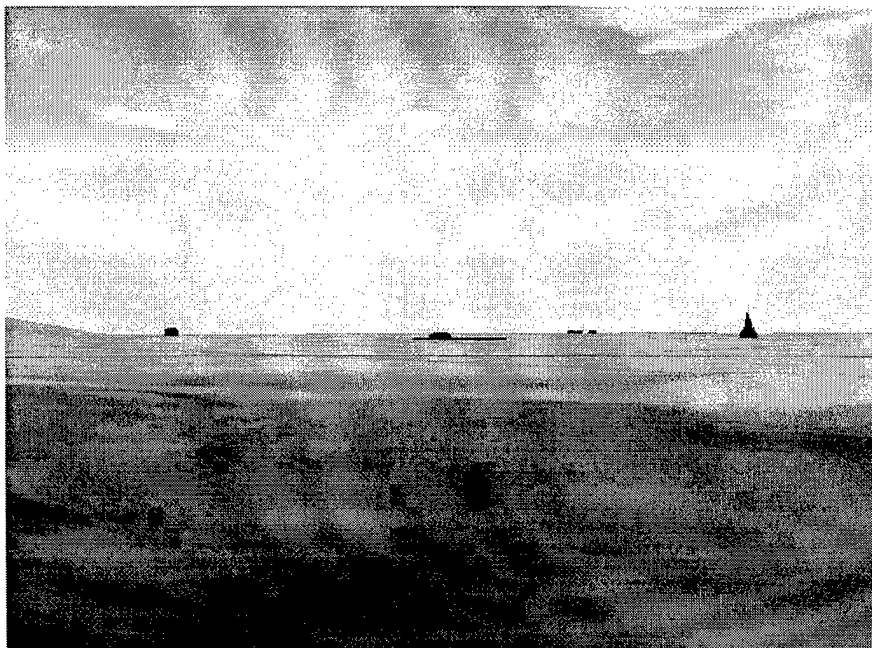


FIGURE A.6. FFOV from a location in the Northeast looking Southwest (225°)

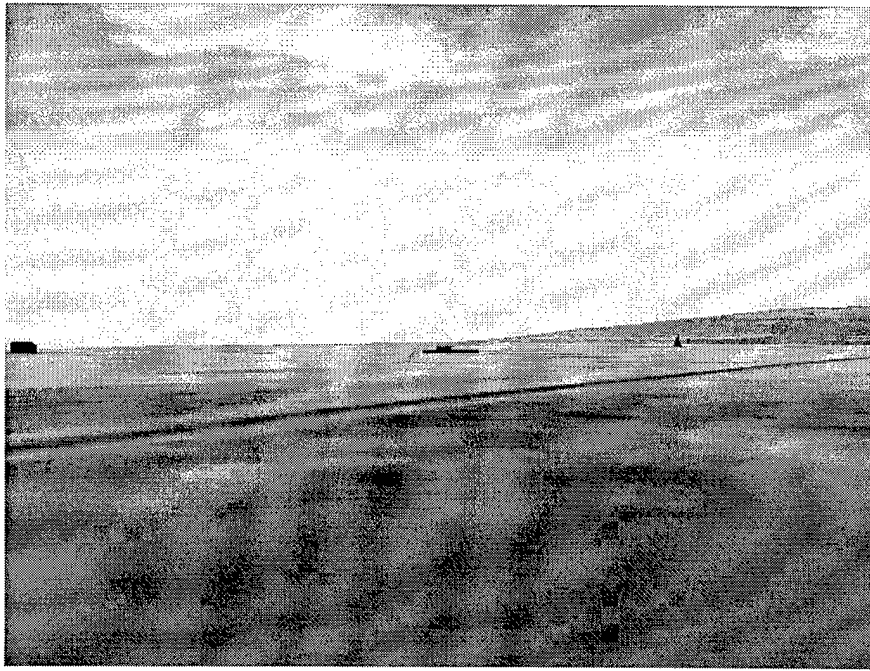


FIGURE A.7. FFOV from a location in the East looking West (270°)



FIGURE A.8. FFOV from a location in the Southeast looking Northwest (315°)

Appendix B

RESIDUAL ANALYSIS PLOTS

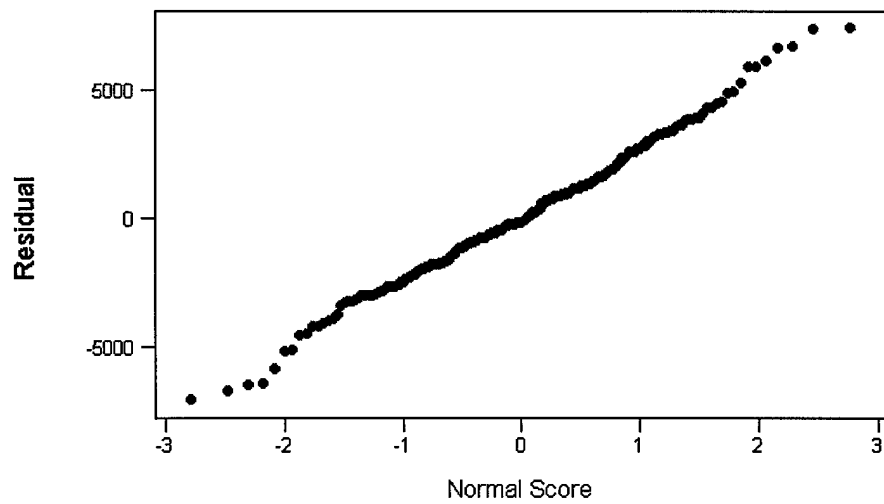


FIGURE B.1. Normal Probability Plot of Residuals for RT

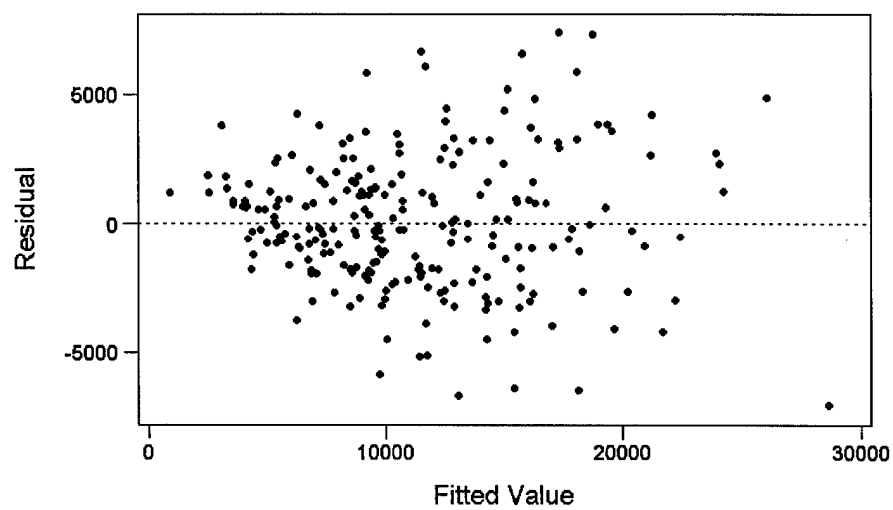


FIGURE B.2. Residuals versus Fitted values for RT

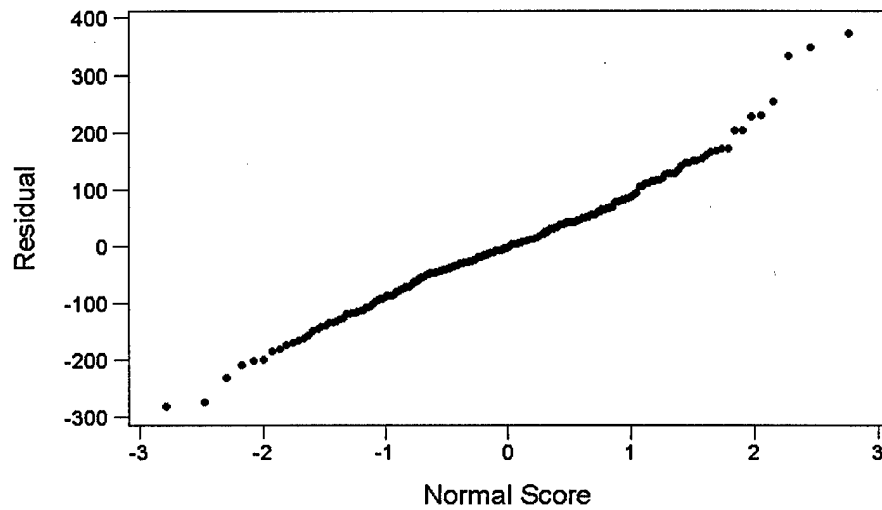


FIGURE B.3. Normal Probability Plot of Residuals for LA

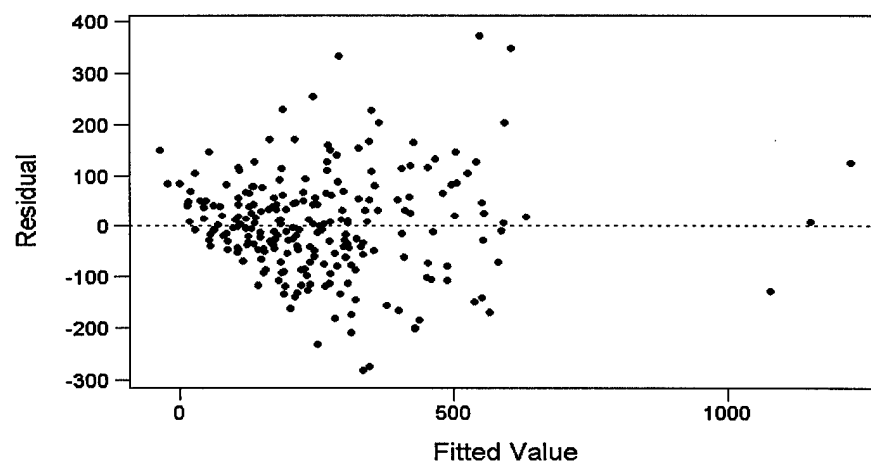


FIGURE B.4. Residuals versus Fitted values for LA

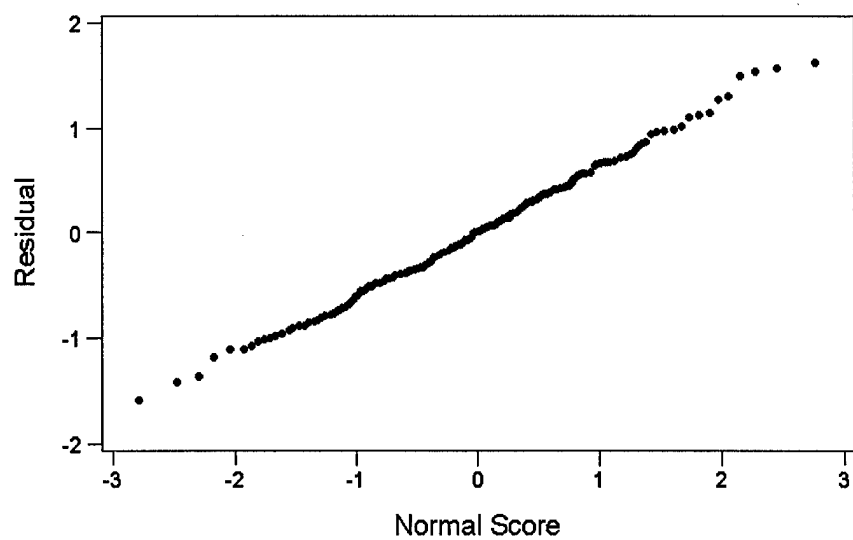


FIGURE B.5. Normal Probability Plot of Residuals for Rating

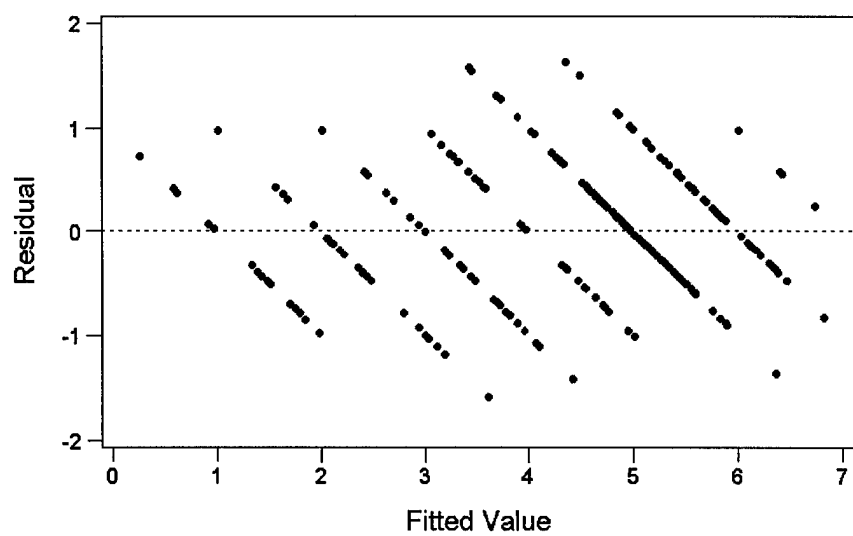


FIGURE B.6. Residuals versus Fitted values for Rating

Appendix C

INFORMED CONSENT DOCUMENTATION

INFORMED CONSENT FORM for HUMAN FACTORS STUDY

The Pennsylvania State University

Title of Investigation: Electronic Navigation Displays for Teleoperated Vehicles

Investigators: Alfred J. Grein, Joseph H. Goldberg, Ph.D.,

Department of Industrial and Manufacturing Engineering

207 Hammond Building; (814) 863-2740

Thank you for your participation in this study. This research is being conducted as part of the master of science degree for Alfred J. Grein. The goal of this study is to determine the cognitive (mental) cues that may be used in the integration of electronically presented navigation displays. You will be asked to determine your location on a 2D map presented on a PC screen by moving and clicking a mouse pointer. By conducting this study, we hope to provide recommendations that can be used in the design of electronic navigation displays for teleoperated vehicles. There is extremely minimal risk in participating in this experiment, however, if for any reason during the experiment you feel discomfort or fatigue, stop and inform the experimenter.

Participation in this study will take approximately one (1) hour. You will receive a payment of \$5/hour for your participation.

This is to certify that I, _____, hereby agree to participate as a volunteer in this research study conducted by Alfred J. Grein. I am entitled to certain rights as an experimental participant:

I understand that all of my data will be anonymous and that my identity will never be associated with the data I provide.

I have been given an opportunity to ask questions regarding the procedure of this study and that these questions have been answered to my satisfaction.

I understand that I am free to withdraw my consent and terminate my participation at any time without loss of pay for the time which was complete in the experiment.

I have been explained the very minimal risks associated with this experiment.

I understand that in the event of injury resulting from this investigation, neither financial compensation nor free medical treatment is provided for such injury, and that further information on this policy is available from the Office of Senior Vice President for Research and Dean of the Graduate School, 114 Kern Graduate Building (814-865-1775).

Your signature below indicates that you have read and understood all of the above information and that you consent to participate in the study.

Printed Name

Signature

Date

Alfred J. Grein

Investigator's Name

Investigator's Signature

PENNSTATE



Vice President for Research
Office for Regulatory Compliance

140 RB 1-75
PA 16802-3000

The Pennsylvania State University
212 Kern Building
University Park, PA 16802-3000

Date: January 22, 1998
From: Candice A. Yekel, Director of Regulatory Affairs
To: Alfred J. Groun
Subject: Results of Review of Proposal - Expedited (#980060-00)

Approval Expiration Date: January 22, 1999

"Electronic Navigation Displays for Teleoperated Vehicles"

The Behavioral and Social Sciences Committee of the Institutional Review Board has reviewed and approved your proposal for use of human subjects in your research. **This approval has been granted for a one-year period.**

Approval for use of human subjects in this research is given for a period covering one year from today. If your study extends beyond this approval period, you must contact this office to request an annual review of this research.

Attached are confidential labels you can use to seal the envelopes that contain the original, signed informed consent forms obtained from the subjects of your study. These envelopes are then to be mailed to the address listed above. Contact this office if you need more labels.

Subjects must receive a copy of any informed consent documentation that was submitted to the Compliance Office for review.

By accepting this decision you agree to notify the Compliance Office of (1) any additions or procedural changes that modify the subjects' risks in any way and (2) any unanticipated subject events that are encountered during the conduct of this research. Prior approval must be obtained for any planned changes to the approved protocol. Unanticipated subject events must be reported in a timely fashion.

On behalf of the committee and the University, I thank you for your efforts to conduct your research in compliance with the federal regulations that have been established for the protection of human subjects.

CAY/dll

Attachments

cc. J. H. Goldberg
A. Ravindran
J. M. Mason, Jr.