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THESIS

EXPERTISE ON COGNITIVE WORKLOADS AND PERFORMANCE DURING NAVIGATION AND TARGET DETECTION

by

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March 2012

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13. ABSTRACT (maximum 200 words)

Today's military pilots are required to perform multiple tasks simultaneously, including maintaining control of the aircraft, navigating, communicating, and detecting targets. Mental workload may affect a pilot's ability to effectively learn to manage these tasks. Studies have shown that there are certain involuntary, physiological changes in eye gaze patterns, such as blink rate, frequency of fixations, and saccade rate that indicate increased mental workload. We hypothesize that experienced pilots, defined by total flight hours, would show more efficient eye scan patterns (higher frequency of fixations, lower dwell durations, and higher frequency of saccades per minute) during simulated tasks that required navigation and target detection and identification (tD&I). This would therefore lead to better performance in tD&I tasks.

Fourteen active duty military pilots completed three different scenarios while operating the flight controls in a helicopter flight simulator: overland navigation, tD&I while on autopilot, and tD&I while completing overland navigation. Eyetracking data were collected while the pilots completed the scenarios. Flight experience did not correlate to scan pattern or task performance. It did, however, show an interaction with cognitive workload as judged by blink rate. Results indicate that implementing eyetracking information into current aviation training programs could improve training effectiveness and efficiency.

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EXPERTISE ON COGNITIVE WORKLOADS AND PERFORMANCE DURING NAVIGATION AND TARGET DETECTION

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Submitted in partial fulfillment of the
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ABSTRACT

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Fourteen active duty military pilots completed three different scenarios while operating the flight controls in a helicopter flight simulator: overland navigation, tD&I while on autopilot, and tD&I while completing overland navigation. Eyetracking data were collected while the pilots completed the scenarios. Flight experience did not correlate to scan pattern or task performance. It did, however, show an interaction with cognitive workload as judged by blink rate. Results indicate that implementing eyetracking information into current aviation training programs could improve training effectiveness and efficiency.

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LIST OF ACRONYMS AND ABBREVIATIONS

CSV   Comma-Separated-Value

CWL   Cognitive Workload

EEG   Electroencephalogram

ERP   Event-related Brain Potential

IP   Instrument Panel

MWL   Mental Workload

NASA TLX   National Aeronautics and Space Administration Task Load Index

OTW   Out the Window

RMS   Root-Mean-Square

SAM   Surface-to-Air Missile

SWAT   Subjective Workload and Assessment Technique

TERP   Task Evoked Pupillary Response

WL   Workload

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I. INTRODUCTION

A. PROBLEM STATEMENT

Operating in the "information age" makes the ability to perform multiple tasks simultaneously a necessary skill. While selection and training focus on this ability, it is keenly critical for military aviators to perform multiple tasks in a time-pressured environment. Single seat aviators are responsible for all aspects of a mission from before takeoff until after they land. Crew aircraft have similar challenges, although the workload is now shared between multiple members. Cognitive workload has been determined to affect how well pilots are able to do multi-tasking.

Cognitive workload defined as the combined interactions of task demands/difficulty, operator workload, other stressors, and primary task performance (Megaw, 2005). Cognitive workload itself can be tracked and monitored with multiple methods. First, performance-based measures such as adherence to a course or number of correct responses quantify how well an individual performs with an increase in task load. Alternately, subjective measures can be acquired simply by asking individuals what they are thinking or how they feel about their workload. While important, this approach is subjective and may not accurately represent the cognitive workload of the individual. Lastly, there are physiological markers, which are universal, that can identify when an individual faces an increase in mental workload (MWL). Some of these markers are brainwaves, galvanic skin response, heart rate, pupil diameter and dilation/contraction rates, and blink data (Jessee, 2010; Megaw, 2005).

Eye behavior generally has been the subject of many studies of mental workload (Jessee, 2010; Fong et al., 2011; Sibley et al., 2011; Marshall, 2007), which can be converted to an objective and measurable index. Using eye tracking technology to observe the movements of the eyes, we are able to relate how much of an increase there may be on an individual's cognitive load when

given multiple tasks to accomplish. What used to require various invasive methods, the technology now exists to give incredibly accurate (±1mm translation, ±1⁰ rotational) results on an individual without being invasive at all. The equipment that will be utilized has no effect on the individuals, and other than knowing the equipment is there, the participant has no interaction with it. This allows for more pure data collection by decreasing the amount of random variability introduced by knowledge of equipment and the inherent discomfort or distractions of wearing it for any extended period.

Our *a priori* expectation is that as an individual's experience and skills increase, the resultant mental workload that they experience should decrease (Sibley et al., 2011). Additionally, expert pilots tend to have a more efficient visual scan pattern than novice pilots (Sullivan, 2010). Previous work has shown that experienced pilots, as defined by flight hours, have more refined and efficient scan patterns that allow them to be able to accomplish difficult tasks (Kasarskis et al., 2001; Starkes & Allard, 1993; Sullivan, 2010). They have more fixations (pauses in eye movement to allow visual intake), shorter durations on each fixation, and more saccades (rapid, simultaneous movements of both eyes to fixate on a common focus). A more efficient scan pattern presumably would decrease cognitive load. Additionally, faster scan times mean that pilots spend less time obtaining information from their instruments and therefore have more attention to devote to the tasks of overland navigation and target detection. Does this refined scan pattern transfer over into a reduced cognitive workload for the pilot?

B.   PURPOSE OF THE THESIS

Currently, it is suspected that expertise has an impact on scan patterns and performance across combination tasks, but this impact is not quantified. This thesis aimed to fill in these important gaps in knowledge by assessing performance and measuring scan patterns and, by implication, workload, while navigating an aircraft in a mountainous region, locate and identify targets of

interest, and a combination of the two. While participants completed the tasks, their visual scan and basic eye characteristics were captured in real time via eyetracking. They also completed surveys prior to and after each scenario in which they indicate the level of perceived task difficulty at each waypoint. Finally, participants completed a demographic survey that asked about relevant flight experience information. Thus, we used performance-based, objective, and subjective objective measures of cognitive workload across the three tasks:

- Performance based measure: adherence to the given route and ability to detect (find along the route) and correctly identify (friend or foe) various contacts along the flight route

- Objective cognitive workload data (scan pattern, saccade rate, fixation data)

- Subjective cognitive workload data (from pre- and post-surveys)

Flight expertise is commonly measured by total flight hours. However, a more useful and nuanced measure of task-specific expertise may be visual scan pattern. Therefore, we used two measures of expertise in analyzing the data: total flight hours and eye scan pattern. Finally, because subjective reports of cognitive workload can be inaccurate, we will compare the subjective surveys to the objective eye scan data. If it is possible to determine how an individual adapts to the change in tasks, and a corresponding change in performance, task saturating situations could be anticipated and, in some cases, mitigated. By identifying when an individual reaches a threshold level of experience, measured by physiological factors such as those studied here, the military could potentially increase training effectiveness by tailoring syllabi focusing on individual tasks.

C. RESEARCH QUESTIONS

- Does self-reported expertise, measured in total flight hours, predict eye scan pattern, measured by fixations, saccades, and dwell

times, across the three tasks of Navigation, Target Detection & Identification, and Navigation and Target Detection & Identification?

- Is expertise associated with less cognitive workload across the three tasks of Navigation, Target Detection & Identification, and Navigation and Target Detection & Identification?

- Can eye scan be used to predict performance?

D.   HYPOTHESES

1.   H0:   There is no significant correlation between total flight hours and eye scan patterns in the Navigation, Target Detection, and Navigation & Target Detection tasks.

HA: More experienced pilots will have more saccades, shorter and more fixations, more fixations on salient instruments and stimuli than inexperienced pilots.

2.   H0:   There is no significant correlation between eye scan pattern and performance in the Navigation, Target Detection, and Navigation & Target Detection tasks.

HA: Pilots with more efficient eye scan patterns (more saccades, shorter and more fixations, fixations on salient instruments and stimuli) will perform better on the navigation (by adherence to the given course and waypoints), task detection (more Correct Detections versus Incorrect and Missed Detections), and combination tasks.

3.   H0:   Regardless of expertise, there will be no difference in blink rates across scenarios.

HA: Pilots with more experience will have a higher blink rate than pilots with less experience.

E.   THESIS ORGANIZATION AND TABLE OF CONTENTS

- Chapter I: Introduction. This chapter describes the problem, lists the research and exploratory questions, presents the hypotheses, and describes the scope and benefits of the study.

- Chapter II: Background. This chapter will provide a literature review of previous work in the field. The review includes current work on cognition, attention, types of workloads, and different methods of measuring an individual's workload while performing tasks.

- Chapter III: Methodology. This chapter describes how the research team designed the experiment, including participant selection, experiment setup, procedures, and equipment configuration.

- Chapter IV: Results and Data Analysis. This chapter will analyze the data collected and present the results and how they apply to the given research questions and hypotheses.

- Chapter V: Discussion, Conclusion, and Recommendations. This chapter will look at the implications of the study and possible future work that can come from it.

- Appendix A: Rating Scales. This appendix contains the rating scales that were referenced for the subjective portions of the experiment.

- Appendix B: Data Figures/Tables. This appendix contains the tables and statistical figures that are not placed in the body of the text.

- Appendix C: Summary Statistics. This appendix contains a summary of the statistical information from the data. Individual

performance is not included, nor are other divisions in the data. If there were divisions, the statistic is for the overall set.

- Appendix D: Approved IRB Protocol. This appendix contains the submitted and approved Institutional Review Board Protocol for the experiment.

- Appendix E: Recruitment E-mail. This appendix contains the e-mail sent to the students, staff, and faculty of the Naval Postgraduate School requesting participants for the experiment.

- Appendix F: Subject Checklist. This appendix contains a checklist used for each participant to ensure consistency between volunteers and verify that all necessary steps have been taken prior to, during, and after the experiment.

- Appendix G: Welcome Script. This appendix contains a short explanation for the participant about how the experiment will progress.

- Appendix H: Eye Scan Calibration Script. This appendix contains the script that we used to set up and calibrate the face tracking equipment.

- Appendix I: Equipment Familiarization Script. This appendix is used during the Practice Scenario in order to allow the volunteer to understand the equipment and the controls.

- Appendix J: Demographic Survey. This appendix allowed the researchers to gather demographic information from the participants regarding various aspects of their experience.

- Appendix K: Pre/Post-Flight Survey. This appendix is the survey given to each participant before and after each scenario.

II. BACKGROUND

A. INTRODUCTION

This thesis focuses on how a pilot performs when presented with different tasks simultaneously. Even in multi-piloted aircraft such as helicopters, the workload inside the cockpit consists of many tasks occurring simultaneously. Early in training new pilots are trained to "Aviate. Navigate. Communicate." This rule helps prioritize when task loading becomes considerable. Most importantly, the job of the pilot is to keep the aircraft in the air. Second, knowledge of where the aircraft is and where it is going is vital to mission success. Lastly, but not to downplay its importance, communication allows the pilot to send and receive information and coordinate actions. Simply put, failing to navigate or communicate may possibly lead to disaster whereas failing to aviate will.

The aviate and navigate portion of this rule have large visual workloads as the pilot scans the cockpit to monitor aircraft performance and parameters, and scans out the window to maintain situational awareness of his location. The scan pattern is also taught early in aviation training and each pilot develops their own pattern as they acquire hours in the cockpit. In the beginning, the scan is inefficient as it has long dwell times, less fixations, and a less refined "flow" around the cockpit than those with more experience (Kasarskis et al., 2001; Sullivan, 2010). According to Sullivan, experts take less time to take in the salient details in a scene, shifting their gaze more frequently and overlapping successive scans in order to create a finer mental picture of their environment. Additionally, less experienced pilots will fixate on less salient features while taking longer to encode and process what their seeing in order to understand their respective situations.

There are various methods of detecting and measuring changes in cognitive workload. We examined previous work on attention, vigilance,

cognition, multitasking, and the ways in which these combine to give an individual the situational awareness, or sight picture, of what is going on during navigation, target detection, or the combination of the two. Different methods exist for measuring workload of an individual, namely performance, subjective, and physiological. By using all three of these in the research, it is possible to correlate not only one's actual performance, but also their perceived performance. Technology today has progressed to the point where it is possible to measure an individual's workload empirically without any imposing equipment that may have an effect on the data. To be able to assess an individual's cognitive workload in real time and detect visual scan patterns associated with differing cognitive loads gives the potential for tailored training that can improve performance and maximize and throughput.

B.   ASSESSMENT OF WORKLOAD

Proctor and Van Zandt (2008) define workload as "an estimate of the cognitive demands of an operator's duties." In order to explore workload, it is necessary to define precisely the tasks and benchmarks. Empirical methods for measuring workload include primary task, subjective measures, secondary task, and physiological (Proctor & Van Zandt, 2008; Megaw, 2005). Analytical methods exist as well, defined similarly in the same sources; however, these are often used early in the development of a system to predict behavior. As such, only the empirical methods will be reviewed and used in this research.

1.   Performance Measures

Performance measures of workload, also known as primary-task measures, are those that measure how well an individual performs a task. Performance and workload are, in general, not linearly related. Instead, with workload on the x-axis, they typically follow an inverted "U" shape, commonly described as the Yerkes-Dodson law (Aral et al., 2007; Proctor & Van Zandt, 2008). Shown in Figure 1, the Yerkes-Dodson Law states that performance is

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not highest the simpler a task is nor with less arousal or stimulation. Previous work shows that with simple tasks, an individual's performance can be just as poor as if confronted with a mentally taxing, high cognitive workload task (Megaw, 2005; Proctor & Van Zandt, 2008). In the Navy, one tenet of Crew Resource Management is that of Situational Awareness (SA). In the MH-60S helicopter Naval Air Training and Operating Procedures (NATOPS) manual, task overload and underload are recognized as factors that can cause a drop in SA, which can have dramatic effects on the performance of a flight. Because of this, the level of vigilance and arousal must be kept at a level that capitalizes on the increase in performance without overtasking the individual.
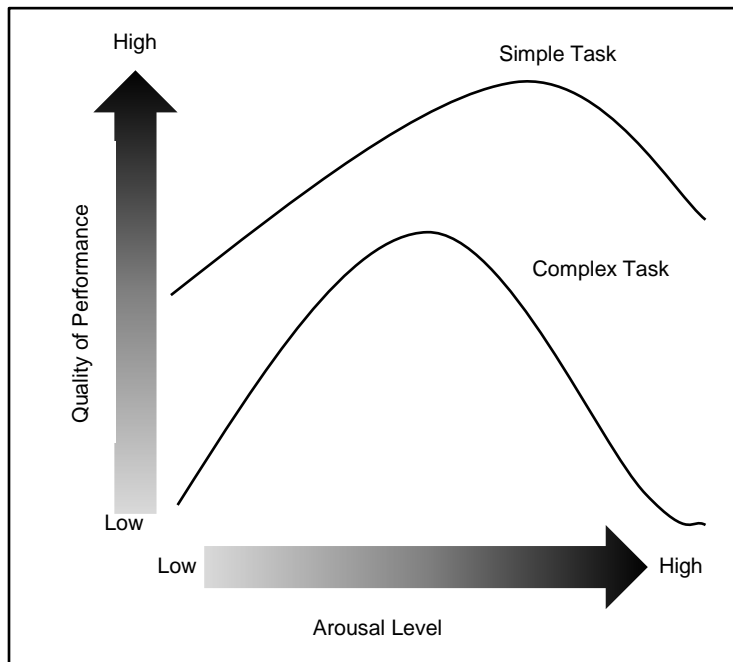
Figure 1.   Yerkes-Dodson Law (After Yerkes & Dodson, 1908)

Measuring workload via performance is done using a scoring system. This can range anywhere from an exam in school, a time in a race, or simply staying inside the lines while coloring a child's picture. Megaw (2005) states that "while poor human performance can be indicative of task demands being too

high, acceptable performance does not necessarily reflect task demands." Because of this, if one is to use performance measures to assess workloads, it is best to use multiple measures (Proctor & Van Zandt, 2008). Different measures of performance measure different aspects of workload. If we were to use just one, there would be a hole in the data that could lead to incorrect assumptions and conclusions.

With respect to the scenarios presented to our participants, we expect that performance (adherence to assigned route and quality of target detection) will be higher in the scenarios in which these two tasks individually are the sole tasks being asked of the participant. When combined into one scenario, the mental workload will have to be allocated accordingly in order to complete both tasks. Depending on the individual, they may give more attention to the target detection and identification at the expense of the navigation.

2. Subjective Measures

Subjective measures of performance are based on the opinions and feelings of the individuals immediately after the completion of their task. As such, these methods are subject to biases, such as hindsight (Pezzo, 2011), mood congruent (Mayer & Bower, 1985), and egocentricity (Epley et al., 2004; Fellner et al., 2004) and have certain shortcomings when it comes to using one as a sole measure of workload. Subjective measures include rating scales and questionnaires. Proctor and Van Zandt (2008) point out three issues with using subjective measures:

- They may not be sensitive to aspects of task environment that affect primary-task performance,

- Operators may confuse perceived difficulty with perceived expenditure of effort,

- Many factors that determine workload are inaccessible to conscious evaluation (such as ability to compartmentalize, prior training, or fatigue, etc).

There are a variety of methods to measure subjective workload. The following three measures are those that form the backbone of most current subjective measuring scales.

a. Cooper-Harper

The Cooper-Harper method (Cooper & Harper, 1969) uses a single 10-point scale to which subjects would rate their experiences. Originally designed for analyzing aircraft handling, the scale is adaptable to a wide variety of fields. The scale ranges from having "Major Deficiencies" (10 points), to "Excellent, Highly Desirable" (1 point). Other than major deficiencies, the rest are grouped in threes that make for easy classification and navigation, essentially providing an objective path to the subjective measure.

b. SWAT

The Subjective Workload Assessment Technique shown in Appendix A was developed as an alternative to the Cooper-Harper method and uses a series of cards to assess workload. These cards are differentiated from each other by time load, mental effort load, and stress load (Proctor & Van Zandt, 2008). There are three levels for each of the subcategories and all combinations are represented on the cards for a total of 27 cards. Through the ordering of the cards and applying a "conjoint measuring technique" (Megaw, 2005) to place each of the 27 cards on a 1–100 point scale. The SWAT technique is time consuming and the weighing of each subcategory differs between participants.

c. NASA-TLX

One of the most widely used methods of acquiring a subjective measure of performance is NASA's Task Load Index. Using six scales similar to

the oft-used Likert scale, TLX takes a user's input as a gradient, matching their rating on the particular scale to a score between 0 to 100 (Hart & Steveland, 1988). Appendix A shows the scales that TLX utilizes. In Hart and Steveland's report, there was a weight given to the measurements that would make the data analysis take slightly longer. Further studies with and without the weights have suggested that this step is superfluous; however, they have been countered just as often with studies showing the weights give a "small but significant contribution" (Megaw, 2005).

3.   Psychophysiological Measures

One of the most effective ways to get a true gauge on the workload an individual is experiencing is through psychophysiological measurements. These typically fall into two categories: arousal and brain activity (Proctor & Van Zandt, 2008). As the name implies, brain activity focuses on the minute electrical impulses that are detectable with various methods. Arousal is measured via a variety of subconscious reactions that occur in the body when exposed to different levels of stress and workload. These indicators, largely in the sympathetic nervous system, include pupil diameter, pupil dilation/contraction rate, heart rate and variability, galvanic skin response, blood pressure, blink data, and respiration rate, among others (Proctor & Van Zandt, 2008; Marshall, 2000; Marshall, 2007; Jessee, 2010; Fong et al., 2011; Sibley et al., 2011).   The responses can be measured with a variety of accurate and dependable instruments.

a.   Brain Activity

Brain activity is a second measure of mental workload. Using an electroencephalogram (EEG), it is possible to measure brain activity in response to given stimuli (Megaw, 2005; Proctor & Van Zandt, 2008). The EEG uses a network of electrodes attached to the scalp that measure tiny variations in voltage and translates it into a visual representation of mental activity. Event-

related brain potentials (ERP) are the changes in brain activity that occur when the events occur that require a differing amount of processing. Data analysis is required to determine the difference between these ERPs and the background, normal brain activity (Megaw, 2005). Other brain measurements include positron emission tomography, functional magnetic resonance imaging, magnetoencephalography, transcranial Doppler sonography, and optical brain imaging (Proctor & Van Zandt, 2008). These methods provide much more detailed data, but as they are intrusive, we opted not to utilize any of them.

b. Cardiac and Galvanic Skin Response

Cardiac activity and galvanic skin response are two factors that a mentally loaded individual may be conscious of, but over which they would have no control. These responses come from the sympathetic nervous system and are noticeable manifestations of the "fight or flight" response and show an increase or decrease in heart rate (Megaw, 2005; Roscoe, 1984), or the increase of skin moisture (sweat) thereby increasing skin conductivity. Megaw proceeds to describe how "there is a lack of understanding as to why or how mean heart rate should increase with increasing mental demands." Like measuring brain activity, measuring these two markers of mental workload are intrusive and were not used in this study.

Although advances in technology allow for better measurement of arousal, these techniques remain cumbersome and intrusive (Marshall, 2000). Measuring brain activity still involves attaching electrodes to the scalp and therefore remains to be more intrusive than other methods. This process affects a participant in more ways than one. First, the equipment itself can be cumbersome, causing discomfort or hot-spots if left on for an extended period of time (Marshall, 2000). Second, the knowledge of the equipment itself can cause the body to have subconscious reactions that can affect the data. An aviator flying a simulation while being recorded is barely different from them doing it just being observed (which occurs all the time); having them fly while hooked up to

wires and equipment can put undue stressors and pressures on their mind. As will be discussed next, eye-tracking technology allows the experimenter to measure accurately a participant's reaction to workload without being intrusive. Being able to disconnect the detection equipment from the individual allows for a more natural environment and therefore a more pure collection of data.

c. Eye Tracking

Eye tracking is one field that has progressed greatly in the past few decades. Originally, the equipment needed to track one's eye movements was bulky and was worn on the head. As mentioned, this can skew the data collected if the individual is uncomfortable or just thinking about the equipment. Now, being able to detect and collect data from eye-trackers is completely non-intrusive to an individual, save the knowledge that there are cameras observing them.

(i) Eye blink activity. As every schoolchild knows, one of the main purposes of blinking is to lubricate the eye. There is a variety of other purposes, but the eye will also blink for seemingly spontaneous reasons (Stern et al., 1984). Stern et al. call this the endogenous blink. At the time of their publication, there was little work done on cognitive activity and blink rate. Almost thirty years later, there has been much research relating blink rate to cognition. Studies have shown that when a blink occurs, the brain temporarily shuts down visual input (Stern et al., 1984; Jessee, 2010). Additionally, blinks tend to occur after taking in visual information, possibly as the brain switches from a visual workload (VWL) (taking in the information) to a mental workload (processing the information) (Megaw, 2005). In some situations, blink rate decreases with an increase in VWL, such as driving and flying. However, Megaw (2005) and Stern et al. (1984) both state that blink rate increases in other cases where visual processing is not as demanding. Although published more than twenty years later, Megaw sums it up concisely saying, "The inconsistent results relating to blink rate may indicate a diagnostic potential for the measure with the acquisition

of visual information being associated with lower blink rates, and visual cognitive processes with higher rates." While performing demanding tasks, regardless of difficulty, the blinks tend to occur at times when there is no need for steady and constant visual intake (Stern et al., 1984). In tracking tasks, such as those used in this thesis, if an individual knew a visually demanding portion of the task was approaching, blink rate would increase prior to and after the portion, with a drop in between (Stern et al., 1984).

(ii) Saccadic events. Saccades are periods of time when the eye is actively in motion. During this movement, uptake of visual information is temporarily paused (Carlson-Radvansky, 1999). Because of this, the time in between saccadic events, the fixation, is when the eyes actually take in the scene before them. Fixations and saccades are not related on a one-to-one scale. There can be multiple saccades from one fixation to the next as the eye rotates to the next object of interest (Marshall, 2007). Times in between saccades (fixation or dwell times) vary as well; longer fixations imply more time required for the visual uptake and the VWL. A NASA report found that novice pilots spend more time per fixation than expert pilots (Tole et al., 1983). The expert pilots in this study were able to acquire the information they needed in a much more expedient fashion and proceed with their scan. This does not necessarily indicate a lower cognitive workload, only that they are able to process more information in a shorter amount of time than the inexperienced pilots.

With larger shifts in focus, it is necessary to move the eye through an increased number of degrees in the field of view. As mentioned, when the eye is moving, there is no uptake of visual information. This would therefore lead to the conclusion that with larger shifts, there is a longer amount of time spent without visual input. Jessee (2010) mentions that although having objects close together would lead to less VWL, the ability to discern one from another would lead to an increase in MWL.

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(iii)   Pupillometric Measurements.   With the increase of computing power and the ability to collect and analyze data in real time, we can observe an individual's pupils for telltale signs of cognition. Poker players for centuries have known that when presented with an appealing hand, the pupils will dilate, giving a tell that is extremely hard to control.   Multiple studies corroborate the hypothesis that pupil size increases with an increase in arousal and motivation (Fong et al., 2011; Sibley et al., 2011; Jessee, 2010; Megaw, 2005; Just et al., 2003). When using pupils as a tool to measure MWL and VWL, the experimenter has to be aware of the environment. Pupils are very sensitive to changes in illumination level and if there are fluctuations, this can confound the data (Megaw, 2005).   The eyes and pupils also vary between individuals. Although it can be said that pupil size will increase with an increase in workload, there is no given method to say they will increase or decrease a given amount. Even within an individual, pupil size can vary due to what Jessee (2005) calls "operator state variables." These would be such things as fatigue level, caffeine intake, alcohol, drugs, etc. that would affect the individual on the physiological level.

Pupil size is not the only indicator that we can use from this type of data. The dilation and contraction rate is useful in revealing an increase in cognitive workload and how much of an increase there is. In Sibley et al. (2011), they describe how pupil size is greatest in the beginning of a task of increased difficulty, and would then decrease. Additionally, as the individuals learn the task and become accustomed to it, the amount of dilation would decrease and the rate at which they return to normal would increase with the same cognitive stimulation. In Fong et al. (2011), they also showed that the dilation rate is inversely related to the change in cognitive workload that an individual experiences.   Their method of measuring, Task Evoked Pupillary Response (TERP), relies more on the change in size vice the size itself and is therefore more resistant to the confounding factors mentioned.

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4. Secondary Task Measures

Secondary tasks are those tasks that an individual performs in addition to their primary task. Also referred to as dual or concurrent tasking, the purpose of secondary task measures is to measure the amount of remaining cognitive processing power while completing the primary task (Megaw, 2005). As the names imply, the primary task should be the focus of the attention during the exercise. Measuring performance using secondary tasks does not necessarily mean measuring performance *of* the secondary task. The two basic types of secondary task techniques are the loading task paradigm and the subsidiary task paradigm. With the former, a researcher instructs the participant to maintain performance on the secondary task. The goal is to measure the degradation in the primary task, thus indicating what kind of effect the secondary has. The second type, subsidiary task, is the opposite. It instructs the participant to maintain priority on the primary task while measuring the decrease in performance on the secondary task. Both of these measures rely on the use tasks that make use of similar psychological resources (e.g., visual, oral, or auditory). Megaw states that when the two tasks share none of the same processes, there is no interference and an individual can reasonably perform both tasks with no degradation in performance.

C. NAVIGATION

Navigation as a skillset within flying is one that, behind maintaining actual flight, has the most potential on outcome of a flight. Training on navigation begins before pilots even sit inside a cockpit with basic understanding of terrain, features, flight paths, and obstacles. By the time the student sits in the aircraft with their instructor, the expectation is that they can successfully find their way to an outlying field at which they will begin training, even without knowing how to control the aircraft quite yet. As they progress in the training pipeline, the navigation becomes an automated task with the student recognizing certain

waypoints by features and within a few months, the student can be flying solo, capable of handling all tasks required of the solo flight in the training areas.

1. Confidence of Navigation

In the operational squadrons, and specific to helicopters, flying is a crew effort with one pilot at the controls (PAC), and one pilot not-at-controls (PNAC), handling tasks *not* involved with actual control of the aircraft. Navigation is among the tasks typically designated to the PNAC and it is his responsibility to maintain the flight on course and on time (Lennerton, 2004; Hahn, 2005). A given route is not intended to be followed exactly. The flight has the ability and the responsibility to be dynamic. If a threat is discovered, or weather moves in, it is up to the aircraft commander to adjust the course in order to keep the helicopter and the crew safe. Sullivan (2010) describes four areas by which we can assess navigation performance, as shown in Table 1. The table shows how confident the individual is at their perceived location versus intended location. This matrix depicts that being off-track should not always be penalized, as a pilot can be off-track but still know exactly where they are and where they are going.

Assessing Navigation Performance		Confidence	
		Low	High
Correctness Perceived and Actual positions match	Low	Struggling. No accurate fix, aware that aircraft is off track.	Dangerous. Lost and doesn't realize it. Positively misidentified correlating features.
	High	On course and lucky. Accurate fix, but not confident in navigation solution.	Skilled performer. On track and certain.

Table 1.   Matrix for Assessing Navigational Skills (From Sullivan, 2010)

2.   Navigation Methods

For a typical low-level flight, the non-flying pilot will have a 1:50,000 chart like the ones used in this thesis. Sullivan (2010) writes that sub-skills involved in helicopter navigation are dependent on certain goal-seeking methods that develop and change with experience. As a novice, a pilot is primarily means-based—following practices and procedures known through rote memorization and represent hard and fast guidelines by which to fly. With a little more experience, an intermediate pilot moves on to schema-based navigation. They have a plan and they have the ability to see beyond the "now" and provide information to the flying pilot as to what they *will* see or what to expect. Lastly, an expert's method of navigation is rule-based meaning they will describe a set of rules that lead to the ultimate goal. Actual execution of the rules is left to the discretion of the PAC, however the PNAC will continually asses and update his rules as the flight progresses.

Being able to navigate successfully involves being able to take the 2-dimensional representation of the terrain represented on the chart and associating it with the 3-dimensional out-the-window (OTW) view. For novices or anyone without overland navigation experience, this typically is a difficult task. With experience, an individual is able to understand which OTW features will be easily noticed on the chart, and conversely, which chart features can be used for navigation. Key terrain features include checking features ("on the right track"), channeling features ("follow to the next point of interest"), and limiting features ("you have gone too far") (Lennerton, 2004; Hahn, 2005). The ability to go from chart-to-OTW and OTW-to-chart comes with practice and is enhanced with an efficient scan within and without the cockpit. This creates two distinct phases of navigation, depending on how the pilot perceives their current situation: maintenance and repair.

a. Maintenance

Maintenance of navigation is the practice of knowing where one is and keeping control over their location on the chart. The search/scan pattern of an individual in a maintenance regime is directed and deliberate. They are looking for confirmation on their location rather than trying to determine where they are (Sullivan, 2010). Pilots in maintenance mode are confident in their location regardless of how much the flight may deviate from the route. As shown in Table 1, when they are high on "correctness," this is good and would be the performance expected of more experienced pilots. According to Sullivan's dissertation, less experienced pilots "will have increased dwell time, taking longer to capture and encode features in the OTW view." Ideally, staying in the maintenance phase should be easier than repair as one only has the task of matching and not searching.

b. Repair

Repair strategy involves perceiving that one has unintentionally strayed from the assigned route and finding a solution to recover. As shown in Table 1, repair would not occur if the pilot were purposefully off track for something such as terrain, weather, or threat avoidance. Sullivan (2010) calls this a naïve search in that the pilot does not have the confidence of his location by which to make a matchmaking maintenance search. Experts in repair select a few key features across a wide swath that will allow them to better triangulate their position. The repair search of a novice is focused on relevant and non-relevant features in a smaller region leading to further lack of confidence in their position. For this experiment, if an individual recognized they were lost, the research team member gave them a heading to fly in order to put them back on course.

3. Navigation and Workload

In a crewed aircraft, navigation occurs with cooperation from all members being able to pick out and describe salient features from the surrounding terrain (Sullivan, 2010; NATOPS, 2008). In a single-seat aircraft, the pilot must accomplish this task concurrently with the aviation and communication portions of the flight, thereby increasing their workload. At 150' above ground level (AGL) in a mountainous region, terrain avoidance has consequences that are even more serious should it be ignored. Thus, the pilot has even greater workload when flying in this type of environment. One could slow down in order to provide more time with which to process the scene, but in an operational environment, this is not practical, as a slow aircraft is an easier target. Additionally, if one slows too much, they enter a zone where the airspeed-altitude combination is dangerous should an emergency occur (NATOPS, 2008). In our experiment, although flying a simulated helicopter, we put the participants in a single-seat aircraft to increase their workload beyond just navigating or just target detection.

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III. METHODOLOGY

A. INTRODUCTION

The purpose of this thesis was to identify differences in scan patterns among pilots of varying experience in order to gain insight into (1) how these differences can relate to workload and (2) to capitalize on these differences to create more effective and efficient pilot training. We built upon previous work (Sullivan, 2010) that investigated neurophysiological cues of pilots in a single task environment. In order to address differences in workload, we chose two scenarios that, by themselves, are not particularly stressing—navigation, and target detection and identification. We also created a scenario in which pilots had to perform both tasks simultaneously (combined task). In dual-piloted aircraft, these tasks are often split between the pilots in order to reduce the workload and increase safety. By having two tasks and examining the pilots in each single task as well as the combined task, we could identify changes in their behavior as the cognitive task load increases.

1. Overview of the Tasks

The research team created three experimental scenarios and one practice scenario. Each scenario was designed to elicit appropriate responses for the task(s) at hand; i.e., the navigation task assessed navigation skills. In all cases, the Practice Scenario was the first one to be administered. Scenario 2 (navigation only) followed in order to decrease the possibility of an order effect when analyzed with an earlier navigation experiment. The order of Scenarios 3 (navigation and target detection & identification) and 4 (target detection & identification only, auto-navigation) were counterbalanced in order to reduce confounds and order effects for this experiment. All scenarios simulated flight in an area near Twenty-Nine Palms, CA, which has an established military training area. The routes flown were typical of low-level routes that could be expected in both training and real world missions. Although all scenarios were in the same

general region of Twenty-Nine Palms, none of them reused waypoints, nor did the routes of flight intersect.

Although we seek realism in training environments, there are limitations on what we have and what we can use. The variation inherent in the past flight experiences of the pilots made it so that a simplification of the cockpit was necessary.

For the navigation task, we instructed the pilots to navigate their way around a series of waypoints. We measured their performance on this task as adherence to the straight line, waypoint-to-waypoint route. Utilizing root-mean-square (RMS) error, we calculated their distance from the given route at each data collection instance. Although there is no way to score a 0 (perfect adherence), namely because turns are inherently off the sharp corner of the route, this is constant across all pilots and is therefore already controlled. The pilots did not have complete control of the aircraft during the navigation tasks. In order to reduce random variability, they only had control of the heading of the aircraft. Altitude was constant at 150' above ground level; airspeed was a constant 60 knots. This simplified the controls and minimized variability in "basic air work" which involves the overarching task of maintaining control of an aircraft so that more attention could be applied to what we wanted to measure—navigation performance.

The target detection and identification task, as the name implies, was a two-piece task. The Practice Scenario, Scenario 3, and 4 each had two types of targets interspersed along the route. Because detection of the target could be as simple as discerning anomalies in the simulated terrain, we added identification as a method to get the pilots to concentrate more on the target. Along with increasing the mental workload, this had the added bonus of allowing the eye tracking equipment to detect more accurately when the individual identified the target. Downed aircraft, designated with a "crashed" A-10 Warthog, represented friendly targets for the identification portion. A SAM launcher represented the

enemy target. Figure 2. shows the two types of targets. The targets were immobile objects inserted into the scenario and did not move or in any way react to the helicopter flying past them.

Figure 2.   Friendly Downed Aircraft and Enemy SAM Launcher

B.   PARTICIPANTS

Research participants were recruited from the student body at the Naval Postgraduate School (NPS). Participants were eligible if they were pilots or have had formal training in overland navigation experience. With approval from the Institutional Review Board, an e-mail was distributed requesting volunteers (Appendix C). Additionally, flyers were distributed around school and the team provided equipment demonstrations to recruit participants.

We had 14 volunteers from which we collected data. Eleven of the volunteers were pilots. Two of the remaining individuals had extensive passenger experience as troops in the back of helicopters. One individual was a Surface Warfare Officer who was allowed to participate and only after completion of all four scenarios did the research team learn he was neither a pilot nor did he have overland navigation experience. Preliminary analyses of the data indicate that these three participants were consistent outliers; therefore, they were excluded from analyses for hypothesis testing. Although the experiment was open to all faculty, staff, and students at the school, all participants were male between the ages of 25–45. For the pilots that participated, there was a variety

of experience and backgrounds, as detailed in Table 2. For counts, individuals without any flight experience are tallied with the 40+ group for their "Months Since Last Flight." Adjusted flight hours shows the flight hours data without the three outliers previously described.

Category	Sub-category	Total	Category	Sub-category	Total
Age Group	25-35	6	Months Since Last Flight	0-10	2
	36-45	8		11-20	3
Branch of Service	Navy	7		21-30	3
	Marine Corps	1		30-40	2
	Army	2		40+	4
	Air Force	2	Flight Hours	Mean	1230.7
	International	1		Median	1100
Years of Experience	0-5	5		STD	945.5
	6-10	4	Adjusted Flight Hours	Mean	1561.8
	11-15	4		Median	1400
	15+	1		STD	774.1

Table 2.   Participant Demographics

C.   EQUIPMENT

1.   Hardware

a.   Computers

The overall setup for the experiment consisted of three systems. Laptops, desktops, an Apple iPad, and a CAVE system provided the necessary methods to track, collect, and maintain the data. The computer setup for the experiment consisted of interconnected laptops and desktop computers. Three laptops, one for each set of cameras, collected the eye tracking data. The data were kept locally on the laptops until manually moved to another system for analysis. The laptops were identical with the following specifications:

- Intel T7200 @ 2.0 GHz CPU

- 1 GB RAM

- Mobile Intel 945 Express Chipset Family Graphics

- Windows XP Service Pack 3 Operating System

Three desktop computers created the scenes, controlled the flights, gave supervisory authority, and aggregated the data from the laptops. Each desktop was identical in its specifications:

- Intel T7200 @ 2. GHz

- 3 GB RAM

- NVidia GeForce 8800 Ultra graphics card

- Windows XP Service Pack 3 Operating System

Although identical in components, the desktops performed very different jobs. The X-Plane system handled the actual flight of the helicopter. Participant input from the joystick was handled via the system in the Practice Scenario, 2, and 3. The X-Plane system also provided output to the instructor system for administrative capabilities. Terrain generation and rendering were performed by Delta3D and OpenSceneGraph.

The instructor system gave the research team the ability to maintain control over the flow of the scenarios. From this station, and with input from the X-Plane system, the instructor knew where the subject was on the chart (as well as in relation to the given route), what they see on all three screens, and with input from the FaceLAB computers, a general locus of their gaze.

The CAVE system consisted of an identically configured desktop, screens, and projectors, the latter of which we will discuss below. The desktop's primary job was to take display outputs from the other computers and route them to the appropriate projectors and displays. This computer generated the instrument panel located inside the cockpit for the participant's use. This system also provided the output files for the researchers.

Lastly, on the display aspect, an Apple iPad displayed the chart for the participant. Although physically fixed in position to allow calibration with the IR cameras, the pilot could rotate the chart on the screen to maintain his orientation if he desired. The iPad communicated with the rest of the system wirelessly to a Macbook Pro, which was physically (wired) connected to the NPS intranet and the other computers from there.

b. Physical Setup

The most noticeable pieces of the physical setup of the apparatus were the cockpit and the screens. The cockpit (Figure 3. is a model cockpit without any instrumentation of its own. To reduce variation from the two seats, and to maintain one configuration of the cameras, pilots sat in the right seat. In front of them, in the cockpit, a 10.6″ × 17.3″ (20″) screen displayed the virtual instrument panel. The screen had the following instruments:

- Airspeed
- Barometric altitude
- Time
- Heading

To the pilot's left, within arm's reach, was the iPad. Both cockpit displays (instrument panel and iPad) were in fixed locations to maintain calibration with the cameras.

The CAVE system provided the out-the-window (OTW) display for the experiment. Encompassing over 180⁰ (~103⁰ left, ~118⁰ right), three screens provided a wrap-around view for the flight. Three projectors connected to the CAVE computer backlit three 96″ × 72″ (120") screens in full 1024 × 768 resolution. The positions of the screens were fixed to allow calibration with the IR cameras. Figure 3 shows the cockpit setup (with one extra configuring laptop) and the large display screens. This system had on it X-Plane 9.0, the image generator, the data logger, and Delta3D and OpenSceneGraph in order to create the graphics for the scenarios.

Figure 3.   Cockpit Setup

Due to the fixed position of the seat and screens, there could be minor differences between viewing angles per individual. Figure 4 shows the arrangement of the cockpit. From the center of the seat, the right screen is 30″ away, the front (center) screen is 80″, and the left screen is 66″. The iPad sits on the empty seat, arm level, 22″ from pilot's center. The seat bottom is 36" from the floor.   Each screen is raised 17.5″ from the ground.   With these measurements, we can approximate the field-of-view.   The elevation and depression angles given in Table 2 are calculated for an American male in the 50th percentile for sitting eye-height (31.5") (Phaesant & Haslegrave, 2006). As mentioned above, the transverse angles are 103° to the left and 118° to the right.
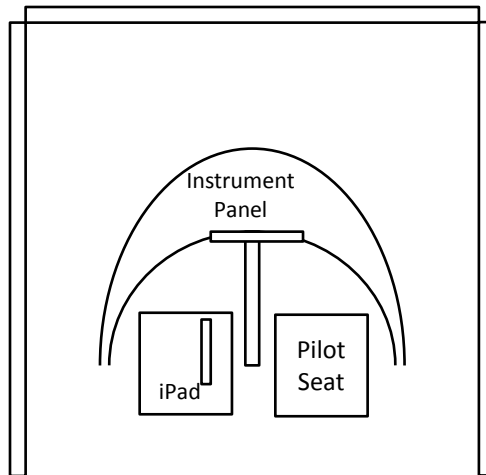
Figure 4.   Overhead Cockpit Arrangement

	Left	Right
Elevation	18º	36º
Depression	37º	59º

Table 3.   Viewing Angles from Pilot's Seat

Three sets of IR cameras provided the input to FaceLAB for the eye tracking data. These were arranged around the cockpit in order to collect gaze parameters from any normal rotation of the head.   In general, they were positioned to be unobtrusive for the participants, sitting well below their line of sight if they were to look at the bottom of the large displays (the lowest display in the setup). As such, the cameras provided a "look-up" view of the participants. Calibration occurred for each participant prior to the commencement of the practice scenario.

2.   Software

The software package used in this experiment was similar to the package used in Sullivan (2010). FaceLAB 5.0 collected the incoming data from all camera pairs and integrated into one file with FaceLAB Link 2.0. The collection process included from which camera the gaze data came, as some eye positions

could be tracked by more than one set of cameras (e.g., center OTW display). FaceLAB required a one-time calibration per individual. After this calibration, the participant had reasonable range of head rotation in the transverse and frontal planes for the duration of the experiment. The programs used to render and collect data were:

- X-Plane 9.0
- FaceLAB 5.0
- Delta3D and OpenSceneGraph

D. SCENARIOS

Charts for Scenarios 2, 3, and 4 can be found in Appendix B.

1. Practice Scenario

The Practice Scenario is a combination scenario involving both navigation and target detection and identification. It contained both tasks, and although data collection occurred, this scenario was done to ensure the equipment was properly set up and functioning and to introduce the individuals to the equipment and allowed them to acclimate to differences from equipment or platforms on which they may have previous experience. When situated, the research member "unfroze" the simulator, thus commencing the flight and giving the participant control of the aircraft. The participant flew through the established waypoints detecting targets as they showed in his view.

2. Scenario 2–Navigation without Targets

Scenario 2 involved strictly navigation without the burden of target detection and identification. Twelve waypoints provided approximately six to nine minutes of flight time depending on the accuracy of the pilot in maintaining adherence to the given course. Although just a single task, navigation is the second hardest of the three tasks because the pilot must physically maintain the heading of the aircraft, and keep track of the location of the aircraft. This meant looking out the window, taking in visual cues from the terrain, and comparing

them to what was presented on the chart in order to mentally place and track the movement of the aircraft through the scenario.

3. Scenario 3–Navigation and Target Detection and Identification

Scenario 3 was the combination task involving both navigation and target detection and identification. The purpose of this scenario was to determine how the individual performed when presented with multiple tasks simultaneously. They were given no instruction as to which task to prioritize. Upon commencement of the scenario, the individuals flew around 12 designated waypoints while detecting 11 targets. Targets were placed such that if gaze data was available, there would not be confusion as to which target an individual is observing (i.e., there was ample lateral separation between targets as viewed from the vicinity of the given course).

4. Scenario 4–Target Detection and Identification on Auto-Pilot

Scenario 4 involved target detection and identification while the software controlled the movement of the helicopter (i.e., while on autopilot). Although given a chart study period, this was for consistency as there was no need and the pilot could not influence the direction of the helicopter. As with Scenario 3, seven waypoints were provided, among which 10 targets were placed. Total flight time ranged from approximately seven to nine minutes. This scenario explored the pilot's ability to concentrate strictly on one task, which although slightly more complicated than just detection, we deemed as the simplest of the three experimental scenarios.

E. MEASURES

1. Surveys

a. *Demographic*

We collected demographic data from all participants prior to the commencement of the experiment. Appendix G shows the demographic survey.

The purpose of this survey was to collect information regarding the participants' backgrounds and experience, including flight hours and time since their last flight. Pertinent information collected for this experiment is detailed in Table 2.

b.   Pre/Post-Experiment

The pre- and post-flight surveys (Appendix H) served the purpose of both determining how confident the individual was that he would be able to accomplish the tasks just from the chart study period, and then after the scenario, how confident they were that they actually did accomplish the tasks. The surveys make use of the Likert scale and ask the participants to rank their difficulty on a scale. Instead of using a 1–5 ordinal scale, we opted for a line graphic which allowed the participants to select a continuous value along the line. Immediately after the chart study, we gave the pre-flight survey to the participant and they filled it out. Upon completion, the research team member proceeded with the scenario. With the scenario complete, the researcher gave the individual the post-flight survey, which asked the same questions, this time acquiring a *post-facto* representation of the flight performance.

2.   Data Collection

Data collection began before the individual had control of the aircraft. The instructor would start the scenario with the model on motion freeze, meaning the scenario was running, data was being collected, but the simulated helicopter would not move. Once the researcher confirmed correct operation, the participant was given control of the aircraft and taken off motion freeze. Data from FaceLAB would be aggregated in one file per participant per scenario. Table 5 shows the fields captured in the data logs. Additionally, a Canon VIXIA HF R11 camera captured audio and visual during each trial. The audio/visual data was not utilized in the analysis of this data.

3.   Procedure

Upon arrival at the lab, we briefed each participant on the structure of the experiment and had him sign consent forms illustrating the voluntary nature of the experiment. The volunteer filled out the demographic survey described above anonymously. To decrease confounds coming from vision differences, we administered a basic eye test using the Snellen eye chart to ensure that all participants had corrected vision of at least 20/30 in one eye. They would then take their place in the right seat of the cockpit and the instructor would proceed to calibrate the cameras (Appendix F).

Prior to commencing each scenario, we gave the participants a topographical land map on the scale of 1:50,000. These charts are familiar to pilots as they are often used in low-level flight planning and execution. Each one featured the assigned route, headings, and straight-line times between subsequent waypoints. After a five-minute chart study, we administered the surveys as described in the surveys portion of this chapter. This allowed us to collect subjective data from the participants on how difficult they think the flight will be. Once complete with the chart study, the individuals commenced the mission. Actual flight times varied per individual and scenario, but most runs did not last any more than about 10 minutes.

During the flight, the researcher would monitor progress from the instructor station. If the participant at any time admitted to being lost they would be given a heading to get them back on track. If they were more than 2 km off track at any point, the researcher would ask them where they thought they were, then proceed to give them a heading back to the last waypoint that was successfully found. At the completion of the scenario, we gave the participant a *post hoc* survey to reassess the difficulty of the scenario.

IV.   RESULTS AND DATA ANALYSIS

A.   DATA PREPARATION / PRELIMINARY ANALYSIS

This section will look at the collected data and analyze it as it pertains to the hypotheses. We use the software packages Microsoft Office Excel v14 and JMP Pro v9.0.0 to perform our analysis.   Unless otherwise stated, each hypothesis is analyzed per scenario with comparisons made thereafter.

1.   Data Preparation

The data was collected from Image Generator, FaceLAB, and X-Plane. The output came as one comma-separated-value (.csv) file per participant, per scenario for a total of 60 csv files. Participant 13 had corrupted FaceLAB data and was removed. This left 14 participants with quality data for analysis.

The data required substantial preprocessing before statistical analysis could begin. The initial portion of the analysis dealt with removing FaceLAB data that was acquired before and after the actual commencement of the scenario. For continuity and thoroughness of data, collection began before the participant was given control of the aircraft (helicopter held in constant position) and ended after the scenario was frozen at the end. These rows of data had to be removed in order to have only the data that occurred while the participant was in control of the helicopter and engaged in the scenario. As all scenarios started out with the helicopter heading in a roughly northerly direction, latitude would have the quickest deviation once the scenario was unfrozen. This allowed a comparison of the latitudes as the benchmark of when the scenario actually began. A $\Delta^0 =$ .000005º (corresponding to one-half meter on the ground) was chosen as the benchmark for helicopter movement apart from scenario initialization.   This corresponds to approximately half a meter of movement at the scenarios' specific latitudes. After cleaning the header of every scenario run, the data files were reversed and run through the algorithm again, effectively eliminating the footers

of every file.   Additional prepreocessing was performed in Python v2.7 to examine the csvs, we created valid files that had strictly the data from when the participants were in active control of the helicopter.

a.   Blink Data

The next step of data preparation was to extract the necessary values to explore the hypotheses. Blink data was extracted from the raw data by comparing subsequent values from the "Blink" column in the csvs. For the blinks, a "1" represents the time when the individual is in the process of blinking while a "0" means the eyes are open. When the value transitioned from 1 to 0 or vice versa, the column and appropriate information was collected and written to a new file. We collected tally information for the entire sample group in a separate file. As we were only concerned with the blink rate (number of blinks per minute), this was the extent of blink data extraction.

b.   Saccade Data

Saccade data was extracted in a similar manner to the blink data by comparing their respective cells in subsequent frames. As shown in Table 6. data collection represents a saccade with the value of "1." "Zeros" showed when the eyes were fixated for the saccade data. Saccade extraction included not just when a saccade occurred, but data as to on which screen the saccade occurred.

c.   Fixation Data

Because FaceLAB and Image Generator both take data points ranging from 30–60Hz, it was necessary to filter the data to eliminate noise. Fixations that did not last 70 msec or more were considered noise and filtered out of the data. All fixations longer than 70 msec were sorted to count the number of fixations that the individual had while focused either out-the-window (OTW), at the instrument panel (IP), or at the chart (Map) so that they could be tallied per area.   Individual assessments of each subject-scenario pairing

included the time and location of each fixation. The overall tally had the collective time of each pairing's total saccades, and the count and time of each of the three generalized scan locations detailed below.

d. Scan Pattern Data

Scan data was collected by first determining at which screen the participant was focused on. If scan data was unavailable, i.e., there was no gaze intersection, the scan data for those particular frames was ignored. Given this issue and the need to aggregate scan data, the possible scan locations were grouped into three locations: out-the-window, instrument panel, and map. These corresponded to respective "screenNames" from FaceLAB. Individual assessments of each subject-scenario pairing had merely the elapsed time and screenName, which were then run through a third program to gather counts for every transition. Given three scan locations (OTW, IP, Map), this gave six possible transitions (OTW-IP, OTW-Map, IP-OTW, IP-Map, Map-OTW, Map-IP), which were also calculated.

The three measures named above comprise the "salient stimuli" referenced in the hypotheses. To minimize differences in actual flying ability, controls were in place to keep the helicopter at a constant altitude (150') with a constant airspeed (90 knots). Although we provided multiple instruments, with the above parameters on autopilot, the only instrument on the instrument panel under the participants' was the heading indicator (if used). With this knowledge, "salient stimuli" represents an understanding of where the individual is focused to determine where they are gathering their information (OTW, IP, Map).

e. Eye Scan Efficiency

We calculated eye scan efficiency using the overall fixation count, median dwell times, and saccades per minute (SPM). Due to the ability of a few long dwells to skew the mean times (whether actual or from the inability of the equipment to detect a shift in attention), we opted to use the median dwell times

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as these more truly represent the length of time spent fixated on an area across the entire scenario. SPM shows a normalized representation of how often the participants shifted their gaze and equalizes the differences in total saccades due to increased scenario run times. Otherwise, eye scan efficiency is the effects of these parameters and required no further calculations or data preparation.

f.   Target Detection Data

Target detection data was analyzed from the set of deheadered/defootered files. Button press was the initial parameter for target detection. The initial filter program looked at when a button was depressed and compared it to the gaze intersection. A tolerance of .01° (≈1 km) on gaze intersection straight line distance as calculated from the difference of lat/long positions was considered "in sight" for an accurate detection[1]. Although 1 km may seem large, this value allowed for eye movement while processing the visual image, and the reaction being relayed to the hand to depress the button. True positive and false positive determination came from the button the participant pressed compared to the target's nature. A secondary analysis was conducted to determine if a strictly distance-wise collection could be done vice the gaze data. This turned out to result in worse detection data as the participants often sighted the targets (adversary missile or crashed plane) from a distance greater than within the provided tolerance (Δ = .005°). As such, this avenue was abandoned and we reverted to gaze data with the following deeper looks. Because gaze data was not available for every frame of data collection, the individual files were manually analyzed to determine whether the individual could reasonably have been looking at a target even though the gaze data was not collected.

There were two levels to analyzing target detection data in the absence of gaze data. The first was if the helicopter was in a position that could be in sight

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[1] Although longitudinal degree distance varies with latitude, due to the small latitudinal range of the study, a Euclidean distance suffices for distances from each lat/long pairing.

of the target (Δ = .005⁰). Secondly, the button presses examined in the context of their surroundings. If an appropriate button was pressed, at a point when it could be considered reasonable to press said button, within a reasonable distance from the target, the target was designated as a "Probable" detection in the matrix. In 0, the detections are shown by whether they were detected via eye gaze information, helicopter distance, or reasonable surrounding data. For calculations, we classified "probable" detections as true detections (true positives). Lastly, if there were button presses that could not be explained with a detection on target, they were classified as false negatives. For obvious reasons, there is no "true negative" detection as that would indicate the participant did not push a button when there was no button to push. Target detection analysis is summarized in Table 7 in Appendix B.

Analyzing the individual data sets occurred following the previous data filtering. Each hypothesis had a different requirement of data and therefore the code created separate csv files to analyze. Summary statistics are shown in Figure 24. Appendix C. The following sections discuss these results.

2.   Preliminary Analysis

Preliminary analysis of the data began with a comparison of Total Flight Hours versus Overland Flight Hours. As this is a navigation task based on land features, we collected both data points from the demographic surveys given to each participant. However, as Figure 12. illustrates, there is a very strong relationship between total flight hours and overland hours (p < .001, F = 101.4), meaning that one may reasonably be thought of as a proxy for the other. Therefore, we considered experience as based on Total Flight Hours, as this is a more typical measure of a flight experience. The flight hours were categorized as ordinal data such that the participant with the least flight hours was denoted as "1." These ranked hours then were used for hypothesis testing.

The second portion of the preliminary analysis involved determining how the participants fit in the context of the group. Using JMP to create various fit models and correlation models, we noticed that three individuals were consistently outliers from the rest of the group. Participants 8, 15 and 1 had either no flight hours or the lowest amount of flight hours (0, 0, and 50, respectively). It was deemed that these individuals constituted a different population of interest, i.e., non-pilots. (One participant is a Naval Flight Officer who, in the beginning of his training, received 50 hours of flight time, but whose primary job in the Navy is not a pilot, although it does involve spending a lot of time on tasks such as navigation.) Their data is excluded for the remainder of this thesis, bringing the participant count to 11.

The design intention was for the scenarios to have increasing difficulty from Target Detection and Identification only (Scenario 4), to Navigation Only (Scenario 2), and lastly Navigation and Target Detection and Identification (Scenario 3). However, the scenario designs may have been skewed as will be discussed further in Chapter V. Data for the Practice Scenario was excluded from the analysis as the scenario was used to train the participants and the collection method was not controlled and structured as the other three scenarios were.

B. HYPOTHESIS TESTING

This section will describe the testing of each hypothesis using the prepared data. All hypothesis testing use one-tailed significance of $\alpha = 0.05$.

1. Hypothesis One

H01: There will be no significant correlation between total flight hours and eye scan patterns in the Navigation, Target Detection, and Navigation & Target Detection tasks.

HA1: More experienced pilots will have more saccades, shorter and more fixations, more fixations on salient instruments and stimuli than inexperienced pilots.
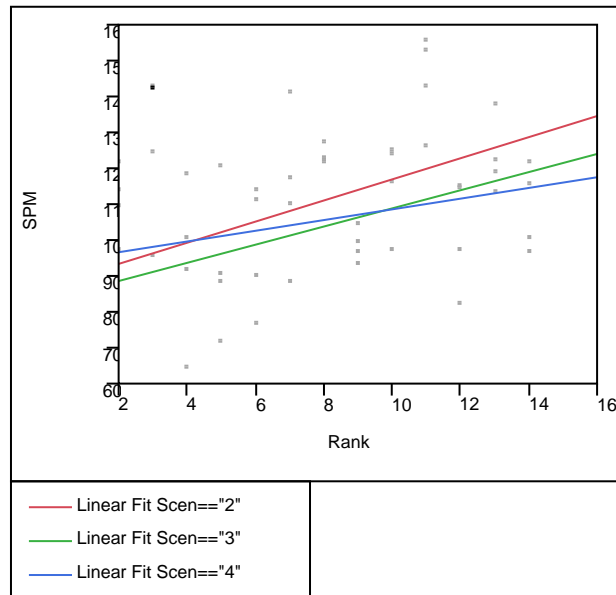
Figure 5.   Increasing Trend of Saccades per Minute by Ranked Experience Across All Scenarios.

As shown in Figure 5. , there is an increasing trend across all scenarios of more saccades per minute with increased experience. There was no significant correlation (Spearman's ρ ranged from .24–35), which could possibly be due to the small sample size.

Figure 6. is representative of the overall dwell times of the individuals. Although this is from one specific scenario for one participant (Participant 114, Scenario 4), all other distributions in the data set showed a common trend of being heavily weighted to the left side, i.e., shorter fixations. The small number of long fixations skew the mean of the data dramatically. Overall, the average difference between the means and the medians of fixation times is just under ¼

of a second (.2495sec). As such, we analyzed the data using median values as this more truly represents the representative values of the data set.

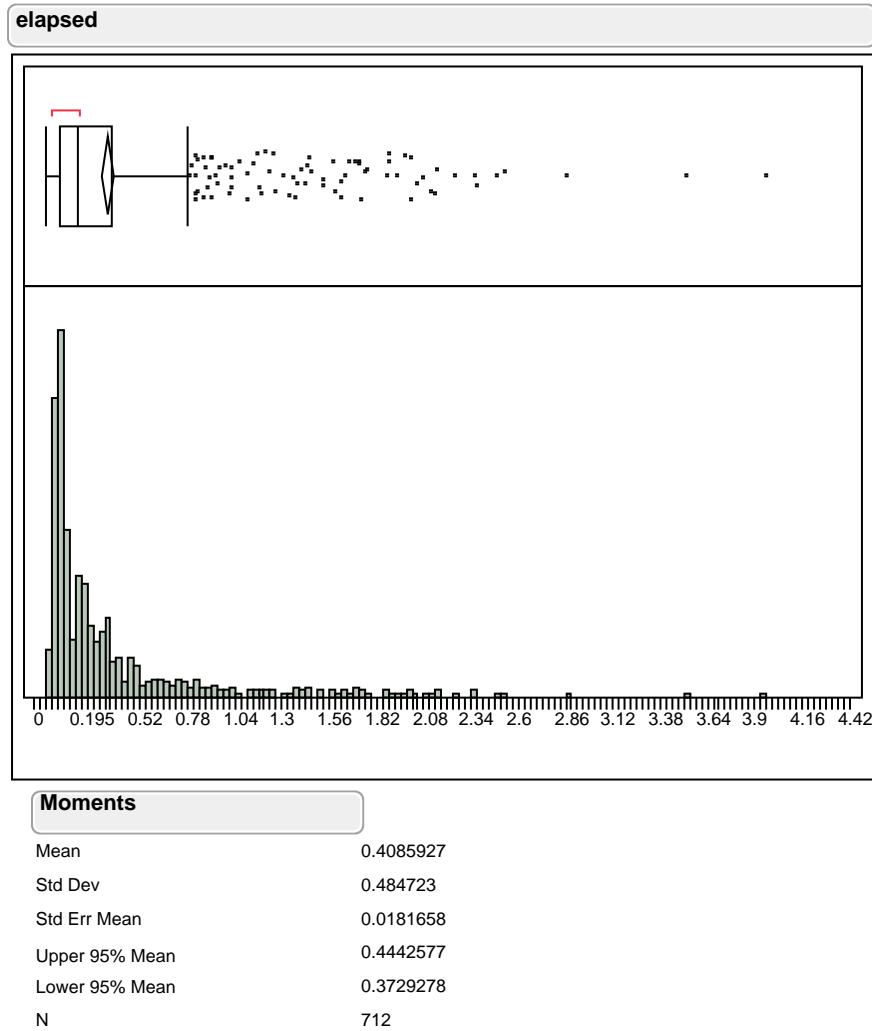| elapsed	
Moments	
Mean	0.4085927
Std Dev	0.484723
Std Err Mean	0.0181658
Upper 95% Mean	0.4442577
Lower 95% Mean	0.3729278
N	712

Figure 6.   Distribution of Dwell Times

Figure 13.   (Appendix B) demonstrates the multivariate relationships between fixation numbers, fixation durations, and ranked experience. As shown, there is no significant relationship between the average number of fixations across all scenarios and ranked experience ($\rho = 0.127$, $p = 0.482$). As would be

expected, a strong, negative correlation between dwell time and fixation number was found (ρ = -0.604, p < 0.001), indicating that participants with longer dwell times had fewer fixations. The results indicate that although more experienced pilots do trend towards more saccades, surprisingly, they do not have shorter dwell times or greater numbers of fixations. In this study, overall, the more experienced pilots do not have more fixations than inexperienced pilots do. Although saccades correlate to fixations in two out of three scenarios (Figure 14. ; see Appendix B), the statistical results do not show that experience correlates to fixations.

The amount of time or number of times that an individual fixates on a certain area was not significant for both cases. Figure 15. and Figure 16. (see Appendix B) show the multivariate and Spearman correlations for the time spent in each designated area (OTW, IP, Map) and how many times the individual's gaze went there. For the most part, the results are not significant. However, one condition stands out as significant—experience on median map dwell time (ρ = -0.376, p = 0.031). This shows that as the experience of the participant increased, they spent less of their scan time looking at the map. Although not significant, a slight trend is also seen in a bivariate regression of the times and fixation counts on the map and instrument panel. These two fixation locations show decreases in both areas with increased experience. Correspondingly, a slight increase in out-the-window dwell times and fixation occurs.

Figure 17.   in the Appendix shows the trends in gaze locations by scenario. When we look at the OTW graph, we see that all experience levels look out the window most when the task is strictly target detection & identification (Scenario 4).   The IP and map regressions are relatively inconclusive for Scenarios 3 and 4, but in Scenario 2, there was a trend of decreasing fixations with experience. These will be discussed more in the following chapter.

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2.   Hypothesis Two

H02: There will be no significant correlation between eye scan pattern and performance in the Navigation, Target Detection, and Navigation & Target Detection tasks.

HA2: Pilots with more efficient eye scan patterns (more saccades, shorter and more fixations, fixations on salient instruments and stimuli) will perform better on the navigation (by adherence to the given course), target detection (more Correct Detections versus Incorrect and Missed Detections), and combination tasks.

a.   Navigation

We analyzed navigation performance via the fixation count, median dwell time, saccades per minute, and the respective interactions between the three. Only Scenarios 2 and 3 were analyzed as Scenario 4 was on autopilot and the minor differences in RMS error were due to randomness in the applications rather than pilot ability. Figure 18.   shows the multivariate interactions between these variables. As shown in Hypothesis 1, there is a strong and logical correlation between fixation count, median dwell time, and saccades per minute. However, none of these variables appears to have any effect on the root-mean-square (RMS) error in the navigation tasks. When we test the interactions between the effects (Figure 19.   ), we do not get any statistically significant results. However, given the sample size, there are some candidates for significance if a larger sample could be attained: overall fixations ($p = 0.186$), fixation × median dwell time ($p = 0.086$), and median dwell time × SPM ($p = 0.238$). Additionally, we ran RMS error against total flight hours and ranked experience and found that neither of these had any effect on the accuracy of navigation (flight hours $p = 0.927$, ranked experience $p = 0.849$). This supports the findings by Sullivan (2010) and could be explained by a more

experienced pilot's purposeful deviation from a given path for obstacle avoidance, timing, or possible other reasons.

b.   Target Detection

Using similar methodologies, we analyzed target detection using the correct detections from Scenarios 3 and 4.   Although false positive (incorrectly identified detection) data was collected, the false alarm rate was too low to warrant any sort of dependable analysis on the data.   In Scenario 3 (Figure 20.), Navigation & Target Detection, there is a very strong effect factor (p = 0.002, F = 80.64), with significant correlations showing up across all parameters and interactions; overall fixations (p = 0.029), SPM (p = 0.005), median dwell × overall fixations (p = 0.003), median dwell × SPM (p = 0.039), overall fixations × SPM (p < 0.001), overall fixations × median dwell × SPM (p < 0.001).   Interestingly, in Scenario 4 where the participant's only task was to detect and identify the targets, the effects from Scenario 3 did not carry over. The overall model for Scenario 4 was not significant (p = 0.107, F = 4.998) and the only significant predictor was median dwell time (p = 0.046) (Figure 21.) However, overall fixations (p = 0.089), and median dwell × SPM (p = 0.097) both show a possible significance given a larger data set.   In both scenarios, total flight hours and ranked experience did not show any correlation with correct detections.   We did not find any correlation between scan patterns (gaze locations) and target detection performance.

3.   Hypothesis 3

H0:   Regardless of expertise, there will be no difference in blink rates across scenarios.

HA: Pilots with more experience will have a higher blink rate than pilots with less experience.

Hypothesis 3 is not supported by the data.   However, there was a trend towards a lower blink rate as experience increased.   Figure 7.   shows all three

scenarios on one chart for comparison purposes. Although not significant, one can easily see an increasing trend of blink rate across all scenarios. The individual scenario details are shown in Figure 22. Scenario 3 has a dramatic difference in significance compared to the other two scenarios and approaches on statistical significance (p = .059 vs. $p \approx$ .5). As discussed above, given a larger sample size, we believe this value would be significant. Additionally, Figure 23. shows the ANOVA for blink rate by scenario. Scenario (presumably scenario difficulty) has a very significant effect on blink rate ($p < .001$). With further discussion on the compounding effects to blink rate, we will see in the following chapter that the data does not necessarily contradict previous studies.
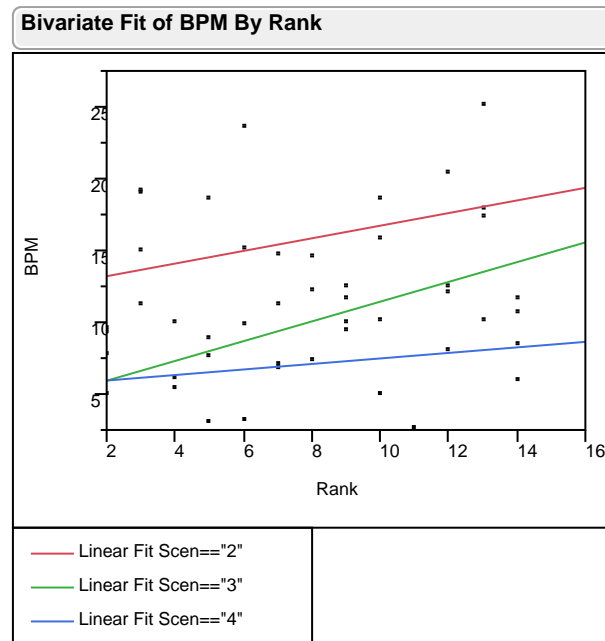

Figure 7.   Comparison by Scenario of Blinks per Minute vs. Ranked Experience

V. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

A. DISCUSSION

The purpose of this study was to analyze the effects of expertise and skills that would typically be associated with expertise during navigation, target detection, and combination tasks on a flight simulator. Although the results do not support all of the hypotheses, we will discuss what would affect the data. One common denominator across the hypotheses is the small sample size on which the team conducted the tests. With the population available at the Naval Postgraduate School, the ability to recruit larger samples is not always a readily viable option. However, even with a small sample size, we are able to glean some insights into the effects of experience on various tasks.

1. Hypothesis 1

HA1: More experienced pilots will have more saccades, shorter and more fixations, more fixations on salient instruments and stimuli than inexperienced pilots—partially accepted.

Although the regression for the saccades per minute by ranked experience did not show any significance, there is an increasing trend between the two that may show significance if we had a larger sample population. We propose that experienced pilots are looking around the scene more, acquiring more visual information, and presumably, processing this information faster than inexperienced pilots to create a more thorough mental picture of their environment.

Contrary to the above inference, the lack of a significant relationship between fixations (dwell time and total fixations) and experience provides an intriguing result. We found a strong correlation between median dwell time and the overall fixations ($p < .001$), which should come from an analysis of cause-effect—in order to have more fixations in a set time, one must reduce the length

of each one. However, total flight hours did not correlate with either of these. With a positive correlation between SPM and expertise, and the lack of correlation between fixations and expertise, it could be possible that the filter time used to separate a fixation from noise (t = 70msec) was too large. We conducted an exploratory analysis on the data with t = 50msec and t = 40msec but did not find any significant correlation with these two times either.

From a conceptual point of view, we believe that this lack of correlation comes as an artifact of the sample population. As mentioned, all participants (save the three whose data were outliers) are military pilots going to NPS. They had completed at least one tour of duty in their respective services and those services consider them "experts" capable of commanding and being responsible for one or more aircraft. This means that our participants have all developed a scan pattern that works for them. They are capable of rapidly surveying the scene and acquiring the information they need to complete the tasks. Were we able to utilize a less experienced population, perhaps those still in the training squadrons or young winged aviators that are still fresh, we may begin to see a breakout in the measurements of the scan patterns.

Interestingly, OTW was the only location where overall fixation count trended upwards with experience in each scenario. Although each pilot has their own scan pattern, it would be expected that an experienced pilot spends more time, thus have more fixations, in the area which he or she deems most salient at for the given flight portion. As these were primarily visual tasks, OTW would be most salient and it is not surprising that experienced pilots spend an increasing amount of time there than at the instrument panel or the map. When we look at the results from the IP and Map counts, Scenario 2 has a non-significant decrease with experience, but the other two scenarios are almost flat across experience. It may be that the pilots with more experience are able to maintain a mental picture of the chart for longer and track where they are mentally, without the need to look at the chart as often as the inexperienced pilots are.

Additionally, although in a real aircraft the instrument panel provides a large amount of salient information, our instrument panel displayed only a few instruments that the pilots may or may not have used. It would make sense that an experienced pilot could analyze how often he or she needs to look at the instrument panel and the map, and they could allocate more fixations out the window, as shown in Figure 17.

2.   Hypothesis 2

HA2: Pilots with more efficient eye scan patterns (more saccades, shorter and more fixations, fixations on salient instruments and stimuli) will perform better on the navigation (by adherence to the given course), target detection (more Correct Detections versus Incorrect and Missed Detections), and combination tasks—partially accepted.

Data collected also partially supported Hypothesis 2. Eye scan pattern did not show any correlation to performance in the navigation tasks. Again, this could be an artifact of the sample population that participated in the experiment. As discussed in Sullivan (2010), this could also be due to deliberate and calculated deviations from course by the pilot. Without having had collected any data that could illustrate whether the individual was purposefully off-track or if they were lost, we cannot predict whether their eye scan pattern—although possibly more refined and efficient—would have led to any improvement in navigation if kept on track.

Unrelated to experience, more saccades, more fixations, and shorter dwell did predict better performance on the target detection and identification tasks in both scenario 3 and 4. Scenario 3 had dramatic significant effects from all parameters and their interactions (Figure 20.). From this, we can reiterate that those with more efficient scan patterns will be able to detect and identify targets (or other anomalies) outside with better accuracy than those with less efficient scan patterns. This does not say anything for the rate of detection and only

stands for targets such as those in our experiment that were stationary. The non-moving property of the targets is actually beneficial to the aspect of visual workload and cognitive workload as the human eyes are more adept at detecting an object in motion than an inert one. If we did have moving targets, detection would presumably occur sooner, but we can say nothing on the accuracy of identification.

3. Hypothesis 3

HA:3 Pilots with more experience will have a higher blink rate than pilots with less experience—ACCEPTED.

The design of the experiment had the intention of Scenario 3 (navigation with target detection & identification) being the most difficult with 2 (navigation only) being second and 4 (target detection and identification only) being the easiest. Our results did show a trend toward significance with blink rate and expertise (Figure 7. and Figure 22.) as a positive relationship in all three scenarios.

Interestingly, Scenario 2 (Navigation only) recorded the highest levels of blink rates in all participants, followed by Scenario 3 then 4. Our initial thought was that Scenario 3 would be the most taxing scenario. However, if we look again at how Megaw (2005) summarized the literature on the subject, "acquisition of visual information [is] associated with lower blink rates, and visual cognitive processes with higher rates." For navigation only, the predominant workload would be cognitive, and target detection and identification would be visual. We did not instruct the participants as to which task they should give priority in the combination task. Given that navigation is a much more cognitive process (matching a profile view of terrain to a topographical view) than looking out a window and finding targets, it follows that navigation *should* have higher rates than target detection & identification.

The question from here is why Scenario 3 (Navigation and Target Detection and Identification) does not have even higher blink rates than Scenario 2? We believe this is an artifact of the route design. Scenario 2's design had 12 navigation waypoints through which the pilots would fly. This may have increased the level of difficulty in Scenario 2 such that it eclipsed the combined difficulty of Scenario 3's combination task. Assuming this position, if blink rate in general increases with higher cognitive workloads, we would find the within subject layout as shown in Figure 22.

From here, there is still a trend of increasing blink rates between subjects with experience. We suggest that the pilots with more experience have an increased visual workload. The results show that they have more saccades, and whereas this did not translate into more fixations (given our threshold) or shorter dwell times, they are moving their eyes more. Within the saccades they are still gathering visual information. Through their years of experience, they can spend more time looking around (taking in more visual scenes) and less time concentrating on *what* they saw. The inexperienced pilots would spend more time thinking about what they saw and comparing it to a mental map (however fleeting the mental image may be from the last time they looked at the chart). In short, our experienced pilots acquired more visually, processed less, and the inexperienced pilots were vice versa.

4. Benefits of the Study

Although this thesis focused on pilots, results from the thesis will benefit the Navy and other military services by providing a metric by which trainers and instructors can potentially save time and money, particularly in tasks where the operator receives information as a burst (such as in a scan) and processes the information while not staring at their interface. In addition to a cockpit, other places where this work may apply would be any sort of dynamic environment such as infantry squad movement or on the bridge of a ship. If we can show that task loading can be reliably detectable with comparable results, thresholds and

limits can be established primarily in the training commands so that individualized training syllabi can be developed. Additionally, in the operational squadrons, it can be utilized to determine which individuals are naturally inclined towards certain mission sets and tracks can be defined for further training.

B. CONCLUSION

The realm of cognition is broad and in a military environment specifically, anything that can maintain the balance between performance and arousal level is beneficial. However, we must be able to detect these changes in individuals in real time. Experience was not found to have significance in many of the analyses we conducted. As mentioned in the discussion for Hypothesis 1, we posit that our sample size may have been too small to get significance from the experiment. With a Spearman's correlation accounting for the flight hour bias in the study, we did get significance showing that more experience can be detected by an increase in saccades. Although we were not able to determine how the saccades related to scan pattern, the increase in saccades allows for more fixations, which should lead to a greater intake of visual information. It is in the processing of this visual information where experience would come into play. A more experienced pilot should be able to process what he or she is seeing with better efficiency than an inexperienced pilot.

Our results from the navigation portion support previous research done by Sullivan (2010). Navigation is a fluid process where unless told otherwise, one is able to make adjustments on the fly. Knowing that waypoints are (most often) not optional, the ability for an experienced pilot to make adjustments along his route of flight is one aspect, and responsibility, that they have in being a senior pilot. We did not show any decrease in RMS error along the flight route as experience increased, but as explained above, this could possibly be the experienced pilots merely making up for lost time, earlier deviations, threats, terrain, or weather by adjusting their route.

Cognitive workload in this experiment, although not statistically significant, showed a nice trend to support the given literature. In a task that requires more processing of the visual information, our blink rates supported what Megaw (2005) wrote regarding both the increase within tasks (between individuals) and between tasks. To be able to use this metric in future work would be reliable as it does not require the fidelity and resolution that pupillometry would require.

C.   RECOMMENDATIONS

1.   Future Work

This research can benefit from further study in multiple areas. Presented below are a few of the areas, but any one of them could be expanded or narrowed in order to refine the process of detecting cognitive workloads.

a.   *Pupil Data*

In Chapter II, we explained how pupils are effective indicators of cognitive workload. When collected, the data can provide a much more precise indicator of when an individual is experiencing cognitive load. Although one can consciously control blinks if they wanted to, they cannot control the fine workings of the pupil. It will contract and dilate unbeknownst to the individual and in response to certain environmental and cognitive cues. With this experiment, we were not able to capture enough pupil data to make this a viable option. As of this writing, another experiment is being designed at NPS to explore pupillometry and cognitive workload further, but it could benefit from larger populations, and populations that are more diverse.

b.   *Use Fleet and Training Squadrons*

One major obstacle at NPS is that of sample populations. A majority of military officers (U.S. and international) that have already completed one or more tours of duty in their respective services attends the school. As such, and as mentioned, our pool of pilots was, in the eyes of the military,

experienced. Those with less hours than our population would be found in the fleet squadrons (< ~800 hours), the Fleet Replacement Squadrons (< ~300 hours), and the training squadrons (< ~200 hours). To be able to use those populations as well would create a much more dynamic mix of experience from the truly novice in the training squadrons, to the officers with multiple fleet tours of experience. The Navy's initial core training occurs in a few cities in Florida, Texas, and Mississippi. If those training squadrons are not available to use, the Fleet Replacement Squadrons in Virginia, California, and Florida would provide the next layer of experience. This would consist of officially designated pilots that have completed flight training and are learning their operational aircraft. The other services have similar programs that would allow a more assorted selection of individuals and training regimes. Lastly, only one participant could be considered "current" with his flight hours, with the rest having not flown in none less than five months. Access to the squadrons would reduce this variability as well as pilots in fleet squadrons are required to maintain a minimum monthly flight hour quota.

c. Allow Full Flight Control

The discussion for Hypothesis 3 mentioned how our navigation scenario may have been more difficult than planned. In actual flight, one is not only maintaining heading and possibly looking for targets on the ground. They would be maintaining altitude and airspeed, communicating with other forces, checking the status and health of the aircraft, along with a myriad of other tasks. In a crewed aircraft this can, and is, divided among the members, but in a single-seat aircraft, one individual is responsible for the entirety. To test cognitive workload and truly see how experienced pilots manage their scans and tasks, we would need an experiment that incorporates more of these tasks, perhaps in increments. It would be interesting to see how experienced pilots cope when they finally reach their cognitive workload threshold. Which tasks do they shed (if any) in order to give priority to the more essential jobs? Is there a method they

use to remain at the peak of the arousal-performance curve? What happens when they start falling one way or another on the curve?

2. Training Applications

Training applications with the use of cognitive workload detection would have to be refined and incorporated into current training syllabi in order to be effective. In a concurrent thesis at NPS, an individual has taken the eye tracking equipment to simulators in existing fleet squadrons to study scan patterns in relation to controlled flight into terrain. This shows that the equipment can be set up and operated in operational commands. To be able to use it regularly to analyze the pilots' gazes and scan patterns could provide instant feedback and allow them to consciously adjust their scan if need be. For obvious reasons, the equipment use in an actual aircraft is not feasible for safety reasons, but being able to set it up temporarily or permanently in a simulator is safe.

If we could detect and analyze cognitive workloads in real time, the training environment could change dramatically. Trainers and instructors would know what tasks an individual has difficulty on and concentrate on those while spending less time on a task in which the individual shows proficiency. It could also allow a young pilot to fine tune his or her scan prior to entering the actual cockpit. As time is at a premium in the military, optimization of the time and resources available can lead to a better product in the end.

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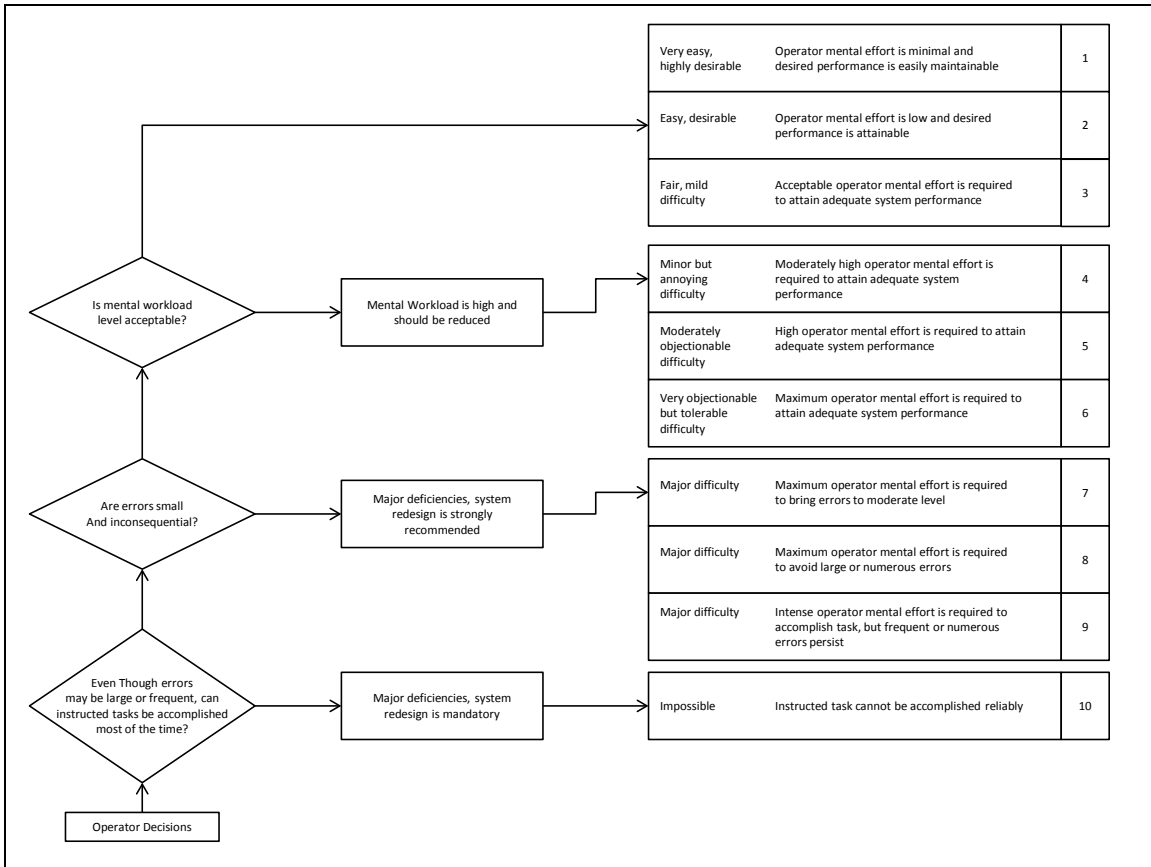
APPENDIX A. RATING SCALES

Very easy, highly desirable	Operator mental effort is minimal and desired performance is easily maintainable	1
Easy, desirable	Operator mental effort is low and desired performance is attainable	2
Fair, mild difficulty	Acceptable operator mental effort is required to attain adequate system performance	3
Minor but annoying difficulty	Moderately high operator mental effort is required to attain adequate system performance	4
Moderately objectionable difficulty	High operator mental effort is required to attain adequate system performance	5
Very objectionable but tolerable difficulty	Maximum operator mental effort is required to attain adequate system performance	6
Major difficulty	Maximum operator mental effort is required to bring errors to moderate level	7
Major difficulty	Maximum operator mental effort is required to avoid large or numerous errors	8
Major difficulty	Intense operator mental effort is required to accomplish task, but frequent or numerous errors persist	9
Impossible	Instructed task cannot be accomplished reliably	10

Decision nodes:
- Is mental workload level acceptable?
- Are errors small And inconsequential?
- Even Though errors may be large or frequent, can instructed tasks be accomplished most of the time?
- Operator Decisions

Action boxes:
- Mental Workload is high and should be reduced
- Major deficiencies, system redesign is strongly recommended
- Major deficiencies, system redesign is mandatory

Figure 8.   Cooper-Harper Rating Scale (From Cooper & Harper, 1969)

Time Load	Mental Effort Load	Stress Load
1. Often have spare time. Interruptions or overlap among activities occurs infrequently or not at all	1. Very little conscious mental effort of concentration required. Activity is almost automatic, requiring little or no attention	1. Little confusion, risk, frustration, or anxiety exists and can be easily accomodated
2. Occasionally have spare time. Interruptions or overlap among activities occurs frequently.	2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamilitarity. Considerable attention required.	2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
3. Almost never have spare time. Interruptions or overlap among activities occurs frequently, or occur all the time.	3. Extensive mental effort or concentration is necessary. Very complex activity requiring total attention	3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required

Table 4.   SWAT (From Proctor & Van Zandt, 2008; Megaw, 2005)

Title	End Points	Description
Mental demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Low/High	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally or physically) to accomplish your level of performance?
Frustration level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Table 5.   NASA-TLX Rating Scale (From Hart, 1998)

Field	Description
elapsedTime (sec)	Continuous measurement of time from the point when data collection began
faceLABFrameNum	Ordinal count used by FaceLAB to maintain order of the data over time
headTrackingState (int)	1–4 tracker of the quality of the head model in FaceLAB
leftEyeQuality (int)	1–3 tracker of the quality of the left eye model in FaceLAB
rightEyeQuality (int)	1–3 tracker of the quality of the right eye model in FaceLAB
screenName	Delineates which screen and which camera were used for detection of the Frame
headX (pixels)	Orthogonal X intersection on the screen of the direction the forehead is facing
headY (pixels)	Orthogonal Y intersection on the screen of the direction the forehead is facing
gazeX (pixels)	Screen X intersection of the point of focus
gazeY (pixels)	Screen Y intersection of the point of focus
saccade	1/0 value indicating if the eyes were in movement or fixed. 1 = saccade, 0 = fixed
blink	1/0 value indicating if the eyes were in the process of blinking
heloLat (deg)	xPlane latitude of the helicopter model
heloLon (deg)	xPlane longitude of the helicopter model
heloAlt (m)	xPlane pressure altitude of the helicopter model
heloAltAGL (m)	xPlane Above Ground Level altitude of the helicopter model
heloHeading (deg)	xPlane heading of the helicopter model
heloPitch (deg)	xPlane angle along lateral axis of helicopter model
heloRoll (deg)	xPlane angle along longitudinal axis of helicopter model
otwIntersectLat (deg)	Out-the-Window latitudinal intersection on the xPlane chart of the gaze
otwIntersectLon (deg)	Out-the-Window longitudinal intersection on the xPlane chart of the gaze
otwIntersectAlt (m)	Elevation of the gaze intersection on the xPlane chart
iPad_rotation (radians)	Angle of rotation of the chart on the iPad
iPad_scale	Zoom of the chart on the iPad
iPadIntersectLat	Latitudinal intersection of the gaze while fixed on the iPad
iPadIntersectLon	Longitudinal intersection of the gaze while fixed on the iPad
button1	1/0 indication of if button1 was depressed indicating an identified SAM
button2	1/0 indication of if button1 was depressed indicating an identified crashed plane

Table 6.   CSV Table Fields

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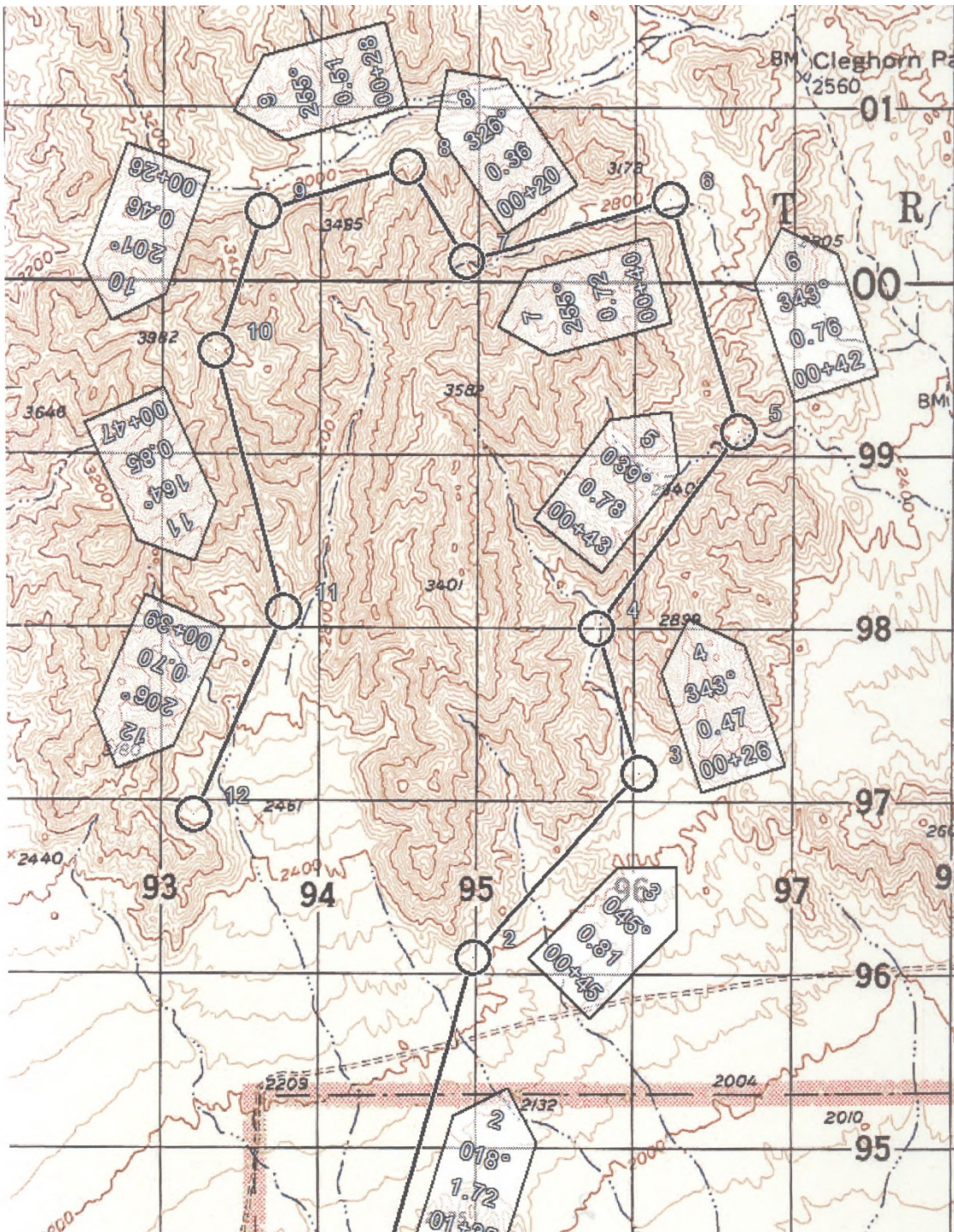
APPENDIX B. SCENARIO CHARTS
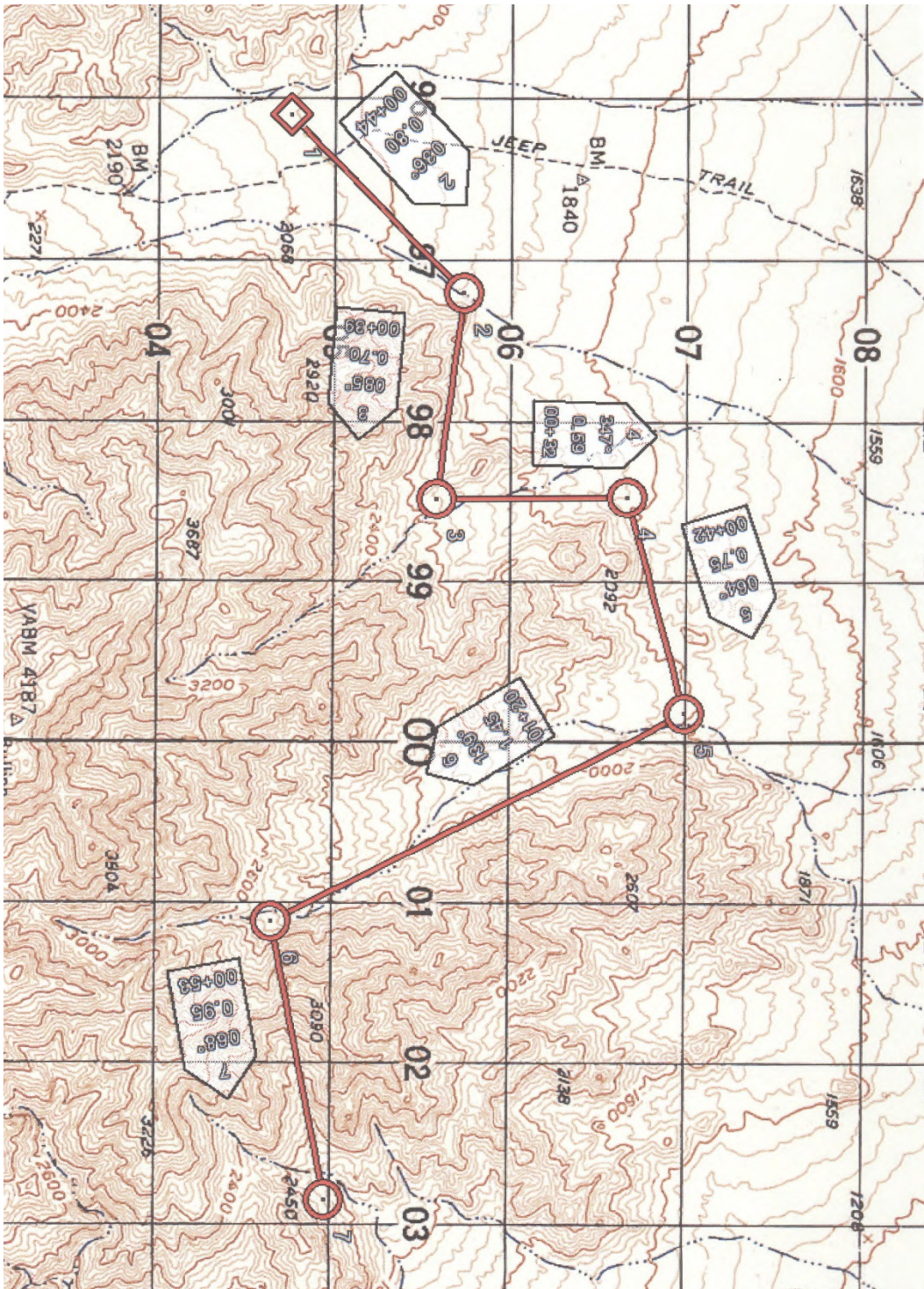

Figure 9.   Scenario 2 – Navigation Only

Figure 10.   Scenario 3 – Navigation and Target Detection and Identification
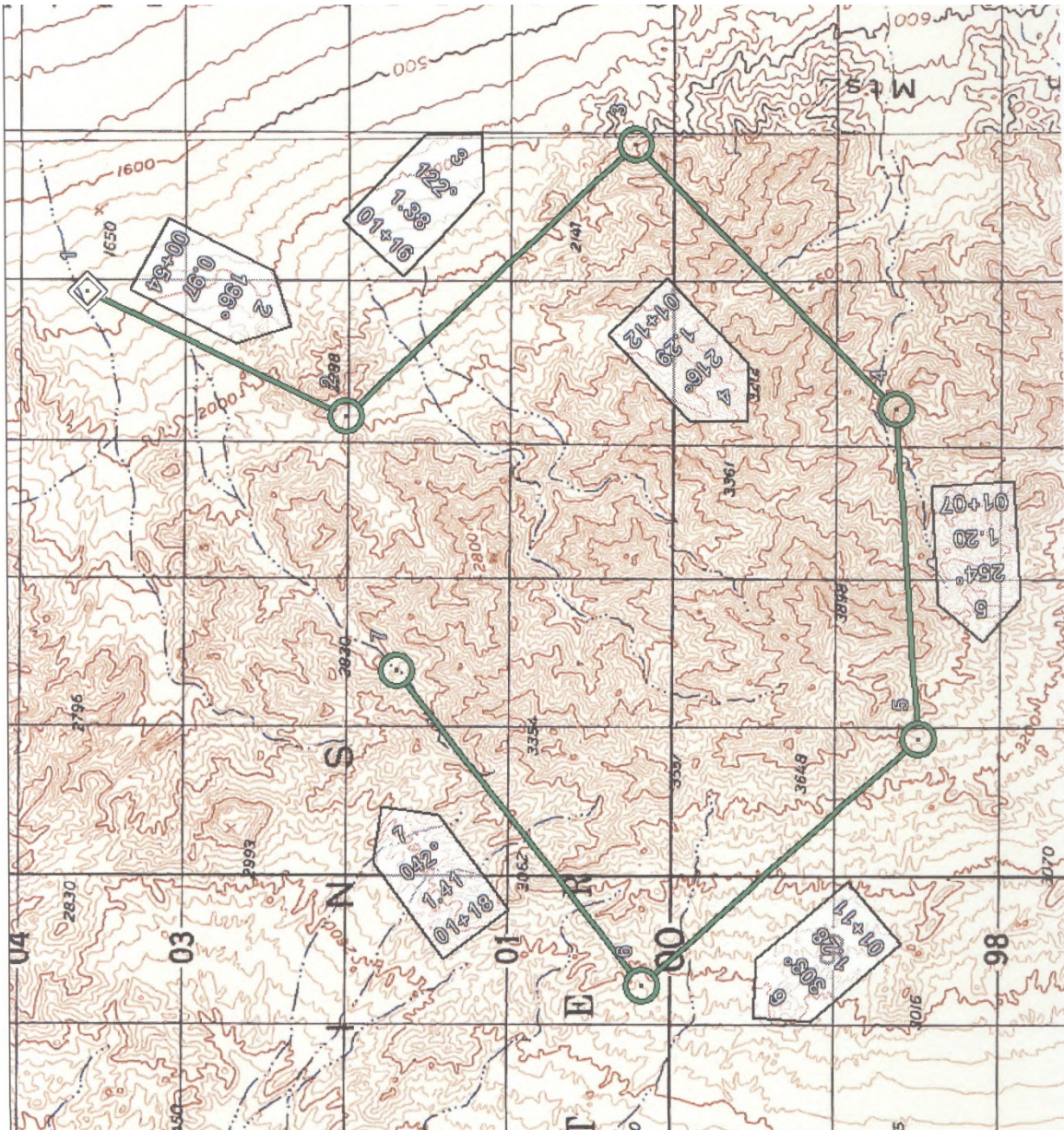
Figure 11.   Scenario 4 – Target Detection and Identification on Auto-Pilot

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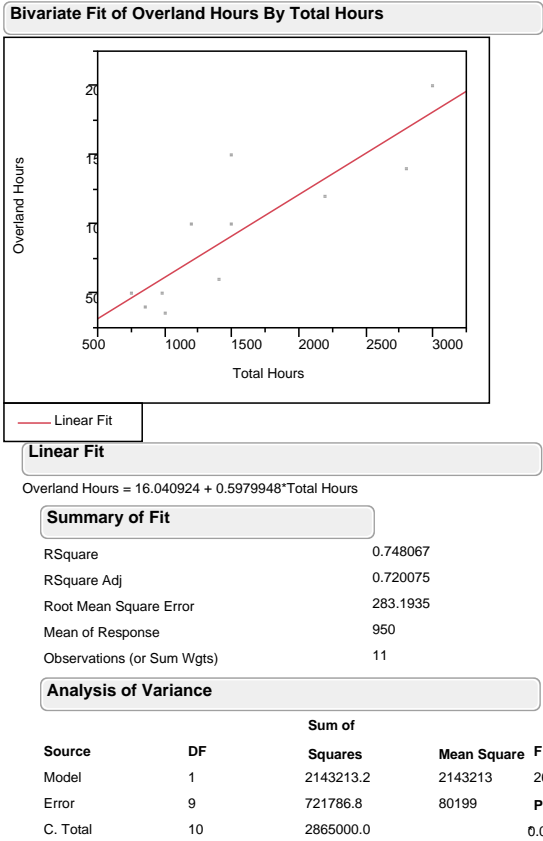
APPENDIX C. DATA FIGURES/TABLES

Bivariate Fit of Overland Hours By Total Hours

— Linear Fit

Linear Fit

Overland Hours = 16.040924 + 0.5979948*Total Hours

Summary of Fit

RSquare	0.748067
RSquare Adj	0.720075
Root Mean Square Error	283.1935
Mean of Response	950
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ra
Model	1	2143213.2	2143213	26.7
Error	9	721786.8	80199	**Prob**
C. Total	10	2865000.0		0.000

Figure 12.   Total Flight Hours vs. Overland Hours Correlation

Route	Type	Lat	Lon	108	115	101	103	111	102	112	109	106	107	105	104	114	110
Practice	SAM	34.303032	-115.895676		0.004		0.006		0.008								
	SAM	34.3148167	-115.8903167				0.005		0.005							0.002	
	Crashed Plane	34.3185	-115.883533						0.010								
	SAM	34.319767	-115.876033						0.012		0.007						
	Crashed Plane	34.3208	-115.87055						0.016								
	Crashed Plane	34.324863	-115.857674						0.005					0.004		0.005	
	SAM	34.330303	-115.85276														
	SAM	34.336517	-115.856308			0.002	0.002										0.010
	Crashed Plane	34.362141	-115.869911														
	Crashed Plane	34.367672	-115.889862				0.003									0.003	0.007
	SAM	34.340786	-115.888756				0.003										
	Crashed Plane	34.335411	-115.892281				0.003				0.004						
		True Positive Plane		1	4	3	5	2	5	2	5	4	4	3	2	5	5
		False Positive Plane		1	0	0	0	1	0	0	0	0	1	1	0	0	0
		True Positive SAM		3	4	4	3	2	6	1	3	4	3	3	2	5	6
		False Positive SAM		0	1	1	0	0	0	0	0	1	0	0	0	0	0
		False Negative		0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Missed Detection		7	3	4	4	7	1	9	4	3	4	5	8	2	1
Nav and Identify	Crashed Plane	34.386154	-115.95			0.005		0.006						0.005	0.003		
	SAM	34.387405	-115.943802											0.009	0.007		
	SAM	34.392745	-115.941994						0.006					0.008	0.005	0.003	0.004
	SAM	34.389198	-115.939331													0.004	0.004
	Crashed Plane	34.392277	-115.928734			0.005	0.003	0.001		0.002			0.001		0.002		
	Crashed Plane	34.40279	-115.927483											0.007			
	SAM	34.3988	-115.914169				0.006			0.007					0.006		0.006
	Crashed Plane	34.394493	-115.911667														
	SAM	34.384644	-115.909927				0.005		0.009								
	Crashed Plane	34.379684	-115.90448				0.001										0.003
	Crashed Plane	34.382454	-115.883095				0.002	0.009	0.011								
		True Positive Plane		3	3	4	5	4	3	4	1	2	3	3	3	3	2
		False Positive Plane		0	1	0	0	1	2	0	1	0	1	0	0	1	0
		True Positive SAM		4	4	3	4	4	5	4	5	2	4	2	4	5	5
		False Positive SAM		1	0	0	0	0	0	0	0	0	0	0	0	0	0
		False Negative		0	0	0	1	1	0	0	0	0	0	0	0	0	0
		Missed Detection		3	3	4	2	2	1	3	4	7	3	6	4	2	4
Auto Pilot	Crashed Plane	34.361977	-115.769272														
	SAM	34.356796	-115.767075														
	Crashed Plane	34.351295	-115.773979	0.003					0.013	0.003							0.002
	SAM	34.343479	-115.763817				0.004	0.007			0.002			0.005	0.002	0.007	0.004
	SAM	34.343895	-115.756401					0.004	0.012	0.003				0.008		0.005	
	Crashed Plane	34.329517	-115.764389	0.003			0.006	0.013						0.005			
	SAM	34.327057	-115.772789							0.005	0.005						0.005
	Crashed Plane	34.326965	-115.785065	0.004		0.008	0.004	0.004		0.005		0.007	0.010			0.008	
	Crashed Plane	34.329311	-115.805344	0.007	0.006		0.002		0.013	0.004			0.008				
	SAM	34.354527	-115.787178												0.006		
		True Positive Plane		5	3	4	4	4	4	3	2	3	5	3	3	3	3
		False Positive Plane		0	0	0	0	0	0	0	1	0	0	0	0	0	0
		True Positive SAM		3	5	4	2	5	4	4	3	4	4	3	3	4	4
		False Positive SAM		0	0	0	0	0	0	0	0	0	0	0	0	0	0
		False Negative		0	0	0	0	2	0	0	2	0	0	0	1	0	0
		Missed Detection		2	2	2	4	1	2	3	4	3	1	4	4	3	3

Legend:
Detected ...
Detected ...
Probable D...
Not Detec...
0.004 From Helo...

Table 7. Target Detection Matrix

Multivariate

Correlations

	Overall Fixations	Rank	Median Overall
Overall Fixations	1.0000	0.0468	-0.5901
Rank	0.0468	1.0000	-0.2143
Median Overall	-0.5901	-0.2143	1.0000

Scatterplot Matrix
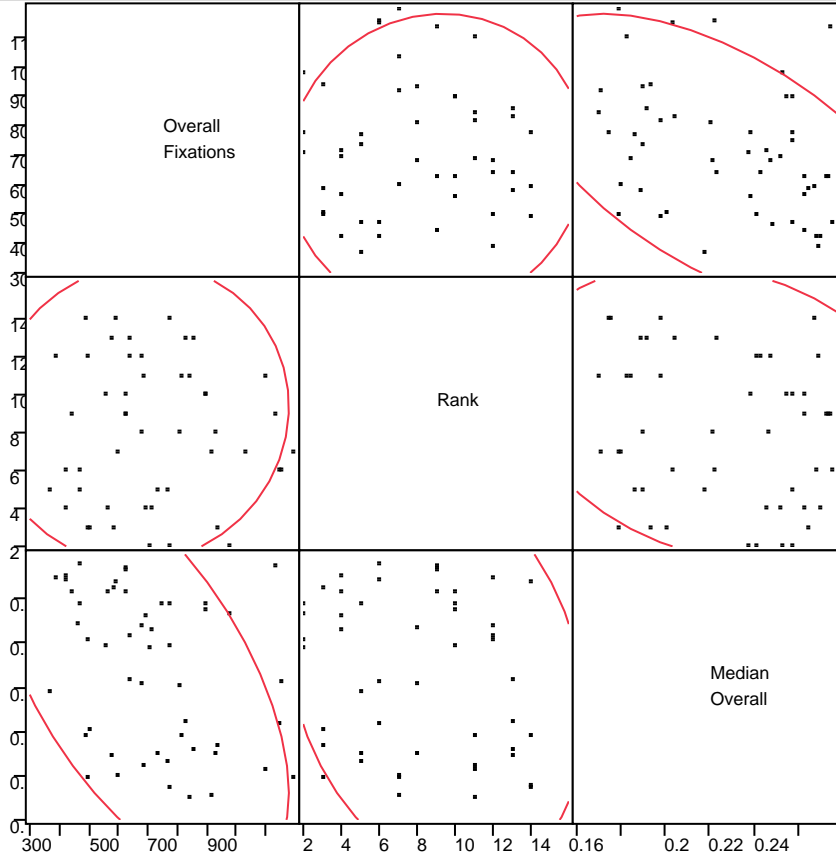
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	
Rank	Overall Fixations	0.1268	0.4819	
Median Overall	Overall Fixations	-0.6036	0.0002	
Median Overall	Rank	-0.2053	0.2517	
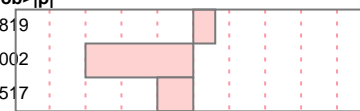
Figure 13.   Multivariate Overall Median Dwell Times, Overall Mean Fixations, Ranked Experience

Bivariate Fit of Fixations Overall By SPM Scen=2
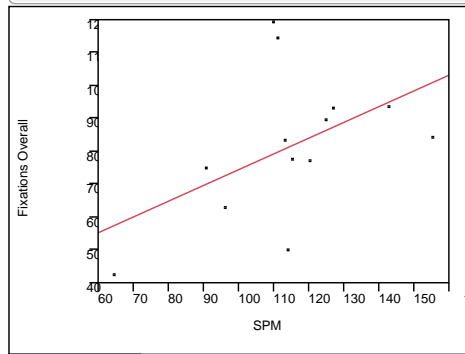
Linear Fit

Fixations Overall = 264.24394 + 4.7926986*SPM

Summary of Fit

RSquare	0.197978
RSquare Adj	0.108865
Root Mean Square Error	224.021
Mean of Response	810.3636
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Rat
Model	1	111493.94	111494	2.2210
Error	9	451668.61	50185	**Prob**
C. Total	10	563162.55		0.1703

Bivariate Fit of Fixations Overall By SPM Scen=3
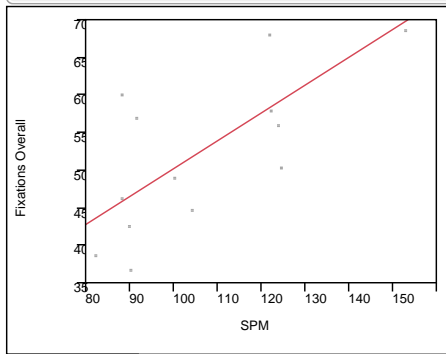
Linear Fit

Fixations Overall = 130.84499 + 3.7060986*SPM

Summary of Fit

RSquare	0.519688
RSquare Adj	0.46632
Root Mean Square Error	81.04128
Mean of Response	524.7273
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Rat
Model	1	63954.98	63955.0	9.737
Error	9	59109.20	6567.7	**Prob**
C. Total	10	123064.18		0.0123

Bivariate Fit of Fixations Overall By SPM Scen=4
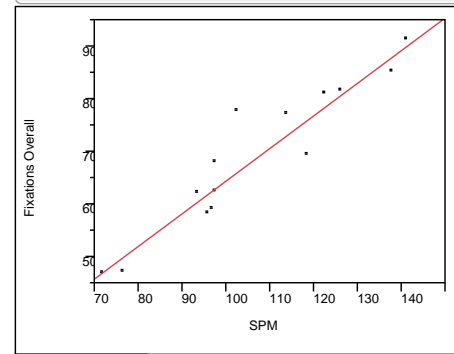
Linear Fit

Fixations Overall = 22.586731 + 6.2015821*SPM

Summary of Fit

RSquare	0.952394
RSquare Adj	0.947105
Root Mean Square Error	34.27248
Mean of Response	686.4545
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Rat
Model	1	211491.30	211491	180.0
Error	9	10571.43	1175	**Prob**
C. Total	10	222062.73		<.0001

Figure 14.   Saccades per Minute vs. Total Fixations

Correlations

	Fixations OTW	Fixations IP	Fixations Map	Rank
Fixations OTW	1.0000	0.0570	-0.2447	0.2544
Fixations IP	0.0570	1.0000	0.3507	-0.1255
Fixations Map	-0.2447	0.3507	1.0000	-0.1372
Rank	0.2544	-0.1255	-0.1372	1.0000

Scatterplot Matrix
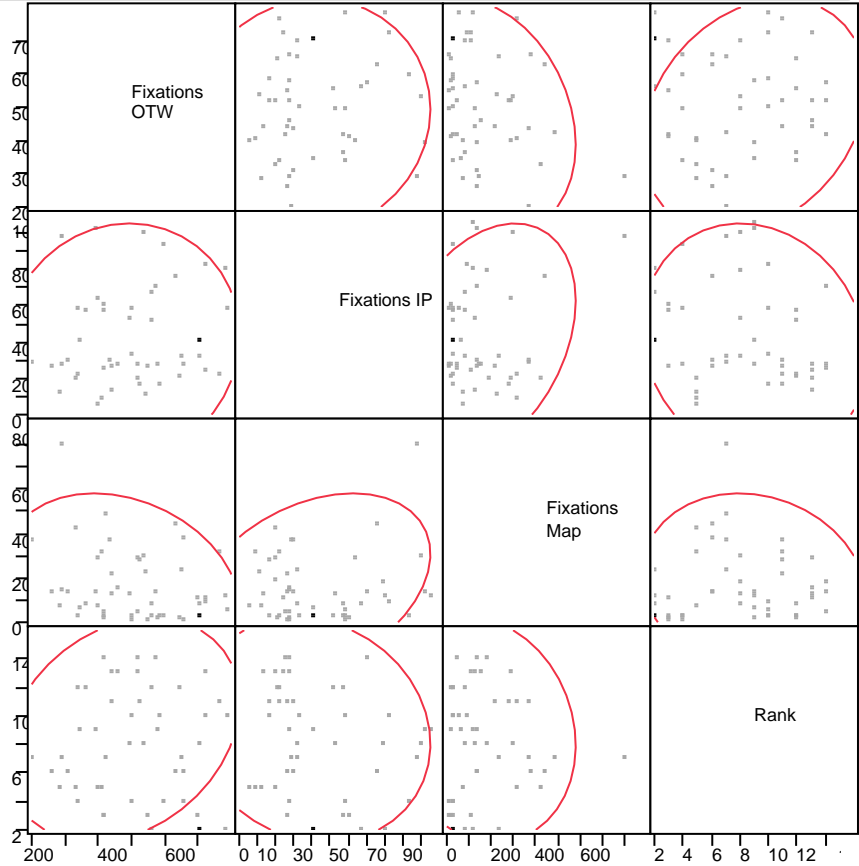
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	
Fixations IP	Fixations OTW	0.0853	0.6369	
Fixations Map	Fixations OTW	-0.2288	0.2003	
Fixations Map	Fixations IP	0.1938	0.2799	
Rank	Fixations OTW	0.2737	0.1232	
Rank	Fixations IP	-0.1712	0.3407	
Rank	Fixations Map	-0.0292	0.8719	
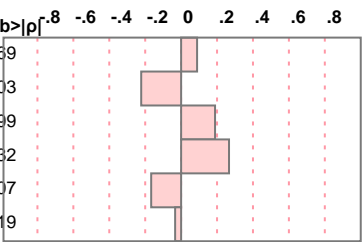
Figure 15.   Multivariable Fixation Counts (by Location), Rank

Multivariate

Correlations

	Median OTW	Median IP	Median Map	Rank
Median OTW	1.0000	0.3982	0.4237	-0.2780
Median IP	0.3982	1.0000	0.5997	0.0211
Median Map	0.4237	0.5997	1.0000	-0.2013
Rank	-0.2780	0.0211	-0.2013	1.0000

Scatterplot Matrix
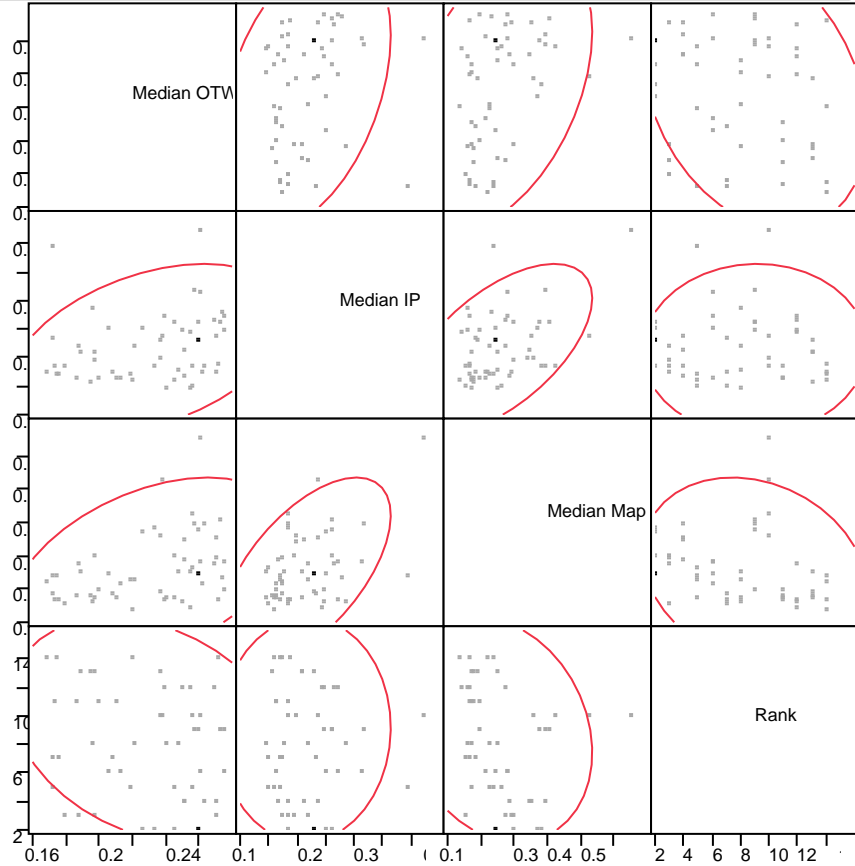
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	
Median IP	Median OTW	0.4248	0.0137	
Median Map	Median OTW	0.4285	0.0129	
Median Map	Median IP	0.3523	0.0444	
Rank	Median OTW	-0.2808	0.1135	
Rank	Median IP	0.0533	0.7681	
Rank	Median Map	-0.3764	0.0309	
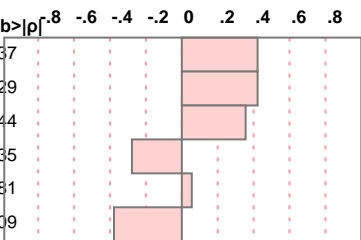
Figure 16.   Multivariate Median Fixation Times (by Location), Rank
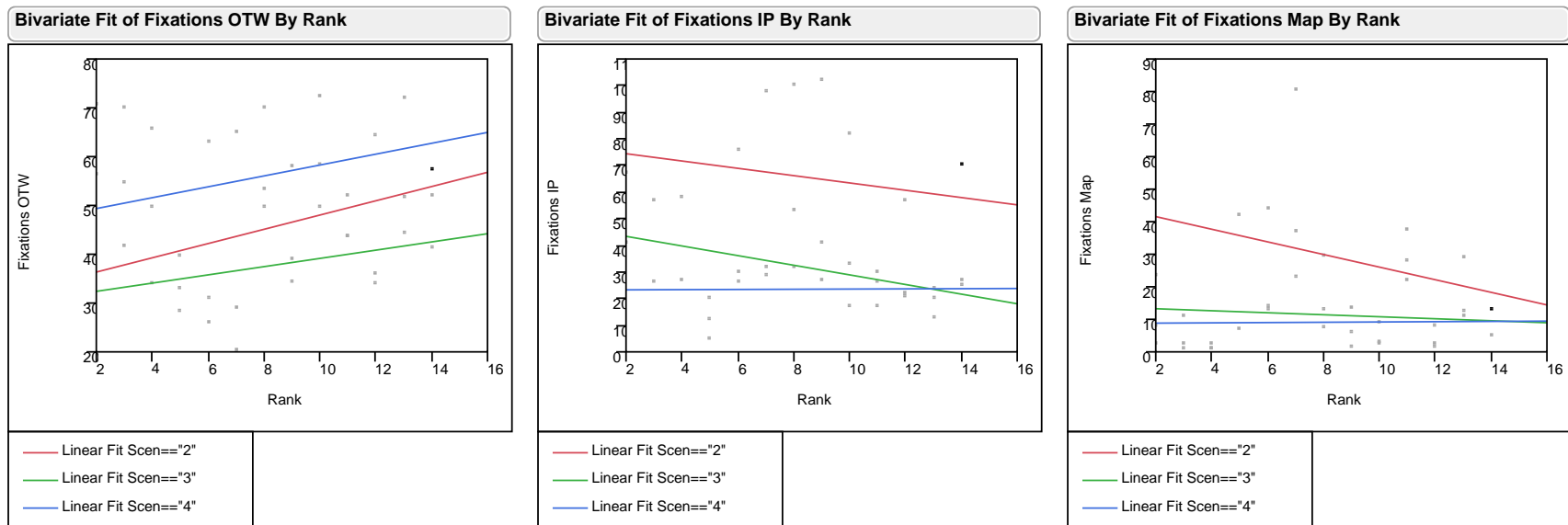
Figure 17.   Bivariate Trends of Ranked Experience vs. Areas of Fixation per Scenario

Multivariate

Correlations

	Fixations Overall	Median Overall	SPM	RMS
Fixations Overall	1.0000	-0.5446	0.4976	-0.0338
Median Overall	-0.5446	1.0000	-0.5771	-0.0190
SPM	0.4976	-0.5771	1.0000	0.0347
RMS	-0.0338	-0.0190	0.0347	1.0000

Scatterplot Matrix
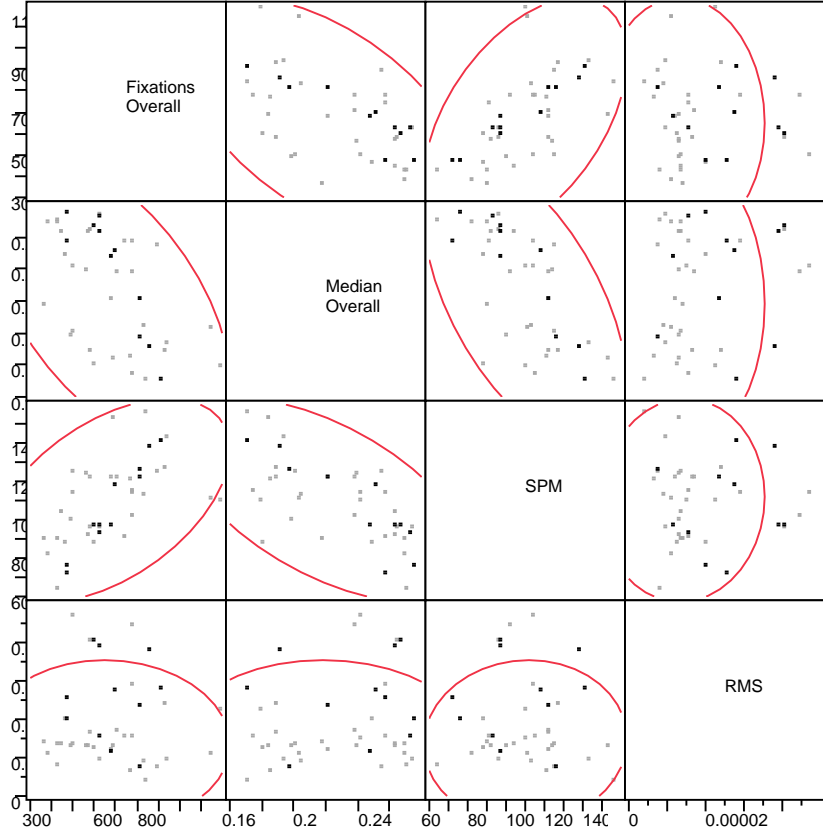
Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	
Median Overall	Fixations Overall	-0.5878	0.0040	
SPM	Fixations Overall	0.6217	0.0020	
SPM	Median Overall	-0.5144	0.0143	
RMS	Fixations Overall	-0.1232	0.5850	
RMS	Median Overall	-0.1582	0.4820	
RMS	SPM	0.0384	0.8652	
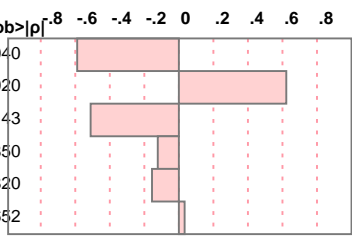
Figure 18.   Multivariate Navigation RMS Error, Median Dwell, Fixation Count, Saccades per Minute

Whole Model

Actual by Predicted Plot

RMS Predicted P=0.5525

RSq=0.30 RMSE=8.9e-6
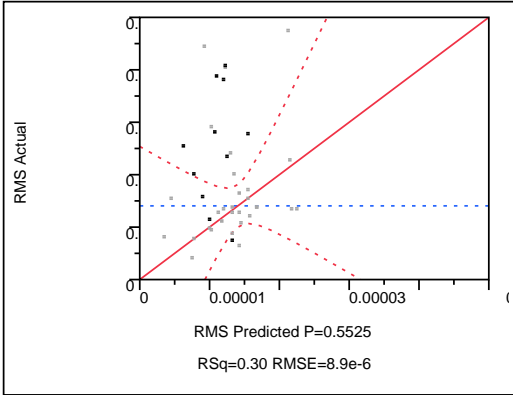
Summary of Fit

RSquare	0.303141
RSquare Adj	-0.04529
Root Mean Square Error	8.92e-6
Mean of Response	0.000014
Observations (or Sum Wgts)	22

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	4.8456e-10	6.922e-11	0.8700
Error	14	1.1139e-9	7.956e-11	**Prob > F**
C. Total	21	1.59845e-9		0.5525

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Pro
Intercept	1.0949e-5	2.751e-5	0.40	0.69(
Fixations Overall	-1.739e-8	1.251e-8	-1.39	0.18(
Median Overall	-4.203e-6	7.831e-5	-0.05	0.95(
SPM	1.4408e-7	1.831e-7	0.79	0.44/
(Fixations Overall-667.545)*(Median Overall-0.21996)	-7.571e-7	4.107e-7	-1.84	0.08(
(Fixations Overall-667.545)*(SPM-110.114)	-5.18e-10	9.42e-10	-0.55	0.59(
(Median Overall-0.21996)*(SPM-110.114)	5.5161e-6	4.475e-6	1.23	0.23(
(Fixations Overall-667.545)*(Median Overall-0.21996)*(SPM-110.114)	1.5892e-9	1.961e-8	0.08	0.93(

Figure 19.   Fit Model of Navigation RMS Error with Fixation Count, Median Dwell
Time, Saccades per Minute, and Associated Interactions

Whole Model

Actual by Predicted Plot

Total TP Predicted P=0.0021
RSq=0.99 RMSE=0.1969
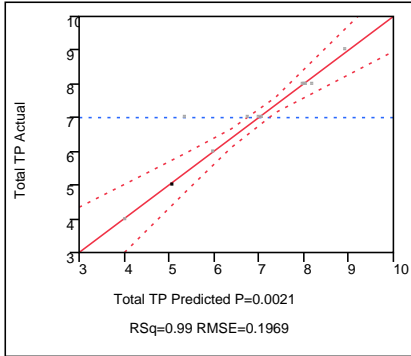
Summary of Fit

RSquare	0.994714
RSquare Adj	0.982379
Root Mean Square Error	0.196894
Mean of Response	7
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	21.883698	3.12624	80.6413
Error	3	0.116302	0.03877	**Prob > F**
C. Total	10	22.000000		0.0021

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob
Intercept	-3.333842	1.301857	-2.56	0.083
Median Dwell Overall	4.2067863	2.485314	1.69	0.189
Fixations Overall	0.0016498	0.000416	3.96	0.028
SPM	0.0693427	0.009319	7.44	0.005
(Median Dwell Overall-0.21333)*(Fixations Overall-810.364)	0.1571406	0.016899	9.30	0.002
(Median Dwell Overall-0.21333)*(SPM-113.948)	-0.634273	0.180412	-3.52	0.039
(Fixations Overall-810.364)*(SPM-113.948)	-0.001522	8.746e-5	-17.41	0.000
(Median Dwell Overall-0.21333)*(Fixations Overall-810.364)*(SPM-113.948)	0.0330067	0.00173	19.07	0.000

Figure 20.   Scenario 3 True Positive Target Detection with Fixation Count, Median Dwell Time, Saccades per Minute, and Associated Interactions

Whole Model

Actual by Predicted Plot

P=0.1069 RSq=0.92 RMSE=0.649
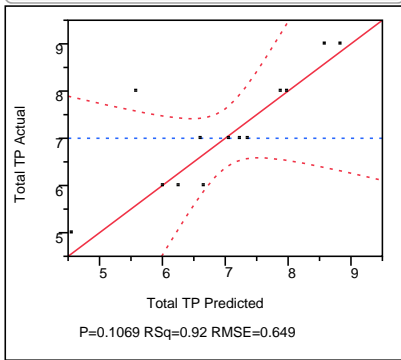
Summary of Fit

RSquare	0.921024
RSquare Adj	0.736748
Root Mean Square Error	0.649002
Mean of Response	7
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	14.736390	2.10520	4.9981
Error	3	1.263610	0.42120	**Prob > F**
C. Total	10	16.000000		0.1069

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob
Intercept	48.385978	13.68171	3.54	0.038
Median Dwell Overall	-107.3142	32.57656	-3.29	0.045
Fixations Overall	-0.028324	0.011414	-2.48	0.089
SPM	0.0469147	0.043498	1.08	0.359
(Median Dwell Overall-0.23775)*(Fixations Overall-686.455)	-0.544123	0.299429	-1.82	0.166
(Median Dwell Overall-0.23775)*(SPM-107.048)	4.9406972	2.066117	2.39	0.096
(Fixations Overall-686.455)*(SPM-107.048)	-0.000145	0.000267	-0.54	0.625
(Median Dwell Overall-0.23775)*(Fixations Overall-686.455)*(SPM-107.048)	0.0013246	0.003101	0.43	0.698

Figure 21.   Scenario 4 True Positive Target Detection with Fixation Count, Median Dwell Time, Saccades per Minute, and Associated Interactions

Bivariate Fit of BPM By Rank Scen=2
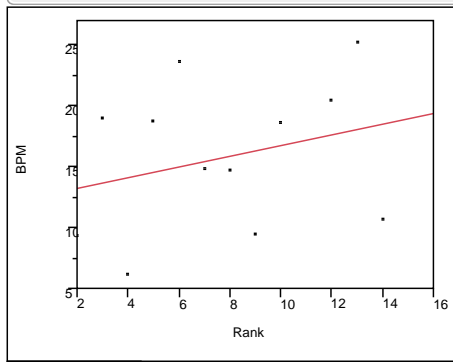
Linear Fit

BPM = 12.326916 + 0.4395733*Rank

Summary of Fit

RSquare	0.058522
RSquare Adj	-0.05916
Root Mean Square Error	6.40565
Mean of Response	16.19516
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	20.40452	20.4045	0.49
Error	8	328.25877	41.0323	Prob > F
C. Total	9	348.66329		0.500

Bivariate Fit of BPM By Rank Scen=3
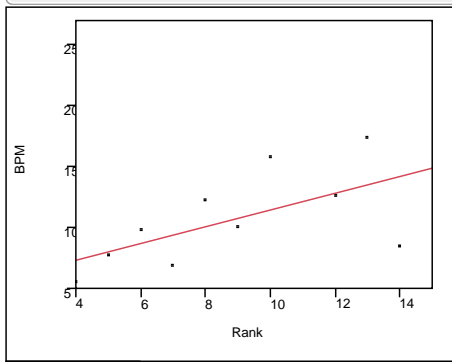
Linear Fit

BPM = 4.5533593 + 0.6879464*Rank

Summary of Fit

RSquare	0.376788
RSquare Adj	0.298886
Root Mean Square Error	3.214484
Mean of Response	10.60729
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	49.97734	49.9773	4.83
Error	8	82.66326	10.3329	Prob > F
C. Total	9	132.64060		0.059

Bivariate Fit of BPM By Rank Scen=4
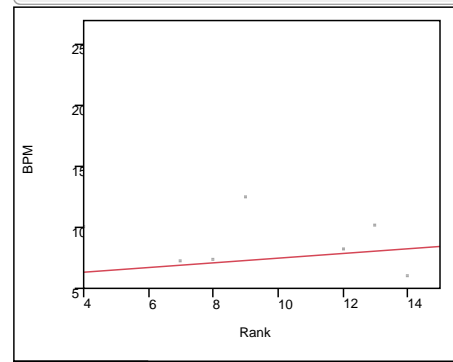
Linear Fit

BPM = 5.5560071 + 0.1923554*Rank

Summary of Fit

RSquare	0.046371
RSquare Adj	-0.07283
Root Mean Square Error	3.169252
Mean of Response	7.248735
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.907265	3.9073	0.38
Error	8	80.353271	10.0442	Prob > F
C. Total	9	84.260537		0.550

Figure 22.   Bivariate Fit of Blinks per Minute to Ranked Experience by Scenario

Oneway Analysis of BPM By Scen
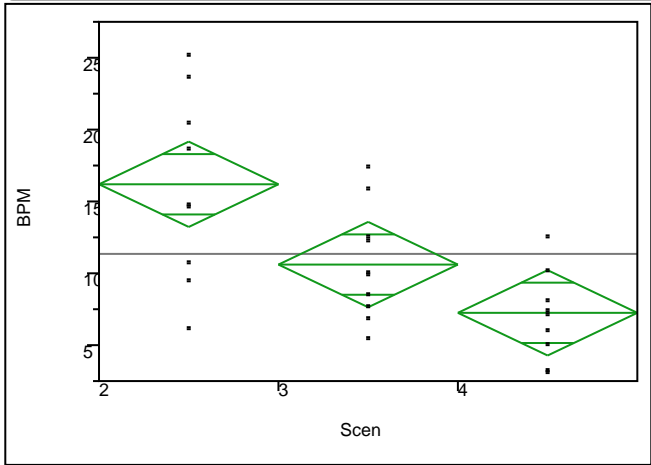
Excluded Rows   12

Oneway Anova

Summary of Fit

Rsquare	0.419362
Adj Rsquare	0.376352
Root Mean Square Error	4.576771
Mean of Response	11.35039
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob
Scen	2	408.47575	204.238	9.7503	0.000
Error	27	565.56443	20.947		
C. Total	29	974.04018			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95
2	10	16.1952	1.4473	13.226	19.165
3	10	10.6073	1.4473	7.638	13.577
4	10	7.2487	1.4473	4.279	10.218

Std Error uses a pooled estimate of error variance

Figure 23.   ANOVA of Blinks per Minute by Scenario

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APPENDIX C. SUMMARY STATISTICS

		Practice	Navigation Only	Navigation and Target Detection and Identification	Target Detection and Identification
Total Time	Mean (STD)	582.9 (180.9)	573.3 (161.3)	370.7 (60.7)	480.0 (27.6)
	Median	590.2	531.7	357.1	471.8
Blinks per Minute	Mean (STD)	14.3 (6.9)	10.3 (4.80)	7.3 (3.7)	10.4 (4.2)
	Median	14.7	9.7	7.3	11.2
Saccades per Minute (sec)	Mean (STD)	112.8 (17.7)	114.1 (21.9)	107.4 (20.6)	106.4 (20.9)
	Median	115.7	113.8	102.4	99.8
Mean Dwell Time (sec)	Mean (STD)	0.476 (0.092)	0.468 (0.136)	0.478 (0.087)	0.489 (0.104)
	Median	0.447	0.43	0.477	0.494
Median Dwell Time (sec)	Mean (STD)	0.228 (.050)	0.217 (0.038)	0.227 (0.033)	0.241 (0.033)
	Median	0.233	0.204	0.23	0.254
STD Dwell Time (sec)	Mean (STD)	0.975 (.815)	0.821 (0.462)	0.735 (0.255)	0.768 (0.240)
	Median	0.744)	0.719	0.704	0.784
Fixations Overall	Mean (STD)	886.8 (288.4)	867.4 (288.6)	531.6 (111.2)	577.1 (118.2)
	Median	937	834	530	582.5
Mean Fixations per	Mean (STD)	2.88 (0.52)	2.39 (0.27)	2.76 (0.44)	3.46 (0.76)
	Median	0.2.95	2.41	2.74	3.32
Median Fixations per	Mean (STD)	1.79 (0.43)	1.43 (0.51)	1.64 (0.50)	1.93 (0.27)
	Median	2	1	2	2
STD Fixations per View	Mean (STD)	3.64 (1.16)	2.26 (0.41)	3.19 (0.82)	4.30 (1.59)
	Median	3.6	2.31	2.95	3.69
Total Scan Time (sec)	Mean (STD)	413.6 (143.4)	367.1 (127.9)	271.5 (54.2)	409.3 (49.3)
	Median	410.1	353.7	265.7	412.4
Friendly Detections	Mean (STD)	3.57 (1.40)	N/A	3.07 (1.00)	3.50 (0.85)
	Median	4	N/A	3	3
Enemy Detections	Mean (STD)	3.50 (1.45)	N/A	3.93 (1.00)	3.71 (0.83)
	Median	3	N/A	4	4
Missed Targets	Mean (STD)	0.214 (0.426)	N/A	3.64 (1.60)	2.71 (1.07)
	Median	0	N/A	3.5	3
Navigation RMS Error	Mean (STD)	N/A	2.79E-05 (1.16E-05)	1.46E-05 (1.1E-05)	1.39E-05 (2.34E-06)
	Median	N/A	2.78E-05	1.03E-05	1.34E-05

Figure 24. Summary Statistics Across All Scenarios

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APPENDIX D. APPROVED IRB PROTOCOL

Naval Postgraduate School
Human Research Protection Office
Request for Waiver of Informed Consent or Elements of Informed Consent
Updated 9-6-11

Obtaining informed consent from potential research subjects before starting any research activities is a requirement of 32 CFR 219. However, an IRB may recommend approval of a consent procedure that does not include, or which alters, some or all of the elements of informed consent, or waive the requirements to obtain informed consent, provided the IRB finds and documents that criteria required by 32 CFR 219.116 have been met.

Principal Investigator: Dr. Quinn Kennedy

Protocol Title: Expertise on Cognitive Workloads and Performance during Navigation and Target Detection

The waiver is requested for the following research populations: NPS students that participated in NPS 2011.0075-IR-EP7-A.

1. Request waiver of the requirement to obtain formed consent from research subjects.
☐ No, skip to question 2.
☒ Yes. Proceed to 3.

2. Request alteration of the elements of informed consent.
☐ Yes. Check the elements of informed consent that you wish to waive, then proceed to 3.

Elements of informed consent:

☐ A statement that the study involves research
☐ An explanation of the purpose(s) of the research
☐ The expected duration of the subject's participation
☐ A description of the procedures to be followed
☐ Identification of any procedures which are experimental
☐ A description of any benefits to the subject or to others which may reasonably be expected from the research
☐ A disclosure of appropriate alternative procedures or courses of treatment, if any, that might be advantageous to the subject
☐ An explanation of how the institution/investigator will maintain confidentiality of records.
☐ For research involving greater than minimal risk, an explanation regarding whether medical treatment is available if injury occurs.
☐ Contacts for further information about the research study and about the rights of the subjects. If research-related injury is possible, subjects must be told whom to contact should injury occur.
☐ A statement that participation is voluntary, refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and the subject may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled.

3. Provide protocol specific findings for each criteria for one of the following criteria sets.

Criteria Set #1 - 45 CFR 46.116(c)

The research involves no more than minimal risk to participants.	The research does not involve any further research with the participants.
The waiver or alternation will not adversely affect the rights and welfare of participants.	The research is analyzing data collected from NPS 2011.0075-IR-EP7-A. All rights from that experiment will be maintained. Privacy is guaranteed by removing all personally identifying information prior to analysis.
The research cannot practicably be carried out without the waiver or alternation.	Participants may no longer be at NPS.
When appropriate, the participants will be provided with additional pertinent information after participation.	All results from the analysis will be available when the thesis is published via normal NPS avenues.
The research is not FDA regulated.	No.
Criteria Set #2 - 45 CFR 46.116(d)	
The research is conducted by or subject to the approval of state or local government officials.	
The research is designed to study, evaluate, or otherwise examine:	
• Public benefit or service programs	
• Procedures for obtaining benefits or services under those programs	
• Possible changes in methods or levels of payment for benefits or services under those programs.	
The research cannot practicably be carried out without the waiver or alternation.	
The research is not FDA regulated.	

Principal Investigator Signature: _Quinn Kennedy_   Date: _12/3/11_

NPS IRB

APPROVED
DEC 16 2011
EXPIRES
MAR 31 2012

MEMORANDUM

From: LT Neboshynsky, Christopher
Section(s): 399-103

To: Program Officer, MOVES: CDR Duane Davis, USN

Via: (1) Thesis Advisor: Dr. Quinn Kennedy
    (2) Co-Advisor: : Dr. Ji Hyun Yang
    (3) Academic Associate: Prof Mathias Kolsch
    (4) Chair, CS Department: Peter J. Denning
    (5)Chair, MOVES Academic Committee: Mathias Kolsch

Subj: THESIS PROPOSAL
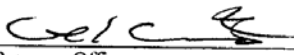
Encl: (1) Modeling, Virtual Environments and Simulation Thesis Proposal
    (2) Institutional Review Board (IRB) Form

1.   Tentative Title of Proposed Thesis: Expertise on Cognitive Workloads and Performance during Navigation and Target Detection
2.   General Area of Proposed Thesis Research: This thesis explores how a pilot's expertise effects his cognitive workload and performance as the type and number of tasks with which he is assigned changes.
3.   Enclosure (1) is the Thesis Proposal with a milestone plan (dates/events) for research and thesis completion.
4.   I expect that my thesis will be unclassified. If Classified, I have read Chapter V of NAVPGSCOLINST 5510.2, and the NPS Research Admin web page (http://intranet.nps.navy.mil/ResAdmin/research1.html) concerning Classified Thesis.
5.   I reviewed the Institutional Review Board (IRB) web page concerning the use of humans in research (htt://www.nps.edu/research/IRB.html). This research does involve Human Subject Research.
6.   I anticipate the following travel or other extraordinary requirements: I/ITSEC

_____
Student Signature

_____
Second Student Signature <if joint thesis>

1. Approved and Forwarded: _____   11/3/11
    Thesis Advisor   Date

2. Approved and Forwarded: _____   11/3/2011
    Co-Advisor   Date

2. Approved and Forwarded: _____   11/7/2011
    Academic Associate   Date

3. Approved and Forwarded: _____   11/15/11
    Chair, CS Department   Date

    _____   11/7/2011
    Chair, MOVES Academic Committee   Date

4. Approved and Forwarded: _____ 7 DEC 1(
                           Program Officer   Date
                        MOVES THESIS PROPOSAL

A. General Information

1. Name: Lieutenant Neboshynsky, Christopher M.

2. Email: cmnebosh@nps.edu

3. Curriculum: MOVES (399)

4. Thesis Advisor: Dr. Quinn Kennedy

5. Co-Advisor: Dr. Ji Hyun Yang

6. Academic Associate: Prof Mathias Kolsch

7. Chair, CS Department: Peter J. Denning
     Chair, MOVES Academic Committee: Mathias Kolsch

8. Date of Graduation: 23-Mar-12

B. Area of Research

This thesis will explore the cognitive workloads that occur as an individual is required to conduct two tasks common in the military – navigation and target detection – separately and at the same time.

C. Research Questions

1. Does expertise predict eye scan pattern across the three tasks of Navigation, Target Detection, and Navigation & Target Detection?

2. Is expertise associated with less cognitive workload across the three tasks of Navigation, Target Detection, and Navigation & Target Detection?

3. Can eye scan be used to predict performance?

Exploratory

1. How does eye scan pattern correlate to cognitive workload when judged via subjective and objective measures?

2. How do subjective measures of mental workload match up with the actual performance of given tasks?

D. Discussion

In today's military, the ability to do more than one task at a time is a necessary skill. From the beginning of many job fields, military members are trained and groomed to be able to accomplish multiple tasks simultaneously. Pilots of single seat aircraft are responsible for all aspects of a mission from the moment they get in the seat. Dual piloted aircraft have similar jobs, although the workload is now shared between two pilots and possibly one or more other crewmen. Even on the ground, it is necessary to be able to be able to do more than one thing, such as navigating through unknown terrain and maintaining situational awareness and a mental image of all aspects of a mission. Earlier work has shown that experienced pilots, as defined by flight hours, have a more refined and efficient scan pattern that allows them to be able to accomplish difficult tasks (Sullivan, 2010). They have more fixations, shorter durations on each fixation, more saccade time (less dwell time), and spend more time looking out the window than inside at a chart while navigating than less experienced pilots. Does this refined scan pattern transfer over into a reduced cognitive workload for the pilot?

Cognitive workload is the combined interactions of task demands/difficulty, operator workload, other stressors, and primary task performance (Megaw, 2005). Cognitive workload itself can be tracked and monitored with multiple methods. First, performance based measures look to quantify how well an individual performs with an increase in task load. Second, a subjective measure can be acquired simply by asking individuals what they are thinking or how they feel about their workload. However, as the name implies, this is subjective and may not accurately represent the cognitive workload of the individual. Lastly, there are physiological markers that are universal that can identify when an individual faces an increase in mental workload. Some of these are brainwaves, galvanic skin response, heart rate, and what this thesis will analyze, and pupil diameter

and dilation/contraction rates (Jessee, 2010). Eye behavior in general has been the subject of many studies into mental workload (Jessee, 2010; Fong, Sibley, Coyne, Baldwin, 2011; Sibley, Coyne, Baldwin, 2011; Marshall, 2007) and can provide an objective and measurable index. By using FaceLab 5.0.2 eye tracking technology to observe dwell times and pupillary dilation, we are able to relate how much of an increase there may be on an individual's cognitive load when given multiple tasks to accomplish. Research methods have come a long way since cognitive workload studies began. What used to require various invasive methods, the technology now exists to give incredibly accurate (±1mm translation, ±1° rotational) results on an individual without being invasive at all. The equipment that will be utilized has no effect on the individuals, and other than knowing the equipment is there, the participant has no interaction with it. This allows for more pure data collection by decreasing the amount of random variability introduced by knowledge of equipment and the inherent discomfort or distractions of wearing it for any extended period of time.

It would be expected that as an individual's experience and skills increase, the resultant mental workload that they experience should decrease (Sibley, Coyne, Baldwin, 2011). The studies show that pupil diameter and other techniques are effective in predicting *when* an individual is fully tasked. What has not been looked at is how the increase in cognitive workload actually affects the performance of an individual. This thesis will look to fill in these gaps with performance in tasks relating specifically to a military environment. Participants will be asked to navigate an aircraft in a mountainous region, locate and identify targets of interest, and a combination of the two. They will be given surveys prior to and after each scenario so that an assessment can be made between how the pilot views the task in terms of difficulty at each point. I will use performance-based, subjective, and objective measures to assess the relationship between flight expertise and cognitive load across the three tasks. I will look at the performance (via adherence to the designated route) within an individual as they go between navigating, target detecting, and a combination of the two. With these methods, three distinct measurements will be attained:

- Objective performance measured by adherence to the given route and ability to detect (find along the route) and correctly identify (friend or foe) various contacts along the flight route

- Objective cognitive workload data (pupil size and dilation/contraction rate)

- Subjective cognitive workload data (from pre- and post-surveys)

Because subjective reports of cognitive workload can be typically inaccurate, I will compare the subjective surveys to the objective eye scan data. I will use two measures of expertise in analyzing the data: total flight hours and eye scan pattern. If it is possible to determine how an individual adapts to the change in tasks, and a corresponding change in performance, situations could be adjusted to avoid those that will be cognitively overbearing for someone. Additionally, by identifying when an individual "gets it," the military could possibly save money on training by tailoring syllabi for more or less training on individual tasks.

E. Scope of the Thesis

The scope of this thesis is to explore the relationship between expertise and cognitive workloads while performing tasks by themselves and in conjunction with each other (navigation, target detection, navigation & target detection). It will also examine eye scan patterns among pilots of varying experience levels across three tasks to determine how eye scan patterns change across the these tasks and they may relate to expertise.

Hypotheses:

1. H0: There will be no significant correlation between total flight hours and eye scan patterns in the Navigation, Target Detection, and Navigation & Target Detection tasks.

   HA: More experienced pilots will have more saccades, shorter and more fixations, more fixations on salient instruments and stimuli than inexperienced pilots.

2. H0: There will be no significant correlation between experience and pupil diameter, pupil dilation/contraction rate, and subjective measures of cognitive workloads in the Navigation, Target Detection, and Navigation & Target Detection tasks.

   HA: Experienced pilots will have smaller pupil diameter, faster pupil dilation/contraction rates, and report lower levels of cognitive workload than inexperienced pilots.

3. H0: There will be no significant correlation between eye scan pattern and performance in the Navigation, Target Detection, and Navigation & Target Detection tasks.

   HA: Pilots with more efficient eye scan patterns (more saccades, shorter and more fixations, fixations on salient instruments and stimuli) will perform better on the navigation (by adherence to the given course and waypoints), task detection (more Correct Detections versus Incorrect and Missed Detections), and combination tasks.

Exploratory

1. H0: There will be no significant correlation between scan patterns and subjective reports of cognitive workloads and pupil diameter and dilation/contraction rate among the pilots during the three tasks.

   HA: Pilots with more efficient scan patterns (more saccades, shorter and more fixations, fixations on salient instruments and stimuli) will have smaller pupil diameter, faster pupil dilation/contraction rates, and report lower levels of subjective cognitive workloads than those with less efficient scan patterns.

2. H0: Subjective measures of cognitive workload will have no significant correlation to the actual performance during the three tasks.

   HA: The subjective measures (pre- and post-surveys) on predicted and actual perceptions regarding the difficulty of the tasks will correlate with the objective measurements of performance.

F. Methodology

This experiment has 15 military officers who vary in their experience in overland navigation and target recognition. The scenarios are designed using X-Plane; one each for navigation, target detection, and navigation & target detection. The navigation only scenario consists of 12 waypoints situated in a simulated mountainous region. The other two scenarios each have five waypoints in different, but geographically similar areas. The three scenarios will be randomly arranged for each participant. Before each scenario, the participants will be given a short survey asking them to predict how difficult they perceive each leg of the transit as it pertains to the scenario. Conversely, after each scenario they will be given another survey asking them how they perceived the difficulty of each leg. Appropriate statistical analyses will be utilized to assess the relationship between the scan patterns, the cognitive workloads, task performance, and the experience levels (as defined by flight hours). Three laptops (T7200, 2 Ghz, .99 GB RAM) running Windows XP, Service Pack 3 with generic Microsoft graphics cards will be used for FaceLab and collect the data. The visuals themselves will be created via X-Plane, running on a 2.67 GHz, 3 GB RAM desktop computer with an NVidia GeForce 8800 Ultra video card, running Windows XP, SP 3 and displayed via projectors on 120" screens. The instructor console and the CAVE desktops will be configured the same as the X-Plane. An iPad will be used for the chart, attached to a Macbook Pro in order to create wired connectivity from the wireless iPad. One 21" monitor will be used to provide a limited instrument panel for the pilots (generated via X-Plane).

G. Chapter Outline

Chapter 1 – Introduction

    Background

    Objective – Research Questions

    Scope, Limitations, and Assumptions

Chapter 2 – Literature Review

Chapter 3 – Methodology

    Experiment setup

    Participant selection

    Equipment Configuration

Chapter 4 – Analysis and Results

Chapter 5 – Conclusions and Recommendations

Appendix A – Simulator Setup

H. Schedule

1. Construct research design: Complete
2. Anticipated date of IRB approval: Complete
3. Literature review: Nov 31

4. Draft thesis, Cover through Chapter 3, and initial list of references completed by Dec 9

5. Chapter 4: Jan 6

6. Draft thesis checked by thesis processor for format: Jan 6

7. Chapter 5: Feb 13

8. Draft thesis to advisor(s): Feb 24

9. Final thesis submission for signatures: Mar 16

I. Benefits of Study

This study will benefit the Navy and other military services by providing a metric by which trainers and instructors can potentially save time and money. If we can show that task loading can be reliably detectable with comparable results, thresholds and limits can be established primarily in the training commands so that individualized training syllabi can be developed. Additionally, in the operational squadrons, it can be utilized to determine which individuals are naturally inclined towards certain mission sets and tracks can be defined for further training.

J. Anticipated Travel/Funding Requirements

I/ITSEC – 28NOV – 1DEC

K. Preliminary Bibliography

Aral, Sinan; Brynjolfsson, Erik; Van Alstyne, Marshall. "Information, Technology, and Information Worker Productivity: Task Level Evidence." National Bureau of Economic Research. Cambridge, MA. 2007.

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Hancock, Peter A.; Szalma, James L. Performance Under Stress. Ashgate Publishing Group. Abington, GBR. 2008.

Jessee, Michael Sage. "Examining the Convergent and Discriminant Validity of Visual and Mental Workload Using Ocular Activity Variables." Army Research Laboratory. Aberdeen Proving Ground, MD. 2010.

Marshall, Sandra P. "Identifying Cognitive State from Eye Metrics." Aviation Space Environment Medicine. Vol. 78 (suppl), 2007: B167-175.

Megaw, Ted. "The Definition and Measurement of Mental Workload." Evaluation of Human Work, ed. Wilson, John R.; Corlett, Nigel. 3rd edition. CRC Press. 2005.

Magedman, Douglas M. "Attentional Drift: An Exploration Study into the Development of an Attention Level Monitoring System Based on Human Eye Fixation." Thesis, Naval Postgraduate School. 2010.

Rowlands, Mark. Body in Mind: Understanding Cognitive Processes. Cambridge University Press. Port Chester, NY. 1999.

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Sibley, Ciara; Coyne, Joseph; Baldwin, Carryl. "Pupil Dilation as an Index of Learning." Proceedings of the Human Factors and Ergonomics Society, 55th Annual Meeting. 2011.

Sullivan, Joseph A. Assessing Neurophysiological Markers for Training and Simulation to Develop Expertise in Complex Cognitive Skills. Diss. Naval Postgraduate School; 2010.

Wickens, Christopher D.; McGee, James P.; Mavor, Anne S. Flight to the Future: Human Factors in Air Traffic Control. National Academies Press. Washington, D.C. 1997.

NPS Human Research Protection Program
IRB Checklist for Student Research
Is this activity human subject research?

For an activity to be considered human subject research it must be all of the following:
(i) a systematic investigation
(ii) designed to develop or contribute to generalizable knowledge
(iii) designed to collect information about living individuals
(iv) involve interaction with a person or persons, or involve collecting information that is both private and personally identifiable.

Directions. Please answer the following questions about the attached research proposal and submit a copy of the completed checklist IRBChecklist@nps.edu.

If questions 1, 2, and 3, and at least one part of question 4 are answered in the affirmative, then before collecting data for the thesis, the student must either contact the HRPP Office for an official determination of whether the study constitutes human subject research, or submit an IRB application for review.
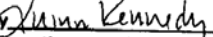
For any doubts about how to answer the questions on this checklist, please contact the IRB Chair CAPT John Schmidt, USN (jkschmid@nps.edu) or the IRB Administrator Ms. Rikki Panis (rapanis@nps.edu).
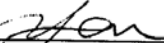
Department: MOVES	
Thesis Advisor: Dr. Quinn Kennedy	
Student Name(s): LT Christopher Neboshynsky	
Title of Research: Expertise on Cognitive Workloads and Performance during Navigation and Target Detection	
	Provide a summary of the research. (You may cut and paste from your research proposal.)
	The scope of this thesis is to explore the relationship between expertise and cognitive workloads while performing tasks by themselves and in conjunction with each other (navigation, target detection, navigation & target detection). It will also examine eye scan patterns among pilots of varying experience levels across three tasks to determine how eye scan patterns change across the these tasks and they may relate to expertise.
1	**Is the activity part of a systematic investigation?** For example, is it part of a planned and structured research investigation? Are you testing a hypothesis or theory? ☒ Yes ☐ No. Please explain below.
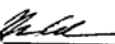
	Analysis of data acquired from NPS.2001.0075-IR-EP7-A. Testing hypotheses correlating flight hours & eye scans, experience & pupil responses, eye scans & performance, and subjective vs. objective measures of performance.	
2	**Is the information you are gathering designed to contribute to generalizable knowledge?** For example, is it possible that the knowledge that you develop could be applied to another domain or another population? Is it possible that another researcher would be interested in advancing your research? Would another researcher be interested in replicating your study with another population? ☒ Yes ☐ No. Please explain below.	
	Data analyzed will be generalizable to any population that requires scanning of an environment for any reason (target detection, navigation, cockpit indications, etc.).	
3	**Is the activity designed to collect information about living individuals?** Example of "about whom": soliciting opinions or attitudes about an institution, policy, service, technology, or processes. ☐ Yes ☒ No. Please explain below.	
	Research involves analysis of the pre-collected data provided by NPS.2011.0075-IR-EP7-A that includes eye scan data, video, audio, demographic information, and survey responses. Data that is analyzed will be anonymous with all direct attributions referred to with their participant numbers.	
4	**Does this activity involve intervention or interaction with a living individual?** For example, does it involve surveys, interviews, online interaction, experiments, audio/video recordings, or equipment testing involving subjects? *or* **Is the data you are gathering both private and individually identifiable?** Example of private information: medical, employment, and school records. Example of individually identifiable information: name, phone number, social security number. ☒ Yes ☐ No. Please explain below.	
	Research involves analysis of the pre-collected data provided by NPS.2011.0075-IR-EP7-A that includes eye scan data, video, audio, demographic information, and survey responses. Data that is analyzed will be anonymous with all direct attributions referred to with their participant numbers.	
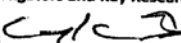
I understand that if questions 1, 2, and 3, *and* at least one part of question 4 are answered in the affirmative, the research may require review and approval by the IRB and NPS President before the research may commence. If questions 1, 2, and 3, *and* at least one part of question 4 are answered in the affirmative, prior to collecting data for this study I will contact the Human Research Protection Office for an official IRB determination or submit an IRB application for initial review to the IRB Administrator, Rikki Panis (rapanis@nps.edu).
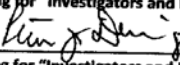
Signature of all faculty in the proposal chain of approval is required.
(Add/remove signature blocks as appropriate.)

Thesis Advisor :_Dr. Quinn Kennedy_____ Date 11/8/11
I have completed the CITI training for "Investigators and Key Research Personnel" ☒ Yes ☐ No

Co Advisor/2nd Reader:_Dr. Ji Hyun Yang_____ Date 11/8/11
I have completed the CITI training for "Investigators and Key Research Personnel" ☒ Yes ☐ No

2nd Reader:_CDR Harrison Schramm_____ Date 11/8/11
I have completed the CITI training for "Investigators and Key Research Personnel" ☐ Yes ☐ No

Program Officer
Academic Associate: _CDR Duane Davis_____ Date 12 DEc 11
I have completed the CITI training for "Investigators and Key Research Personnel" ☒ Yes ☐ No

Chair:_Dr. Peter Denning_____ Date 11/28/11
I have completed the CITI training for "Investigators and Key Research Personnel" ☒ Yes ☐ No
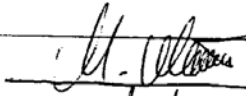
Student: _____ Date 8 NOV 11

Student: _____ Date_____

Student: _____ Date_____

Student: _____ Date_____

A copy of the completed and signed checklist is to be e-mailed to the IRB at IRBChecklist@nps.edu. The file name and subject of the email should be named as follows "Dept__AdvisorLastName_1stStudentLastName_2ndStudentLastName_Date. You may add additional student names when required.

Academic Associate: Dr. Mathias Kolsch _____

Date: 11/21/11

NPS IRB
INITIAL REIVEW CHECK LIST
last updated 10-12-11

Title of Research:	Expertise on Cognitive Workloads and Performance During Navigation and Target Detection

Principal Investigator:	Dr. Quinn Kennedy	Co-Investigator(s):	Dr. Ji Hyun Yang, CDR Harrison Schramm, USN

Student Investigator(s):	LT Christopher Neboshynsky, USN

1.	**PRE-REQUESITES**	YES	NO	N/A
a.	CITI training has been completed by all investigators and key research personnel.	☒	☐	
b.	Complete grant proposal/contract (i.e., SOW - externally funded project or thesis proposal). *If a student thesis, a copy of signatures of supervisor and chair are required.*	☒	☐	
c.	An adequate scientific review has been completed. *Completed by department Chair or designated reviewer.*	☒	☐	
d.	Conflict of interest disclosure form is signed by all engaged researchers.	☒	☐	
e.	All investigators are covered by a appropriate assurance to conduct research involving human subjects.	☒	☐	
f.	Organizational approval is provided for subject populations outside NPS.	☐	☐	☒
g.	Data collection tools are attached.	☐	☐	☒
h.	Application is signed by the principal investigator.	☒	☐	
2.	**SUBJECT POPULATION(S) & RECRUITMENT**	YES	NO	N/A
a.	Access to a population that will allow recruitment of the necessary number of participants.	☒	☐	
b.	Adequate information was provided as to how subjects are to be recruited. *How are subjects identified. How are subjects contacted? Who is contacting subjects and how often? How is subject POC information obtained? Review scripts for telephone/e-mail/and in person recruitment. If it is through personal contacts or legitimate access to groups it should be stated.*	☐	☐	☒
c.	Subject selection is equitable. *Consider factors such as the purposes of the research, the setting in which research will be conducted, special problems of research involving vulnerable populations, recruitment & enrollment procedures, influence of payments.*	☐	☐	☒
d.	Recruitment procedures ensure voluntary participation. *Command should not be involved in recruitment. Senior officers can inform potential participants but cannot recruit or be informed of who participated.*	☐	☐	☒
3.	**METHODOLOGY/DATA DISPOSITION**	YES	NO	N/A
a.	Adequate description of all activities involving human subjects. *Who, what, when, where & how*	☐	☐	☒
b.	Detailed summary of data collection (questionnaires, interviews, observations, standardized tests, other) and methods of data recording (field notes, audiotape, videotape, computer entry, etc.)	☒	☐	
c.	Sufficient explanation of storage/sharing of samples and/or data. *If a online survey tool is being utilized IRB policy memo on third party survey tools is incorporated.*	☒	☐	☐
4.	**POTENTIAL RISKS & BENEFITS**	YES	NO	N/A
	Please note that the IRB: • should consider physical, psychological, social, economic **and** legal risks • should consider **only** those risks & benefits resulting from the research • should **not** consider possible long-range effects of applying knowledge gained in the research			
a.	Adequate descriptions of risks, benefits and alternatives.	☒	☐	
b.	Risks to subjects are minimized:			
	· by using procedures which are consistent with sound research design and which do not unnecessarily expose subjects to risk	☒	☐	
	· whenever appropriate, by using procedures already being performed on subjects for diagnostic or treatment purposes	☐	☐	☒
c.	Risks to subjects are reasonable in relation to:			
	· anticipated benefits, if any, to subjects	☐	☐	☒
	· importance of knowledge reasonably expected to result	☒	☐	
d.	Adequate provisions to protect the **privacy** of subjects. *Only personal data that is relevant and necessary is collected. Data is properly stored and coded if necessary.*	☒	☐	
e.	Adequate provisions to maintain the **confidentiality** of data. *Only members of the research team will have access to data.*	☒	☐	☐

5.	MONITORING OF DATA	YES	NO	N/A
a.	Monitoring of data required to ensure safety of subjects (*i.e. the research poses greater than minimal risk*)	☐	☐	☒
b.	Adequate provisions for data monitoring to ensure safety of subjects (*i.e. changes in frequency/character of adverse events will be detected & reported in a time frame that ensures protection of subjects*)	☐	☐	☒
c.	If NPS is the lead site of a multi-site study, the plan for management of information from the research is adequate.	☐	☐	☒
6.	INFORMED CONSENT	YES	NO	N/A
a.	Legally effective informed consent will be sought from each prospective subject or legally authorized representative. *"N/A" should only be checked if research qualifies for complete waiver of consent (unlikely)*	☐	☐	☒
b.	Information is in language understandable to subjects or representatives.	☐	☐	☒
c.	There is no exculpatory language through which subjects or representatives are made to: · waive or appear to waive any legal rights OR · release or appear to release the investigator, the sponsor, the institution or its agents from liability for negligence.	☐	☐	☒
d.	Informed consent will be obtained prior to research activity.	☐	☐	☒
e.	Informed consent will be appropriately documented .	☐	☐	☒
f.	Circumstances of consent provide sufficient opportunity to for the subject or the subject's legally authorized representative to consider whether or not to participate. (*i.e. time to review consent document in advance.*)	☐	☐	☒
g.	A copy of the consent form will be given to the person signing the consent document.	☐	☐	☒
h.	The circumstances of the consent process minimize the possibility of coercion or undue influence.	☐	☐	☒
i.	The subject or the subject's legally authorized representative will sign the consent document. *If no, a wavier of documented consent should be requested.*	☐	☐	☒
	Basic Elements - 32 CFR 219.116(a)			
j.	Statement that the study involves research. *Statement includes PI and institution name.*	☐	☐	☒
k.	Explanation of the purposes of the research.	☐	☐	☒
l.	Expected duration of subject's participation.	☐	☐	☒
m.	Description of procedures to be followed.	☐	☐	☒
n.	Identification of any procedures which are experimental.	☐	☐	☒
o.	Description of <u>reasonably foreseeable</u> risks or discomforts. *Any risks/discomforts disclosed in the IRB application should be listed in the consent form.*	☐	☐	☒
p.	Description of any benefits to the subjects or to others. *If there is no benefit to the subject the consent form should state "There is no direct benefit to you for participating in the research."*	☐	☐	☒
q.	Disclosure of appropriate alternative procedures or courses of treatments if any. *If there are not alternatives the consent should state "The alternative to participating in the research is to not participate."*	☐	☐	☒
r.	Description of how confidentiality will be maintained. (*i.e. password protected computer, locked office*)	☐	☐	☒
s.	Information on availability of medical treatment if injury occurs an explanation as to whether any compensation is provided and provide the name and contact information of the medical monitor (if research poses greater than minimal risk).	☐	☐	☒
t.	Whom to contact with questions about the research. *PI name and phone #*	☐	☐	☒
u.	Whom to contact with questions about subject's rights. *IRB Chair name and phone #*	☐	☐	☒
v.	Whom to contact in the event of a research related injury.	☐	☐	☒
w.	Statement that participation is voluntary, refusal to participate will involve no penalty or lost of benefits to which the subjects are otherwise entitled, and the subject may discontinue participate and any time without penalty or loss of benefits to which the subject is otherwise entitled.	☐	☐	☐
	Additional Elements (When appropriate) - 32 CFR 219.116(b)			
x.	A statement that the treatment or procedure may involve risks to the subject (or to the embryo or fetus, if the subject is or may become pregnant) which are currently unforeseeable.	☐	☐	☒
y.	Anticipated circumstances under which the subject's participation may be terminated by the investigator without regard to the subject's consent.	☐	☐	☒
z.	Any additional costs to the subject that may result from participation in the research. *If there is not cost state "There are not costs to participate in the research."*	☐	☐	☒

		YES	NO	N/A
aa.	The consequences of a subject's decision to withdraw from the research and procedures for orderly termination of participation by the subject.	☐	☐	☒
bb.	The approximate number of subjects involved in the study.	☐	☐	☒
	Short Form Consent Document (45 CRFR 46.117(b)(2))	YES	NO	N/A
cc.	Will a short form be used to obtain informed consent? *If no or N/A skip to Q7.*	☐	☐	☒
dd.	The consent document states that the elements of disclosure required by regulations have been presented orally to the subject or the subject's legally authorized representative.	☐	☐	■
ee.	A written summary embodies the basic and appropriate additional elements of disclosure.	☐	☐	
ff.	There will be a witness to the oral presentation.	☐	☐	
gg.	For subjects who do not speak English, the witness will be conversant in both English and the language of the subject.	☐	☐	
hh.	The subject or the subject's legally authorized representative will sign and date the consent form.	☐	☐	
ii.	The witness will sign both the short form and a copy of the summary.	☐	☐	
jj.	The person actually obtaining consent will sign a copy of the summary.	☐	☐	
kk.	A copy of the short form will be given to the subject or the subjects legally authorized representative.	☐	☐	
ll.	A copy of the summary will be given to the subject or the subjects legally authorized representative.	☐	☐	
7.	**WAIVER of Documneted Consent (45 CFR 46.117)**	YES	NO	N/A
a.	Is a waiver for documented consent requested?	☐	☒	■
b.	A waiver of <u>documentation</u> of consent may be granted if it is found that either: · The only record linking the subject and the research would be the consent document, and the **principal risk** would be potential harm resulting from a breach of confidentiality. <u>Each subject will be asked whether the subject wants documentation linking the subject with the research, and the subject's wishes will govern;</u> **OR**	☐	☐	☒
	· The research presents **no more than minimal risk** of harm to subjects, and involves no procedures, for which written consent is normally required outside of the research context.	☐	☐	☒
c.	Are investigators required to provide subjects with a written statement?	☐	☐	☒
8.	**WAIVER or alteration of informed consent elements (45 CFR 46.116)**	YES	NO	N/A
	Is a waiver or alteration of informed consent being requested?	☐	☒	■
	Does the protocol include experimental subjects? *If yes, you may not approve a wavier of informed consent.*	☐	☐	☒
	Waiver to not include, or to alter, some or all of the elements of informed consent. May be waived if the IRB finds that: Waiver under 32 CFR 46.116.c · The research or demonstration project is to be conducted by, or subject to the approval of, state or local government officials, and is designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs; **and** · The research could not practicably be carried out without the waiver or alteration. **OR**	☐	☐	☒
	Waiver under 32 CFR 46.116.d · The research involves no more than minimal risk to the subjects **and,** · The waiver or alteration will not adversely affect the rights and welfare of the subjects **and,** · The research could not practicably be carried out without the waiver or alteration; **and** · Whenever appropriate, the subjects will be provided with additional pertinent information after participation.	☐	☐	☒
9.	**VULNERABLE POPULATIONS - MILITIARY**	YES	NO	N/A
a.	If the data will be collected from subjects in a command other than NPS, provide evidence the Commanding Officer is aware of the research and agrees to it being conducted.	☐	☐	☒
b.	Senior officers are not present during or responsible for the recruitment or consent process of junior officers.	☐	☐	☒
c.	Investigators consider a plan to manage military that deploy.	☐	☐	☒

10.	VULNERABLE POPULATIONS OTHER	YES	NO	N/A
a.	Reference 32 CFR 46 and IRB Policy/Procedure Chapter 14: Vulnerable Populations for additional protections.	☐	☐	☒
11.	RISK DETERMINATION	YES	NO	N/A
a.	**Minimal Risk:** the probability and magnitude of harm or discomfort anticipated in the research are not greater, in and of themselves, than those ordinarily encountered in daily life, or during the performance of routine physical or psychological examinations or tests. (32 CFR 219)	☒	☐	
b.	**Greater than Minimal Risk:** human subject research that is not minimal risk.	☐	☒	
	· There is an appropriate emergency treatment plan with sufficient supplies and equipment is available to administer immediate care.	☐	☐	☒
	· There is a medical monitor is assigned to the research.	☐	☐	☒
12.	TYPE OF REVIEW	YES	NO	N/A
a.	**Exempt.** Minimal risk and falls into on or more of the exempt review criteria listed below.	☐	☒	
b.	**Expedited** . Minimal risk and falls into one or more of the expedited review criteria listed below.	☒	☐	
c.	**Convened Board.** Greater than minimal risk or minimal risk that does not fall into one of the below expedited review categories.	☐	☒	

Date:	14 DEC 11	Date:		Date:	
Name of Reviewer:	CAPT J K Schmidt	Name of Reviewer:		☐ Approve	
☒ Expedited Review Category:	6	☐ Exempt Review Category:		☐ Modifications to secure approval	
☒ Approve		☐ Approve		☐ Defer. Major modifications required	
☐ Approve pending modifications				☐ Table. Review at next convened meeting	
☐ Defer to convened board		☐ Approve pending modifications		☐ Disapprove	

Continuing Review Required: (in number of months)	
Expiration Date:	31 MAR 12

Initial Review Comments:

Research involves analysis of a pre-collected dataset provided by NPS.2011.0075-IR-EP7-A that includes eye scan, video, audio, demographic, and survey data. Data was deidentified with all direct attributions referenced with participant numbers.

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APPENDIX E. RECRUITMENT E-MAIL

Volunteer Study Participants Needed!

Looking   for   Helicopter   Pilots   and   anyone   with   Land   Navigation
experience.
Anyone with training or experience in interpreting contour maps is
eligible!
We're   running   a   study   involving   virtual   environment   and   training
technology
for improving land navigation   and target detection skills.   The study
takes approximately 60–75 minutes and involves map study and a short
navigation and target detection exercise.   Other than our very sincere
gratitude, there is no compensation for participation.

Please reply via e-mail to jyan1@nps.edu or mqkenned@nps.edu or stop by
Watkins Hall room 212B if you are interested.   Also, if you are looking
for
a thesis topic there are quite of few opportunities spanning a broad
range
of academic disciplines.   Just drop us a line or stop by.   Details
available
here: http://www.movesinstitute.org/TEN/

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APPENDIX F. SUBJECT CHECKLIST

Subject ID:

☐ E-mail confirming date and time

☐ Notify lab participants of data collection time

☐ Validate equipment hardware and software

    o Screen brightness and contrast settings

    o Lab lighting conditions

☐ "Experiment in Progress" signs

☐ Bottled water in fridge.

☐ Introductory Script

☐ Informed Consent

☐ Visual Acuity equipment

☐ Background questionnaire

☐ Map set up

☐ Route brief

☐ Trial period instructions

☐ Calibration script

☐ Video recording equipment (storage media, files naming and backup scheme)

☐ Navigation and target detection exercise

☐ Save and backup data; folder name: subject ID and date

☐ Post exercise questionnaires

☐ Wrap up and thank you, contact information

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APPENDIX G. WELCOME SCRIPT

Date:

Subject ID:

Scheduled Arrival Time:

Actual Arrival Time:

Hello and welcome. Thank you for participating. We hope that your participation will ultimately lead to improvements in our understanding of how pilots train for overland navigation and target detection. This study also may help us understand how we build and evaluate training simulations.

Today we'll be asking you to complete a short navigation exercise using a pc-based simulation. Before and after the navigation and target detection exercises, we'll ask you to fill out some short questionnaires related to your background and experience. We'll have a brief vision test. During the navigation and target detection exercises, we'll be using a system of cameras and software that record your eye movement.

We hope to take less than an hour. We ask for uninterrupted participation. During the simulation exercise and when near equipment, please observe no food/drink restrictions. If you need to use a restroom they are located across the breezeway, through the double doors and to the left. Bottled water is available in the fridge by the door.

Are you ready to go on?

The next step is to make sure you understand any risks, the voluntary nature of participation and our efforts to protect your privacy.

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APPENDIX H. DEMOGRAPHIC SURVEY

Date:

Subject ID:

We are interested in learning about your navigation, target detection, and flight experiences.

1. Please provide the following information:
    Age   Gender

 The following questions ask about your **navigation** experiences.

2. To what extent have you participated in activities other than overland navigation that may contribute to improved navigation skills? (Examples may include sport orienteering, land navigation exercises, boy/girl scouts etc.)?

O	O	O	O	O
No Related Experience	Very Limited Related Experience	Limited Related Experience	Somewhat Significant Experience	Significant Related Experience

3. At your peak of currency, how would you rate your navigation skills in a low-level (below 200' AGL) overland environment?

O	O	O	O	O
Poor	Fair	Average	Good	Excellent

4. If tasked today, how would you rate your navigation skills in a low-level (below 200' AGL) overland environment?

O	O	O	O	O
Poor	Fair	Average	Good	Excellent

5.   How much experience do you have with low level navigation in mountainous desert terrain?

O	O	O	O	O
None	Very Little	Somewhat	Considerable	Extensive

6. How much low level navigation experience do you have in the 29 Palms area?

○	○	○	○	○
None	Very Little	Somewhat	Considerable	Extensive

The following questions ask about your **target detection** experiences.

7. To what extent have you participated in target detection type activities that may contribute to improved target detection skills, such as search and rescue missions and confined area landings?

○	○	○	○	○
No Related Experience	Very Limited Related Experience	Limited Related Experience	Somewhat Significant Experience	Significant Related Experience

8. How much target detection experience do you have?

○	○	○	○	○
None	Very Little	Somewhat	Considerable	Extensive

9. At your peak of currency, how would you rate your target detection skills in a low-level (below 200' AGL) overland environment?

○	○	○	○	○
Poor	Fair	Average	Good	Excellent

10. If tasked today, how would you rate your target detection skills in a low-level (below 200' AGL) overland environment?

○	○	○	○	○
Poor	Fair	Average	Good	Excellent

11. How much experience do you have with low level target detection in mountainous desert terrain?

○	○	○	○	○
None	Very Little	Somewhat	Considerable	Extensive

The following questions ask about your **flight** experiences.
1. Please provide the following information:

   Total flight hours:

   Overland hours:

   Branch of Service:

   Community:

   Years of aviation experience:

2. How many months has it been since your last flight?

3. How many months has it been since your last overland navigation flight?

4. If applicable, how many months has it been since your last search and rescue mission?

5. Describe your operational flying experience:

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APPENDIX I. EYE SCAN CALIBRATION SCRIPT

Date:

Subject ID:

☐   Verify equipment on and running. Set up for 'Precision' mode.
☐   Check lab lighting and 'experiment in progress' signs posted.

We'll now calibrate eye tracking equipment. This should only take a few minutes.

Look straight ahead at the screen in front of you with a neutral expression.

< Ensure OTW stereo cam IR light 1 is the only one illuminated and create head model>

Next we need to calibrate this stereo camera for your gaze. During this portion, you'll see a series of dots presented on the screen. Try to focus directly on the spot without blinking. Please let me know when you are ready and we'll continue…

<Do OTW screen 1 calibration, save with subject ID number>

Look at the center of the screen to your left with a neutral expression.

<Ensure OTW stereo cam IR light 2 is the only one illuminated, create head model>

Next we need to calibrate the next stereo camera for your gaze. Follow the dot as before.

<Do OTW screen 2 calibration, save with subject ID number>

Look at the center of the screen to your right with a neutral expression.

< Ensure OTW stereo cam IR light 3 is the only one illuminated, create head model>

Next we need to calibrate the next stereo camera for your gaze. Follow the dot as before.

<Do OTW screen 3 calibration, save with subject ID number>

Look straight at the map display with a neutral expression.

<Ensure Map stero cam IR light is the only one illuminated and create head model>

Next we'll calibrate the screen used for the map display. As before, please focus on the dot without blinking. Please let me know when you are ready to continue…

<Map Display calibration>

Next we'll link all 4 stereo cameras. We're going to ask to to look in a series of locations both on each OTW screen and on the map display so that the FaceLink system can learn where your gaze travels as you move your head.

<Ensure ALL stereo cam IR lights are illuminated, start FaceLink, link stereo cameras>

APPENDIX J. EQUIPMENT FAMILIARIZATION SCRIPT

Date:

Subject ID:

☐ Verify equipment on and running. Set up for 'Trial' mode.
   o Facelabs systems
   o IG PC
   o Display contrast and brightness settings
   o Instructor/data collection PC
   o Video recording equipment
   o Eye height calibration
☐ Check lab lighting and 'experiment in progress' signs posted.

Please have a seat. (Experimenter's seat.)
Before we start the simulation exercise, we'll let you get familiar with the PC simulator you'll be using. I'll briefly explain the set up and let you fly a sample navigation route to get familiar with the displays and controls. This route also will contain a few targets – SAMS (foe) and downed planes (friend).

The system provides a simulated out the window view on the 3 large screens in front of you and an instrument cluster and map display on the iPad to your right.   The joystick will be used to control the aircraft and the map will be controlled via a touch screen interface. A simulator-specific autopilot is employed to ensure you won't crash. The aircraft is flying at a near-constant 60 knots ground speed, with altitude fixed at a constant 150' AGL. The joystick is used to control heading. Pushing left or right executes a roll turn (it is not possible to turn the aircraft with the tail rotor in this simulator with this autopilot). Releasing the joystick the aircraft will return to wings level. Push up or down on the joystick can also be used to adjust the vertical view, but this will not affect the aircraft's pitch (this is to ensure the aircraft remains at a fixed altitude while allowing you to adjust your view when necessary). Using the trigger will identify SAMs, while using thumb button #1 will identify downed planes.

The map display will respond to touch commands as follows: 1) Drag a single finger across the screen to scroll the map. The map scrolls in the direction of the drag. 2) Move two fingers in a circular motion on the screen to rotate the map.

The instrument cluster contains a compass with a readout of True Heading, an airspeed indicator, MSL altitude (altimeter), AGL altitude (radar altimeter), and a clock. For pilots: because the aircraft's altitude will remain fixed, typical instruments such as the attitude indicator and vertical speed indicator are omitted (attitude control is limited – remember you don't control pitch, the autopilot does). We also omitted the turn coordinator because the horizon should be very apparent in the CAVE view and also because the tail rotor (rudder) is completely controlled by the autopilot.   Before we give the controls a try do you have any questions?

111

<...>

Please have a seat in the operator's station and sit in a position you'll be comfortable in for about an hour. We'll adjust cameras as necessary.

<...>

The map is operated via touch and should be fairly intuitive. I'll give you few minutes to try that out, then we'll move on to the flight controls. You'll notice the route is marked on the map. Please scroll the map to position the route starting point near the center of the screen. When you're comfortable with the map control we'll move on.

<...>

We'll now bring up the main display and let you get familiar with the flight controls. On the screen you see terrain similar to where you will be flying. You'll notice the flight path is depicted on the map is also depicted in this view. You'll now have a few minutes to get familiar with the controls. When you're comfortable, please fly to the second waypoint. We'll pause there and then practice flying the entire practice route while exercising map controls. You are almost certainly going to want to maintain the map oriented to your compass (though some pilots may have another preference).

<...>

You'll now have a few minutes to fly along the depicted route, update the map and use the clock to verify timing. This route consists of 3 legs, each about a minute and a half long. When the route is complete you can repeat it if you would like more practice. Let me know when you are ready and we'll start the practice route along the depicted path. Thank you. Do you have any questions before we move on?

<...>

During the next stage we'll calibrate the eye-tracking equipment. Following this we'll provide a brief on the route you will be flying, provide some time for map study and then let you fly the test route.

APPENDIX K. PRE/POST-FLIGHT SURVEY

Please answer the questions below regarding how difficult you found the navigation and target detection tasks.

1. How difficult was it to simultaneously navigate and detect targets?

○	○	○	○	○
Not At All Difficult	Somewhat Difficult	Moderately Difficult	Very Difficult	Extremely Difficult

2. Describe any strategies that you used to detect targets while trying to stay on course.

Please use the scale below to answer the questions 3 - 5.

Completely trivial	Somewhat difficult	Moderately difficult	Very difficult	Not at all possible

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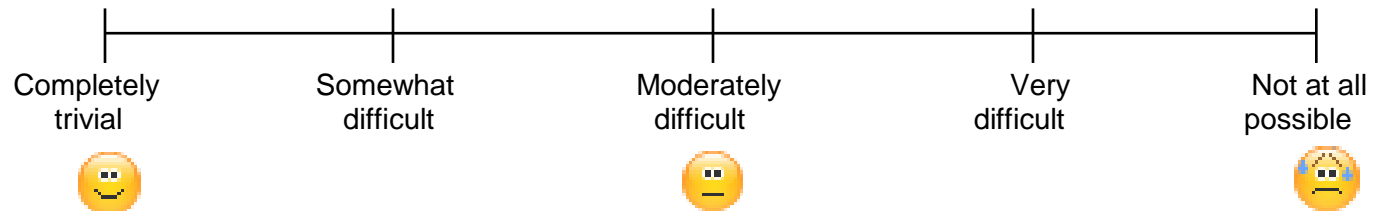
3. For each navigation leg on the route, please rate how difficult it was to navigate by referencing terrain. No response is necessary for the shaded regions.

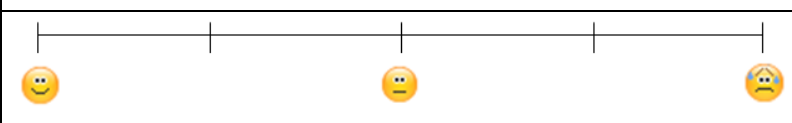|	**Navigation only**	**Target detection and navigation**
Leg 1		
Leg 2		
Leg 3		
Leg 4		
Leg 5		
Leg 6		
Leg 7		

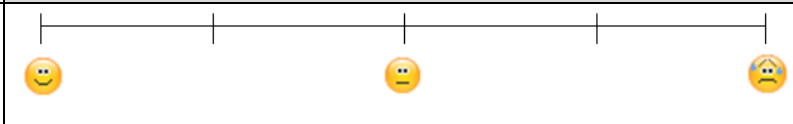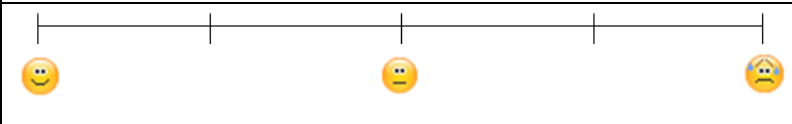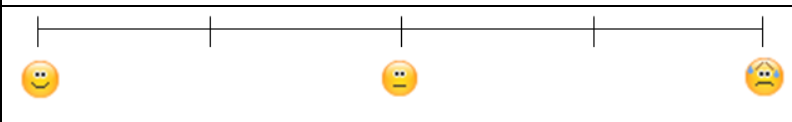|		
Leg 8	😊 😐 😟	
Leg 9	😊 😐 😟	
Leg 10	😊 😐 😟	
Leg 11	😊 😐 😟	
Leg 12	😊 😐 😟	
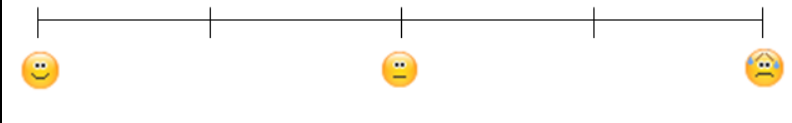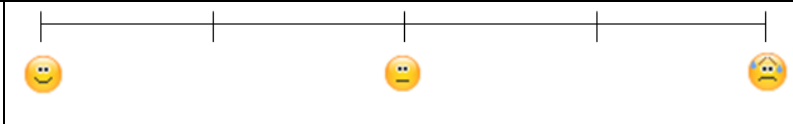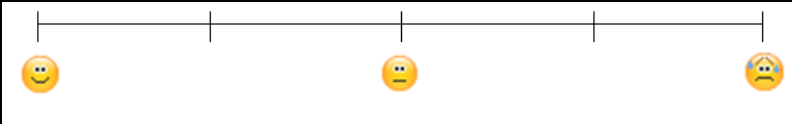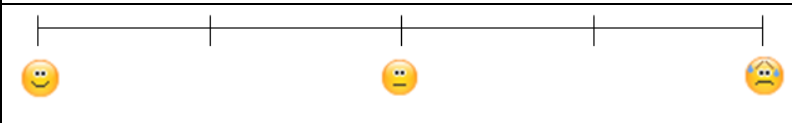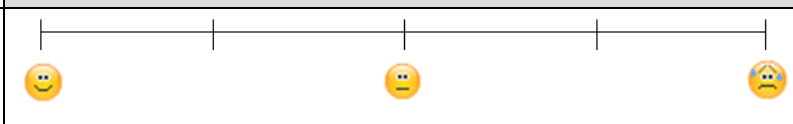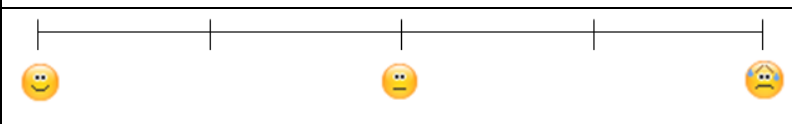
4. For each navigation leg on the route, please rate how difficult it was to detect the targets.

	Target detection and navigation	**Target detection only**
Leg 1	😊 😐 😟	😊 😐 😟
Leg 2	😊 😐 😟	😊 😐 😟

Leg 3	😊　　　😐　　　😰	😊　　　😐　　　😰
Leg 4	😊　　　😐　　　😰	😊　　　😐　　　😰
Leg 5	😊　　　😐　　　😰	😊　　　😐　　　😰

5. For each navigation leg on the route, please rate how difficult it was to identify the target as friend or foe. No response is necessary for the shaded regions.

	Target detection and navigation	Target detection only
Leg 1 Target 1	😊　　　😐　　　😰	😊　　　😐　　　😰
Leg 1 Target 2		😊　　　😐　　　😰
Leg 2 Target 1	😊　　　😐　　　😰	😊　　　😐　　　😰

Leg 2 Target 2		
Leg 3 Target 1		
Leg 3 Target 2		
Leg 4 Target 1		
Leg 4 Target 2		
Leg 5 Target 1		
Leg 5 Target 2		

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6. How confident are you that you detected all targets?

	Target detection and navigation			Target detection only		
	very confident	moderately confident	not at all confident	very confident	moderately confident	not at all confident

7. How confident are you that you correctly identified all targets?

	Target detection and navigation			Target detection only		
	very confident	moderately confident	not at all confident	very confident	moderately confident	not at all confident

LIST OF REFERENCES

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