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Air Traffic Control Specialist Visual Scanning II: Task Load, Visual Noise, and Intrusions Into Controlled Airspace

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16. Abstract

The Federal Aviation Administration (FAA) started an Air Traffic Control Specialist (ATCS) information-scanning program a number of years ago. The goal is to learn about how controllers use information displays and develop techniques for reducing air traffic-related errors. This report describes a research project conducted at the Research Development and Human Factors Laboratory of the FAA William J. Hughes Technical Center. Volunteer controllers participated in a real-time, air traffic control simulation of airspace modeled after their Terminal Radar Approach Control (TRACON) facility. ATCSs worked two different levels of simulated traffic. Some scenarios contained incursions into their Class C airspace, and overflights provided visual noise. Results indicated that the ATCSs' workload increased with higher traffic loads. However, visual noise had more impact on their perceived workload when things were slower and not when they were already busy. An eye tracker recorded eye movements. The visual scanning data included fixations, saccades, blinks, and pupil information. Increased traffic loads decreased the number of fixations on the radarscope. The increase in task load seemed to divert the ATCSs' attention to areas other than the scope, most specifically the keyboard, suggesting they were spending more time updating flight plans and less time scanning the scope. Controllers developed scanning patterns that focused on the areas of highest traffic density. This may be why they identified airspace intrusions late or not at all in some specific cases. Such lapses suggest that intrusion targets must be emphasized with color, blinking, or some other means to draw the controllers attention from established patterns. This may increase airspace safety. This research provides greater understanding of how ATCSs use current information displays. The research results have potential for increasing future ATCS efficiency through improved display technology or application of new training techniques.

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Executive Summary

Air Traffic Control Specialists (ATCSs) work in a dynamic, visually challenging environment that constantly demands their attention. They must monitor, process information, and make decisions under conditions where taskload varies across a range of their capabilities. Engineering Research Psychologists in the National Airspace System Human Factors Branch at the Federal Aviation Administration William J Hughes Technical Center used real time person-in-the-loop simulation to study these issues. They evaluated actual controller performance under two levels of task load. They also evaluated the impact of visual noise in the form of overflights to see if it influenced workload and performance. This was a concept research effort to see if these variables interacted to influence human performance and controllers' use of the visual information displayed for them.

Twelve volunteer Full Performance Level ATCSs from a Terminal Radar Approach Control (TRACON) facility participated in the study. The ATCSs worked simulated traffic under relatively low (6 aircraft for each 15 minutes) and relatively high (12 aircraft for each 15 minutes) conditions. Overflights provided scenarios with the effect of visual noise with two levels of traffic. In addition, six scenarios contained incursions into Class C airspace.

The results of a study like this are complex and involve multiple variables. Each variable has a unique meaning in the overall pattern. Some findings can be predicted based on past research and some could not. For example, the over-the-shoulder observer estimated that controller performance declined under conditions of higher task load. The objective measures of performance in fact showed that controller performance did not decrease.

The participating ATCSs also felt that they worked harder but the quality of control was lower during the high traffic load scenarios. This is a typical finding in simulation studies and could be predicted. The self-reported Situation Awareness measures decreased under high traffic load. Generally, ATCSs were willing to indicate perceived increases in workload, which increased with higher traffic loads.

Visual noise or overflights in the TRACON environment had a complex impact on controller perceptions depending on the task demand under which they were working. If they were already busy with traffic of their own, visual noise had little impact and may have even reduced controllers perceived workload. However, during slower times in their own airspace, the fact that they could see that someone else was using the area that they were scanning added to their perceived workload. This suggests the advantage of filters at least on an optional basis, where appropriate.

Some of the most interesting findings in this study came from the visual scanning data collected with an eye tracker, referred to as an oculometer. This device tracks the movement of the controller's right eye as it scans displays for information. The system also determines where on the dynamic display the controller is actually looking. Visual scanning data included information about eye movement pauses or fixations, eye jumps or saccades, blinks, and pupil diameter. The human visual system can only acquire detailed information during fixations.

Controllers spent most of their time fixating on aircraft targets and data blocks. Fixation time increased significantly when high altitude overflights were present. With an increase in traffic

load, the number of fixations on the radarscope decreased, but the number of fixations on the keyboard increased. This suggests that controllers were spending more time updating data using the keyboard and less time looking at the radarscope. The high altitude overflights seemed to further divert the ATCSs' attention. Fixations on aircraft representations on the radarscope lasted longer than fixations on any other item. These results suggest that ATCSs performed more mental processing when looking at the radarscope and aircraft representations in particular than when looking at any other object. Controllers developed patterns of visually scanning the radar display. These patterns became more structured as the traffic situation developed. ATCSs did not change these patterns with the advent of aircraft intrusions into the airspace. This may explain in part why they noticed these unscheduled targets late or not at all. In the interests of airspace safety, it is not enough to display intrusive targets. Their presence must be emphasized in a way to draw the controller's attention away from his/her established scanning pattern so that he/she can amend plans and avoid potential conflicts.

This research provides greater understanding of how ATCSs use current information displays. The research method has potential for increasing future ATCS efficiency through improved display technology or new training techniques.

1. Introduction

The Federal Aviation Administration (FAA) started a controller information scanning program in 1989 to help understand and reduce errors (Stein, 1989). With applications to Air Traffic Control (ATC) training, error analysis, and equipment design evaluation, the identification of Air Traffic Control Specialists' (ATCSs') visual scanning patterns and quantification of these patterns are necessary. Presently, no objective measures of visual scanning exist to support this program.

This was the second in a series of visual scanning studies of ATCSs conducted at the FAA William J. Hughes Technical Center Research Development & Human Factors Laboratory (RDHFL) at Atlantic City International Airport, New Jersey. The first study (Stein, 1992) addressed the effect of changes in traffic density on visual scanning. With the technology at the time, the experimenters could not synchronize the visual scanning patterns with air traffic events. This RDHFL study was the first to use head-mounted oculometry synchronized with a dynamic Air Traffic Simulator.

This exploratory project forms the basis for analyses on visual, performance, and questionnaire data. The project compared behavior and performance of ATCSs across experimental conditions.

1.1 Background

In 1995, the National Aeronautics and Space Administration (NASA), the Department of Defense, and the FAA published the National Plan for Civil Aviation Human Factors. The purpose of this plan was to enhance aviation safety and improve the efficiency of operations. It identified research areas and emphasized the transfer of research findings to planned and ongoing programs. One of the key issues of the plan was to quantify the effect that new products or procedures have on system and human performance. The plan consists of five areas: Human-Centered Automation, Selection and Training, Human Performance Assessment, Information and Management and Display, and Bioaeronautics. Except for Bioaeronautics, each of these areas states specific research areas that require a national focus. Visual scanning related measures have a potential application across most of these research areas.

The duties of an ATCS involve scanning, projecting, planning, and execution. A radar display and flight progress strips provide visual data, whereas radio and telephone communication systems provide auditory data. The cognitive requirements of ATC involve the processing of dynamically changing information (Kirchner & Laurig, 1971; Means et al., 1988). The ATCS develops an underlying mental model of the ATC situation. This model allows the ATCS to switch attention between the various data sources (Guttman, Stein, & Gromelski, 1995; Mogford, Murphy, Roske-Hofstrand, Yastrop, & Guttman, 1994;). In this study, human factor specialists conducted simulations in real time and collected data on visual scanning, performance, and mental workload.

Researchers have used workload and performance measures extensively to test design alternatives in the ATC environment. In an early visual attention study, Karsten, Goldberg, Rood, and Sultzer (1975) found that ATCSs spend approximately 80% of their time looking at the radar display, 13% looking at flight strips, and 5% looking at input devices. Their equipment was primitive by current standards. With the advancement of technology and recent enhancements in software and hardware, the RDHFL now simulates the ATC environment with a much higher degree of fidelity.

1.1.1 Literature Related to Visual Scanning

The amount of sensory information available to a human being at any one point in time is 1,000,000,000 bits per second at the human sensory level (Grandjean, 1993). This information, although highly filtered before reaching conscious awareness, is still of critical importance to the performance of everyday activities. The most relied upon sensory information comes from the visual system having approximately 90% of a person's daily activities under its guidance.

The visual system provides information about the ATC environment necessary to anticipate changes and to react appropriately. When looking at an object, the eyes move rapidly from one point of interest to another. These fast jumps, called saccades, are ballistic movements that, once started, will continue until they reach their target destination (Carpenter, 1977). During a saccade, the visual system obtains little visual information other than the detection of movement. Most of the time, humans look at objects without moving their eyes. During these stationary periods between saccades, called fixations, humans register most visual information. In a 30-minute scenario, ATCSs have roughly 3600 fixations with an average duration of approximately 500 ms (Stein, 1992).

A fixation is a four-part process. First, the visual system stores an image in short-term visual memory. Second, the visual system encodes the raw image and stores the codes in working memory. In the third stage, further mental processing takes place and, in the fourth stage, the visual system prepares for the next saccade. The preparation time for the next saccade increases with an increase in the magnitude of the future saccade (Kapoula, 1983). Kapoula showed that the proximity of previous fixations influenced fixation duration on subsequent points of interest.

Like most human neuromotor control systems, the oculomotor system uses open and closed loop control, depending on the situation. In closed loop control, information acquired during a fixation directs the subsequent saccade (Kapoula, 1983; Rayner & Pollatsek, 1981; Vaughn, 1982). The visual system uses closed-loop control in active information searching during situations with potential points of interest in close proximity. In open-loop control, information processing independent of the current visual information in the visual field determines the next saccade (Ellis, 1986). An open-loop system scans the visual field in the periphery for potential points of interest. Higher level cognitive processes determine the target of the next saccade in open-loop control.

Experienced participants tend to scan for pertinent information in a stratified random manner (Card, 1983; Engle, 1977; Groner & Groner, 1982; Inditsky & Bodmann, 1980; Kraiss & Knauper, 1983; Krendel & Wodinsky, 1960; Senders, 1966; Weir & Klein, 1970; Wewerinke, 1981). A structured model gives priority to objects or groups that need more attention while updating the total picture of the process under control. Less experienced participants do not have a well-structured model available in long term memory and tend to follow events that can lead them astray. An example is tunneling, when an ATCS loses the overall picture and focuses on a single problem only.

1.1.2 Literature Related to Workload

Studies aimed at improving the safety of air traffic often include ATCSs' performance and workload. Researchers have developed a variety of assessment techniques to evaluate workload. Subjective techniques have dominated this research area because of the ease of administration, low cost, and lack of obtrusiveness. The variety of available measures indicates a lack of consensus among researchers and presents an obstacle when attempting to generalize and integrate research findings. The NASA Task Load Index (TLX) (Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT) (Reid & Nygren, 1988) serve a wide variety of research needs. The TLX and the SWAT assess mental workload at the end of the scenario or experiment and break down mental workload into several components. Other subjective mental workload assessment techniques follow a more holistic approach. The Air Traffic Workload Input Technique (ATWIT) (Stein, 1985), derived from earlier work by Stein and Rosenberg (1983), uses a single 10-point scale to assess perceived workload. The ATWIT collects assessments of perceived workload during the scenario. An experiment should incorporate both objective and subjective measures to fully assess workload.

When reaching working memory limits, mental workload increases and performance decreases. Performance shows an inverted U-shaped dependency on workload with poor performance occurring at extremely low and high mental workload levels. Optimal performance will often occur between these two extremes (Tole, Stephens, Harris, & Ephrath, 1982).

1.2 Purpose

The study explored the eye movement characteristics of Terminal Radar Approach Control (TRACON) Full Performance Level (FPL) ATCSs under different levels of task load, with and without overflying aircraft (visual noise), and with and without aircraft intrusions. It answered seven research questions that addressed visual scanning, subjective ratings, over-the-shoulder (OTS) ratings, questionnaire scores, and performance scores.

Depending on the scenario, the ATCS encountered airspace intrusions, different task loads, and en route aircraft primary radar returns. Researchers determined if changes in experimental conditions altered performance and behavior. The questions related to these changes are as follows:

a. Do eye movement characteristics of ATCSs differ across experimental conditions?

b. Do subjective mental workload estimates (ATWIT) differ across experimental conditions?

c. Do OTS ratings differ across scenarios?

d. Do responses to Post-Scenario Questionnaires differ across scenarios?

e. Do performance scores differ across experimental conditions?

f. Do eye movement characteristics differ depending on Visual Flight Rules (VFR) intrusion presence?

g. Do eye movement characteristics differ depending on Instrument Flight Rules (IFR) intrusion presence?

1.3 Scope

This study compared visual scanning behavior, system activity, ATCS performance, workload, and pilot-ATCS interactions under conditions that differed in traffic load, presence of visual noise, and aircraft intrusion in Class C terminal airspace.

2. Method

2.1 Participants

Twelve active FPL ATCSs from a TRACON facility participated in the study. The participants actively controlled traffic for at least 16 hours in the month preceding the experiment. The ATCSs gave their verbal informed consent to participate in the experiment. The research team ensured them that their data were completely confidential. Participants had visual acuity not less than 20/30 corrected. ATCSs could wear corrective lenses and soft contact lenses. The oculometer design limitations excluded bifocals, trifocals, or hard contact lenses.

2.2 Facility

The experiment took place in three areas of the RDHFL: Experiment Room Four (ER4), Experiment Observation Room Two (EOS2), and Experiment Room 2 (ER2). ER4 contains a high fidelity, state-of-the-art ATC simulator run by ATCoach (1992) simulation software. This station can mimic up to an ARTS IIIA radar system and consists of a 22-inch, high-resolution (2000 x 2000 pixels) color radar display, a three-button trackball, and an ARTS IIIA keyboard. The system operated in networked mode linked to the ER2 that contained the simulation pilot workstations. ER4 and EOS2 contained video cameras and recorders synchronized with ATCoach, the ATWIT panels, and UNIX network hardware. The simulation workstation included a flight strip bay with time-ordered flight progress strips. The staff modeled the TRACON and interfaced ATCoach with an Applied Science Laboratories (ASL) oculometer. The oculometer consists of an eye/head tracking system that recorded the point of gaze (POG) and pupil diameter of a person by using near infrared reflection outlines from the pupil and cornea. For a detailed description of the equipment used in the simulation, see Appendix A.

2.2.1 Support Personnel

The study employed three simulation pilots. To allow rotation, researchers trained nine simulation pilots using procedures from past experiments with additional procedures for VFR aircraft. One simulation pilot read back clearances. A second simulation pilot keyed in entries sent to the computer that updated the movement of the displayed aircraft. The third simulation pilot manually recorded simulation commands corresponding to clearances. The training of the simulation pilots lasted 3 weeks. Training included procedures related to simulation pilots' commands and familiarization of simulation equipment. The simulation pilots trained at every position.

A research team composed of a research psychologist, a human factors engineer, and a subject matter expert (SME) conducted the simulations. The team created the scenarios, conducted the OTS ratings and the experiments, performed the data analyses, and wrote the final technical report. RDHFL support engineers ensured that the hardware and software functioned properly.

2.3 Operation

During the simulations, a personal computer recorded the eye movements. The simulator software recorded aircraft activities. Off-line software programs integrated the POG data and the data provided by the simulator. Programs developed by RDHFL software engineers reduced the eye movement data and calculated fixation, saccade, blink, and pupil characteristics. For each fixation, the software determined the radarscope objects (aircraft, airports, fixes, etc.) within a 2-inch radius from the center of a fixation.

2.4 Design

The objective of this study was to compare visual scan patterns of ATCSs during high and low task load, presence and absence of visual noise, and presence and absence of VFR or IFR intrusions. The design was a 2 x 2 (task load x overflight) repeated measures full factorial design. Task load had two levels, low (6 aircraft per 15 minutes) and high (12 aircraft per 15 minutes), and there were scenarios with and without overflights.

2.4.1 Independent Variables

The independent variables (IVs) were visual noise, task load, and intrusions. Visual noise and task load differed between scenarios, whereas intrusion type changed within scenarios over time. Each scenario consisted of simulated air traffic of the TRACON modeled in ATCoach for previous experiments (Guttman et al., 1995)

The experiment included scenarios with and without visual noise. In the visual noise condition, researchers modeled overflying aircraft into the scenario as visual noise using primary radar returns. In the no visual noise condition, there were no overflights. Flight strips from an Air Route Traffic Control Center (ARTCC) formed the basis for the calculation of the number of aircraft and the traffic composition of all overflights.

The research team varied traffic volume and traffic frequency across scenarios. The low task load condition had an average of 6 aircraft entering the airspace per 15 minutes with 6 aircraft visible on the radar screen at any given time. The high task load condition had an average of 12 aircraft per 15 minutes with 12 aircraft visible on the radar screen at any given time. The actual scenario composition varied depending on how the ATCS worked the airspace.

The simulations included intrusions as aircraft making an unscheduled entry into Class C airspace. The intrusions included both aircraft under VFR or IFR with special care given to prevent the ATCS from anticipating the onset of an intrusion. The levels of the intrusion IVs were no intrusion (baseline), VFR intrusion, or IFR intrusion.

The research team created eight scenarios reflecting the levels of the IVs [overflights (yes, no), task load (low, high), and intrusion type (IFR, VFR)]. For a detailed description of the experimental and practice scenarios, see Appendix B. The TRACON used in these scenarios consisted of two sectors (north and south), worked by a single ATCS. To keep the scenarios realistic, they, at most, included two intrusions. IFR intrusions only occurred under the overflight condition.

2.4.2 Dependent Variables

Researchers averaged the following sets of dependent variables (DVs) over 5-minute intervals:

a. Subjective Workload Assessment. The ATWIT device (Stein, 1985) assessed the workload of the ATCS. The ATWIT measure is a workload estimate based on a scale from 1 (very low or no workload) to 10 (extremely high workload). The ATCS, prompted by a low tone, made a workload rating every 5 minutes. Each participant made 9 ATWIT ratings in a 45-minute scenario allowing calculation of the mean and maximum rating for each scenario.

b. Questionnaires. The experimenters used three types of self-report questionnaires adapted from previous experiments. The questionnaires (see Appendix C) included an Entry Questionnaire, Post-Scenario Questionnaire, and Exit Questionnaire (Abbott, Nataupsky, & Steinmetz, 1987; Guttman et al., 1995; Sollenberger & Stein, 1995; Stein, 1992). The Entry Questionnaire contained questions concerning demographic information. The Post-Scenario Questionnaire contained questions about various aspects of controlling traffic during a scenario. The Exit Questionnaire provided feedback about the experiment.

c. Over-the-Shoulder Ratings. The research team rated the performance of the ATCSs for each scenario. They used a form that captures a wide range of ATC-related performance issues (adapted from Guttman et al., 1995). (See Appendix D.)

d. Performance. The automated data reduction module developed at the RDHFL provided performance data broken down by conflicts, complexity, error, communications, and task load (Algeo and Pomykacz (1996). Further analysis used a subset of these performance variables (see Appendix E).

e. Visual Scanning. The oculometer data formed the basis for the variables related to visual scanning. For each scenario and 5-minute interval, the research team calculated the variables in Appendix F, Table F-2. Visual scanning targets were radarscope, keyboard area, ATWIT device, flight strip bay, aircraft, static objects, departure list, system settings, preview area, and Conflict Alert/Low Altitude (CA/LA) area. See Appendix F for a more detailed description and information about the computation of the visual scanning DVs.

2.5 Procedure

Twelve FPL ATCSs participated in the experiment during the workweek. The morning of their first day consisted of a briefing and a familiarization period. The research team explained the experiment, the oculometer, differences between ATCoach and their own equipment, and the confidentiality of ATCSs' identity. They provided an informed consent briefing, and participants gave a verbal commitment to the experiment and their understanding of informed consent doctrine. The ATCSs then completed an Entry Questionnaire that included demographic questions about age, experience level, and need for corrective glasses. Researchers assigned the participants to an experimental condition.

After receiving instructions about the Letter of Agreement (LOA) and the Standard Operating Procedures (SOPs), the ATCSs familiarized themselves with the laboratory equipment. The laboratory equipment included the 2K display and the simulation configuration of the sector. Then, the ATCSs completed a 20-minute familiarization scenario with the oculometer. After a break, the first of three scenarios was run. Each experimental run consisted of setup and calibration of the oculometer, a simulation run, and a Post-Scenario Questionnaire. After the initial scenario, there was a break for lunch after which the ATCSs worked two scenarios with a 30-minute break between each scenario. The second day consisted of a brief simulation review followed by two scenarios in the morning and three scenarios in the afternoon. Finally, the participants filled out an Exit Questionnaire. Appendix G presents a detailed schedule of activities.

2.5.1 Data Reduction

2.5.1.1 Questionnaires

Researchers administered the Entry, Post-Scenario, and Exit Questionnaires in paper and pencil format and transcribed the responses into a spreadsheet. Researchers created a data set for each questionnaire.

2.5.1.2 Over-the-Shoulder Ratings

Researchers entered the ratings from the OTS questionnaires into a spreadsheet. The data set consisted of SME ratings of each ATCS for all eight scenarios.

2.5.1.3 Visual Scanning Data

The oculometer recorded eye movements in terms of horizontal and vertical positions. The Magnetic Head Tracker (MHT) provided position and orientation of the head in six degrees of freedom. The software integrated the eye and head movement data to determine the POG. The oculometer identifies the plane at which the ATCS looked and records the coordinates relative to that plane. The sampling rate of the oculometer and the MHT was 60 samples per second. Experimenters reduced the raw data and expressed it as fixations, saccades, and blinks. Fixation characteristics included time of onset, duration, the plane being looked at, the area covered by small eye movements within the fixations, and the coordinates relative to the plane. Appendix H contains a description of the output after this first stage of data reduction. Saccade characteristics include information on the magnitude of the saccade and the average velocity during the saccade. Researchers summarized a number of variables derived from the fixation and saccade data per scenario and 5-minute interval. The first data set contained 8 x 12 (scenarios x ATCSs) records of the visual scanning summary variables per scenario. The records contained ATCS and experimental condition identifications at the scenario level. The second set contained 8 x 12 x 9 (scenarios x ATCSs x intervals) records of the visual scanning summary variables per 5-minute interval.

The research team integrated the eye movement data with simulator information about static objects (airports, VHF Omni-directional ranges (VORs), fixes, intersections, and the system area) and dynamic objects (aircraft and the preview area). Appendix I, Figure I-1 displays a snapshot at 20 minutes into a high task load scenario with visual noise present. Appendix I, Figure I-2, presents the integrated data of the simulator and the oculometer for a similar scenario.

Figures I-3 and I-4 show the advantage of collecting object-related fixation information. Figure I-3 shows the fixations of one participant for a 45-minute low task load scenario without visual noise. Although one sees an increased density of the number of fixations along the runways (shown in Figure I-3), no information is available about how this relates to the fixation distribution across aircraft. Superimposing the flight paths of the 20 aircraft in the scenario did not relate fixation information to aircraft movements. Identifying a target aircraft (e.g., BTA3721) clearly shows that the ATCS follows that aircraft throughout the airspace (Figure I-4).

2.5.1.4 Performance Variables and ATWIT

The Data Reduction & Analysis (DR&A) module processed raw data files produced by ATCoach, ATWIT, and the communications system. The DR&A module produced summary, interval, and error files for each scenario. The interval and summary files formed two separate data sets. The first data set contained 12 x 8 (ATCSs x scenarios) records that included the summary variables calculated per scenario. The second data set with 12 x 8 x 9 (ATCSs x scenarios x intervals) records contained the summary variables calculated per 5-minute interval.

2.5.2 Data Analysis

This section briefly describes the data analysis for DV data sets (ATWIT, questionnaires, OTS rating form, visual scanning, and performance). The statistical methods used for the analysis include Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA). The MANOVA compares averages for several variables simultaneously, tests if these averages are different due to chance alone, and includes the effects of more than one DV. After a significant result of a MANOVA, researchers conducted ANOVAs to investigate individual DVs.

The ANOVAs compare averages of a single variable between multiple conditions and determines if these averages are different due to chance alone. A difference between means is significant if there is a very high probability that the means are actually different. For general concepts in statistics and more detailed information about the statistical methods used in this study, see Appendix J.

2.5.2.1 ATWIT Ratings

For the analysis concerning the subjective ratings, researchers used a MANOVA on maximum and mean ATWIT ratings. This MANOVA, structured as a 2 x 2 (Task load x Visual noise) repeated measures design, addressed the differences across scenarios.

2.5.2.2 Questionnaires

The Entry Questionnaire contained questions about participant background and importance of provided airspace and aircraft information. The analysis of the Entry Questionnaire data consisted of the calculation of means and standard deviations (SD).

The Post-Scenario Questionnaire contained general questions about the simulation, ATCSs' perceived Situation Awareness (SA), and NASA TLX items. If the MANOVA showed statistical significance, subsequent analyses included ANOVAs on the individual variables. The analyses of the SA and NASA TLX items followed the same pattern as the analyses of the general questions.

The Exit Questionnaire collected ATCSs' impressions of the experiment. The analysis of the Exit Questionnaire data consisted of the calculation of means and SDs.

2.5.2.3 Over-the-Shoulder Ratings

The OTS ratings consist of questions relating to six categories: Maintaining Safe and Efficient Traffic Flow, Maintaining Attention and SA, Prioritizing, Providing Control Information, Technical Knowledge, and Communication. The researchers compared OTS rater responses in a two-way, 2 x 2 (overflights x task load) fashion.

2.5.2.4 Visual Scanning

Three MANOVAs tested the hypotheses related to the changes in visual scanning. The first MANOVA addressed visual scanning differences across scenarios and was a 2 x 2 repeated measures analysis (overflights x task load). The second MANOVA addressed the differences between 5-minute intervals in similar scenarios that contained VFR intrusions and the corresponding interval without intrusions. It was a two-way repeated measures MANOVA (i.e., 2 x 5 [VFR presence x conditions]). The third MANOVA investigated differences between intervals in similar scenarios that contained IFR intrusions and the corresponding intervals without intrusions. This MANOVA was of a 2 x 5 (IFR presence x conditions) design.

2.5.2.5 Performance Scores

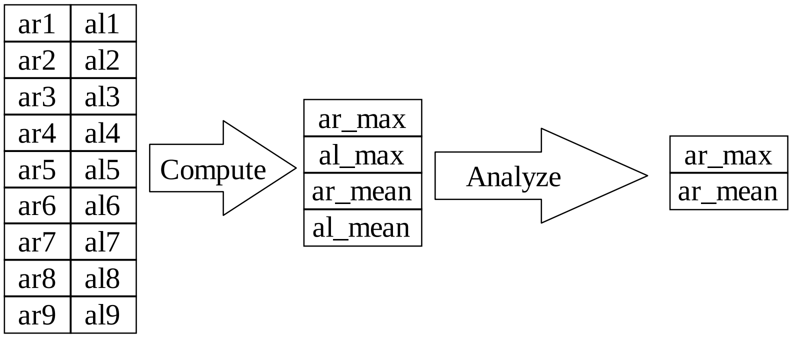
The four categories of variables related to performance included conflicts, separation, complexity, and communications. Four sets of MANOVAs tested the hypotheses related to performance scores on selected performance variables. These MANOVAs addressed the differences across scenarios and were of repeated measures 2 x 2 (overflights x task load) design.

3. Results

Analyses of the Entry and Exit Questionnaires consisted of the calculation of the means and SDs. Analyses of other data sets involved MANOVAs and ANOVAs when appropriate. Appendix K presents overall averages for DVs used in inferential statistics.

3.1 ATWIT

The ATWIT device recorded ATCS ratings and the amount of time it took the ATCS to respond (latencies). Researchers calculated the mean and maximum ATWIT rating and latency for each scenario. Correlations between the mean and maximum on-line ATWIT ratings and the post-scenario TLX workload indicated what drives the post-scenario perception of workload. This report only presents the results of the analyses on mean and maximum ATWIT ratings (Figure 1).



ar[i]: ATWIT Rating for interval [i]
al[i]: ATWIT Latency for interval [i]

Figure 1. Derivation of ATWIT variables from raw ATWIT scores.

The MANOVA of the ATWIT ratings included the mean and the maximum of the ratings within a scenario. The effects of increasing task load and introducing visual noise interacted [$\Lambda = .70$, $F(2, 21) = 4.45$, $p < .05$] (Appendix L, Table L-9). The effect of visual noise was not significant as a simple effect (Table L-9).

Researchers included both the mean and the maximum ATWIT rating items in the MANOVA. To ensure an overall alpha level of .05, the adjusted alpha was .025 for the ANOVAs.

3.1.1 Mean ATWIT Rating

Under high task load conditions, the mean ATWIT rating was significantly higher than under low task load conditions [$F(1, 22) = 92.37$, $p < .05$] (Figure 2). The presence of visual noise did not significantly affect the mean ATWIT ratings.

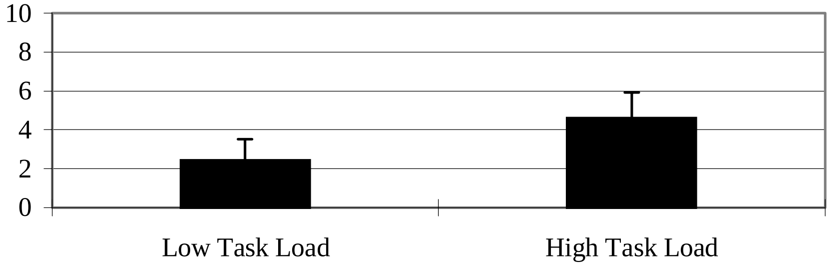


Figure 2. Means and SDs of mean ATWIT ratings as a function of task load.

3.1.2 Maximum ATWIT Rating

The effects of introducing visual noise and increasing task load on the maximum ATWIT rating interacted [$F(1, 22) = 9.19$, $p < .05$] (Appendix L, Table L-10). The simple effects showed that the effect of task load on the maximum ATWIT rating was stronger under the no noise condition (Table L-11). There was no significant effect of the presence of visual noise on the maximum ATWIT rating for both task load levels (Figure 3).

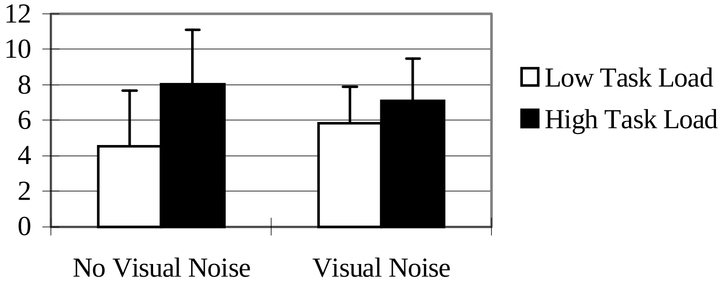


Figure 3. Means and SDs of maximum ATWIT ratings for load-visual noise combinations.

3.1.3 Correlation Between Mean and Maximum ATWIT Ratings and TLX

The post-scenario TLX items showed higher correlations with the mean ATWIT ratings than with the maximum ATWIT ratings. Both the mean and maximum ATWIT rating showed the highest correlation with the TLX item on mental demand ($r = .71$ and $r = .50$, respectively). Table K-3, Appendix K, presents a detailed correlation matrix.

3.2 Questionnaires

3.2.1 Entry Questionnaire

The Entry Questionnaire inquired about participants' general background and preferences of information available on aircraft and radarscope. When asked to indicate an LOA or level of a modality, participants chose from a discrete 10-point scale.

The 12 participants averaged 37 years of age, almost 12 years of ATC experience, and over 8 years at their TRACON. One third of the participants used corrective lenses during the experiments. These volunteers actively controlled traffic for an average of 11.5 months during the last 12 months. Their self-rated ATC skill level was high, and they perceived a moderate stress level. Their motivation and current state of health were good. They indicated moderate preference towards vertical separation, less preference towards vectoring, and no level of preference towards speed control. The self-rated level of experience with video games was low. Table 1 presents detailed values for the means and SDs for the general background variables.

Table 1. General Background Questions (N = 12)

Variable Label	Mean	SDs
Age	37.42	3.55
Lenses	0.33	
ATC Experience	11.67	4.38
Present TRACON Experience	8.42	4.62
Active Control last 12 Months	11.50	1.73
ATC Skill	8.25	1.22
Stress	5.50	2.15
Motivation	7.42	2.11
Health	8.58	1.16
Vertical Separation Preference	6.75	1.36
Vectoring Separation Preference	5.67	1.30
Speed Separation Preference	4.83	1.64
Video Game Experience	3.42	2.15

Table 2 presents the ratings for several aircraft-related variables sorted from most important to least important. The ATCSs rated the current altitude, current location, and assigned altitude as the three most important pieces of information about the aircraft. Least important were entry fix, exit airspeed, and beacon code.

ATCSs indicated that airports, sector boundaries, Instrument Landing System (ILS) approaches, restricted area boundaries, and ILS outer-marker information were most important. Less important were conflict alert, holding pattern, and system clock information.

Table 3 presents detailed information on the ATCS ratings of important radarscope information.

Table 2. Importance of Aircraft Information (N = 12)

Variable Label	Mean	SDs
Current Altitude	9.33	0.89
Current Location	9.33	0.98
Assigned Altitude	9.17	1.03
Arrival Apt. (within sector)	8.67	1.50
Call Sign	8.33	3.45
Departure Apt. (within sector)	8.25	2.30
Near Exit Fix/Arrival Apt.	8.17	2.12
Type	7.92	1.88
Density	7.92	1.31
Exit Altitude	7.58	1.88
Waiting for Hand-off/Release	7.42	2.15
Assigned Heading	7.33	1.56
Current Airspeed	7.17	1.75
Assigned Airspeed	7.00	1.48
Current Heading	6.92	1.93
Entry Altitude	6.58	2.97
Exit Fix	6.58	1.88
ATCS Ownership	6.36	3.80
Holding/Spinning	6.17	2.25
Entry Airspeed	5.58	2.31
Entry Fix	4.92	2.57
Exit Airspeed	4.75	2.45
Beacon Code	4.58	3.26

Table 3. Importance of Radarscope Information (N = 12)

Variable Label	Mean	SDs
Airports	8.83	1.47
Sector Boundaries	8.83	1.40
ILS Approaches	8.75	1.48
Restricted Area Boundaries	8.58	1.51
ILS Outer Marker	8.50	1.68
Runways	7.75	2.18
Fixes	7.50	2.15
VORs	7.42	2.35
Future Act. List	5.50	2.43
Range Rings	5.33	2.67
Obstructions	5.33	2.46
Filter Settings	5.33	2.31
Conflict Alert	5.33	3.70
Holding Patterns	4.67	2.50
System Clock	4.08	2.75

3.2.2 Post-Scenario Questionnaire

The Post-Scenario Questionnaire contained eight general questions concerning realism, representativeness, ATWIT interference, oculometer interference, simulation pilot responsiveness, working hard, quality of control, and difficulty. Table K-1, Appendix K, presents the means and SDs for these questions.

The analysis investigated if a difference in ATCS response occurred when task load changed from low to high or when the scenario changed from having no visual noise to having visual noise. If the analysis showed that the experimental conditions did affect the general questions significantly, the subsequent analyses consisted of ANOVAs on individual variables.

The effects of increasing task load and introducing visual noise on the responses to the general post-scenario questions interacted significantly [$\Lambda = .41$, $F(8, 15) = 2.66$, $p < .05$] (Appendix L, Table L-1). Because of this interaction, researchers analyzed visual noise impact under both low and high task loads and also task load with or without visual noise. The effect of increasing task load on responses to general post-scenario questions was slightly stronger in the absence of visual noise [$\Lambda = .04$, $F(8, 15) = 44.30$ versus $\Lambda = .08$, $F(8, 15) = 22.08$, $p < .05$, or $\eta = .98$ versus .96, respectively]. The effect of introducing visual noise was only significant under high task load conditions [$\Lambda = .41$, $F(8, 15) = 2.65$, $p < .05$].

Because the MANOVA results indicated that the experimental conditions affected the general post-scenario questions, researchers analyzed each of the questions individually. To maintain an overall alpha level of .05, the researchers adjusted the alpha level to .0064 for the analyses. Without the adjustment of the alpha level, the sequence of subsequent univariate analyses may allow the overall probability of error to creep upward. Figure 4 presents the means and SDs for the eight general post-scenario questions.

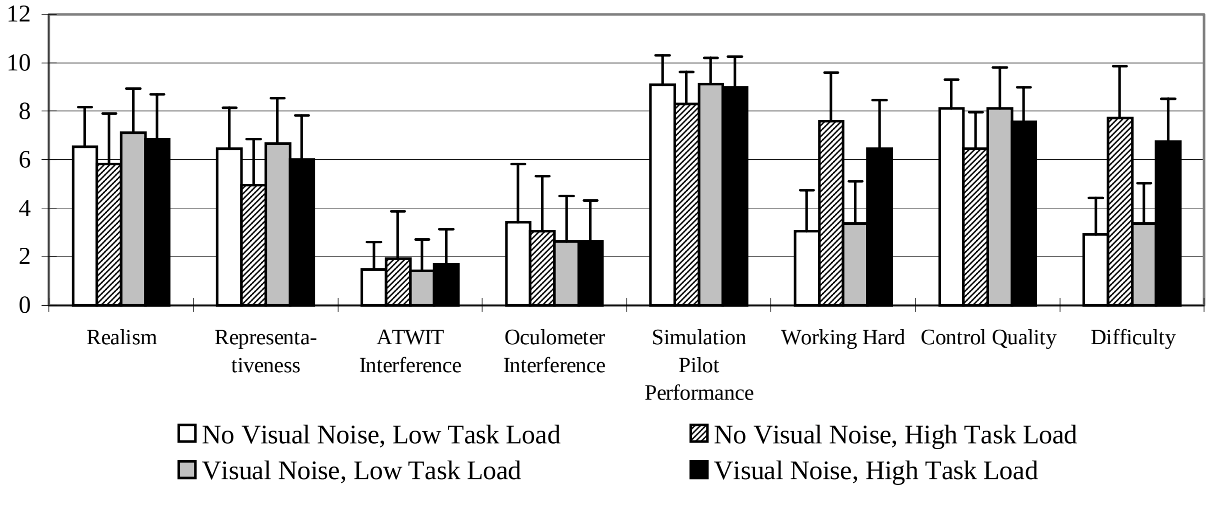


Figure 4. General post-scenario questions as a function of task load and visual noise.

a. Realism and Representativeness

Visual noise made the scenarios slightly more realistic although not statistically significant. The scenarios were equally representative of an average day at the TRACON. Although not statistically significant, ATCSs indicated that the low task load scenarios were more realistic than the high task load scenarios.

b. ATWIT and Oculometer Interference

The ATCS perceived little interference from the ATWIT device. The equipment bothered them even less when the task load was low. The oculometer hardly interfered, but more than the ATWIT device. The ATCSs did not perceive that increased task load caused any greater oculometer interference. Visual noise in the scenario reduced the perceived level of interference caused by the oculometer, although not significantly.

c. Simulation Pilot Responsiveness

The perceived quality of the simulation pilot responses was very high. Increasing task load reduced the perceived quality of these responses, but not significantly. Introducing visual noise did not alter the perceived quality of the responses.

d. Working Hard

The effect of increasing task load on the perception of ATCSs on how hard they worked during the simulation depended on the presence of visual noise [$F(1, 22) = 9.24$, $p < .05$] (Table L-2). Researchers determined simple effects. ATCSs felt they worked harder during high task load scenarios [$F(1, 22) = 296.66$, $p < .05$]. The increase in perceived workload due to an increase in task load was smaller when visual noise was present than when it was absent.

e. Quality of Control

Participants perceived that their control quality was lower under high task load conditions [$F(1, 22) = 14.44$, $p < .05$] (Table L-3). Under high task load conditions, visual noise led to an increase in perceived quality of control, although not statistically significant. Under low task load conditions, visual noise did not affect the perceived quality of performance. The introduction of visual noise showed a trend toward an increase in perceived quality of control, although not significantly.

f. Difficulty

The effects of increasing task load and introducing visual noise on perceived simulation difficulty interacted [$F(1, 22) = 11.21$, $p < .05$] (Table L-2). Visual noise itself did not affect the perceived difficulty, but it altered the effect of increasing task load. Introducing visual noise increased the perceived difficulty under low task load conditions, but it reduced the perceived difficulty under high task load conditions.

g. Situation Awareness Questions

The four post-scenario questions involving SA estimates included overall SA, current aircraft location SA, projected aircraft (A/C) location SA, and potential violation SA. The post-scenario questions that addressed the ATCSs' SA showed a multivariate significance for the effects of increasing task load [$\Lambda = .32$, $F(4, 19) = 10.31$, $p < .05$] and introducing visual noise [$\Lambda = .55$, $F(4, 19) = 3.86$, $p < .05$] (Table L-4). The MANOVA on SA related questions involved responses for four questions. To maintain an overall alpha level of .05, the adjusted alpha level for the analyses on individual questions was .013.

The ATCSs estimated their SA higher under low task load than under high task load conditions [Overall SA, $F(1, 22) = 25.19$, Current A/C Location SA, $F(1, 22) = 42.98$, Projected A/C Location SA, $F(1, 22) = 32.85$, Potential Violations SA, $F(1, 22) = 13.03$, all $p < .05$] (Table L-5). Figure 5 summarizes the means and SDs.

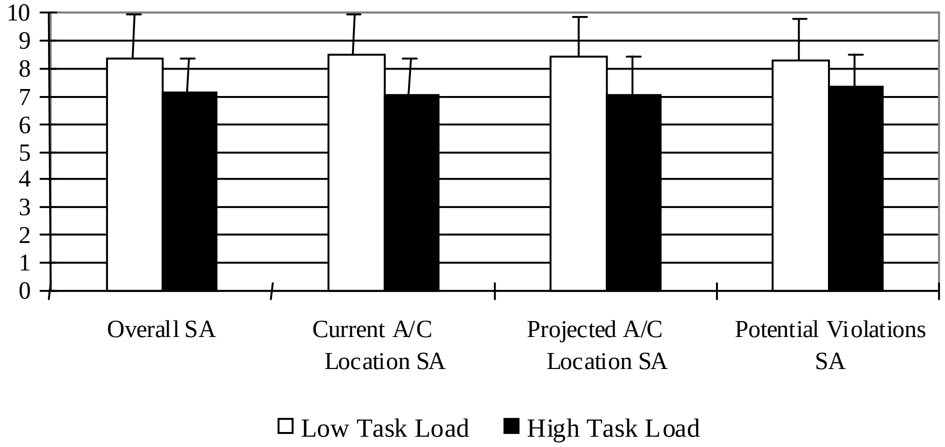


Figure 5. Means and SDs for SA post-scenario questions as a function of task load.

Visual noise affected only the SA question concerning potential violations [$F(1, 22) = 14.63$, $p < .05$] (Table L-6). ATCSs perceived that they had a better SA for potential violations (Figure 6) in the presence of visual noise.

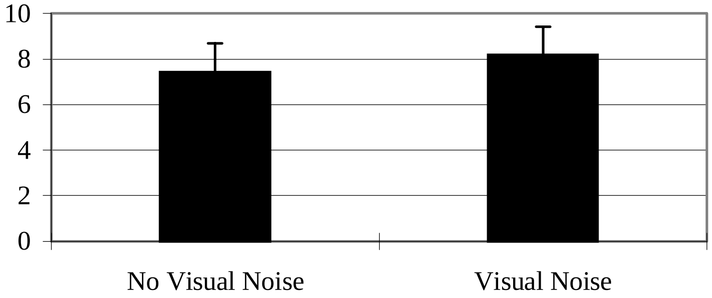


Figure 6. Means and SDs for SA for potential violations as a function of visual noise.

3.2.2.1 Post-Scenario TLX

The items of the NASA TLX were mental, physical, and temporal demand; performance; effort; and frustration. The MANOVA on these items displayed a significant effect of increasing task load [$\Lambda = .06$, $F(6, 17) = 45.17$, $p < .05$]. To ensure an overall alpha level of .05, the adjusted alpha was .0085 for the ANOVAs on all six items.

The mental, physical, and temporal demand; level of effort; and frustration were higher under high task load conditions than low task load conditions [$F(1, 22) = 222.27$, 41.91, 99.95, 23.84, 80.05 respectively, all at $p < .05$]. The performance level was lower under high task load than under low task load conditions [$F(1, 22) = 8.72$, $p < .05$]. Table L-8 presents detailed ANOVA results for the effect of task load. Figure 7 presents the means and SDs of the individual TLX items.

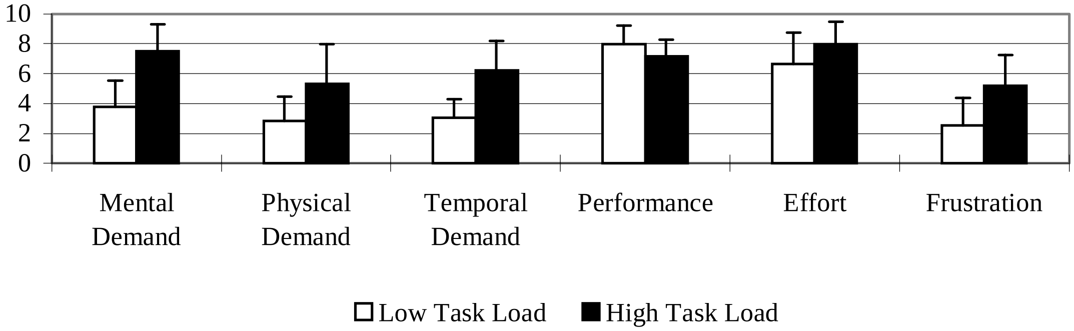


Figure 7. Means and SDs for post-scenario TLX items as a function of task load.

3.2.3 Exit Questionnaire

After the eight experimental scenarios, the participants completed an Exit Questionnaire (Appendix C). The Exit Questionnaire collected their opinions on topics covered in the Post-Scenario Questionnaires. The ATCS rated each item on a scale from 1 to 10. The overall realism of the scenarios was moderately good. The participants perceived the scenarios as a moderately realistic representation of an average day at their TRACON. The participants felt that the ATWIT device hardly interfered with controlling traffic. The oculometer interfered more than the ATWIT device, but the level of interference was low. The simulation pilots performed extremely well. The hands-on training was adequate (Table 4).

Table 4. Exit Questionnaire (N = 12)

Variable Label	Mean	SDs
Realism	6.42	1.44
Representative	5.67	2.15
ATWIT interference	1.58	0.90
Oculometer interference	3.17	2.55
Simulation pilot performance	9.33	0.98
Training adequacy	8.91	1.14

3.3 Over-the-Shoulder Evaluation

3.3.1 Ratings

The OTS rating form contained three sets of questions. The first concerned ATCS performance. The second set consisted of selected items from the Post-Scenario Questionnaire. The third set of questions included the six items of the NASA TLX. Researchers analyzed each of these groups of questions separately.

The general OTS evaluation consisted of questions related to Maintaining Safe and Efficient Traffic Flow, Maintaining Attention and SA, Prioritizing, Providing Control Information, Technical Knowledge, and Communication.

Traffic load manipulation affected all questions related to Maintaining Safe and Efficient Traffic Flow. Under high task load conditions, the OTS rater evaluated maintaining separation and resolving potential conflicts lower and ATCSs sequenced arrival and departure aircraft more efficiently (Figure 8).

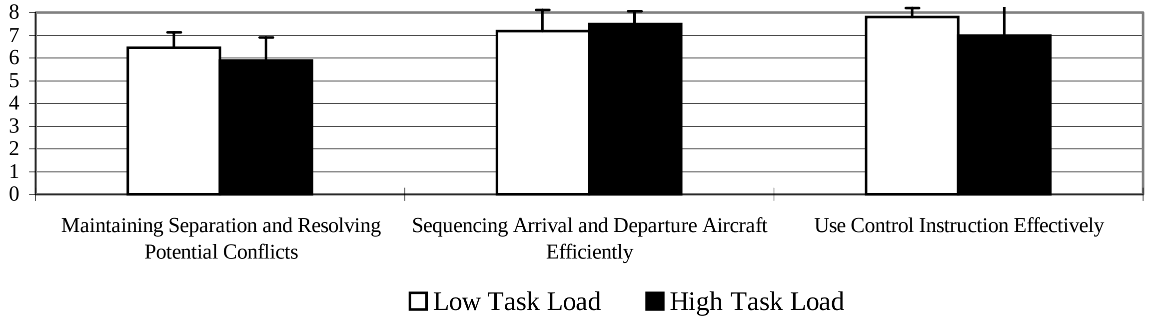


Figure 8. Means and SDs for traffic flow related questions as a function of task load.

Task load manipulation affected all questions related to Maintaining Attention and SA (Figure 9). With increasing task load, the participants maintained awareness of aircraft positions less but ensured positive control. Also, detection of pilot deviations from control instructions was less likely, and ATCSs corrected their own errors in a less timely manner.

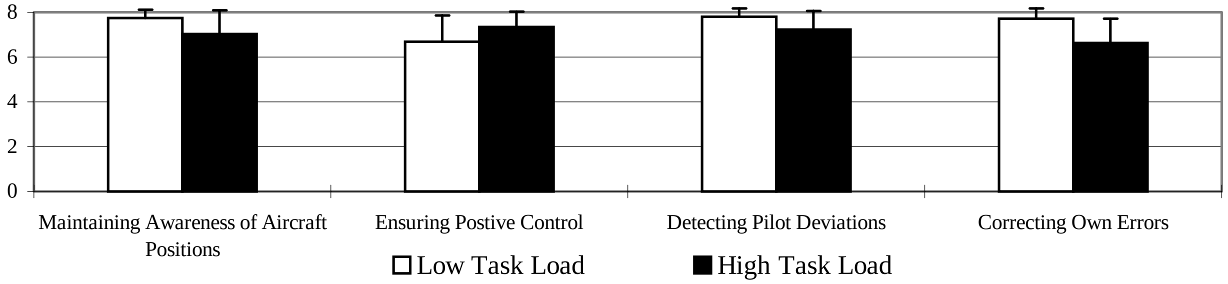


Figure 9. Means and SDs of variables related to maintaining attention and SA as a function of task load.

Task load manipulation affected all questions related to Prioritizing. The OTS rater indicated that all prioritizing-related variables showed a lower performance under high task load (Figure 10). However, mean ratings indicated that overall observers believed performance was on the top third of the scale.

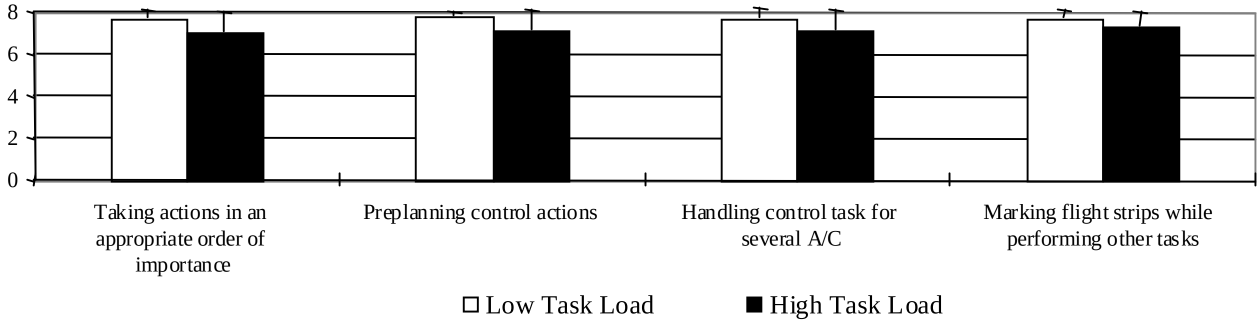


Figure 10. Means and SDs for variables related to prioritizing.

The visual noise manipulation affected preplanning control actions. Participants showed better preplanning when visual noise was present than when visual noise was absent (Figure 11).

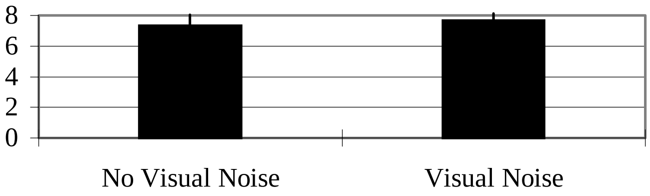


Figure 11. Means and SDs for preplanning control actions as a function of visual noise.

The section in the OTS rater's form on Providing Control Information provided essential ATC information. An increase of task load lowered the OTS rater perception of the quality of providing essential ATC information (Figure 12).

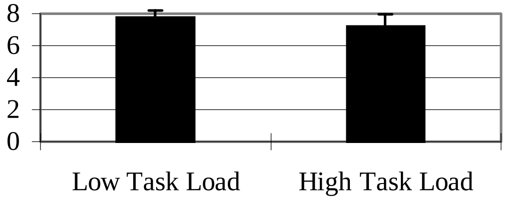


Figure 12. Means and SDs for providing essential ATC information as a function of task load.

The observer perceived a decrease in providing additional ATC information as task load increased. In the absence of visual noise, increasing task load reduced the amount of additional ATC information provided (Figure 13).

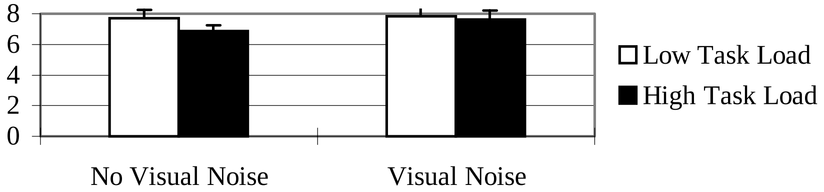


Figure 13. Means and SDs of providing additional control information as a function of task load and visual noise.

The questions on Technical Knowledge consisted of showing knowledge of LOAs and SOPs and showing knowledge of aircraft capabilities and limitations. Neither task load or visual noise affected the responses to these questions.

The issues related to the quality of ATCS Communications were using proper phraseology, communicating clearly and efficiently, and listening for pilot readbacks and requests. Clarity, efficiency, and the quality of listening for pilot readbacks decreased with increasing task load (Figure 14), although the OTS rater did not notice a difference in the use of proper phraseology.

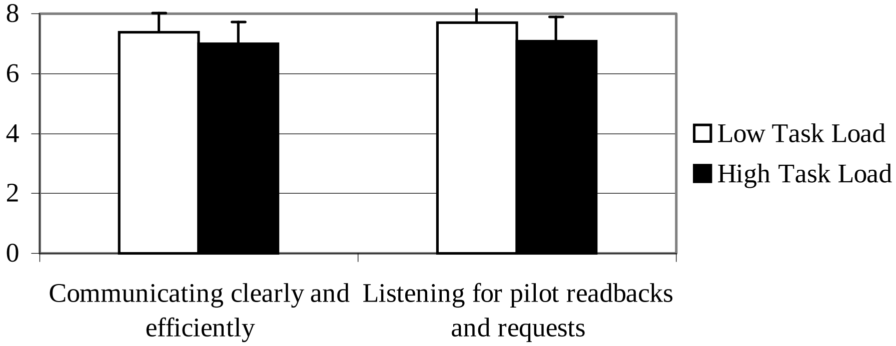


Figure 14. Means and SDs for variables related to communication as a function of task load.

Figure 15 presents the means and SDs of the six NASA TLX items, which are the observer’s estimates of participant workload dimensions. An increase in task load increased the perceived level of Mental Demand, Frustration, Physical Demand, Temporal Demand, and Effort. The presence of visual noise reduced the task load effects for Mental Demand and on Frustration and lowered the level of Performance under high task load.

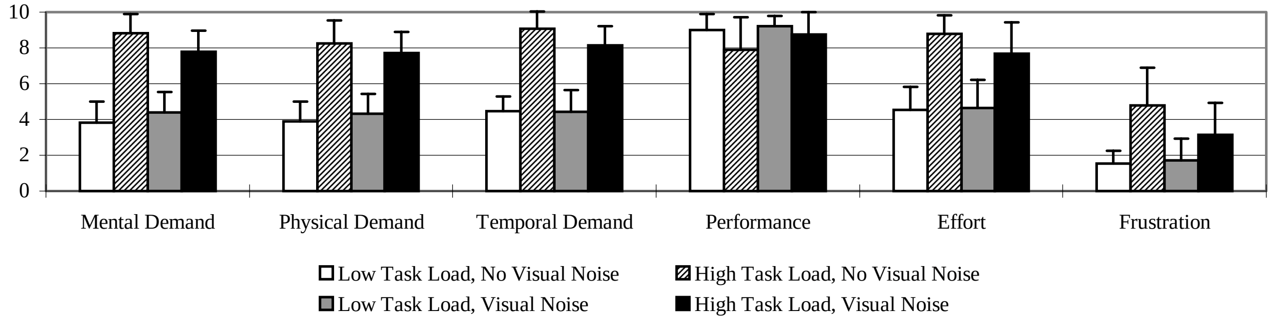


Figure 15. Means and SDs of OTS NASA TLX items by task load and visual noise.

3.3.2 Comments Related to Class C Airspace Violations

The OTS rater comments provided valuable information about how ATCSs dealt with the incursions. According to FAA Order 7110.65J (FAA, 1996), ATCSs must attempt to establish two-way radio communications with any aircraft entering Class C airspace. This study revealed that only a few ATCSs correctly followed this order. The descriptions below are summaries of the comments on the four questions related to controller SA made by the OTS rater.

Scenario 1, a low task load simulation with visual noise present, contained one VFR incursion and one IFR incursion. The VFR incursion flew through Class C airspace at 2,500 feet. The IFR incursion skimmed the top of Class C airspace at 7,000 feet. Several of the ATCSs did not acknowledge the presence of one or both of the intruders. The ATCSs that did recognize the incursion of their airspace displayed a wide variety of actions after the detection of an incursion. The ATCS often recognized the VFR intruders, issued the intruder as traffic to other aircraft, but did not attempt to establish two-way communications. Other ATCSs called local control or the tower to inform them about the presence of a VFR intruder in Class C airspace. Actions taken after detecting the IFR intruder ranged from calling the ARTCC for information about the aircraft, to attempting to establish two-way radio communications.

Scenario 2, a high task load simulation with visual noise present, contained one VFR and one IFR Class C airspace incursion. The VFR incursion aircraft took off from an airport just outside of Class C airspace and flew into Charlie airspace at 2,500 feet. The IFR incursion aircraft descended from high altitude into Class C airspace without announcing itself. Before it became a Class C violator, the aircraft contained neither a limited nor a full data block. Several of the ATCSs failed to detect the incursions into Class C airspace. The observer indicated that “most of the time, the intruder’s limited data block was near the full data block of another aircraft.” Some ATCSs noticed the incursions and took appropriate action. They called adjacent sectors, tried to establish two-way radio communications, and issue the intruder as traffic when appropriate.

Scenario 3, a low task load scenario without visual noise, contained two VFR intruders. One of the intruders entered Class C airspace at 3,000 feet. The other intruder did not actually enter Class C airspace but was traffic for other aircraft. Most of the ATCSs recognized the VFR incursion into Class C airspace, and several of them coordinated with the tower or issued the intruder as traffic to other aircraft.

Scenario 4, a high task load scenario without visual noise, contained two VFR incursions of Class C airspace. This simulation contained two VFR intruders. The first intruder entered Class C airspace at 3,500 feet from a southwest direction. The other intruder entered Class C airspace at 2,500 feet from a northeast direction. Several of the ATCSs did not acknowledge one of the intruders as it flew through Class C airspace even when it passed near other aircraft as traffic. Some of these ATCSs recognized an intruder only after it passed through Class C airspace. Other ATCSs saw both intruders and issued them several times as traffic to other aircraft.

Scenario 5, a low task load simulation with visual noise present, contained two IFR Class C incursions. The first incursion descended from 9,000 feet to 7,000 feet (the ceiling of Class C airspace for this TRACON) and came in from a north/northeast direction. The second incursion descended from 8,500 feet to 7,000 feet from a southwest direction. Both IFR intruders were part of the high altitude overflights that simulated the visual noise. Before becoming an intruder, the aircraft contained neither limited nor full aircraft. Some of the ATCSs did not detect one or both of the intruders, although the traffic load was light. Other ATCSs noticed an intruder only after it had passed through Class C airspace. The response of ATCSs that noticed the intruders varied from calling adjacent sectors to inquire about aircraft, to establishing two way communications, and to issuing traffic when appropriate.

Scenario 6, a high task load scenario with visual noise present, contained two IFR Class C airspace incursions. This simulation contained two IFR intruders that dropped from a higher altitude down to 2,000 feet into Class C airspace from a South/South-West direction. The OTS rater indicated that many of the ATCSs did not notice one or both of the IFR incursions into Class C airspace. In some cases, an ATCS detected an intruder after it had passed through Class C airspace. (The intruder was finally identified about 10 miles before exiting the airspace). In this high task load scenario, several controllers had operational errors that involved an IFR intruder. (The second intruder merged with another aircraft at 3,500 feet without a traffic advisory being issued). Some of the ATCSs detecting one or both of the IFR incursions contacted the tower, but other ATCSs did not take further action.

To assess how many ATCSs missed intrusions, researchers reviewed the OTS rater comments and tallied the number of intrusions the ATCS issued as traffic, inquired with other facilities about, tried to contact, or otherwise acknowledged the intruder. Figure 16 presents the results. Of the eight scenarios, six included incursions into Class C airspace. Four of these scenarios contained high altitude overflights as visual noise. There were three scenarios of each task load level. Although the number of observations was not equally distributed across conditions, researchers calculated the proportion of controllers that either missed both incursions, picked up one of the incursions, or picked up both incursions (Figure 16). In each of the conditions, at least 1 of the 12 participating ATCSs missed one of the intruders. In the extreme case of high task load and presence of visual noise, one fifth of the ATCSs detected both intruders.

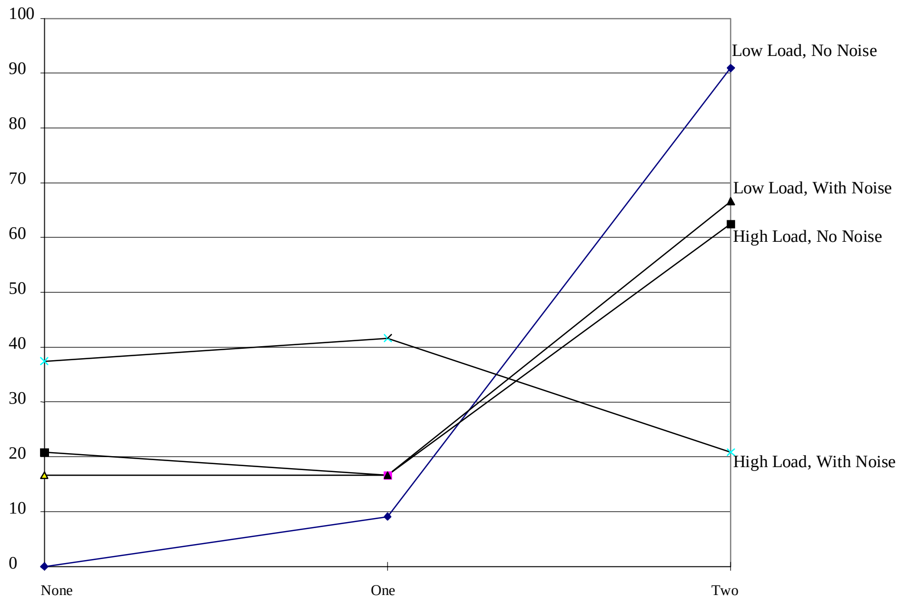


Figure 16. Percent of ATCSs that indicated detection of the Class C airspace violations.

3.4 Visual Scanning

The summary variables for 5-minute intervals formed the basis for the visual scanning data set. The 5-minute intervals enabled rejection of a single interval without loosing the complete simulation. Researchers replaced the variable values for that rejected interval with the average values across all conditions for that interval. Of 864 intervals (12 participants x 8 scenarios x 9 intervals), the researchers rejected 15 intervals due to a low number of saccades (less than 200 saccades in a 5-minute interval) and 10 intervals due to a high number of saccades (more than 800 saccades in a 5-minute interval). For all rejected intervals, researchers substituted the visual scanning variables by overall 5-minute interval means. Therefore, the number of summary data points presented in the Results Section is 864 [based on 12 (participants) x 8 (scenarios) x 9 (intervals) = 864]. The 5-minute interval data formed the basis for the summary data per scenario.

The visual scanning variables represented three levels of detail. The first level included general characteristics of fixations, saccades, blinks and pupil diameter. The second level included characteristics of fixations by scene plane: the radarscope, the ATWIT panel, the flight progress strip bay, and the keyboard/mouse area. The third level included characteristics of fixations on radarscope objects: aircraft, low altitude and conflict alert areas, system area, tab list, static objects (airport, runways, fixes, VORs), and preview area. The following sections discuss each of the levels.

3.4.1 General Eye Movement Characteristics

Variables reflecting general eye movement characteristics included fixations, saccades, blinks, and pupil diameter. The variables used to analyze differences in general eye movement characteristics between conditions were

a. number of fixations,
b. mean fixation duration,
c. mean fixation area,
d. visual efficiency,
e. mean saccade duration,
f. mean saccade distance,
g. eye motion workload,
h. mean pupil diameter,
i. motion workload,
j. number of blinks,
k. mean blink duration, and
l. mean blink distance.

Appendix F presents definitions for several of the general eye movement variables. Appendix L, Table L-12 presents the results of the MANOVA. The only effect on general eye movement characteristics was due to the task load manipulation [$\Lambda = .35$, $F(5, 18) = 6.68$, $p < .05$]. The reader should bear in mind that the DVs used in the multivariate analyses are somewhat correlated. The correlations between the DVs used in the multivariate analysis do not reach a level where one of the variables is redundant. Table L-13 shows the details of the ANOVA results for the effect of task load on general eye movement characteristics.

To maintain an overall alpha of .05 with 11 DVs, the adjusted alpha used in the univariate ANOVAs was .0047. Increasing task load or introducing visual noise did not affect the number of fixations. Only mean fixation area showed a significant increase between the low and the high task load conditions [$F(1, 22) = 19.54$, $p < .05$] (Figure 17). Although introducing visual noise affected how much the fixation area increased with task load, this interaction did not reach statistical significance.

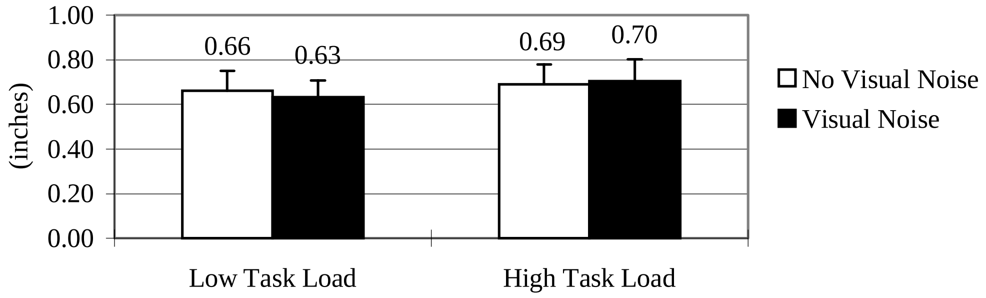


Figure 17. Means and SDs of fixation area as a function of task load and visual noise.

Although saccade distance decreased as a function of task load, it did not reach statistical significance (Figure 18).

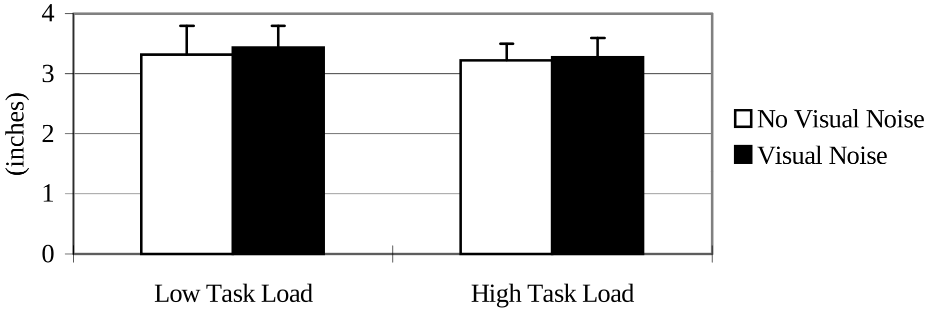


Figure 18. Means and SDs of the saccade distance as a function of task load and visual noise.

3.4.2 Scene Plane Fixations

The scene plane fixation variables included the number and duration of fixations on the radarscope, flight strip bay, ATWIT device, and keyboard area. The MANOVA results showed an interaction between load and visual noise [$\Lambda = .25$, $F(4, 19) = 14.20$, $p < .05$] on scene plane fixation characteristics (Table L-14).

To maintain an overall alpha level of .05 with eight variables, researchers used the adjusted alpha level of .00639. Table L-15 presents the ANOVA results for the interaction between the effects of task load and visual noise.

The introduction of visual noise interacted significantly with the effect of increasing task load on the number of fixations on the radarscope [$F(1, 22) = 15.62$, $p < .05$]. The number of fixations on the radarscope within a scenario was higher when task load was low. The number of fixations on the radarscope was larger when visual noise was present under low and smaller under high task load conditions (Figure 19).

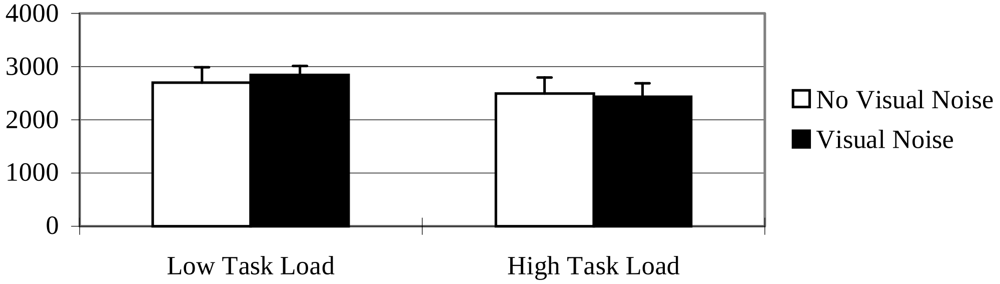


Figure 19. Mean and SD of the total number of fixations on the radarscope as a function of visual noise and load over a 45-minute scenario.

Increasing task load and introducing visual noise interacted for duration of fixations on the radarscope [*F*(1, 22) = 17.49, *p* < .05]. The mean fixation duration on the radarscope in the absence of visual noise was higher for low task loads than for high task loads. The presence of visual noise reversed this effect, and the mean fixation duration increased under high task load conditions (Figure 20).

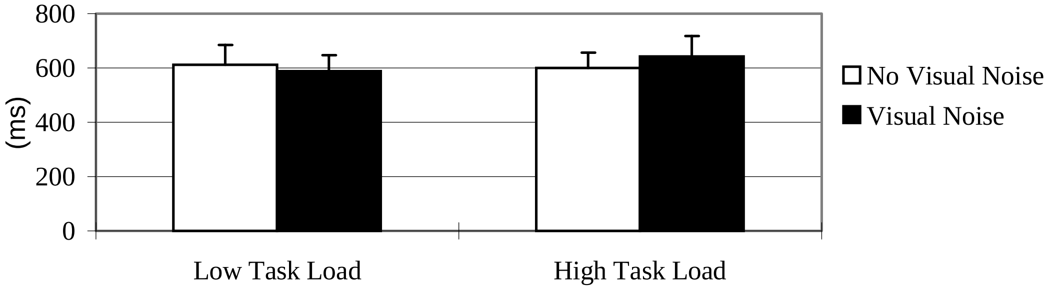


Figure 20. Mean and SD of fixation duration on the radarscope as a function of visual noise and task load.

The load and visual noise interaction effect for the number of fixations on the flight strip bay [*F*(1, 22) = 14.72, *p* < .05] was significant. The number of fixations on the flight strip bay stayed the same under low and high task load conditions when visual noise was absent. When visual noise was present, the number of fixations on the flight strip bay increased under high task load conditions. When the task load was low, the introduction of visual noise changed the number of fixations on the flight strip bay only marginally. Under high task load, the introduction of visual noise introduced a substantial increase in the number of fixations on the flight strip bay (Figure 21).

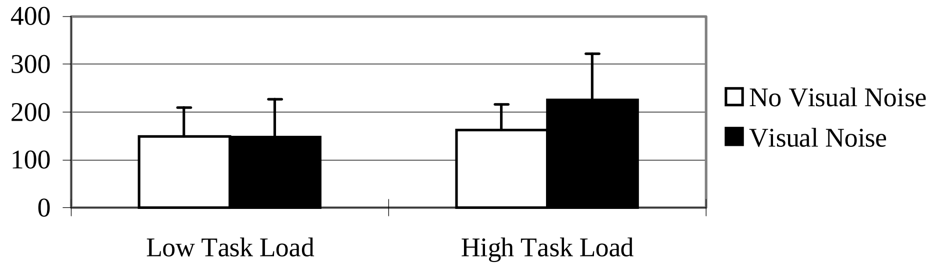


Figure 21. Mean and SD of number of fixations on the flight strip bay as a function of visual noise and task load.

Task load and visual noise manipulation did not interact for the duration of fixations on the flight strip bay. The fixations were significantly shorter in duration for high task load conditions than for low task load conditions [*F*(1, 22) = 36.95, *p* < .05] (Figure 22).

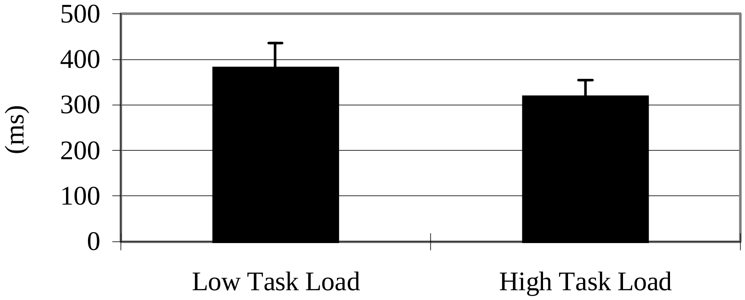


Figure 22. Mean and SD of the mean fixation duration on the flight strip bay as a function of task load.

Increasing task load significantly increased the number of fixations on the keyboard area [*F*(1, 22) = 131.55, *p* < .05] (Figure 23). The number of fixations on the keyboard area increased by approximately 41%. Increasing task load or introducing visual noise did not affect the number or the duration of fixations on the ATWIT device or the fixation duration on the keyboard area.

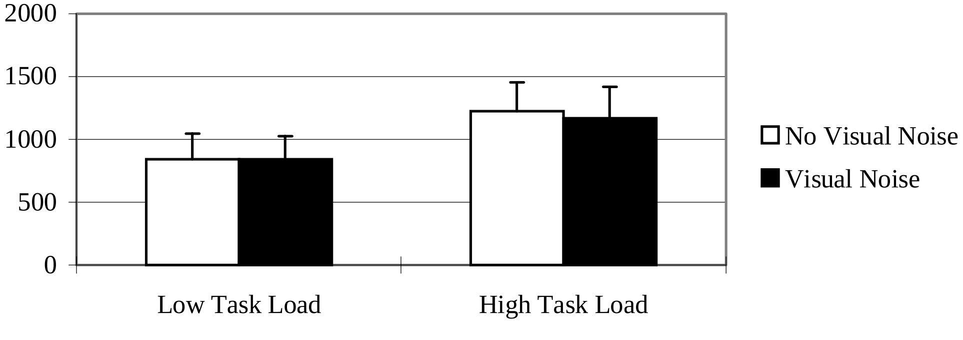


Figure 23. Means and SDs of the number of fixations on the keyboard area as a function of task load and visual noise.

3.4.3 Radarscope Fixations

The changes in the fixation characteristics on objects on the radarscope due to task load and visual noise were not independent [$\Lambda = .15$, $F(1, 22) = 19.20$, $p < .05$] (Table L-16). Because of the interaction between visual noise and task load increase, researchers calculated multivariate simple effects. The alpha level after adjusting for the 10 DVs to maintain an overall alpha of .05 was .0051.

The effects of increasing task load and introducing visual noise on the number of fixations on the system area influenced one another [$F(1, 22) = 10.54$, $p < .05$] (Table L-17). There were fewer fixations on the system area under high task load. Introducing visual noise reduced the number of fixations on the system area. This reduction was less pronounced under high task load conditions (Figure 24).

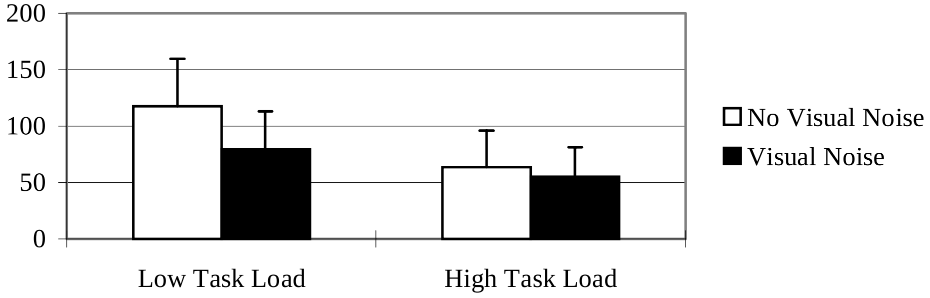


Figure 24. The number of fixations on the systems area as a function of task load and visual noise.

Increasing task load resulted in a significant [$F(1, 22) = 44.09$, $p < .05$] decrease in the fixation duration on the system area (Figure 25 and Appendix L, Table L-18). Introducing visual noise did not significantly alter the duration of fixations on the system area.

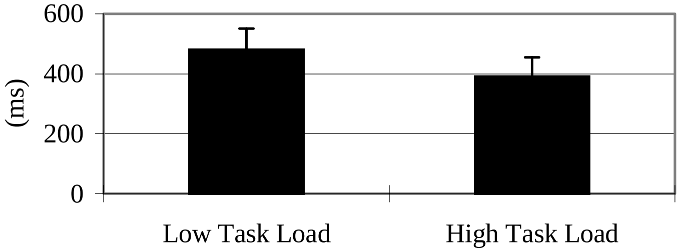


Figure 25. Mean fixation duration on the systems area as a function of task load.

The mean number of fixations on static objects showed an interaction effect of the manipulation of task load and visual noise [$F(1, 22) = 58.26$, $p < .05$]. Under high task load conditions, introducing visual noise did not significantly change the number of fixations on the system area. Under low task load conditions introducing visual noise significantly reduced the number of fixations on static objects (Figure 26). ATCSs spent more time scanning moving objects when visual noise was present, but the number of aircraft under control was low. The impact of these overflight aircraft targets on scanning is less when ATCSs are already busy with more demanding traffic for which they are responsible.

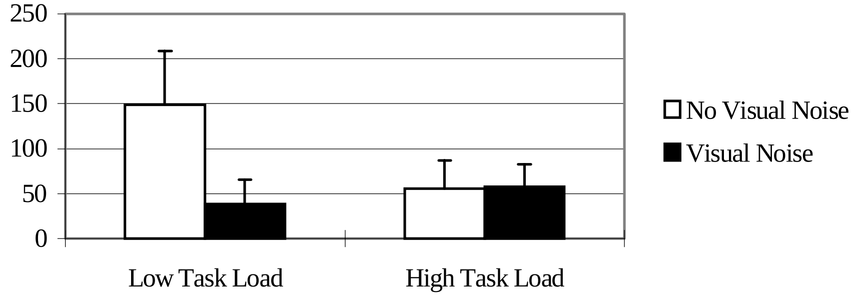


Figure 26. Mean number of fixations on static objects as a function of task load and visual noise.

The effects of the introduction of visual noise and the increase of task load on the duration of fixations on static objects interacted [*F*(1, 22) = 12.91, *p* < .05]. Under low task load conditions, the fixation duration was longer when visual noise was absent. Under high task load conditions, the fixation duration increased with the introduction of visual noise (Figure 27). ATCSs fixated on fewer objects for longer periods. The visual noise introduced a need to be more selective and concentrate more.

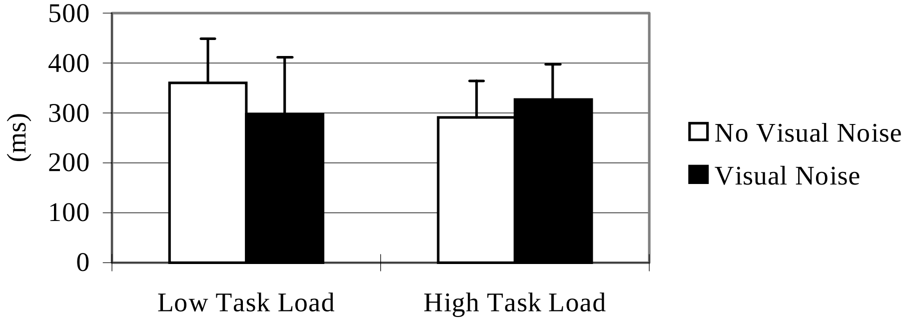


Figure 27. Mean fixation duration on static objects as a function of task load and visual noise.

The mean number of fixations on the tab list showed an interaction between the task load and the visual noise manipulation [*F*(1, 22) = 20.85, *p* < .05]. In the absence of visual noise, increasing task load led to a reduction of fixations on the tab list. The presence of visual noise reversed this effect (Figure 28).

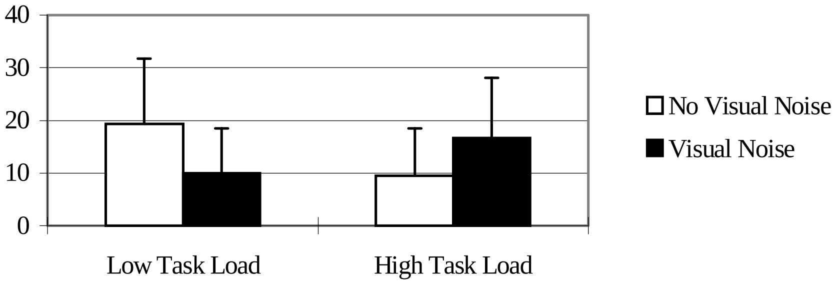


Figure 28. Mean number of fixations on tab list as a function of task load and visual noise.

The mean duration of fixations on the tab list did not change significantly between conditions. Shorter fixation duration under low task load conditions in the presence of visual noise showed a trend, but it was not statistically significant (Figure 29).

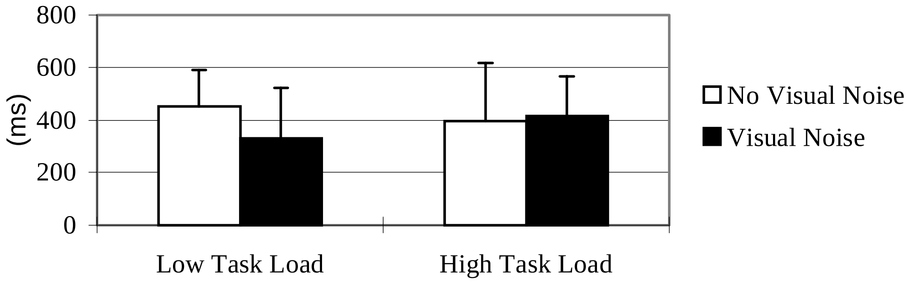


Figure 29. Mean fixation duration on tab list as a function of task load and visual noise.

The mean number of fixations on the preview area did not show a significant interaction between increasing task load and introducing visual noise. An increase in task load led to a significant [$F(1, 22) = 13.70$, $p < .05$] reduction of the number of fixations on the preview area (Figure 30).

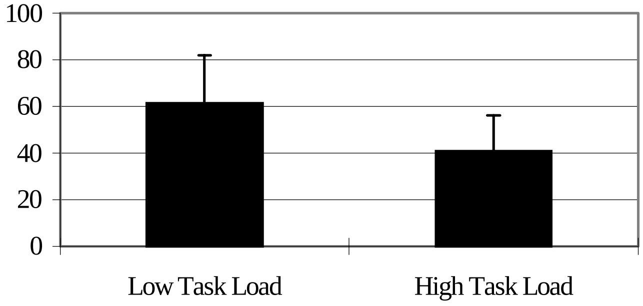


Figure 30. Mean number of fixations on preview as a function of task load.

Introducing visual noise led to a significant [$F(1, 22) = 26.40$, $p < .05$] reduction in the number of fixations on the preview area (Figure 31).

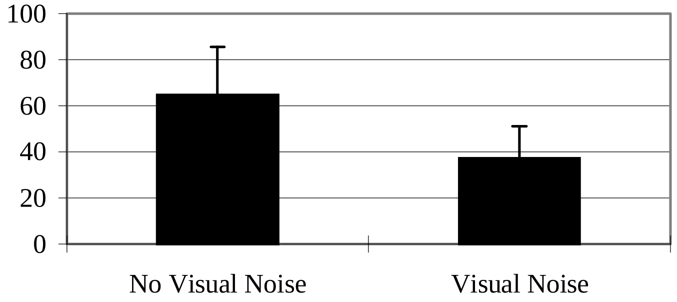


Figure 31. Mean number of fixations on preview as a function of visual noise.

Researchers could not study the effects of task load and visual noise manipulation on the number of fixations on aircraft independently because they interacted significantly [*F*(1, 22) = 46.85, *p* < .05]. Under low task load conditions, introducing visual noise did not significantly change the number of fixations on aircraft. Under high task load conditions, introducing visual noise reduced the number of fixations on aircraft (Figure 32).

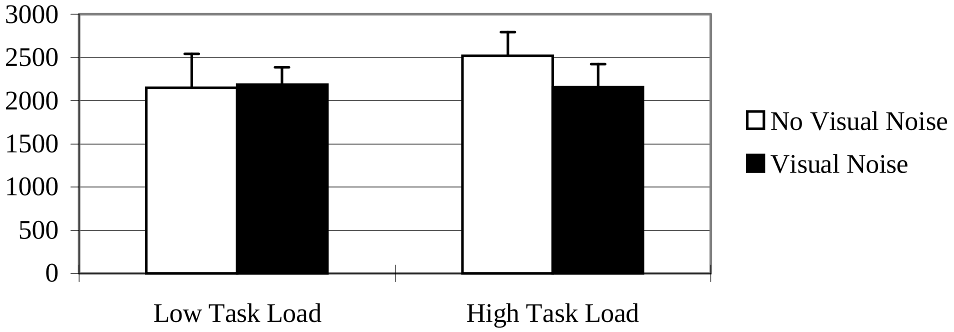


Figure 32. Mean number of fixations on aircraft as a function of task load and visual noise.

An interaction between task load and visual noise manipulation existed for the fixation duration [*F*(1, 22) = 28.22, *p* < .05]. Introducing visual noise under low task load conditions led to a reduction in the mean duration of fixations. Under high task load conditions, introducing visual noise resulted in an increase in the mean fixation duration (see Figure 33).

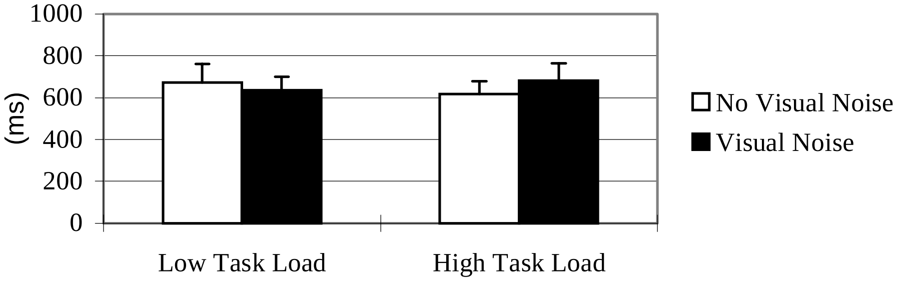


Figure 33. Mean fixation duration on aircraft as a function of task load and visual noise.

3.4.4 Intrusions

The scenarios for each participant included six VFR and six IFR intrusions. The researchers isolated the 5-minute intervals that included an intrusion for the analysis of eye movements. The study contained 2 (load) x 2 (visual noise) x 2 (replication) scenarios. The analyses compared the intervals that included intrusions with intervals of the scenario without intrusions that replicated the conditions. For five of the VFR and IFR intrusions, such an interval existed. For the other interval, the VFR intrusion coincided with an interval that contained an IFR intrusion in the replication scenario.

The research team conducted repeated measures ANOVAs on the DVs. At a .05 level of significance, there was only an interaction between the effect of the presence of intrusions and the task load and visual noise conditions for saccade duration (Table L-19). To maintain an alpha level of .05 with 12 DVs, researchers reduced the adjusted alpha level to .0043. At this level, the effects of conditions and presence of intrusions on eye movements do not interact. There was no effect of intrusions on any of the general eye movement characteristics (Table L-20). The data pooling procedures may have washed out any existing effects.

3.4.5 Radarscope Objects

The researchers tested the significance of the difference between fixation duration on several radarscope objects using a measure called “object type.” The analysis showed the presence of higher order interactions (up to the three way interaction between objects, load, and visual noise [$\Lambda = .56$, $F(1, 22) = 3.57$, $p < .05$] (Table L-21). The mean fixation duration on radarscope objects differed significantly for each of the task load and visual noise conditions. The aircraft fixations have the highest durations with a mean of 655 ms (Figure 34). For a discussion of the effects of task load manipulation and visual noise on the individual radarscope objects refer to Section 3.4.3.

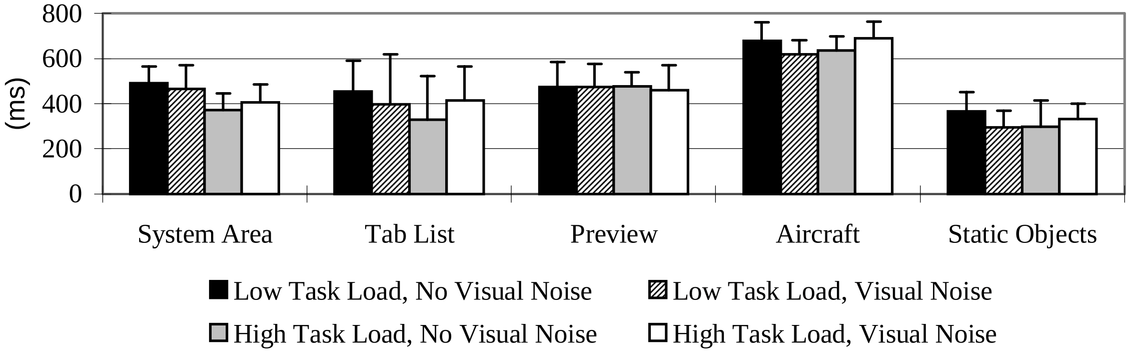


Figure 34. Mean and SD of radar object fixation duration (ms) as a function of task load and visual noise.

The number of fixations varied significantly between objects. The effects of both increasing task load and introducing visual noise significantly interacted with the effect of object on the number of fixations. The emphasis on aircraft representations becomes even clearer when presenting the time spent on radarscope objects as a percentage of the total time (45 minutes). Compared to the time spent on aircraft representations, the ATCS allocates a negligible amount of time for the other objects. ATCSs spent about 55% of the total simulation time on fixating aircraft representations. Figure 35 displays the percentage of time spent on radarscope objects. The figure does not display the data point for aircraft to allow the reader to compare the percentages between objects other than aircraft.

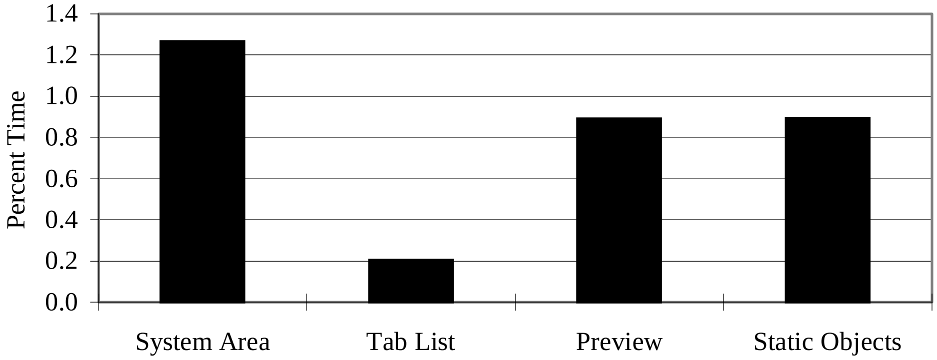


Figure 35. Percent of total simulation time fixated on selected radarscope objects.

3.5 Performance Measures

The performance measures used in the analyses consisted of conflicts, errors, communications, and task load-related variables. The following sections will discuss each of the categories of variables.

3.5.1 Conflicts

The DR&A module identifies variables in this section as conflict related based on IFR. In the simulations, both IFR and VFR aircraft were present. The conflict-related variables do not necessarily reflect the occurrence of operational errors. The conflict data calculated on IFR caused the DR&A module to report VFR aircraft being in conflict when no conflict existed. This report contains information about conflict-related variables with the caveat that they reflect a tightness of control, not necessarily a reflection of operational errors. The following sections contain descriptive analyses of the conflict-related variables.

The number of standard terminal conflicts increased with an increase in task load. The presence of visual noise strengthened this effect. The effect of visual noise reduced the number of standard terminal conflicts under low task load, but high task load reversed this effect (Figure 36).

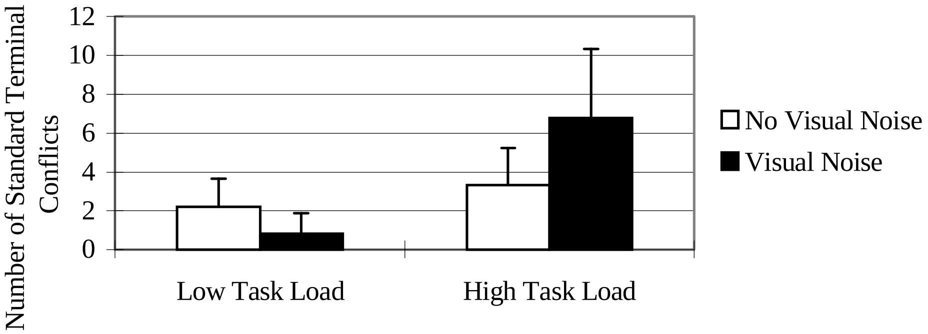


Figure 36. Means and standard deviations for number of standard conflicts as a function of task load and noise.

Neither load nor noise affected the mean duration of standard conflicts. Under high task load conditions, noise increased the number of between-sector conflicts. In the absence of visual noise, task load manipulation increased the number of between-sector conflicts. The presence of visual noise reduced this effect (Figure 37).

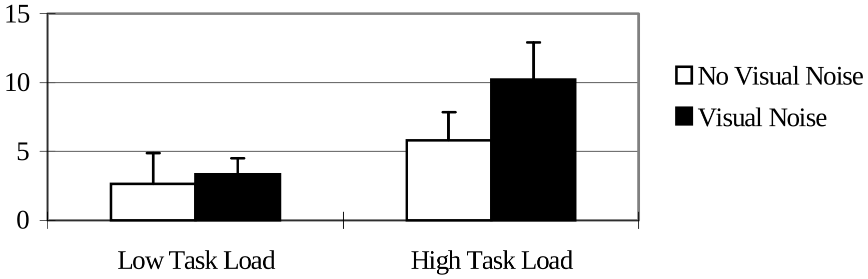


Figure 37. Mean number of between-sector conflicts as a function of task load and visual noise.

Under low task load conditions, the presence of visual noise did not affect the duration of between-sector conflicts. Under high task load conditions, visual noise increased the duration of between-sector conflicts. The manipulation of task load affected the duration of between-sector conflict when visual noise was absent and present. The presence of visual noise increased the duration of between-sector conflicts (Figure 38).

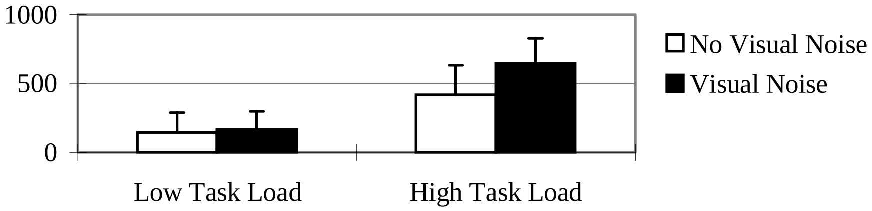


Figure 38. Mean duration of between-sector conflicts as a function of task load and visual noise.

3.5.2 Separation

Separation-related variables reflect the tightness of control. The analysis includes closest point-of-approach, the horizontal and vertical separation, and the aircraft-proximity-index.

The repeated MANOVA showed an interaction between the effects of task load and visual noise manipulation on separation-related variables [$\Lambda = .50$, $F(4, 19) = 4.72$, $p < .05$]. The effect of visual noise was not present under low task load conditions. Under high task load conditions, visual noise significantly affected separation [$\Lambda = .11$, $F(4, 19) = 40.20$, $p < .05$]. In the absence of visual noise, there was a small effect of task load manipulation on separation [$\Lambda = .59$, $F(4, 19) = 3.35$, $p < .05$, $\eta = .64$]. In the presence of visual noise, there was a stronger effect of task load manipulation [$\Lambda = .51$, $F(4, 19) = 4.57$, $p < .05$, $\eta = .70$].

To maintain an overall alpha level of .05 with four DVs, the adjusted alpha for the univariate analyses is .0127. The manipulation of task load had a significant effect on the closest point-of-approach [$F(1, 22) = 13.37$, $p < .05$] (Figure 39).

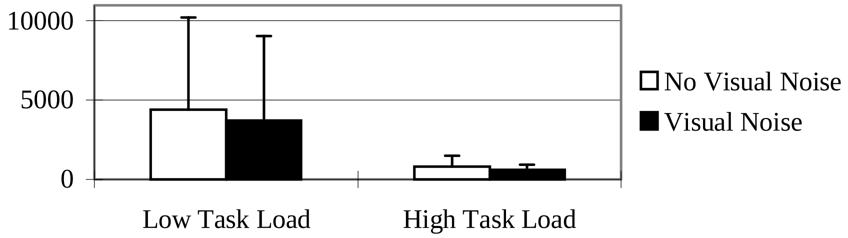


Figure 39. Mean closest-point-of-approach (feet) as a function of task load and visual noise.

Task load significantly decreased the horizontal separation [$F(1, 22) = 13.03$, $p < .05$]. Visual noise did not affect the horizontal separation (see Figure 40).

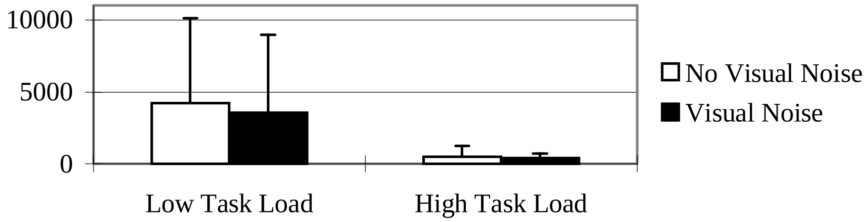


Figure 40. Mean horizontal separation as a function of task load and visual noise.

3.5.3 Communications

Communications-related variables included the number of ATCS messages and pilot message keystrokes. Task load manipulation only affected communications [$F(2, 21) = 217.33$, $p < .05$].

With only two DVs used in the MANOVA, the adjusted alpha level to be used in subsequent ANOVAs is .025 to maintain an overall alpha level of .05.

The number of ATCS messages showed a significant increase with an increase of task load [*F*(1, 22) = 54.10 and *F*(1, 22) = 103.72, both at $p < .05$] (Figure 41). The presence of visual noise did not significantly affect the number of ATCS messages.

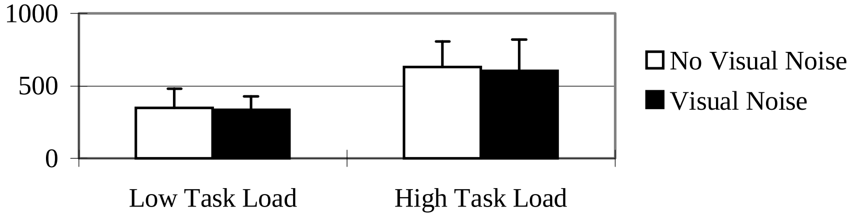


Figure 41. Mean number of ATCS messages as a function of task load and visual noise.

The number of simulation pilot message keystrokes showed a significant increase [*F*(1, 22) = 103.72, $p < .05$] with an increase in task load (Figure 42). The presence of visual noise did not significantly affect the number of simulation pilot message keystrokes.

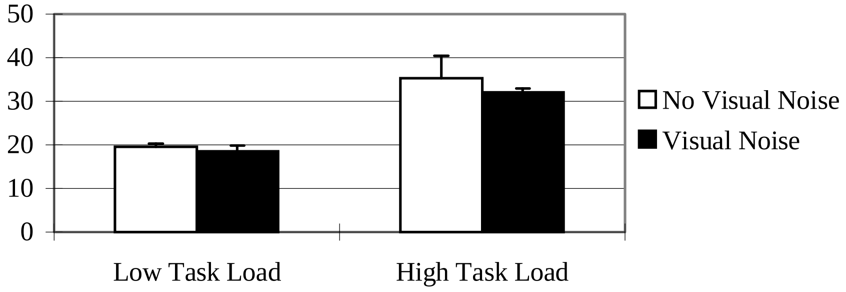


Figure 42. Mean number of pilot message keystrokes as a function of task load and visual noise.

3.5.4 Task Load

The task load related variables showed the effect of the task load manipulation. These variables did not provide further insight in the effect of the conditions on ATCS performance and did not undergo further analysis. The task load related variables did not go further statistical analysis.

4. Discussion

The discussion addresses the representativeness of the simulations, the effect of increasing task load and introducing visual noise on workload measures, the effect of increasing task load and introducing visual noise on SA measures, and the effect of a task load and visual noise on eye movements. Appendix M discusses the potential for alternative analyses with the format of the data as collected during the current experiment. Appendix N contains recommendations for modifications to data reduction algorithms and future research.

4.1 The Representativeness of the Scenarios

A high level of fidelity of the scenarios allows application of the experimental findings to an operational setting. Researchers designed representative scenarios of an active TRACON. The TRACON radar display shows aircraft under control or within the filter limits and the raw radar returns of aircraft outside the filter limits. The ATCSs acknowledged the high fidelity of the scenarios by positively rating the realism and representativeness of the scenarios. The Post-Scenario Questionnaires indicated that, on average, the scenarios were moderately realistic and representative of a normal day at their TRACON. Scenarios were only moderately difficult, which is an indication that the low and high task load scenarios were well balanced. The interference of the oculometer was low although higher than the interference of the ATWIT device.

4.2 The Effect of Time-on-Task, Task Load, and Visual Noise on Workload Measures

The effect of task load manipulation was stronger without visual noise than when visual noise was present. ATCSs rated all TLX items except performance higher when task load increased. The rating for the performance item decreased with increasing task load. Although OTS observations showed an interaction between the effects of increasing task load and introducing visual noise, they corresponded well with ATCSs' own ratings. These findings are common in studies using self-reported workload. Perceived performance declines at higher levels of workload given professional respondents who are trying to accurately gauge their accomplishments.

The average ATWIT rating as a function of time showed the effect of the structure in the scenarios used in this study. The traffic in these scenarios increased in the first 10 minutes and tapered down at the end of the 45-minute scenarios. On average, the ATWIT ratings reflected this trend. ATCSs rated the workload low in the beginning of the scenarios, increasing up to the third 5-minute interval, and decreasing somewhat at the end of the scenarios. Only task load affected the mean ATWIT scores. The high task load scenarios resulted in a higher perceived workload. Visual noise had no effect on the mean ATWIT ratings. The effect of task load resulted in a higher maximum ATWIT rating, and the presence of visual noise resulted in an increased contrast between low and high task load conditions.

The disadvantage of using post-scenario estimates of the perceived workload during a scenario is that the ATCS has to rely on memory for the workload across a 45-minute period. To investigate if an ATCS remembers the average or the maximum workload perceived during a scenario, researchers computed the correlations between the average and maximum on-line ATWIT ratings with the post-scenario TLX items. The TLX item on mental demand showed the highest correlation with the average ATWIT rating, explaining 50% of the variance. The correlation between the TLX item on mental demand and the maximum ATWIT rating was much smaller and explained only 25% of the variance. The ATWIT ratings showed a trend similar to the TLX ratings. The maximum ATWIT rating displayed an interaction between the effect of increasing task load and introducing visual noise. The ATWIT device required the ATCS to enter a subjective workload rating every 5 minutes. The amount of time required responding to the ATWIT device was minimal as reflected by the oculometer measurements. On average, ATCSs spent less than 1.5 seconds per 5-minute interval fixating on the ATWIT device.

One item in the Post-Scenario Questionnaire asked controllers to rate workload on that run. The effects of visual noise and task load were not additive. The presence of visual noise influenced perceived workload. This is a subtle effect, possibly related to the way controllers filter information. With visual noise present, the filters are active, and the workload does not seem as intense. When visual noise was present, the ATCSs perceived that they worked harder under low task load conditions but were not working as hard under high task load conditions.

The simulations used in this experiment included high altitude overflights as visual noise. The presentation of the visual noise was a close replication of the traffic normally seen over the airspace. Therefore, ATCSs may have developed efficient filtering mechanisms to distinguish between aircraft within and outside their airspace. During the site visits to the TRACON, ATCSs indicated that they filtered out the representations of high altitude aircraft. In a TRACON level 3 airspace, VFR aircraft may enter the airspace represented on the radarscope in an identical fashion as the high altitude aircraft. When asked how they distinguished between VFR aircraft within the airspace and the high altitude aircraft, ATCSs responded that they compare speeds. This indicates that controllers do observe the high altitude aircraft. If that were the case, the presence of visual noise would increase the demand on cognitive resources. The workload measures used in the current experiment do not support this. There is no reported increase in workload with the introduction of visual noise. This filtering is undoubtedly a subattentive cognitive process that experienced controllers develop so that they can make optimal use of limited attentional resources.

4.3 The Effect of Increasing Task Load and Visual Noise on Situation Awareness Measures

When task load increased, ATCSs perceived that their SA decreased. This is true for general SA, SA for current and projected aircraft locations, and SA for potential conflicts. Introducing visual noise increased the perceived SA for potential conflicts slightly but significantly. These are controllers' perceptions that may not accurately reflect what they have captured in working memory.

How well does this correspond with the OTS rater’s observations? The OTS rater did not observe an effect of introducing visual noise on ATCSs’ SA. The OTS rater observed that maintaining awareness of aircraft position was lower under high task load. The OTS rater’s observation corresponded well with ATCSs’ own perception of an SA decrease for current and projected aircraft positions. The OTS rater observed a decreased ability to detect pilot deviations, to correct their own errors, and to maintain separation. These observations corresponded well with ATCSs’ own perception of decreased SA for potential conflicts. The fact that the OTS rater was aware that the visual noise did not interfere with air traffic in the sector may explain why the ATCSs’ own perception of a heightened awareness for potential conflicts with introducing visual noise did not surface in the OTS rater’s observations.

Asking even an experienced ATCS to estimate the SA of someone else is admittedly asking a lot. Observer expectations and biases have to play a role. These data are suggestive, at best. Only the operating controllers really knows what they are thinking, and experience and other factors filter even that.

In the presence of visual noise, the radarscope contains many more aircraft representations than without visual noise. In the field, the radarscope contains the visual noise as well. The task environment with visual noise is closer to ATCS reality than one without it. The processing strategies used by ATCSs to separate aircraft may include or even depend, to some extent, on the presence of the high altitude aircraft representations. ATCSs are experts in the task they perform. Expertise is very susceptible to small changes in the task environment. The participants in this study were active ATCSs for many years. For them, the absence of visual noise may be more out of the ordinary than the situation with visual noise and could explain the ATCSs' perception of a better awareness for potential conflicts.

4.4 The Effect of Task Load and Visual Noise on Eye Movements

ATCSs are supervisory controllers, that is, they indirectly act upon the equipment that is under their control. Pilots are, in this respect, the human actuators that implement the ATCS instructions. Compared with operators of other equipment, the ATCSs have additional challenges. The objects on their display, unlike other operational environments, are not stationary but move across the radarscope. The location of the radar return represents the aircraft position at one point in time in the airspace, and the relative movement and history trails represent the heading of the aircraft. The data block itself contains four additional variables: aircraft call sign, altitude, speed, and model. ATCSs sample these variables continuously to update their understanding of the current state of the airspace.

The visual system uses fixations to retrieve information. During saccades, the visual system moves the eyes but does not retrieve additional information. The participants spent 78% of the time in fixations. Researchers calculated two percentages describing fixations broken down by scene plane: the percentage of the total time and the percentage of the fixation time. The total time is the actual time available in a 5-minute interval (i.e., 300 seconds). The fixation time is the total time spent in fixations (i.e., on average, 235 seconds). The percentage of the fixation time is a good indication of the distribution of information retrieval across the scene planes. The average duration of fixations is similar to those reported elsewhere (Fitts, Jones, & Milton, 1950; Stein, 1992). Average saccade durations are comparable to other sources as well. Given these data, the eyes are moving and not picking up any viable information 22% of the total time.

The literature suggests that longer fixation durations are due to the processing time necessary for interpretation of the information presented within the field of view and the programming time necessary to plan the next saccade. Careful interpretation of the current results suggests that ATCSs performed more cognitive processing during fixations on the ATWIT device and the radarscope than on the keyboard area and flight strip bay. When the ATWIT device prompted the ATCS to rate the current workload, it seemed to require considerable cognitive processing to interpret the 10-point scale and compare the current workload to that scale. Alternatively, the ATWIT device is both a display and an input device. Once ATCSs determine the perceived workload level, they enter that level by touching the number on the ATWIT device. The fixations to guide the hand to the correct number on the device may be quite long. Researchers interpreted the longer fixation durations on the radarscope and aircraft in a similar fashion. Considerably more cognitive processing takes place during fixations on aircraft than on any other radarscope object. The fixation durations on aircraft correspond well with durations found on cockpit instruments (Fitts et al., 1950), meter monitoring (Senders, Elkind, Grignetti & Smallwood, 1964) and radar watching (Moray, Neil, & Brophy, 1983) (see Figure 43). The relatively low mean fixation duration on TRACON radar in the study by Stein (1992) may be because the researchers made no distinction between objects at which the ATCSs looked. In this study, the fixations on aircraft had by far the longest durations. Inclusion of other objects and scene planes would drastically reduce the average duration of the fixations.

When divided by scene plane, a difference in fixation durations was apparent. Fixations on the radarscope average 620 ms and were similar in duration for fixations on the ATWIT device. The number of fixations on the ATWIT device was very few, as expected. Fixations on the flight strip bay and the keyboard area were much shorter in durations (320 and 450 ms, respectively).

The human visual system only acquires information during fixations. ATCSs spent 75% of the total fixation time on the radarscope and 69% of the fixation time on aircraft representations. ATCSs tend to focus on aircraft rather than static objects such as airports, VORs, and intersections. The effects of increasing task load and introducing visual noise and the number of fixations on the radarscope interacted. For high task load conditions, the number of fixations on the radarscope was lower than for low task load conditions. Introducing visual noise changed the number of fixations on the radarscope. The total number of fixations did not change significantly. The reduction in the number of fixations on the radarscope resulted in an increase in fixations on other scene planes. The finding of decreased fixations on the radarscope when increasing task load is contrary to the idea that human observers would fill in redundant fixations with a reduction of the number of targets. If a difference would occur, one pointing towards an increase in fixations would have been more plausible. Under high task load, this situation presents an ATCS with more potential targets.

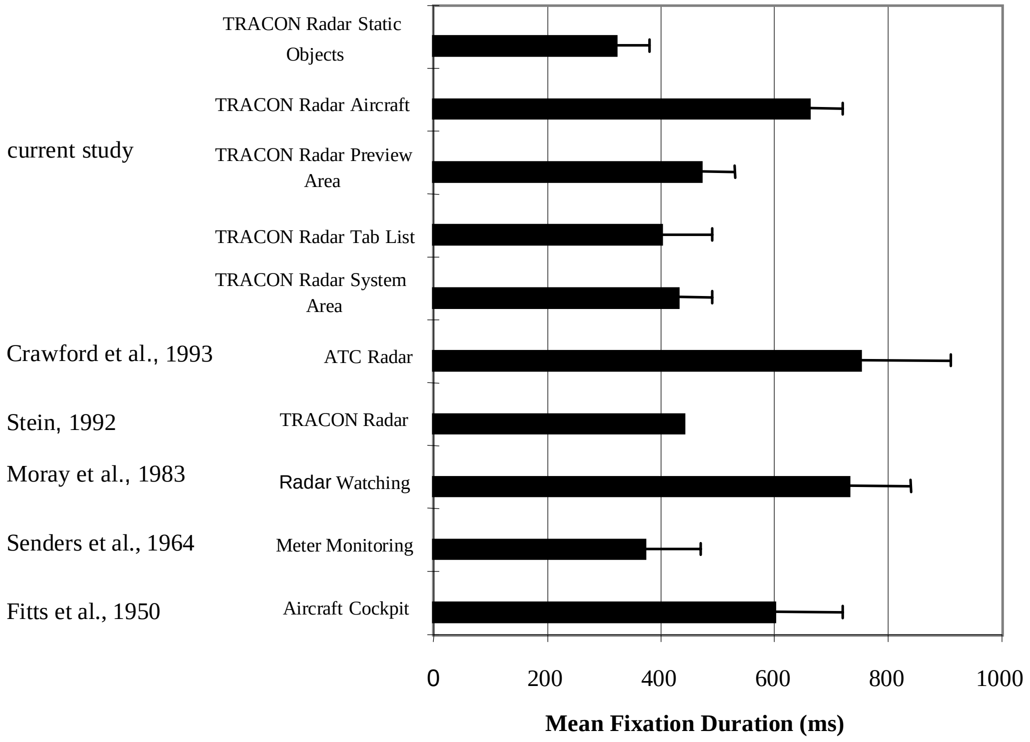


Figure 43. Means and SDs of fixation duration in other studies.

Researchers postulate that the reduction in fixations on the radarscope resulted from ATCSs spending more time on flight strip maintenance under high task load conditions. In a TRACON environment, ATCSs move active flight progress strips to the console and create new flight progress strips for incoming VFR aircraft. The data suggest that increasing task load diverts some of the ATCS's attention to these tasks resulting in fewer fixations on the radarscope. Indeed, for high task load conditions in the presence of visual noise, both the number of fixations on the flight strip bay and the number on the keyboard area increased. The fixation duration of fixations on the flight strip bay decreases as a result of an increase in task load.

At the most detailed level, this study distinguished between fixations on objects on the radarscope. The average duration of fixations on aircraft stood out markedly with 660 ms. This is a relatively long fixation allowing less than two stops per second to gather information. It suggests considerable cognitive processing by the ATCS. To provide a baseline for comparison, people in everyday activities probably scan 3 to 5 times per second. Other objects on the radar display had fixations that ranged on average from 30 ms to 400 ms. The number of fixations on the preview area decreased with an increase in task load. With higher task load demands, the ATCS spends less time verifying the correctness of the data entered through the keyboard, although the keyboard data indicate that ATCSs type in more information under high task load conditions. ATCSs seem to become more tactical and less strategic as time demands impinge due to higher task load. The visual scanning data appear to document what was anecdotal in the past.

On average, the number of fixations on the radarscope is about 1 per second. With an update rate of the radar of 4.5 seconds, that allows a controller to scan the present situation in four fixations. Unless the controller has found a way to get around working memory limitations, this would not allow him to keep the "picture" up to date. Even if the only thing that changes is the aircraft position, this will introduce uncertainty into the controller's awareness of the current state of the system. In a TRACON environment, many aircraft are on a climbing or descending course, which increases the level of uncertainty the controller must take into account when making decisions. All this becomes even more remarkable when we take into account Moray's comment on forgetting (Moray et al., 1983). He suggests that forgetting sampled material stored in working memory takes place after 12 to 15 seconds. Therefore, if the controller uses working memory, by the time the controller has updated the current state of, at most, 12 aircraft, his uncertainty increases, not only because of the change in the state of the aircraft but because of memory decay as well.

The approach used in this study to analyze the effects of intrusions compared 5-minute intervals between replication scenarios. For each task load/visual noise combination, two simulations existed. The analysis consisted of a comparison of eye movement characteristics between a 5-minute interval that contained an intrusion with that same interval in the simulation that replicated the task load/visual noise combination. The analysis of the general eye movement characteristics did not show an effect of intrusions. Several explanations of the lack of eye movement characteristic changes exist. First, the approach of using 5-minute intervals may be a window of time that is too wide to detect an effect of an intruder. Alternative analysis methods may be necessary to detect short-term (less than 5 minutes) effects of intruders on general eye movement characteristics. Second, the current approach assumes that the intruder detection takes place at the time the aircraft first becomes an intruder. The current study did not include a procedure to track actual intruder detection times. Comments by ATCSs suggest there are more than 5 minutes between the introduction of an intruder and the time of actual detection. Some of the ATCSs exclaimed "where did he come from!" after an aircraft flew through Class C airspace and subsequently was on its way out of the airspace. This can result in the effect of intruder detection to occur in a 5-minute interval other than the one where the intrusion initially occurred. Finally, the research team went out of its way to present the ATCSs with a simulated airspace closely resembling their actual airspace. The VFR aircraft that entered Class C airspace as intruders represented business as usual. If the ATCS should see business as usual, one would not expect a change in general eye movements. Also, ATCSs are experts in the sense that they have developed highly automated cognitive processes to digest large amounts of data. The cognitive part of the visual system in case of highly automated processes can drive perception. This would lead the ATCS to not see or perceive unexpected items or situations. The IFR intrusions in the current study "fell" into Class C airspace, an event that occurs very infrequently. The visual system's automaticity may prevent the ATCS from noticing the anomaly, resulting in general eye movements that do not show an effect of the introduction of Class C incursions.

Although the analysis of intervals that contained incursions into Class C airspace did not reveal a difference in eye movement characteristics, the comments by the OTS rater clearly showed that some of the controllers did not detect one or both of the Class C airspace violations. This was especially frequent for scenarios with high task load and visual noise conditions. The OTS rater indicated that under baseline condition (i.e., low task load, no visual noise) present, 90% of the controllers observed both intruders. Under worst case conditions (i.e., high task load, visual noise present) only 20% of the controllers indicated that they had observed both intruders.

5. Conclusions

Increasing task load led to a larger area covered per fixation, a decreased number of fixations on the radarscope, and more fixations on the flight strip bay. The effects of task load and visual noise on ATCSs visual scanning characteristics are often complex. When task load and visual noise do not interact, they sometimes produce additive effects.

Scanning behavior is much more complex than solely looking at information displays. Environmental context has a critical impact. Past ATC experience likely influences ATCS decision rules on how and where to apportion the limited attentional resources and will temper the visual scanning strategies.

Visual noise and task load affect fixations related to radarscope objects and scene planes more than general eye movements. It seems that a relevant metric to capture visual scanning characteristics should relate eye movements to operationally relevant information.

This research provides greater understanding of how ATCSs use current information displays. The research results have potential for increasing future ATCS efficiency through improved display technology or application of new training techniques.

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Acronyms

ANOVA	Analysis of Variance
API	Aircraft Proximity Index
ASL	Applied Science Laboratories
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATWIT	Air Traffic Workload Input Technique
DR&A	Data Reduction & Analysis
DV	Dependent Variable
EOS2	Experiment Observation Room 2
ER2	Experiment Room 2
ER4	Experiment Room 4
FAA	Federal Aviation Administration
FPL	Full Performance Level
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IV	Independent Variable
LED	Light Emitting Diode
LOA	Letter of Agreement
MANOVA	Multiple Analysis of Variance
MHT	Magnetic Head Tracker
NASA	National Aeronautical and Space Administration
OTS	Over-the-Shoulder
POG	Point of Gaze
RDHFL	Research Development and Human Factors Laboratory
SA	Situation Awareness
SD	Standard Deviation
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SWAT	Subjective Workload Assessment Technique
TLX	Task Load Index
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VOR	VHF Omni-directional Range

Appendix A
Equipment Description

Console Configuration

The experiment consisted of one ATCS station equipped with a radarscope, full flight strip bay, an ARTS III keyboard, and a trackball. The radarscope ran on a 2,000 by 2,000 pixel video display unit.

Simulation Pilot Terminal Configuration

A network permitted chaining of two simulation operator displays. Researchers saved all data into a directory named uniquely for each ATCS (ATCS code, data source, and scenario run).

Each simulation pilot station, configured for the simulation pilots, allowed entry of simulation pilot and ghost ATCS commands. A secondary radar representation allowed the readback position to track aircraft. The terminals located in ER2 were sound proofed from ER4.

Video Camera and Video Tape Configuration

Researchers taped the video images of both the ATCS and a replication of the Plan View Display. The ATCS position and flight strip bay were video taped using a low light, black and white camera. The video monitors in EOS2 provided a video display of all experiment rooms and computer screens to the experimenter.

Communications Configuration

Researchers set up communication links between the ATCS, OTS observer, simulation pilots, and experimenters. The equipment monitored communications and recorded times and frequencies for subsequent submission to the Data Reduction and Analysis (DR&A) module.

Oculometer

The ASL eye tracking system consists of a headband with a camera, optics system, a visor, a scene camera assembly, a camera control unit, an eye tracking system control unit, a personal computer with interface cards, and software.

Headband Assembly

The headband assembly is an adjustable headband with an optics module and a clear plastic visor plate. The optics module contains an eye camera and illuminator. The illuminator creates a near infrared beam. The researchers aim one part of the beam at the left half of the visor mounted in front of the viewer’s eye. The left half of the visor has a coating that is very reflective in the near infrared range and transmissive in the visible spectrum. The visor deflects the beam into the left eye of the viewer, illuminating the viewer's pupil and cornea. An eye camera connected to a camera control unit collects the image reflected by the visor. The scene camera provides a reference frame for line of gaze positioning. This camera mounts either on the headband or on a stationary object. The control unit feeds the outgoing signal of both the eye and scene cameras into the eye tracker control unit.

Safety

The safe level of an oculometer Light Emitting Diode (LED) is 10 mW/cm^2. ASL (Borah, May 1996, personal communication) testing found that the highest radiance level that the LED delivers to the plane of the eye is 0.8 mW/cm^2. Under normal conditions, ASL estimates the LED radiance level to be between 0.1 and 0.3 mW/cm^2, or more than a factor of 30 lower than the safe level (J. Borah, personal communication, March 11, 1996).

Eye Tracker Control Unit

The eye tracker control unit (Series 4000) houses an electronics unit, three video monitors, a control and connector panel, and power supplies. The control unit, through an interface with a PC, uses the eye tracker signal to gain the elements of interest, i.e., the pupil and corneal reflection outlines of the viewer's eye. The unit translates the data into pupil diameter and line of gaze information then stores the data into data files. One of the control unit monitors displays the pupil and corneal reflection outlines while another camera displays the image from the scene camera.

Hardware

A Magnetic Head Tracker (MHT) provided head position and orientation determined in six degrees of freedom. This option allows for the integration of eye and head position to determine the POG of the user in world coordinates. The MHT hardware is an Ascension Technology magnetic tracking system that consists of a control box and a source and sensor module. The source module transmits a magnetic field picked up by the sensor module mounted on the headband.

Appendix B

Detailed Flight Plans

Scenario 1

Type: Departure Arrival Overflight	Call in Time: Includes VFR Call in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:10 (00:20)	S	Carnival 5008	0714	B737	020	310		ACY/13 LEEAH SMYRNA DUPONT ./. HARRISBURG
Arrival	02:45	C	Carnival 5347	6412	B737	070		250	BALTIMORE ./. SWANN SMYRNA LEEAH ACY
Arrival	05:00	C	Spirit Wings 192	6334	DC9	080		250	BOSTON ./. MANTA DRIFT HARBO BRIGS ACY
Departure	07:15 (07:30)	S	USA1552	1574	B73F	020	300		ACY/13 LEEAH WATERLOO SALISBURY ./. NORFOLK
Popup (VFR)	**07:30 - Do not call in**	**V**	**N3907N**	**0102**	**Cesna 172 (C172)**	**008**	**025**	**130**	**BADER CEDAR LAKE WOODSTOWN DUPONT BUCKS ./. WILLOW GROVE AIRBASE**
Departure	at 1200 feet (10:10)	**V**	N1671G	**0104**	Bonanza 36 (BE36)	012	055		WWD/13 SEA ISLE AVALO BRIGS MANTA ./. EAST HAMPTON AIRPORT
Arrival	12:30	C	Jetlink 3761	3323	AT42	040		240	JFK ./. COYLE HOWIE ACY
Overflight	15:00	C	Deuce 40	3275	DC10	050		250	ANDREWS ./. GARED SMYRNA CEDAR LAKE COYLE ./. WRI
Overflight	17:30	C	Deuce 41	3175	DC10	050		250	ANDREWS ./. GARED SMYRNA CEDAR LAKE COYLE ./. WRI
U	**18:10 (IFR Bust) Do Not Call In**	**C**	**N845MG**	**0747**	**King Air 90 (BE90)**	**170**	**070**	**210**	**BALTIMORE ./. AGARD DONIL ACY PANZE ZIGGI ./. JFK**
Departure	19:30 (19:55)	S	Viscount Air 3502	7051	B737	020	350		ACY/13 LEEAH SMYRNA DUPONT ./. HARRISBURG
Overflight	22:30	**V**	N4771E	**0101**	MARK 20 (MO20)	045		130	PHILLY ./. WOODSTOWN SEA ISLE SNOW HILL ./. NORFOLK
Arrival	25:00	**V**	N98786	**0100**	C172	045		110	JFK ./. COYLE HOWIE ACY
Departure	27:15 (27:30)	S	Viscount Air 8804	2544	B737	020	310		ACY/13 LEEAH WATERLOO SALISBURY ./. NORFOLK

Type: Departure Arrival Overflight	Call in Time: Includes VFR Call in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Overflight	30:00	**V**	N66874	**0103**	PA31	055		180	NOTTINGHAM ./. GARED SMYRNA CEDAR LAKE COYLE DIXIE ./. JFK
Overflight	32:30	**V**	N8014K	**0105**	Bonanza 36 (BE36)	065		150	JFK ./. COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Departure (VFR)	34:45 (35:00)	S **(V)**	N1171M	**0736**	Bonanza 36 (BE36)	020	065		ACY/13 LEEAH SMYRNA DUPONT ./. HARRISBURG
Overflight	37:30	**V**	N8014T	**0106**	C172	045		110	JFK ./. DIXIE COYLE LEEAH CEDAR LAKE WATERLOO SALISBURY ./. NORFOLK
Arrival	40:00	S	Air Shuttle 5264	3060	Beech 02 (BE02)	050		200	PHILA ./. WOODSTOWN CEDAR LAKE ACY
Arrival	42:30	C	Spirit Wings 544	3351	DC9	070		250	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Arrival	45:00	C	Chatagua 906	2436	SF34	080		250	EAST HAMPTON ./. MANTA DRIFT HARBO BRIGS ACY
Arrival	47:30	C	Spirit Wings 205	2115	DC9	050		250	PHILLY ./. WOODSTOWN CEDAR LAKE ACY

Scenario 2

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:45	S	Air Shuttle 5373	0503	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Departure	02:45	S	Spirit Wings 540	2135	DC9		350		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Arrival	07:32	C	RYN 451	7070	B737	080		230	Norfolk ./. SalIbury Waterloo Sea Isle Atlantic City
Departure	08:45	S	UCA 572	5636	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	09:48	C	N1075C	0544	MO20	070		230	Harrisburg ./.Smyrna Cedar Lake Coyle ./. JFK

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	12:45	S	Spirit Wings 224	2145	DC9		310		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Arrival	13:50	V	N62980	0107	PA31	065		180	Norfolk ./. Salesbury Waterloo Sea Isle Atlantic City
Overflight	14:10	V	N999PL	0113	BE36	065		160	JFK ./. Coyle LEEAH Waterloo Salesbury ./. Norfolk
Arrival	15:45	V	N8220W	0112	PA32	065		180	Norfolk ./. Salesbury Waterloo Sea Isle Atlantic City
Overflight	16:00	V	N6924C	0110	PA32	065		180	JFK ./. Coyle Cedar Lake Smyrna Salesbury ./. Norfolk
Bust (IFR)	16:10	S	Chatagua 10J	0745	FK27	095		165	JFK ./. Coyle HOWIE TUBER LEEAH DONIL
Overflight	17:20	C	N8036V	1077	BE36	060		160	JFK ./. Coyle LEEAH Waterloo Salesbury
Arrival	17:34	C	N69ZR	0260	BE02	050		180	OTT ./. AGARD Woodstown Cedar Lake Atlantic City
Departure	17:45	S	Viscount Air 3502	7051	B737		310		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Overflight	18:47	C	N7709R	3321	BE36	060		160	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	20:20	V	N3025V	0103	BE02	055		180	AGARD Woodstown Cedar Lake Atlantic City
Arrival	21:07	C	N109YV	2410	BE02	050		180	OTT ./. Woodstown Cedar Lake Atlantic City
Overflight	24:00	V	N201BT	0101	MO20	065		210	JFK ./. Coyle LEEAH Smyrna Salesbury ./. Norfolk
Arrival	24:10	C	N65253	7044	BE02	040		180	JFK ./. Coyle Cedar Lake Atlantic City
Departure	24:45	S	RYN 446	7477	B737		350		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Popup (VFR)	27:00 Do not call in	V	N43713	0177	C172		025		AIY/11 Bader Field Atlantic City PANZE Robinsville ./. Trenton
Arrival	27:30	V	N4348F	0105	PA28	065		180	JFK ./. Coyle Cedar Lake Atlantic City
Departure	28:45	V	N4213T	0104	PA28		045		ACY/13 LEEAH Smyrna Salesbury ./. Norfolk
Arrival	29:06	C	RYN 404	7436	B737	080		230	Norfolk ./. Salesbury Smyrna Sea Isle Atlantic City
Overflight	29:30	V	N43790	0106	PA28	065		180	JFK ./. Coyle Cedar Lake Smyrna ./. Harrisburg
Overflight	30:40	V	N236WH	0102	BE36	065		180	JFK ./. Coyle LEEAH Waterloo Salesbury ./. Norfolk
Departure	32:48	S	Air Shuttle 5256	1701	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Arrival	33:36	C	N65371	1711	BE02	050		180	Harrisburg ./. Woodstown Cedar Lake Atlantic City
Departure	35:45	S	N1911L	4765	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	36:00	V	N7788H	0111	BE36	075		180	Norfolk ./. Salesbury Waterloo LEEAH Coyle ./. JFK
Arrival	36:10	V	N14KC	0115	PA28	065		180	JFK ./. Coyle LEEAH Atlantic City

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	36:48	S	Air Shuttle 5252	0563	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	38:28	C	N8014T	1032	BE36	070		180	Norfolk ./. Salesbury Waterloo LEEAH Coyle ./. JFK

Scenario 3

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:45	S	Spirit Wings 544	3351	DC9		310		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Departure	02:15	S	Jetlink 3727	0576	AT42		040		ACY/13 Cedar Lake Woodstown Philadelphia
Departure	06:15	S	N38253	1013	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Arrival	08:10	C	Spirit Wings 322	7627	DC9	080		230	Islip ./. PANZE Atlantic City
Overflight	10:00	C	N1831D	4506	BE36	060		180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Pop Up (VFR)U	10:30 Do Not Call In.	S	N7032A	0177	C172	030			AIY/11 Bader Field Atlantic City Cedar Lake Woodstown Dupont ./. Harrisburg
Arrival	13:20	C	N42251	3375	BE02	080		180	OTT ./. AGARD Woodstown Cedar Lake Atlantic City
Arrival	14:00	V	N1732	0103	BE36	055		180	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Arrival	15:40	C	N62552	6505	BE02	080		180	Phila. ./. Woodstown Cedar Lake Atlantic City
Overflight	18:40	V	N2061A	0127	BE36	065		180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Overflight	18:40	C	N2089L	7730	BE36	060		180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Departure	19:15	S	Air Shuttle 5259	7044	BE02		040		ACY/13 Cedar Lake Woodstown Philadelphia
Popup (VFR)	24:30 Do Not Call In	S	N3416Y	0106	C172		030		MIV/10 Millville LEEAH Waterloo Salisbury ./. Norfolk
Arrival	26:10	C	N65237	7006	BE02	080		180	Phila ./. Woodstown Cedar Lake Atlantic City

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Overflight	29:00	V	N1835F	0113	BE36	065		160	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Overflight	29:10	C	N2610B	0105	BE36	055		180	Norfolk ./. Salisbury Smyrna Cedar Lake Coyle ./. JFK
Arrival	29:30	C	N65271	7057	BE02	080		180	Phila ./. Woodstown Cedar Lake Atlantic City
Departure	30:15	S	Jetlink 3721	5663	AT42		050		ACY/13 PANZE Robinsville ./. Trenton
Overflight	33:40	C	N326J	5709	BE58	060		160	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	34:00	C	Air Shuttle 5388	7053	BE02	080		180	Phila ./. Woodstown Cedar Lake Atlantic City

Scenario 4

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:10 (00:25)	S	Jetlink 9506	3025	AT42	020	050		ACY/13 PANZE DIXIE ROBINSVILLE ./. TRENTON
Departure	at 1200 feet (01:16)	V	N1672G	0100	Bonanza 36 (BE 36)	012	055		WWD/13 SEA ISLE AVALO BRIGS MANTA ./. EAST HAMPTON
Departure	at 1200 feet (02:24)	V	N52407	0101	Cesna 172 (C172)	010	045		MIV/10 SMYRNA SWANN ./. BALTIMORE
Arrival	03:36	C	RYN446	5477	B737	070		250	BALITMORE ./. SWANN SMYRNA SEA ISLE ACY
Departure (VFR)	04:20 (04:35)	S (V)	N7872E	0566	Bonanza 36 (BE 36)	020	065		ACY/13 LEEAH SMYRNA DUPONT ./. HARRISBURG
Arrival	06:00	C	Spirit Wings 175	3664	DC9	070		250	BALTIMORE ./. SWANN SMYRNA SEA ISLE ACY
Overflight	07:12	C	N78MM	2765	Learjet 25 (LR 25)	060		210	EAST HAMPTON ./. MANTA DRIFT HARBO SEA ISLE SNOW HILL ./. NORFOLK
Arrival	08:24	C	RYN456	3677	B737	070		250	BALTIMORE ./. SWANN SMYRNA SEA ISLE ACY
Departure	09:15 (09:31)	S	Spirit Wings 318	3647	DC9	020	350		ACY/13 LEEAH WATERLOO SALISBURY ./. NORFOLK
POPUP	10:45 (Do Not Call)		N5810F	0102	MO20	008	035	150	MIV HOWIE COYLE DIXIE ./. JFK
Overflight	12:00	C	Spirit Wings 225	3637	DC9	070		250	NORFOLK ./. SALISBURY WATERLOO DIXIE ROBINSVILLE ./. TRENTON
Arrival	13:12	C	Jetlink 3421	2627	AT42	040		230	JFK ./. DIXIE COYLE HOWIE ACY
Overflight	14:24	V	N7517T	0103	Bonanza 36 (BE 36)	055		155	NOTTINGHAM ./. GARED SMYRNA CEDAR LAKE COYLE DIXIE ./. JFK
Arrival	15:36	C	N845ZZ	4701	King Air 90 (BE90)	070		210	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Arrival	16:48	C	Air Shuttle 5371	1711	Beech 02 (BE02)	050		200	PHILLY ./. DUPONT WOODSTOWN CEDAR LAKE ACY
Overflight	18:00	V	N5217G	0104	Centurion II (C210)	045		160	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Arrival	19:12	C	ROCK70	1561	C130	080		220	JFK ./. CAMRN KARRS PANZE ACY

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	20:08 (20:20)	S	BATON08	1573	C130	020	050		ACY/13 PANZE DIXIE ROBINSVILLE YARDLY
Arrival	21:36	C	Air Shuttle 5276	3177	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Arrival	22:48	V	N3073W	0105	Lance (PA32)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Arrival	25:12	C	Air Shuttle 5299	3065	Beech 02 (BE02)	030		200	BALTIMORE ./. SWANN SMYRNA LEEAH ACY
Departure (VFR)	25:55 (26:10)	S (V)	N2183M	0544	Bonanza 36 (BE 36)	020	065		ACY/13 LEEAH WATERLOO SALISBURY ./. NORFLOK
POPUP	26:30 (Do Not Call)		N3334I	0106	Bonanza 36 (BE 36)	008	025	150	JFK ./. COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Overflight	27:36	V	N2171T	0107	Bonanza 36 (BE 36)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE JFK
Overflight	28:48	V	N9557Z	0110	Bonanza 36 (BE 36)	065		150	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Departure	at 1200 feet (30:00)	V	N8220X	0112	Lance (PA32)	010	045		MIV/10 LEEAH WATERLOO SALISBURY ./. NORFOLK
Overflight	31:20	V	N1831S	0113	Bonanza 36 (BE 36)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE JFK
Overflight	32:24	C	N67414	1645	Bonanza 36 (BE 36)	060 auto-descends to 040		150	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Departure	33:15 (33:30)	S	COM8812	4612	CL44	020		260	ACY/13 LEEAH GARED ./. NOTTINGHAM
Arrival	34:48	C	Air Shuttle 5294	0530	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Overflight	36:00	V	N7616J	0114	Bonanza 36 (BE 36)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE ./. JFK

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Arrival	37:12	C	Spirit Wings 192	6334	DC9	080		250	EAST HAMPTON ./. MANTA DRIFT HARBO BRIGS ACY
Overflight	38:24	V	N8036W	0115	Bonanza 36 (BE 36)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE JFK
Overflight	39:36	V	N7148W	0116	Bonanza 36 (BE 36)	065		150	JFK ./. DIXIE COYLE LEEAH WATERLOO NOTTINGHAM
Overflight	40:48	V	N2089F	0117	Bonanza 36 (BE 36)	075 auto-descends to 055		150	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE ROBINSVILLE ./. TRENTON
Departure	41:40 (41:55)	S	EGJ11	4611	FK27	020	140		ACY/13 LEEAH DONIL GARED ./. NOTTINGHAM
Arrival	43:12	C	N78GM	2265	Learjet 25 (LR 25)	080		210	JFK ./. MANTA DRIFT HARBO BRIGS ACY
Departure	at 1200 feet (44:30)	V	N7520Z	0120	Cardinal 177 (C177)	010	045		MIV/13 HOWIE COYLE DIXIE ./. JFK
Arrival	45:36	C	Air Shuttle 5296	3577	Beech 02 (BE02)	050		180	BALTIMORE ./. SWANN SMYRNA LEEAH ACY
Departure	46:43	C	Viscount Air 8310	6541	B737	020	350		ACY/13 LEEAH SYMRNA DUPONT ./. HARRISBURG
Overflight	48:00	C	N3268M	2705	Bonanza 36 (BE 36)	040	140		JFK ./. DIXIE COYLE LEEAH WATERLOO ./. NOTTINGHAM

Scenario 5

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:10 (00:20)	S	VVLV128	7336	P3	020	050		ACY/13 PANZE ZIGGI DIXIE ./. TRENTON
Arrival	05:00	C	Spirit Wings 191	7376	DC9	080		250	BOSTON ./. MANTA DRIFT HARBO BRIGS ACY
Overflight	07:30	C	N5577J	0552	Baron 58 (BE58)	070		180	BALTIMORE ./. AGARD DONIL SEA ISLE HARBO MANTA ./. EAST HAMPTON
Arrival	10:00	C	Spirit Wings 313	2670	DC9	070		250	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Overflight	12:30	S	N18400	3452	Duke 60 (BE60)	060		180	ISLIP ./. MANTA DRIFT HARBO BRIGS SEA ISLE WATERLOO ./. NOTTINGHAM
Overflight	15:00	V	N9572X	0101	King Air (BE90)	065		180	JFK ./. COYLE LEEAH SALISBURY ./. NORFOLK
Arrival	17:30	C	N232DM	3062	Citation II (C550)	080		220	BOSTON ./. MANTA DRIFT HARBO BRIGS ACY
Arrival	20:00	V	N178JB	0102	PA31	045		170	JFK ./. COYLE HOWIE ACY
Departure	22:20 (22:30)	S	N622T	4512	Baron 58 (BE58)	020		180	ACY/13 LEEAH WATERLOO SALISBURY ./. NORFOLK
Arrival	25:00	C	Air Shuttle 5299	2605	Beech 02 (BE02)	050		200	PHILA ./. WOODSTOWN CEDAR LAKE ACY
IFR BUST (DO NOT CALL IN)	27:00	C	Alleghany 3541	0505	DC9	090	070	250	JFK ./. DIXIE COYLE LEEAH SMYRNA ./. BALTIMORE
Arrival	27:30	C	COM8819	4614	CL44	070		220	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Overflight	30:00	V	N6458C	0103	Baron 58 (BE58)	065		160	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Arrival	32:30	V	N400AE	0104	Huron (BE20)	065		140	ISLIP ./. CAMRN PANZE ACY
Departure	34:50 (35:00)	S	EJA330	2436	Citation III (C650)	020		250	ACY BRIGS HARBO DRIFT PLUME ./. BOSTON

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
IFR BUST (DO NOT CALL IN)	37:00	C	Alleghany 3533	0443	DC9	085	070		BALTIMORE ./. DONIL LEEAH COYLE ./. JFK
Overflight	37:30	V	N17824	0106	Baron 58 (BE58)	075 auto-descends to 055		160	NORFOLK ./. SALISBURY WATERLOO LEEAH COYLE DIXIE ./. JFK
Overflight	40:00	V	N5634X	0105	Baron 58 (BE58)	065		160	JFK ./. DIXIE COYLE CEDAR LAKE SMYRNA GARED ./. PATUXENT
Departure	42:15 (42:30)	S	Spirit Wings 123	7040	DC9	020	310		ACY LEEAH WATERLOO SALISBURY ./. NORFOLK
Departure	44:40 (44:50)	S	Spirit Wings 529	2405	DC9	020	310		ACY LEEAH SMYRNA BALTIMORE
Overflight	46:00	C	N8168R	0542	Baron 58 (BE58)	070		180	NOTTINGHAM ./. GARED WATERLOO AVALO BRIGS MANTA ./. ISLIP
Overflight	48:00	C	N18410	3555	Duke 60 (BE60)	060		180	ISLIP ./. MANTA BRIGS SEA ISLE WATERLOO GARED ./. NOTTINGHAM
Departure	at 1200 feet (02:35)	V	N6792G	0100	Mark 20 (MO20)	012	055		WWD SEA ISLE HARBO MANTA ./. EAST HAMPTON

Scenario 6

Type: Departure Arrival Overflight	**Call in Time: Includes VFRCall in Time**	**Initial Controlling Sector (S = ACY; C = Wash. V = VFR)**	**Aircraft Call Sign**	**Beacon Code**	**Aircraft Type**	**Altitude (Initial)**	**Altitude (Requested)**	**Speed**	**Flight Plan**
Departure	01:00	S	Spirit Wings 715	0564	DC9	310			ACY/13 LEEAH Smyrna Salisbury ./. Norfolk
Departure	02:30	S	Spirit Wings 541	1323	DC9	310			ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Departure	05:30	S	Jetlink 3917	2176	AT42	060			ACY/13 LEEAH Smyrna ./. Baltimore
Arrival	07:20	V	N236WH	0161	BE36	035		100	Dover DONIL LEEAH Atlantic City

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Overflight	08:30	V	N3113N	0102	BE36	015	055	100	McGuire AFB Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	08:30	C	Spirit Wings 192	0524	DC9	130	065	210	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Departure	09:30	V	N92297	0101	BE02	055			ACY/13 PANZE Robinsville ./. Trenton
Overflight	09:30	C	N67414	1645	BE36	140	060	180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Overflight	12:20	C	N2036A	2610	BE36	140	060	180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	12:50	C	N401AC	2472	LR25	130	080	210	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Departure	13:30	S	Air Shuttle 5237	1706	BE02	040			ACY/13 Cedar Lake Woodstown Philadelphia
IFR BUST	14:27	C	Spirit Wings 245	0433	DC9	092		330	OTT ./. AGARD DONIL Atlantic City PANZE ./. JFK
Overflight	16:00	C	N9873Q	4725	BE55	130	070	230	Norfolk ./. Salisbury Smyrna Cedar Lake Coyle ./. JFK
Arrival	17:05	C	Spirit Wings 184	0546	DC9	110	080	210	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Overflight	17:20	V	N8168R	0105	BE58	065	065	180	Boston ./. DRIFT FALON Coyle LEEAH Waterloo Salisbury ./. Norfolk
Departure	17:30	V	N31560	0122	BE02	055			ACY/13 PANZE Robinsville ./. Trenton
Arrival	17:45	C	N38764	7074	BE02	140	080	160	Boston ./. DRIFT FALON Coyle Cedar Lake Atlantic City
Arrival	18:20	C	N8036V	1077	BE36	120	080	160	JFK ./. Coyle Cedar Lake Atlantic City
Overflight	20:00	V	N20HJ	0106	C172	015	055	100	Philadelphia Smyrna Cedar Lake Coyle ./. JFK
Arrival	20:20	C	N53779	0677	BE02	140	060	160	Boston ./. DRIFT FALON Coyle Cedar Lake Atlantic City
Arrival	21:05	C	Spirit Wings 227	1127	DC9	110	080	210	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Departure	21:30	S	Air Shuttle 5299	3014	BE02	040			ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	21:40	C	N8772R	0535	BE55	120	060	180	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	24:00	C	Spirit Wings 191	1541	DC9	130	080	200	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Overflight	24:30	C	N761JT	2020	BE36	140	060	160	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	25:30	V	Air Shuttle 5372	0147	BE02	045			ACY/13 Cedar Lake Woodstown Philadelphia
IFR BUST	28:06	C	Carnival Airlines 53HB	0733	B737	270		186	Pendleton, OR Sea Isle Atlantic City PANZE ./. JFK
Arrival	28:30	C	N99351	1631	BE02	120	068	160	JFK ./. Coyle Cedar Lake Atlantic City
Departure	29:30	S	Spirit Wings 205	2115	DC9	310			ACY/13 LEEAH Smyrna Dupont ./. HAR
Overflight	30:10	C	N5577J	0552	BE58	120	060	170	JFK ./. Coyle Cedar Lake Smyrna Salisbury ./. Norfolk
Overflight	31:20	V	N999PL	0103	BE36	065	065	120	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Departure	33:30	S	Air Shuttle 5294	0556	BE02	040			ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	35:30	V	N3113B	0104	BE36	015	065	100	McGuire AFB ./ Coyle LEEAH Waterloo Salisbury ./. Norfolk
Departure	37:30	V	N13281	0150	BE02	055			ACY/13 PANZE Robinsville ./. Trenton

Scenario 7

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	01:00	S	Air Shuttle 5255	0525	BE02		40		ACY/13 Cedar Lake Woodstown Philadelphia
Departure	04:00	S	N845MD	4701	BE90		50		ACY/13 PANZE Robinsville ./. Trenton
Departure	10:00	S	Spirit Wings 235	6543	DC9		310		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Overflight	11:10	V	N63767	0103	C172	65		160	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	13:30	V	N83950	0101	BE02	55		180	Washinton, DC ./. Woodstown Cedar Lake Atlantic City
Overflight	15:10	C	N33PA	3336	C182	50		230	Norfolk ./. Salisbury Waterloo LEEAH Coyle ./. JFK
Departure	16:00	S	Air Shuttle 5251	3324	BE02		60		ACY/13 Cedar Lake Woodstown Philadelphia

Type: Departure Arrival Overflight	**Call in Time: Includes VFRCall in Time**	**Initial Controlling Sector (S = ACY; C = Wash. V = VFR)**	**Aircraft Call Sign**	**Beacon Code**	**Aircraft Type**	**Altitude (Initial)**	**Altitude (Requested)**	**Speed**	Flight Plan
Arrival	17:20	V	N735YA	0110	C182	65		210	JFK ./. Coyle Cedar Lake Atlantic City
Overflight	18:00	C	Spirit Wings 188	3646	DC9	60		210	Norfolk ./. Salisbury Waterloo LEEAH Coyle ./. JFK
Arrival	20:00	V	N49TT	0106	MO20	55		230	Norfolk ./. Salisbury Smyrna Sea Isle Atlantic City
Departure	22:00	S	Air Shuttle 5294	0530	BE02		40		ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	23:20	V	N3526U	0105	C182	65		210	JFK ./. Coyle LEEAH Waterloo Salisbury ./. Norfolk
Arrival	23:30	C	Spirit Wings 811	5714	DC9	80		210	Harrisburg ./. Smyrna Sea Isle Atlantic City
Arrival	24:09	C	Spirit Wings 178	3647	DC9	80		210	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Arrival	26:00	C	N22099	2743	BE36	60		180	JFK ./. Coyle HOWIE Atlantic City
Departure	28:00	S	Spirit Wings 173	6012	DC9		60		ACY/13 LEEAH Smyrna Dupont ./. Harrisburg
Arrival	31:00	V	N2555Q	0104	PA28	55		180	Norfolk ./. Salisbury Waterloo Sea Isle Atlantic City
Departure	34:00	S	N69ZR	2330	BE02		40		ACY/13 Cedar Lake Woodstown Philadelphia
Overflight	37:00	V	N53379	0102	BE02	45		180	JFK ./. Coyle LEEAH Smyrna Salisbury ./. Norfolk
Overflight	40:30	V	N761JT	0107	BE36	65		160	JFK ./. Coyle Cedar Lake Smyrna ./. Harrisburg

Scenario 8

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	00:15 (00:25)	S	Spirit Wings 715	3564	DC9	020	310		ACY/13 LEEAH SMYRNA DUPONT ./. HARRISBURG
Departure	at 1200 feet (01:15)	V	N1672G	0100	Bonanza 36 (BE36)	012	055		WWD/13 SEA ISLE AVALO BRIGS MANTA ./. EAST HAMPTON
Departure	at 1200 feet (02:27)	V	N52407	0101	Skyhawk 172 (C172)	010	065		MIV/10 LEEAH SEA ISLE SNOW HILL ./. NORFOLK
Arrival	03:36	C	Spirit Wings 188	3646	DC9	070		250	BALTIMORE ./. SWANN SMYRNA SEA ISLE ACY
Departure	4:30 (04:48)	S	N279MB	4714	FK27	020	180		ACY/13 LEEAH SMYRNA DUPONT ./. WILLOW GROVE AIRBASE
Arrival	06:00	C	N845ME	4754	King Air 90 (BE90)	070		190	BALTIMORE ./. SWANN SMYRNA SEA ISLE ACY
Departure	at 1200 feet (07:14)	V	N6925C	0102	Lance (PA32)	010	055		AIY/11 BRIGS HARBO DRIFT ./. JFK
Arrival	08:24	C	Blueridge 193	3545	BA46	080		250	JFK ./. DIXIE COYLE HOWIE ACY
Arrival	09:36	C	Carnival 8349	3174	B737	070		250	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Arrival	10:48	C	Air Shuttle 5253	1565	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Overflight	12:00	C	Spirit Wings 190	6334	DC9	060		250	EAST HAMPTON ./. MANTA DRIFT HARBO BRIGS SEA ISLE SNOW HILL ./. NORFOLK
Departure	13:00 (13:12)	S	VV7W516	4741	C12	020	050		ACY/13 PANZE ZIGGI DIXIE ./. TRENTON
Overflight	14:24	C	USAir 1139	6334	B737	060		250	BOSTON ./. MANTA DRIFT HARBO BRIGS SEA ISLE SNOW HILL ./. TAMPA
Overflight	15:36	V	N4794M	0104	Bonanza 36 (BE36)	055		155	NOTTINGHAM ./. GARED SMYRNA CEDAR LAKE COYLE DIXIE ./. JFK
Arrival	16:48	C	Air Shuttle 5251	4744	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Overflight	18:00	V	N3334C	0105	Bonanza 36 (BE36)	045		140	NEW HAVEN ./. DIXIE COYLE HOWIE LEEAH WATERLOO SALISBURY ./. NORFOLK

Type: Departure Arrival Overflight	**Call in Time: Includes VFRCall in Time**	**Initial Controlling Sector (S = ACY; C = Wash. V = VFR)**	**Aircraft Call Sign**	**Beacon Code**	**Aircraft Type**	**Altitude (Initial)**	**Altitude (Requested)**	**Speed**	Flight Plan
Departure	19:00 (19:12)	S	Carnival Air 7218	4514	B737	020	350		ACY/13 LEEAH WATERLOO SALISBURY ./. NORFOLK
Arrival	20:24	C	N28R	6354	Mystere Falcon 900 (DA90)	070		250	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY
Overflight	21:36	V	N456DM	0111	Bonanza 36 (BE36)	055		145	NOTTINGHAM ./. GARED SMYRNA CEDAR LAKE COYLE DIXIE ./. JFK
Overflight	22:48	V	N8014T	0112	Bonanza 36 (BE36)	065		140	JFK ./. DIXIE COYLE HOWIE LEEAH WATERLOO SALISBURY ./. NORFOLK
Departure	23:20 (23:30)	S	Jetlink 3917	2176	AT42	020	060		ACY/13 LEEAH SMYRNA ./. BALTIMORE
Departure	25:00 (25:12)	S	Viscount Air 8311	7035	B737	020	350		ACY/13 LEEAH SMYRNA GARED ./. NOTTINGHAM
Arrival	26:24	C	Air Shuttle 5299	2702	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Departure	27:20 (27:36)	S	N9551M	5554	Mark 20 (MO20)	020	060		ACY/13 LEEAH SMYRNA ./. BALTIMORE
Overflight	28:48	V	N2061B	0106	Bonanza 36 (BE36)	065		140	JFK ./. DIXIE COYLE HOWIE LEEAH WATERLOO SALISBURY ./. NORFOLK
Overflight	30:00	V	N3684A	0113	Bonanza 36 (BE36)	055		140	NOTTINGHAM ./. GARED SMYRNA CEDAR LAKE COYLE DIXIE ./. JFK
Arrival	31:12	C	OPEC22	3124	DC9	070		250	ANDREWS ./. SWANN SMYRNA SEA ISLE ACY
Departure	32:10 (32:24)	S	Spirit Wings 519	2155	DC9	020	310		ACY/13 LEEAH SMYRNA BALTIMORE
Overflight	33:36	V	N55MD	0110	Bonanza 36 (BE36)	065		140	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Overflight	34:48	C	Spirit Wings 812	6224	DC9	060		250	EAST HAMPTON ./. MANTA DRIFT HARBO BRIGS SEA ISLE SNOW HILL ./. NORFOLK
Overflight	36:00	C	Carnival Air 5323	6554	B737	070 auto-descends to 050		250	CHARLESTON ./. SALISBURY WATERLOO LEEAH COYLE DIXIE ./. NEWARK

Type: Departure Arrival Overflight	Call in Time: Includes VFRCall in Time	Initial Controlling Sector (S = ACY; C = Wash. V = VFR)	Aircraft Call Sign	Beacon Code	Aircraft Type	Altitude (Initial)	Altitude (Requested)	Speed	Flight Plan
Departure	37:00 (37:12)	S	Devil 91	4734	F-16	020	170		ACY/13 BRIGS MANTA RICED
Arrival	38:24	V	N9557N	0114	Bonanza 36 (BE36)	055		140	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Overflight	39:36	V	N3235D	0107	Bonanza 36 (BE36)	045		140	JFK ./. DIXIE COYLE CEDAR LAKE SMYRNA SALISBURY ./. NORFOLK
Departure	40:15 (40:30)	S	Hamer 21	4522	F-16	020	170		ACY/13 BRIGS MANTA RICED
Arrival	42:00	C	Air Shuttle 8337	3163	Beech 02 (BE02)	050		200	PHILLY ./. WOODSTOWN CEDAR LAKE ACY
Departure (VFR)	43:00 (43:12)	S (V)	N7731J	0115	PA32	020	045		ACY/13 CEDAR LAKE WOODSTOWN MODENA BUCKS ./. WILLOW GROVE AIRBASE
Overflight	44:24	C	N9341C	6664	King Air 90 (BE90)	060		190	EAST HAMPTON ./. MANTA DRIFT HARBO BRIGS SEA ISLE SNOW HILL ./. NORFOLK
Arrival	45:36	C	Blueridge 198	3515	BA46	060		250	JFK ./. DIXIE COYLE HOWIE ACY
Arrival	48:00	C	Spirit Wings 214	7535	DC9	070		250	NORFOLK ./. SALISBURY WATERLOO SEA ISLE ACY

Scenario 0 - Practice

Type: Departure Arrival Overflight	**Call in Time: Includes VFR Call in Time**	**Initial Controlling Sector (S = ACY; C = Wash. V = VFR)**	**Aircraft Call Sign**	**Beacon Code**	**Aircraft Type**	**Altitude (Initial)**	**Altitude (Requested)**	**Speed**	**FLIGHT PLAN**
Departure	00:30	S	Air Shuttle 5299	5104	BE02		040		ACY/13 CEDAR LAKE WOODSTOWN PHILADELPHIA
Departure	04:00	V	Air Shuttle 5349	0130	BE02		045		ACY/13 CEDAR LAKE WOODSTOWN PHILADELPHIA
Departure	08:00	S	Air Shuttle 5238	2104	BE02		040		ACY/13 CEDAR LAKE WOODSTOWN PHILADELPHIA
Arrival	12:00	C	Jet Link3729	0515	AT42	080		210	JFK ./. DIXIE COYLE ATLANTIC CITY
Arrival	12:50	V	N66874	0101	PA31	065		190	JFK ./. DIXIE COYLE ATLANTIC CITY

Type: Departure Arrival Overflight	**Call in Time: Includes VFR Call in Time**	**Initial Controlling Sector (S = ACY; C = Wash. V = VFR)**	**Aircraft Call Sign**	**Beacon Code**	**Aircraft Type**	**Altitude (Initial)**	**Altitude (Requested)**	**Speed**	**FLIGHT PLAN**
Arrival	13:15	C	Viscount 8503	7473	B737	050		230	SALISBURY SMYRNA SEA ISLE ATLANTIC CITY
Overflight	16:27	C	N72578	2075	BE36	060		180	JFK ./. DIXIE COYLE LEEAH SMYRNA SALISBURY ./. NORFOLK
Arrival	17:14	C	N201JA	1736	MO20	080		150	JFK ./. DIXIE COYLE ATLANTIC CITY
Arrival	17:40	V	N5652M	0102	MO20	045		150	JFK ./. DIXIE COYLE ATLANTIC CITY
Overflight	22:14	C	N1159P	3052	MO20	060		150	JFK ./. DIXIE COYLE LEEAH WATERLOO SALISBURY ./. NORFOLK
Overflight	25:00	V	N4961L	0103	PA28	045		180	JFK ./. DIXIE COYLE CEDAR LAKE SMYRNA ./. NOTTINGHAM

Appendix C

Questionnaires

Entry Questionnaire

1. What is your age in years? __________ years
2. Are you wearing corrective lenses during this experiment? ☐ Yes ☐ No
3. How many years have you actively controlled traffic? __________ years
4. How many years have you controlled traffic at the Atlantic City TRACON? __________ years
5. How many months in the past year have you actively controlled traffic? __________ months
6. What is your current position as an air traffic controller? ☐ Developmental ☐ Full Performance Level ☐ Other:

7. Please circle the number that best describes your **current skill as an air traffic controller**. not skilled 1 2 3 4 5 6 7 8 9 10 extremely skilled

Comments: ______________________________

8. Please circle the number that best describes the **level of stress** you have experienced during the last several months no stress 1 2 3 4 5 6 7 8 9 10 extremely high level of stress

Comments: ______________________________

9. Please circle the number that best describes your **motivation** to participate in this study. not motivated 1 2 3 4 5 6 7 8 9 10 extremely motivated

Comments: ______________________________

10. Please circle the number that best describes your **state of health** not healthy 1 2 3 4 5 6 7 8 9 10 extremely healthy

Comments: ______________________________

11. Do you **search the PVD in one special way for information**? If it depends on certain factors, what are they?

Comments:

12. Please circle the number that best describes your **preference for vertical separation**

no vertical separation 1 2 3 4 5 6 7 8 9 10 always vertical separation

Comments:

13. Please circle the number that best describes your **preference for separation through "vectoring"**

no vector separation 1 2 3 4 5 6 7 8 9 10 always vector separation

Comments:

14. Please circle the number that best describes your **preference for speed control**

no speed control 1 2 3 4 5 6 7 8 9 10 always speed control

Comments:

15. Please circle the number that best describes your **experience with video games**.

not experienced 1 2 3 4 5 6 7 8 9 10 extremely experienced

Comments:

	Please circle the number that best describes the **importance** of the following **aircraft** information:.												
16.	Aircraft Call Sign	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
17.	Aircraft Type	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
18.	Aircraft Beacon Code	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
19.	Controller Ownership	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
20.	Entry Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
21.	Entry Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
22.	Entry Fix	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
23.	Exit Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
24.	Exit Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
25.	Exit Fix	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
26.	Arrival Airport (within sector)	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
27.	Departure Airport (within sector)	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
28.	Current Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
29.	Current Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
30.	Current Heading	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
31.	Current Aircraft Location	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
32.	Most Recently Assigned Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
33.	Most Recently Assigned Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
34.	Most Recently Assigned Heading	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
35.	Aircraft Holding/Spinning	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
36.	Aircraft Waiting for Hand-off/Release	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
37.	Aircraft Near Exit Fix/Arrival Airport	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
38.	Density of Aircraft on Radar Display	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

	Please circle the number that best describes the **importance** of the following **radar display** information:.												
39.	Range Rings	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
40.	System Clock	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
41.	VORs	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
42.	Fixes	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
43.	Airports	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
44.	Restricted Area Boundaries	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
45.	ILS Approaches	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
46.	ILS Outer Marker	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
47.	Runways	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
48.	Holding Patterns	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
49.	Obstructions	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
50.	Sector Boundaries	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
51.	Filter Settings	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
52.	Future Aircraft List	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
53.	Collision Alert	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

Post-Scenario Questionnaire

ID:	Scenario:	Date:

1. Please circle the number that best describes **how realistic the simulation** was.	extremely unrealistic	1	2	3	4	5	6	7	8	9	10	extremely realistic

Comments:

2. Please circle the number that best describes **how representative the scenario was** of a typical workday.	not representative	1	2	3	4	5	6	7	8	9	10	extremely representative

Comments:

3. Please circle the number that best describes if the **ATWIT device interfered** with controlling traffic.	no interference	1	2	3	4	5	6	7	8	9	10	extreme interference

Comments:

4. Please circle the number that best describes if the **oculometer interfered** with controlling traffic.	no interference	1	2	3	4	5	6	7	8	9	10	extreme interference

Comments:

5. Please circle the number that best describes **how well the simulation-pilots responded** to your clearances in terms of traffic movement and call-backs.	extremely poor	1	2	3	4	5	6	7	8	9	10	extremely well

Comments:

6. Do you have any other comments about your experiences during the simulation?

Comments:

7. Please circle the number below that best describes **how hard you were working** during this scenario.

not hard 1 2 3 4 5 6 7 8 9 10 extremely hard

Comments: ____________________

8. Please circle the number that best describes **how well you controlled traffic** during this scenario

extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well

Comments: ____________________

9. Please circle the number that best describes **overall situational awareness** during this scenario

extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well

Comments: ____________________

10. Please circle the number that best describes **situational awareness for current aircraft locations** during this scenario.

extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well

Comments: ____________________

11. Please circle the number that best describes **situational awareness for projected aircraft locations** during this scenario.

extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well

Comments: ____________________

12. Please circle the number that best describes **situational awareness for potential violations** during this scenario.

extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well

Comments: ____________________

13. Please circle the number that best describes **how difficult** this scenario was.	extremely easy	1 2 3 4 5 6 7 8 9 10	extremely difficult

Comments: ______________________________

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NASA TLX

14. Please circle the number that best describes the **mental demand** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
15. Please circle the number that best describes the **physical demand** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
16. Please circle the number that best describes the **temporal demand** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
17. Please circle the number that best describes your **performance** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
18. Please circle the number that best describes your **effort** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
19. Please circle the number that best describes your level of **frustration** during this scenario.	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high

Exit Questionnaire

1. Please circle the number that best describes **how realistic the simulations** were.	extremely unrealistic	1 2 3 4 5 6 7 8 9 10	extremely realistic

Comments: ____________________

2. Please circle the number that best describes **how representative the scenarios were** of a typical workday. | not representative | 1 2 3 4 5 6 7 8 9 10 | extremely representative |

2. Please circle the number that best describes **how representative the scenarios were** of a typical workday.	not representative	1 2 3 4 5 6 7 8 9 10	extremely representative

Comments: ____________________

3. Please circle the number that best describes if the **ATWIT device interfered** with controlling traffic.	no interference	1 2 3 4 5 6 7 8 9 10	extreme interference

Comments: ____________________

4. Please circle the number that best describes if the **oculometer interfered** with controlling traffic.	no interference	1 2 3 4 5 6 7 8 9 10	extreme interference

Comments: ____________________

5. Please circle the number that best describes **how well the simulation-pilots responded** to your clearances in terms of traffic movement and call-backs.	extremely poor	1 2 3 4 5 6 7 8 9 10	extremely well

Comments: ____________________

6. Please circle the number that best describes if the **hands-on training was adequate on day 1**.	not adequate	1 2 3 4 5 6 7 8 9 10	adequate

Comments: ____________________

7. Was there anything that you found particularly unique in the simulation that you would not see at your home facility?
Comments: ______________________________

8. Were you constantly aware of wearing the oculometer, or did you tune it out?
Comments: ______________________________

9. Do you search the PVD in one special way for information or does it depend on certain factors and if so, what are they?
Comments: ______________________________

10. How do you decide whether or not to suppress data?
Comments: ______________________________

11. Is there anything about the study that we should have asked or that you would like to comment about?
Comments: ______________________________

Appendix D
Observer Checklist

Instructions for questions 1-24

This form was designed to be used by instructor certified air traffic control specialist to evaluate the effectiveness of controllers working in simulation environments. Observers will rate the effectiveness of controllers in several different performance areas using the scale show below. When making your ratings, pleas try to use the entire scale range as much as possible. You are encouraged to write down observations and you may make preliminary ratings during the course of the scenario. However, we recommend that you wait until the scenario is finished before making your final ratings. The observations you make do not need to be restricted to the performance areas covered in this form ands may include other areas that you think are important. Also, please write down any comments that may improve this evaluation form. Your identity will remain anonymous, so do not write your name on the form.

Rating	Label Description
1	Controller demonstrated extremely poor judgment in making control decisions and very frequently made errors
2	Controller demonstrated poor judgment in making some control decisions and occasionally made errors
3	Controller make questionable decisions using poor control techniques which led to restricting the normal traffic flow
4	Controller demonstrated the ability to keep aircraft separated but used spacing and separation criteria which was excessive
5	Controller demonstrated adequate judgment in making control decisions
6	Controller demonstrated good judgment in making control decisions using efficient control techniques
7	Controller frequently demonstrated excellent judgment in making control decisions using extremely good control techniques
8	Controller always demonstrated excellent judgment in making even the most difficult control decisions while using outstanding control techniques

Maintaining Safe and Efficient Traffic Flow

1. Maintaining Separation and Resolving Potential Conflicts 1 2 3 4 5 6 7 8
   - using control instructions that maintain save aircraft separation
   - detecting and resolving impending conflicts early

   Comments: ____________________

2. Sequencing arrival and Departure Aircraft Efficiently 1 2 3 4 5 6 7 8
   - using efficient and orderly spacing techniques for arrival and departure aircraft
   - maintaining safe arrival and departure intervals that minimize delays

   Comments: ____________________

3. Using Control Instructions Effectively 1 2 3 4 5 6 7 8
   - providing accurate navigational assistance to pilots
   - avoiding clearances that result in the need for additional instructions to handle aircraft completely
   - avoiding excessive vectoring or over-controlling

   Comments: ____________________

4. Overall Safe and Efficient Traffic Flow Scale Rating 1 2 3 4 5 6 7 8

   Comments: ____________________

Maintaining Attention and Situation Awareness

5. Maintaining Awareness of Aircraft Positions 1 2 3 4 5 6 7 8
   - avoiding fixation on one area of the radarscope when other areas need attention
   - using scanning patterns that monitor all aircraft on the radarscope

   Comments: ____________________

6. Ensuring Positive Control 1 2 3 4 5 6 7 8

   Comments: ____________________

7. Detecting Pilot Deviations from Control Instructions 1 2 3 4 5 6 7 8
   - ensuring that pilots follow assigned clearances correctly
   - correcting pilot deviations in a timely manner
   - avoiding excessive vectoring or over-controlling

   Comments: ____________________

8. Correcting Own Errors in a Timely Manner 1 2 3 4 5 6 7 8

   Comments: ____________________

9. Overall Attention and Situation Awareness Scale Rating 1 2 3 4 5 6 7 8

   Comments: ____________________

Prioritizing

10. Taking Actions in an Appropriate Order of Importance 1 2 3 4 5 6 7 8
- resolving situations that need immediate attention before handling low priority tasks
- issuing control instructions in a prioritized, structured, and timely manner

Comments:

11. Preplanning Control Actions 1 2 3 4 5 6 7 8
- scanning adjacent sectors to plan for inbound traffic
- studying pending flight strips in bay

Comments:

12. Handling Control Tasks for Several Aircraft 1 2 3 4 5 6 7 8
- shifting control tasks between
- avoiding delays in communications while thinking or planning control actions

Comments:

13. Marking Flight Strips while Performing Other Tasks 1 2 3 4 5 6 7 8
- marking flight strips accurately while talking or performing other tasks
- keeping flight strips current

Comments:

14. Overall Prioritizing Scale Rating 1 2 3 4 5 6 7 8

Comments:

Providing Control Information

15. Providing Essential Air Traffic Control Information 1 2 3 4 5 6 7 8
- providing mandatory services and advisories to pilots in a timely manner
- exchanging essential information

Comments:

16. Providing Additional Air Traffic Control Information 1 2 3 4 5 6 7 8
- providing additional services when workload is not a factor
- exchanging additional information

Comments:

17. Overall Providing Control Information Scale Rating 1 2 3 4 5 6 7 8

Comments:

Technical Knowledge

18. Showing Knowledge of LOAs and SOPs 1 2 3 4 5 6 7 8
    - controlling traffic as depicted in current LOAs and SOPs
    - performing hand-off procedures correctly

Comments: ______________________________

19. Showing Knowledge of Aircraft Capabilities and Limitations 1 2 3 4 5 6 7 8
    - avoiding clearances that are beyond aircraft performance parameters
    - recognizing the need for speed restrictions and wake turbulence separation

Comments: ______________________________

20. Overall Technical Knowledge Scale Rating 1 2 3 4 5 6 7 8

Comments: ______________________________

Communicating

21. Using Proper Phraseology 1 2 3 4 5 6 7 8
    - using words and phrases specified in ATP 7110.65
    - using ATP phraseology that is appropriate for the situation
    - avoiding the use of excessive verbiage

Comments: ______________________________

22. Communicating Clearly and Efficiently 1 2 3 4 5 6 7 8
    - speaking at the proper volume and rate for pilots to understand
    - speaking fluently while scanning or performing other tasks
    - clearance delivery is complete, correct and timely
    - providing complete information in each clearance

Comments: ______________________________

23. Listening for Pilot Readbacks and Requests 1 2 3 4 5 6 7 8
    - correcting pilot readback errors
    - processing requests correctly in a timely manner

Comments: ______________________________

24. Overall Communicating Scale Rating 1 2 3 4 5 6 7 8

Comments: ______________________________

Instructions for questions 25-35

The following questions have as scale ranging from 1 to 10. Where 1 represents “extremely low,” “extremely infrequent,” “strongly disagree”, etc. and 10 represents the other extreme of the spectrum.

These questions are the same as we have asked the controller after the scenario. We would like you to give us your impression of how these questions will be rated by the controller.

25. Please circle the number that best describes the controller’s **preference for vertical separation**	no vertical separation	1	2	3	4	5	6	7	8	9	10	always vertical separation

Comments:

26. Please circle the number that best describes the controller’s **preference for separation through “vectoring”**	no vector separation	1	2	3	4	5	6	7	8	9	10	always vector separation

Comments:

27. Please circle the number that best describes the controller’s **preference for speed control**	no speed control	1	2	3	4	5	6	7	8	9	10	always speed control

Comments:

28. Please circle the number below that best describes **how hard the controller was working** during this scenario.	not hard	1	2	3	4	5	6	7	8	9	10	extremely hard

Comments:

29. Please circle the number that best describes **how well the controller controlled traffic** during this scenario	extremely poor	1	2	3	4	5	6	7	8	9	10	extremely well

Comments:

NASA TLX

30. Please circle the number that best describes the **mental demand** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
31. Please circle the number that best describes the **physical demand** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
32. Please circle the number that best describes the **temporal demand** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
33. Please circle the number that best describes the overall **performance** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
34. Please circle the number that best describes the **effort** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

35.	Please circle the number that best describes the level of **frustration** during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

Appendix E

Performance Variable

Table E-1. Performance Variables

Performance Data	**Units**
Conflicts:	
1. No. Conflicts	
2. Dur. Conflicts	seconds
3. No. Standard Conflicts	
4. Standard Conflicts API (Aircraft Proximity Index)	
5. Mean Standard Conflicts API	
6. Dur. Standard Conflicts	seconds
7. No. Longitudinal Conflicts	
8. No. Longitudinal Conflicts API	
9. Mean Longitudinal Conflicts API	
10. Closest-Point-of-Approach	feet
Complexity:	
11. Cumulative Average System Activity	
12. Altitude Changes	
13. Heading Changes	
14. No. Speed Changes	
Error:	
15. No. hand-offs Outside Boundary	
16. No. Turn/Hold Delays	
17. Dur. Turn/Hold Delays	seconds
18. No. Start Point Delays	
19. Dur. Start Point Delays	seconds
Communications:	
20. No. Ground-to-Air Contacts	
21. Dur. Ground-To-Air Contacts	seconds
22. No. ATCS Messages	
23. No. Pilot Message Key Strokes	
Task load:	
24. No. Aircraft Handled	
25. Dur. Aircraft Time Under Control	seconds
26. Distance Flown	miles
27. No. Completed Flights	
28. No. Departure Altitude Not Attained	
29. No. Arrival Altitude Not Attained	
30. No. hand-offs Accepted	
31. Hand-off Accept Delay Time	seconds

Appendix F

Visual Scanning Variables

Target

Targets are objects, either stationary of moving that can be looked at by an ATCS (Table F-1)

Table F-1. Visual Scanning Targets

Targets	ID needed
Stationary	√
Radar Returns	√
Data Blocks	√
Keyboard	
Track Ball	
Flight Strips	√
ATWIT Panel	

When an ID is needed that will mean that the total number of targets includes each of the targets within a category. Stationary targets are ATCoach fixes like the VORs, ILS lines, flight table, etc.

Fixation

A fixation is a sequence of at least 6 oculometer samples with an intersample distance of less than 1 degree of visual angle. At 1 meter distance this corresponds to a circle with a 8.73 mm radius. The distance between two samples is the norm of the vectorial difference of the sample coordinates. If 2 fixations are not separated by either a blink or a saccade (see definitions below), these fixations should be combined within one fixation. In summary:

Fixation if:

$$D = \sqrt{((x_i - x_{i+1})^2 + (y_i - y_{i+1})^2)} \quad > 8.73 \text{ mm}$$

with D the distance between to subsequent samples x and y the horizontal and vertical point of gaze coordinates in mm respectively

and:

$n > 6$ with n the number of samples in a sequence

and

separated by a blink or a saccade

Related to a fixation the following variables need to be calculated: Fixation Duration and Fixation Area. Fixation Area is an approximation of the area covered by the POG due to eye movements within a fixation.

Fixation Duration:

FIXDUR = $t_{sample} * \Sigma samples$

with t_{sample} where the duration of a sample ($^1/_{60}$ second) and Σsample is the total number of samples within a fixation

Fixation Area:

FIXAREA = $(\max(x_{fix})-\min(x_{fix}))*(\max(y_{fix})-\min(y_{fix}))$

with x_{fix} and y_{fix} the sequences of horizontal and vertical POG coordinates within a fixation respectively

Blink

A blink is the complete or partial closure of the eye. The oculometer will suggest that the velocity at the start and end of a blink was greater than 700 degrees per second which corresponds with 6.108 $^m/_s$. This is physically impossible, but it does give us a way to determine start and end of a blink. A blink starts after the last sample of the previous fixation and stops before the first sample of the next fixation. In summary:

Blink if:

VEL = $\sqrt{((x_i-x_{i+1})^2 + (y_i-y_{i+1})^2)} / t_{sample} > 6.108\ ^m/_s$

with VEL being the a crude estimate of the tangential velocity and x and y the horizontal and vertical point of gaze coordinates in mm respectively. The index denotes the current sample i and next sample i+1 respectively

and:

$n > 12$ with n the number of samples in a sequence

Related to a blink the following variables need to be calculated: Fixation Duration and Blink Distance. Blink Distance is the distance covered by the POG due to eye movements during a blink.

Blink Duration:

BLNKDUR = $t_{sample} * \Sigma samples$

with t_{sample} where the duration of a sample ($^1/_{60}$ second) and Σsample is the total number of samples within a blink

Blink Distance:

BLNKDST = $(x_n-x_p)*(y_n-y_p)$

with x and y the horizontal and vertical point of gaze coordinates in mm respectively. The index denotes the last sample of the previous fixation p and first sample of the next fixation n respectively

Saccade

A saccade is the ballistic movement of the eye from one fixation to the next. A saccade is characterized by fast eye movements of up to 700 degrees per second. The cut-off for a saccade is a difference in distance between two subsequent saccades that is greater or equal to 8.73 mm, lasts at least 3 samples (or a velocity of 0.524 $^{m}/_{s}$), and the velocity is less or equal to 700 degrees per second (6.108 $^{m}/_{s}$). The saccade will start at the end of the last sample of the previous fixation and will end at the beginning of the first sample of the next fixation. In summary:

$$0.524 > VEL > 6.108\ ^{m}/_{s}$$

and:

$$n > 2$$

Related to saccades a number of variables need to be calculated: Saccade Duration, Saccade Distance, and Saccade Velocity. The saccade distance is the angular distance traveled during a saccade in degrees. The saccade velocity is the average velocity within a saccade in degrees per second.

Saccade Duration:

$$SACDUR = t_{sample} * \Sigma samples$$

with t_{sample} where the duration of a sample ($^{1}/_{60}$ second) and Σsample is the total number of samples within a saccade

Saccade Distance:

$$SACDST = (x_n - x_p)*(y_n - y_p)$$

with x and y the horizontal and vertical point of gaze coordinates in mm respectively. The index denotes the last sample of the previous fixation p and first sample of the next fixation n respectively

Saccade Velocity:

$$SACVEL = \Sigma\ (\sqrt{((x_i - x_{i+1})^2 + (y_i - y_{i+1})^2)})\ /\ t_{sample} * n_{saccade}$$

with t_{sample} where the duration of a sample ($^{1}/_{60}$ second) and $n_{saccade}$ is the number of samples within the saccade

Dwell

A dwell is defined as a sequence of fixations that return to a location within 1 degree of visual from a target location or within 1 degree of visual angle if the POG does not rest on a target. This way included in a dwell are also moving targets.

Related to dwells a number of variables need to be calculated: Dwell Duration and Dwell Area. Dwell Duration is the duration between the start of the first sample of the first fixation and the end of the last sample of the last fixation within a dwell sequence. Dwell Area is an approximation of the area covered by the POG within a dwell.

Dwell Duration:

$$DDUR = t_{n,fix\ m} - t_{1,fix\ 1}$$

with $t_{1,fix\ 1}$ is the start of the first sample of the first fixation and $t_{n,\mathrm{fix}\ m}$ is the end (sample n) of the last fixation (fixation m).

Dwell Area:

$$\mathrm{DAREA} = (\max(x_{fix})-\min(x_{fix}))*(\max(y_{fix})-\min(y_{fix}))$$

with x_{fix} and y_{fix} the sequences of horizontal and vertical POG coordinates within a dwell respectively

Visual Efficiency

Visual efficiency is defined as the proportion of the total scanning time that is spent fixating.

Visual Efficiency:

$$\mathrm{VISEFF} = (\mathrm{mean}(\mathrm{FIXDUR}) * N_{fix}) / (\mathrm{mean}(\mathrm{FIXDUR}) * N_{fix} + \mathrm{mean}(\mathrm{SACDUR}) * N_{sac})$$

In fact, this is nothing more than the portion of the time that the eye is fixed once the blinks are removed:

Visual Efficiency:

$$\mathrm{VISEFF} = \Sigma\mathrm{FIXDUR} / (\Sigma\mathrm{FIXDUR} + \Sigma\mathrm{SACDUR})$$

with ΣFIXDUR the sum of the duration of the fixations, ΣSACDUR the sum of the duration of the saccades and TIME the total time in seconds.

Eye Motion Workload

Eye Motion Workload is defined as the average saccade motion in degrees by the number of saccades, or:

Eye Motion Workload:

$$\mathrm{EYEMWL} = \mathrm{mean}(\mathrm{SACDST}) * N_{sac} / \mathrm{TIME}$$

with N_{sac} the number of saccades within the interval under study and TIME the total time in seconds.

In fact, this is nothing more than the total distance traveled divided by the total the time:

Eye Motion Workload:

$$\mathrm{EYEMWL} = \Sigma\mathrm{SACDST} / \mathrm{TIME}$$

with ΣSACDST the sum of the distance of the saccades in degrees and TIME the total time in seconds.

Pupil Motion Workload

Pupil Motion Workload is defined as the sum of the average pupil diameter within a fixation divided by the total time within the interval under consideration.

Pupil Motion Workload

$$\text{PUPMWL} = \Sigma\|\text{mean}(\text{PUPDIAM})_{\text{fix } i} - \text{mean}(\text{PUPDIAM})_{\text{fix } i+1})\| / \text{TIME}$$

with PUPDIAM the pupil diameter in mm based on a conversion from ASL arbitrary units to mm of 0.044 mm per ASL unit. The index fix i and fix i+1 denote the i-th and the i+1th fixation respectively

It seems if the author of the article that this measure was based on was after the "distance" traveled during an interval. I is of course possible to separate the oculometer samples that do not include blinks and then to calculate the cumulative sum of the pupil diameter differences. This may be a more accurate estimate of pupil workload:

Pupil Average Work:

for fixations or saccades:

$$\text{PUPAW} = \Sigma\|\text{PUPDIAM}_i - \text{PUPDIAM}_{i+1}\|$$

with i and i+1 oculometer sample i an i+1 respectively. In this case the oculometer samples that occur during blinks are removed from the timeseries of data.

Conditional Information

The conditional information is defined by Brillouin (1962) as described in Ellis (1986). The formula will here be given without getting too much into the details:

$$\text{CONINF} = \Sigma\, p_i * [\Sigma\, p_{i,j} * \log_2 (p_{i,j})] \text{ with } i \neq j$$

with p_i is simple probability of viewing target i, and $p_{i,j}$ is the probability of a transition from target i to target j. Simple probability was defined by Ellis (1986) as the percentage of time spent on each particular target or jumping between each target. Here we will calculate it not as a percentage of time, but the ratio of the number of times on a target and the total number of fixations and the number of transitions and the total number of saccades for p_i and $p_{i,j}$ respectively.

The current experiment used the selected visual scanning listed in Table F-2

Table F-2. Visual Scanning Variables

Visual Scanning	**Units**
1. Number of Fixations	
2. Mean Duration of Fixations	seconds
3. Mean Fixation Area	inches^2
4. Number of Blinks	
5. Mean Blink Duration	seconds
6. Mean Distance Traveled Within A Blink	inch
7. Mean Duration of Saccades	seconds
8. Mean Distance of Saccades	inch
9. Mean Pupil Diameter	millimeter
10. Mean Duration of Fixations on Radarscope	seconds
11. Mean Duration of Fixations on Keyboard Area	seconds
12. Mean Duration of Fixations on ATWIT Device	seconds
13. Mean Duration of Fixations on Flight Strip Bay	seconds
14. Mean Duration of Fixations on Aircraft	seconds
15. Mean Duration of Fixations on Static Objects	seconds
16. Mean Duration of Fixations on Departure List	seconds
17. Mean Duration of Fixations on System Settings	seconds
18. Mean Duration of Fixations on Preview Area	seconds
19. Mean Duration of Fixations on CA/LA Area	seconds
20. Visual Efficiency	
21. Eye Motion Workload	inch/second
22. Pupil Motion Workload	millimeter/second

Appendix G

Scenarios and Schedule

Table G-1. Overview of Dates and Test Events

Date	Event
May 20 - 24	Pilot Data Collection (2 Ss)
May 27 - June 1	Procedure and Data Screening
June 3 - June 28	Final Data Collection (8 Ss)
July 1 - July 26	Data Analysis
July 29 - August 23	Report Writing

Table G-2. Two Day Timeline for Atlantic City ATCS

Day 1		
Time	Event	Facilities Used
830	Welcome Act's + Entry Questionnaire	Briefing Room
900	Sector Briefing	"
945	Tour Facilities	ER4
1015	Coffee Break	-
1030	Equipment Familiarization Run	ER4/EOS4/Black Room
1100	Break	-
1130	Experimental Run I	ER4/EOS4/Black Room
1230	Lunch	-
1330	Experimental Run II	ER4/EOS4/Black Room
1430	Break	-
1500	Experimental Run III	ER4/EOS4/Black Room
1600	Data Backup	ER4/EOS4

Day 2		
Time	Event	Facilities Used
815	Simulation Review (if necessary)	ER4
830	Experimental Run IV	ER4/EOS4/Black Room
930	Break	-
1000	Experimental Run V	ER4/EOS4/Black Room
1100	Break	-
1130	Experimental Run VI	ER4/EOS4/Black Room
1230	Lunch	-
1330	Experimental Run VII	ER4/EOS4/Black Room
1430	Break	-
1500	Experimental Run VIII	ER4/EOS4/Black Room
1600	Exit Questionnaire	ER4
1630	Data Backup	ER4/EOS4
1700	End	-

Table G-3. Idealized Participant Schedule Broken Down by Days

Month	Date	Day	Participant #
May	20	1	Pilot Participant 1
“	21	2	Pilot Participant 1
“	22	1	Pilot Participant 2
“	23	2	Pilot Participant 2
“	Break to check/redo data/procedures (5/27 is Memorial Day).		
June	3	1	Participant 1
“	4	2	Participant 1
“	5	1	Participant 2
“	6	2	Participant 2
“	Friday - used for post scenario procedures		
“	10	1	Participant 3
“	11	2	Participant 3
“	12	1	Participant 4
“	13	2	Participant 4
“	Friday - used for post scenario procedures		
“	17	1	Participant 5
“	18	2	Participant 5
“	19	1	Participant 6
“	20	2	Participant 6
“	Friday - used for post scenario procedures		
“	24	1	Participant 7
“	25	2	Participant 7
“	26	1	Participant 8
“	27	2	Participant 8

Table G-4. Scenario Number Based on IV Level

Scenario #	Task load	Overflight	Intrusion Type
1	low	yes	IFR, VFR
2	high	yes	IFR, VFR
3	low	no	VFR (2)
4	high	no	VFR (2)
5	low	yes	IFR (2)
6	high	yes	IFR (2)
7	low	no	Baseline
8	high	no	Baseline

Researchers counterbalanced the presentation order of the scenarios (Table G-5).

Table G-5. Counterbalancing Scheme for 12 ATCSs

Week	ATCS #	Scenarios for Day 1	Scenarios for Day 2
1	1	0 1 2 3 4	5 6 7 8
1	2	0 2 3 4 5	6 7 8 1
3	3	0 3 4 5 6	7 8 1 2
3	4	0 4 5 6 7	8 1 2 3
4	5	0 5 6 7 8	1 2 3 4
4	6	0 6 7 8 1	2 3 4 5
5	7	0 7 8 1 2	3 4 5 6
5	8	0 8 1 2 3	4 5 6 7
6	9	0 1 2 3 4	5 6 7 8
6	10	0 2 3 4 5	6 7 8 1
7	11	0 3 4 5 6	7 8 1 2
7	12	0 4 5 6 7	8 1 2 3

Appendix H

Integrated Eye Movement and Simulator Data File Format

The text below is a small portion (less than one second) of a data file that integrates the data recorded by the simulator data with the eye movement data. The eye movement related information is extracted from point of gaze information. The point of gaze information is collected at a rate of 60 samples per second.

```
08:20:49.75498  B:  18   -0.415   -7.230    2.440   -1.850    8.0528    0.3000

08:20:49.77164  S:   2   -7.230   -7.310   -1.850   -2.210    0.3688    0.0167     22.13

08:20:49.85498  0:   6   -7.435   -7.310   -2.595   -2.195    0.0500    0.0833

   D:  USA454          165  165  883  883  1.427    6/6

              D: DAL79          424  424  652  652  1.963    6/6

              D: DAL918          360  360  578  578  2.138    6/6
```

The first line is an example of the format for information related to eye blinks:

- the start time of the observation (08:20:49.75498),
- the type of observation (B:, or a blink),
- the number of point of gaze samples (18),
- start (horizontal :-0.415, vertical: -7.230 inches) and
- end (horizontal: 2.440, vertical: -1.850 inches) radarscope coordinates,
- the distance traveled (8.0528 inches),
- and the duration (0.3000 seconds)

The second line is an example of the format for information related to saccades:

- the start time of the observation (08:20:49.77164),
- the type of observation (S:, or a saccade),
- the number of point of gaze samples (2),
- start and end horizontal coordinates: -7.230   -7.310   and
- start and end vertical coordinates: -1.850   -2.210,
- the distance traveled (0.3688 inches),
- the duration (0.0167 seconds),
- the average velocity (22.13 inches per second)

The third and following lines form an example of the format for information related to fixations:
On the third line:

- the start time of the observation (08:20:49.85498),
- the type of observation (0:, 1:, 2:, 3:, 4:, fixations on scene planes 0-4),
- the number of point of gaze samples (6),

- start and end horizontal coordinates: -7.435   -7.310 and
- start and end vertical coordinates: - -2.595   -2.195,
- the area covered traveled (0.0500 square inches),
- the duration (0.0833 seconds),

The line following the general fixation information displays the object that was closest to the center of the fixation, in this case, USA454. The following indented lines present a list of objects that are within a radius of 2 inches away from the center of the fixation. The format is as follows:

- the type of observation (D:, S: Dynamic or Static Objects),
- start and end horizontal coordinates: 165 165 in pixels and
- start and end vertical coordinates: 883 883 in pixels,
- the distance traveled (1.963 inches),
- the number of samples the object was within the fixation radius (6 out of 6 fixation samples)

Appendix I
Snapshots of Fixation Distributions and Simulator Images and Data

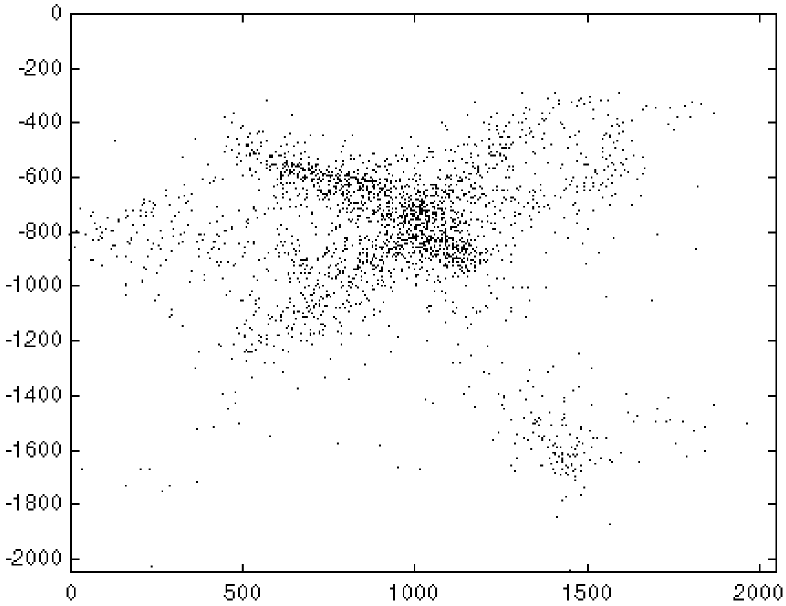

Figure I-1. Fixation Distribution during a 45 minute simulation of a low task load scenario without visual noise. The units for horizontal and vertical coordinates are in pixels. The top left corner corresponds with the top left corner of the radar scope.

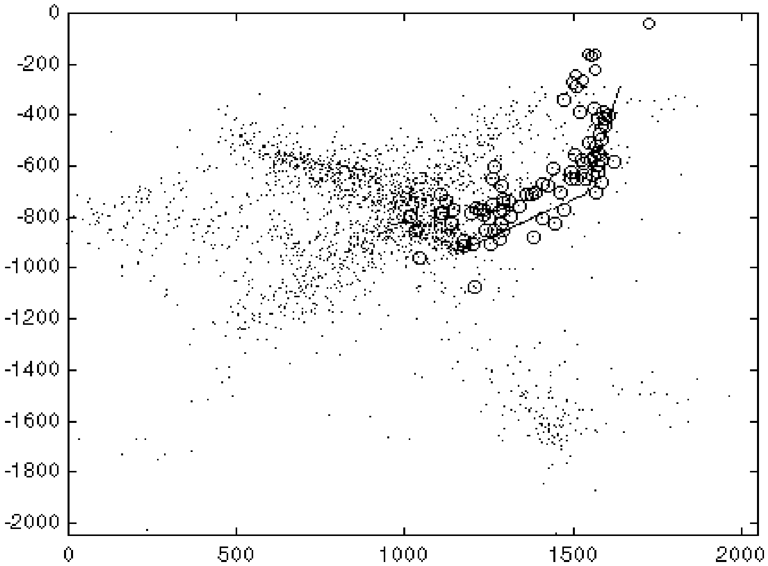

Figure I-2. Fixation Distribution during a 45 minute simulation of low task load scenario without visual noise. The flight path of a departure, BTA3721 is superimposed. The circles represent fixations that were identified as fixation on flight BTA3721. The units for horizontal and vertical coordinates are in pixels.

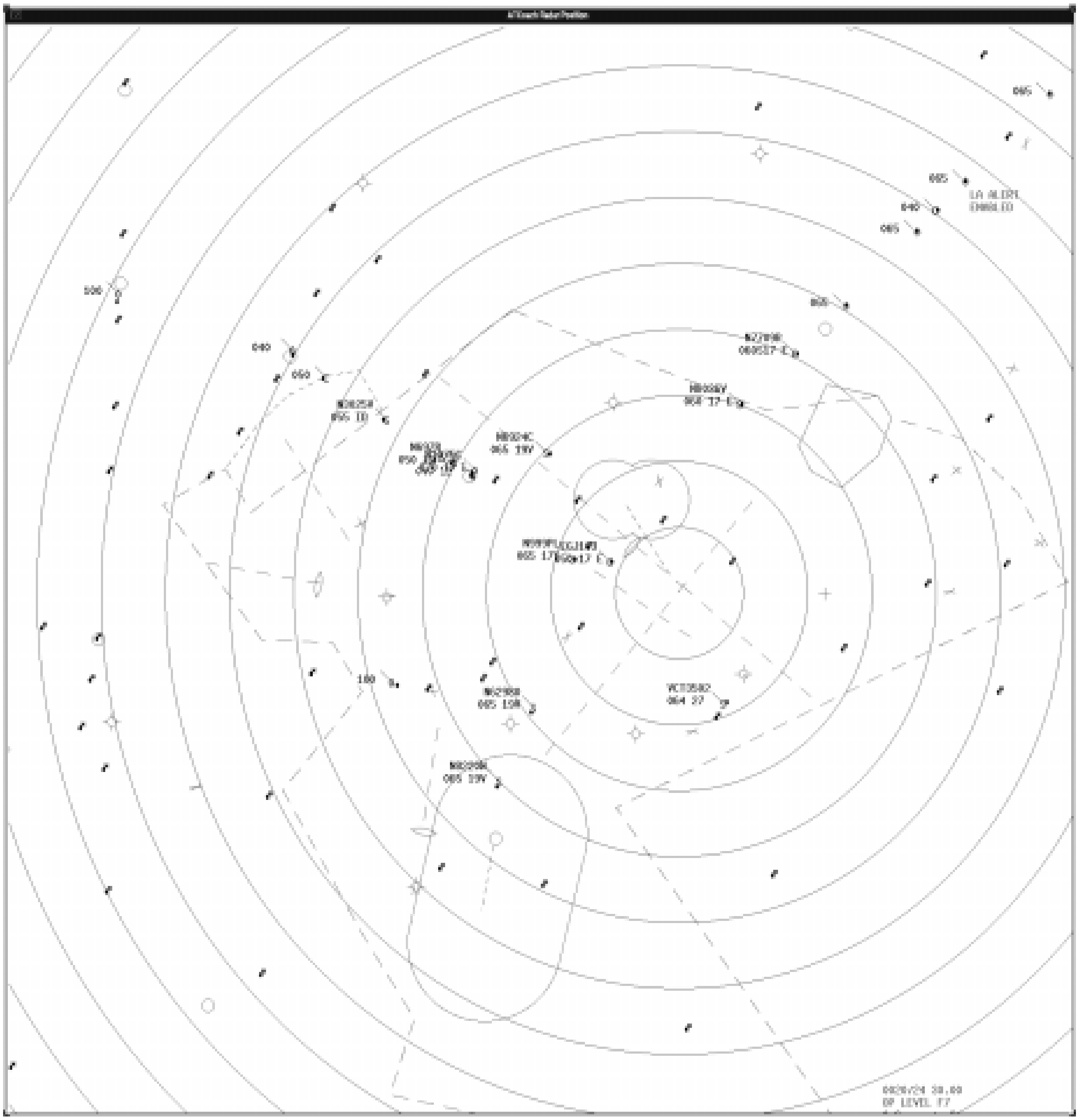

Figure I-3. Simulator Image of a High Task Load Scenario with Visual Noise Present. Range Rings were set to 5 miles.

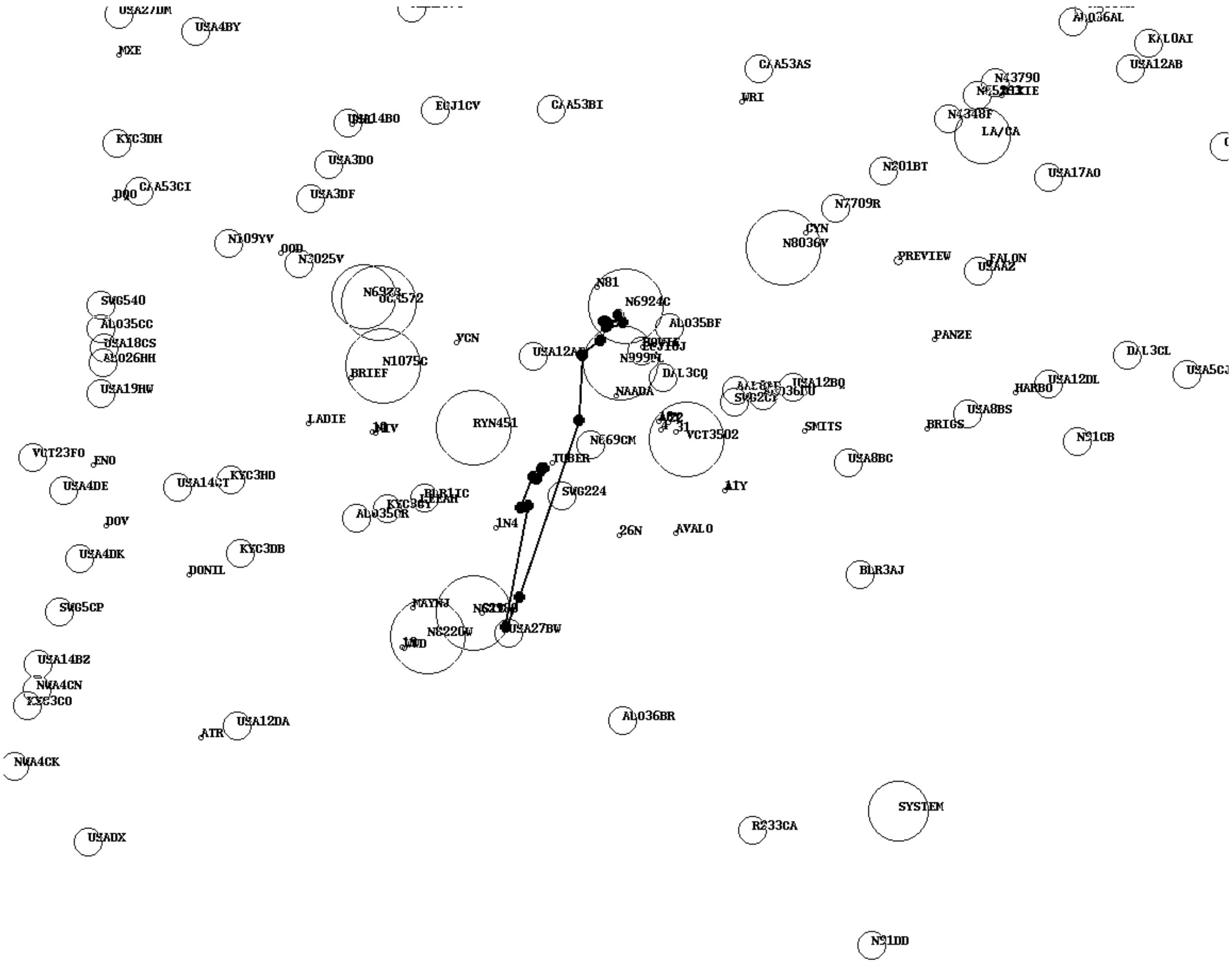

Figure I-4. Simulator data on radar scope object location and size, integrated with point of gaze information. Small open circles represent static objects, medium open circles represent aircraft not under control, large open circles represent aircraft under control, and solid small circles represent point of gaze data at approximately 15 points per second.

Appendix J

Statistical Background

This section provides the reader with background information on the statistical methods used in this report. These statistical methods are powerful tools that allow researchers to determine the most probable outcomes of an experiment based on limited sample sizes. The following paragraphs explain general concepts in statistics, the methods utilized in this study, and some important considerations to use them effectively.

The purpose of any statistical experiment is to determine the effect of certain factors on one or more outcome variables (**dependent variable or DV**). An example of a DV is the number of altitude changes an ATCS makes. This DV could be affected by the type of airspace (terminal, en route, or oceanic), the number of aircraft flying through or to the sector, or many other factors. The manipulated factors of an experiment are the **IVs** (or **IV**s). Each manipulation of an IV (e.g., 25 planes or 45 planes) forms a separate experimental **condition**. Each trial under a particular condition is termed an **observation**.

Experiments can include one or more IVs. When an experiment includes more than one IV, multiple IVs can affect the outcome differently. This is called an **interaction**. It would be impossible to study the effects of type of airspace and number of aircraft independently. When such interactions between IVs occur, the researcher will study the effect by holding one variable constant while varying the others. This is called testing for **simple effects.** In this way, the researcher obtains a picture of how the variables interact by examining the outcome of each manipulation. When researchers study the effect of each IV separately (no interactions), it is termed an analysis of **main effects**. Main effects can only be studied in the absence of interactions.

The number of values for the IVs included in an experiment depends on several practical considerations. For example, if a researcher is studying the decision-making patterns of controllers as a function of type of airspace, the values of the IV, type of airspace (tower, TRACON, enroute), are clear. In other cases the answer would depend upon what type of outcome the researchers needed from the results of the experiment as well as some practical considerations. Different values of IVs, termed **levels**, can increase the number of experimental conditions and thus increase the resources needed to complete the experiment. One can certainly imagine the complexity and length of an experiment in which controllers with experience ranging from 1 to 50 years creating 50 incremental levels were studied. It would be far simpler and easier to study the effect of controller experience by using only three categories: Developmental, Full Performance Level (FPL), and Supervisor.

What is the number of observations required for each test condition? Increasing the number of observations increases the statistical power of the experiment. Increased statistical power means that an increased probability exists that the outcome of an experiment will likely be true for the entire population. However, increasing the number of observations comes at the expense of greater numbers of participants, more time, or both. An efficient experimental design should include enough observations for reasonable statistical power without including unnecessary observations that could dramatically increase demands for resources unless there was an increased need for power.

With insight into statistical terminology as well as some background into considerations involved in experimental design, it is now useful to look into several different categories of experiments and statistical methods used to determine significant outcomes. For simplicity, each of the following categories involve only a single IV (the experience level of controllers). In increasing level of complexity, three categories of experiments will be examined:

1. Observations on a single DV under two conditions (T-test)
2. Observations on a single DV under multiple conditions (ANOVA)
3. Observations on multiple DV under multiple conditions (MANOVA)

Each of these categories is discussed below.

Observations on a Single Variable Under Two Conditions

When a researcher wants to compare two conditions, the average of multiple observations on a single variable are taken under two conditions, and the experimenter performs a **T-test**. However, an average value can often be misleading. Within a group of such observations, some differences will exist in the individual observations that contributed to the average. Some Developmental controllers may be faster learners than others and will use less altitude changes in order to control traffic. The average number of altitude changes for all Developmental controllers can include a wide range of values. The differences between the individual times and the mean number of times represents the **variability** of the data. As the variability in the data increases, the mean value is less useful to the researcher because many of the individual values are far from the mean. Figure J-1 illustrates the variability of data.

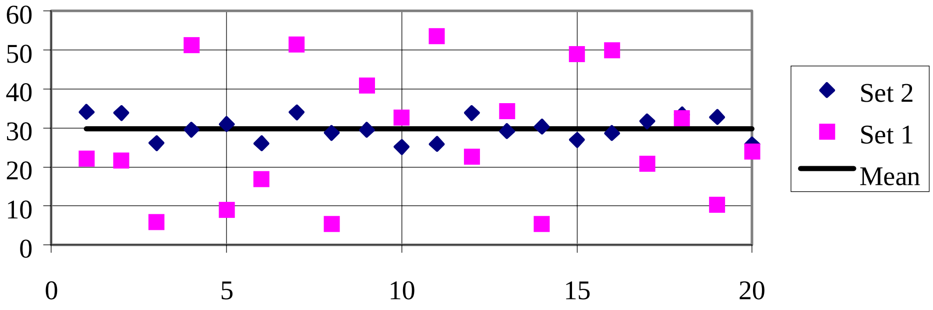

Figure J-1. Two sets of observations with the same means, but very different values.

If a researcher wants to compare two samples, the comparison not only involves comparing the averages but also the variability within the observations. For this reason, the true mean (the mean a researcher would calculate if he/she sampled the number of altitude changes for all Developmental controllers in the world) differs from the sample mean. A researcher must ask if the difference in the means of these two sets of observations is a true difference or caused by chance. This is where **probability** theory aids the researcher. Statistics can help the researcher determine the probability that the two means for the entire population (all controllers) are different from the sample (limited number of controllers). The statistical test used in this case is the **t-test**. The t-test compares two averages and checks if the two averages are different due to chance alone. It is important to recognize that the t-test never gives the researcher 100% assurance that the two means actually differ. It is common practice at accept a 95% assurance (or, in other words, a 5% risk) as sufficient guarantee.

SUMMARY OF A T-TEST: An experiment includes multiple observations on a single variable under two conditions. The average values (means) of the two conditions takes variability into consideration. The analyses determines the probability that the means differ due to chance alone.

Example: When one compares the number of altitude changes between Developmental and FPL controllers at a local center, the comparison involves multiple observations. The multiple observations consist of the number of altitude changes of each individual within the experience level. The variable is the number of altitude changes. The conditions include the two levels of experience. Figure J-2 is a graphical display of this example. Although it shows a difference in number of altitude changes between the two groups, some individual observations overlap. A t-test examines if this difference was caused by chance.

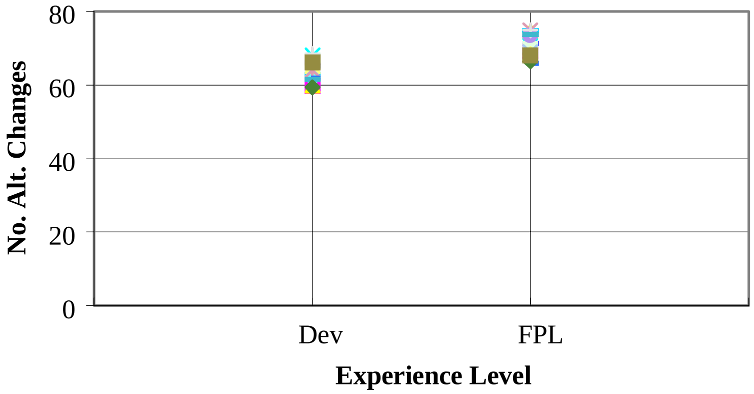

Figure J-2. Multiple observations of altitude changes as a function of experience level.

Observations on a Single Variable Under Multiple Conditions

Where the t-test compared the averages between two conditions, the **analysis of variance** (ANOVA) compares averages of a single variable between multiple conditions (i.e., the number of altitude changes including Developmental, FPL, and Supervisors). An ANOVA tests if these averages are different due to chance alone. The basic test results in an **F value** for a single DV (the number of altitude changes). The value of F ranges from 0 to infinity (∞). A large F value may indicate that the IV (experience level) has a powerful effect on the DV (number of altitude changes) with less likelihood that differences between means occurred by chance. The strength of association (e.g., η) or percent of variance explained is an indication of the difference in the strength of effects between conditions. A difference between means is **significant** if there is a very high probability that the means are actually different (usually greater than 95%). Sometimes, there is a significant difference where the F value is relatively low. This indicates that the IV does not have a very strong effect.

An ANOVA can show that there is a difference in means not caused by chance alone. If the ANOVA indicated that the number of altitude changes varies with experience level, are the mean number of altitude changes for Developmental controllers different than FPL controllers? The mean for Developmental controllers differs significantly from those of FPL but not significantly from those for Supervisors. Therefore, another test needs to compliment the ANOVA. This test is called a **post hoc comparison**. Researchers will use post hoc comparisons to determine which of the pairs of means differ significantly.

<u>SUMMARY OF AN ANOVA:</u> The ANOVA compares averages of a single DV between multiple conditions and tests if these averages are different due to chance alone. The test results in an F value. A large F value indicates less likelihood and a small value indicates increased likelihood that differences between means occurred by chance. A difference between means is **significant** if there is a very high probability that the means are actually different. A post hoc comparison determines which means differ.

Example: When a researcher compares the number of altitude changes between Developmental, FPL, and Supervisors at a local ARTCC, the comparison involves multiple observations. The multiple observations are the number of altitude changes of each individual within each group. The variable is the number of altitude changes. The conditions are the three experience levels. Figure J-3 displays the data related to this example. Some differences in number of altitude changes exist between experience levels, but there is overlap between observations in each experience level. An ANOVA would determine if these differences are due to chance alone. If the ANOVA indicated that there is some difference in experience levels regarding number of altitude changes, post hoc comparisons would indicate which means associated with which experience levels differ.

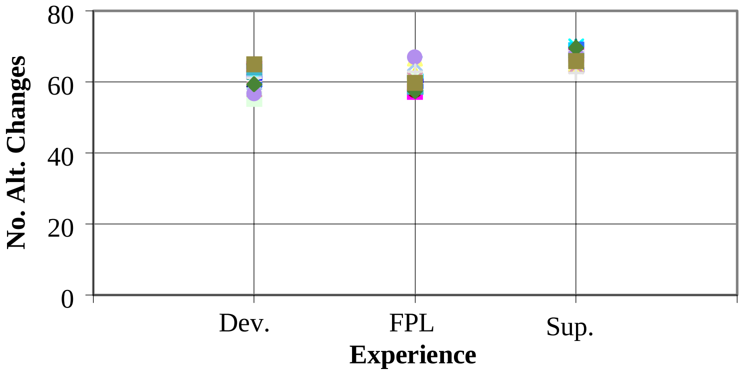

Figure J-3. Multiple observations of altitude changes as a function of experience level.

Observations on a Multiple Variable Under Multiple Conditions

Where an ANOVA compares averages between multiple conditions for a single variable (a **univariate** test), the **multivariate ANOVA** (MANOVA) compares averages for several DVs simultaneously and tests if these averages are different due to chance alone. Suppose that researchers wanted to examine number of altitude changes **and** the number of heading changes. Also suppose that the researchers wanted to test both of these measures as a function of experience level. This presents a case of multiple DVs (number of altitude changes and number of heading changes) and multiple conditions (Developmental, FPL and Supervisor). The experimenters focus on how experience level affects the **set** of variables(number of altitude changes **and** number of heading changes). A researcher would not do two ANOVAs for each of the DVs (number of altitude changes **and** number of heading changes) because misleading outcomes result from multiple ANOVAs. A MANOVA is more appropriate.

The basic MANOVA test results in a value called **Wilk's Lambda** (Λ) that includes the effects of more than one DV (both number of altitude changes and number of heading changes). The value of Wilk's Lambda ranges from zero to one. The lower the value of Λ, the more powerful the effect of the IV (experience level) on the set of DVs and the less likely it is that the differences between means occurred by chance. Sometimes, there is a significant difference where Λ is relatively high. This indicates that the effect is not that strong.

After a significant result of a MANOVA test, researchers then conduct ANOVA tests (one for number of altitude changes and one for number of heading changes. Figure J-4 depicts an example of the steps taken during a MANOVA. The example shown in Figure J-4 includes two DVs.

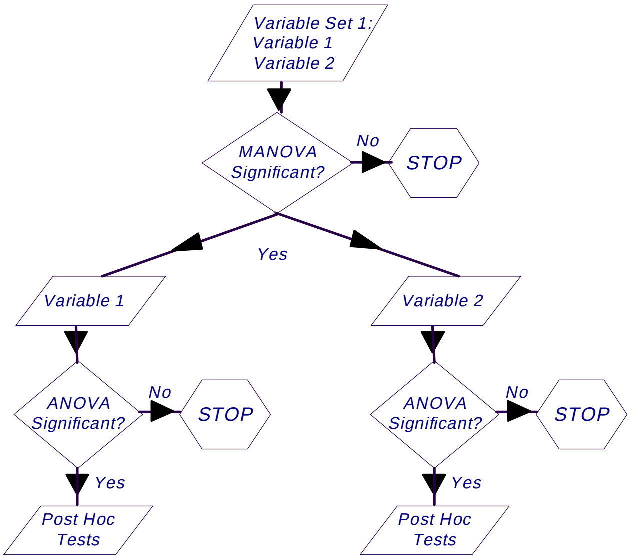

Figure J-4. Example of the steps in a MANOVA.

SUMMARY OF A MANOVA: The MANOVA compares averages for several variables simultaneously and tests if these averages are different due to chance alone. The basic MANOVA results in a value called Λ that includes the effects of more than one DV. The lower the value of Λ, the more powerful the effect of the IV on the set of DVs and the less likely it is that the differences between means occurred by chance. After a significant result of a MANOVA, which indicates that at least two means are statistically different for the system, researchers then conduct ANOVAs.

Example: When one compares the number of altitude changes and number of heading changes between Developmental, FPL and Supervisor at a local center, the comparison involves multiple observations of two variables. The multiple observations are the number of altitude changes and number of heading changes of each individual within the each experience level. The DVs are the number of altitude changes and the number of heading changes. The conditions are formed by the three experience levels. Figure J-5 displays the data for this example. Without looking at the individual variables, one can see that the three experience levels differ. A MANOVA would determine if chance alone caused these differences. If the differences are beyond chance (or significant in statistical terms), ANOVAs on the individual variables are conducted.

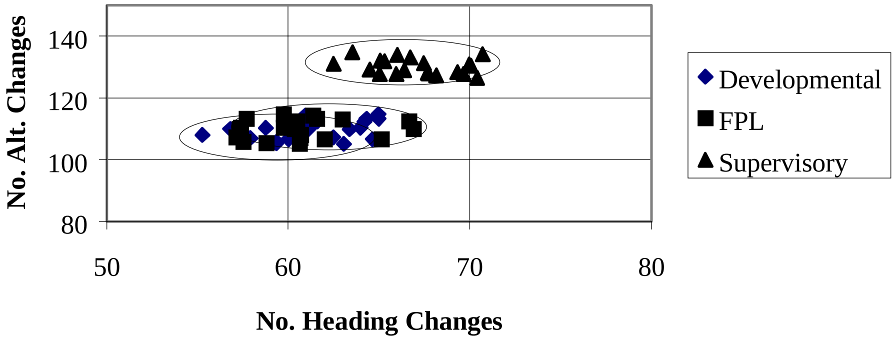

Figure J-5. Multiple observations of number of altitude changes and number of heading changes as a function of experience level.

Summary

The preceding paragraphs give some insight into the statistical methods used by researchers. Statistical methods are very powerful tools for the researcher. They tell the researcher if the experimental conditions affect the dependent measures tested. The type of statistical test that the researcher uses varies with the type of experiment. A good researcher will design experiments so they can use these techniques to the fullest extent.

Appendix K

Descriptive Statistics

Post Scenario Questionnaires

After each scenario, the ATCSs rated several scenario-related items. The Post-Scenario Questionnaire also included the six NASA TLX ratings. There were 12 participants and 8 simulation scenarios or a total of 96 observations. Equipment failure during the simulations caused the loss of one observation. The total number of observations used in the analyses was therefore 95.

Post-Scenario Questions

The scenarios were moderately realistic with a mean of 6.6 and moderately representative of an average day at the Atlantic City TRACON with a mean of 6.0. The ATWIT device hardly interfered with controlling traffic as indicated by a mean rating of interference of 1.6. The oculometer interfered more with controlling traffic but still only moderately with a mean rating of 2.9. ATCSs rated the simulation pilots' responses of very good quality at an 8.9 level. On average, the ATCSs worked moderately hard with a mean of 5.1. The self-rated quality of control was good at 7.6. The overall SA, for current aircraft location, projected aircraft location, and potential violations were good with means of 7.8, 7.8, 7.7, and 7.8, respectively. The scenarios were moderately difficult with a mean of 5.2 (Table K-1).

Table K-1. Post-Scenario Questions (n=95)

Variable Label	Mean	SD
Realism	6.59	1.89
Representative	6.02	1.92
ATWIT Interference	1.62	1.48
Oculometer Interference	2.93	2.09
Sim. Pilot Response	8.87	1.26
Working Hard	5.12	2.70
Quality of Control	7.57	1.60
Overall SA	7.75	1.66
Current Act. location SA	7.75	1.76
Projected Act. location SA	7.74	1.75
Potential Violations SA	7.81	1.65
Scenario Difficulty	5.19	2.74

Post-Scenario TLX

The TLX scores (Table K-2) revealed that the performance and effort ratings were high with means of 7.6 and 7.3, respectively. The level of frustration was relatively low. Mental, physical, and temporal demand were moderate with means of 5.6, 4.1, and 4.6, respectively.

Table K-2. Post Scenario TLX (n=95)

Variable Label	Mean	SD
Mental Demand	5.64	2.70
Physical Demand	4.08	2.61
Temporal Demand	4.63	2.40
Performance	7.56	1.51
Effort	7.31	2.12
Frustration	3.85	2.72

The workload levels found from the ATWIT ratings correlated with the workload levels found by the TLX items in the Post-Scenario Questionnaire (Table K-3). Especially the mental demand item correlated well with the mean ATWIT rating.

Table K-3. Correlations Between Mean and Maximum ATWIT Ratings and Post-Scenario TLX Items

	ARMean	ARMax
Mental Demand	.71	.50
Physical Demand	.46	.43
Temporal Demand	.57	.39
Performance	-.20	-.22
Effort	.34	.17
Frustration	.53	.35

Over-the-Shoulder Rating Forms

An ATC SME conducted an OTS rating. The items on the checklist are similar to the ones used in other studies except for five items that are replications of items on the Post-Scenario Questionnaires and the six TLX ratings. The scale on the comparison and TLX items is 1-10. The other items have a scale from 1-8. The dichotomy in scaling will ease the comparison of results with previous studies and the responses of the participants.

Over-the-Shoulder Ratings

The OTS rater rated overall performance of the ATCS participants moderately good at 6.2. Overall traffic flow efficiency was very good at 7.5. Overall Attention and SA were good at 7.0. Overall prioritizing skills were very good at 7.5. Providing air traffic control information was very good as well at 7.5. The overall technical knowledge of the ATCS participants was excellent at 8.0. The communication skills of the participants were good at 7.0. Table K-4 presents a more detailed breakdown of the OTS ratings.

Over-the-Shoulder ratings of selected Post Scenario questions

To investigate if an OTSR can observe control strategy preferences of the ATCSs, the researchers replicated five questions from the Entry Questionnaire to the OTS rating form. Table K-5 presents the means and standard deviations of these questions. The OTSR perceived the ATCSs to have a preference for vertical separation and vectoring and much less for speed control. The

OTSR rated the work level to be moderate at 5.8. The ATCSs' performance was very good at 8.7.

Table K-4. General Over-the-Shoulder Ratings (n=96)

Label	Mean	Std
Overall Performance	6.18	1.12
Maintaining Traffic Flow	7.33	1.11
Sequencing Traffic Flow Efficiently	7.41	1.09
Efficient Control Instructions	7.48	0.91
Overall Traffic Flow Efficiency	7.38	1.02
SA of Act. Positions	7.18	1.18
Positive Control	7.03	1.47
Detection of Control Instruction Deviation	7.52	1.04
Correcting Own Errors Timely	7.18	1.34
Overall Attention and SA	7.01	1.23
Actions in Order of Importance	7.40	0.96
Preplanning Control Actions	7.48	0.92
Handling Control for Several Aircraft.	7.40	1.00
Flight Strip Marking	7.51	0.92
Overall Prioritizing	7.45	0.87
Providing Essential ATC Info.	7.49	0.85
Providing Additional ATC Info.	7.51	0.86
Overall ATC Info. Rating	7.47	0.85
Knowledge of LOAs and SOPs	7.88	0.36
Knowledge of Act Capabilities	7.97	0.17
Overall Technical Knowledge	7.95	0.27
Proper Phraseology	6.86	0.82
Clear and Efficient Communication	7.19	0.89
Listening for Pilot Readbacks and Request	7.40	0.93
Overall Communication Rating	7.04	0.65

Table K-5. Over-the-Shoulder Ratings of Selected Post-Scenario Questions

Label	N	Mean	Std
Pref. for Vertical Separation	96	8.92	1.29
Pref. for Vectoring	95	8.24	1.60
Pref. for Speed Control	46	3.59	3.12
Working Hard	96	5.80	2.54
Control Performance	96	8.70	1.51

Over-the-Shoulder Ratings of TLX items

The OTSR rated each of the TLX items for each of the simulation runs. On average the mental, physical, and temporal demand were moderate at 6.2, 6.0, and 6.5, respectively. The performance rating on the TLX was very good at 8.7. The TLX effort level was moderate at 6.4. The level of frustration was on average low at 2.8 (Table K-6).

Table K-6. Over-the-Shoulder Ratings of TLX Items (n=95)

Label	Mean	Std
TLX Mental Demand	6.21	2.43
TLX Physical Demand	6.04	2.28
TLX Temporal Demand	6.52	2.35
TLX Performance	8.71	1.31
TLX Effort	6.41	2.35
TLX Frustration	2.79	2.02

Visual Scanning

Several levels of data reduction formed the basis for the results presented here. Fixations, saccades, blinks, and pupil information formed the basis for the visual scanning data set. This data set consisted of the summary variables of 5-minute intervals. This section on descriptive statistics presents the summary statistics across these 5-minute intervals across all conditions. In this experiment, the researchers distinguished three levels of detail in eye movement characteristics. The first level focused on general eye movement characteristics, without making a distinction between objects or groups of objects at which participants looked. The second level focused on scene planes or surfaces on which the ATCSs rested their gaze (radarscope, keyboard area, flight progress strip bay, and ATWIT device).

General Eye Movement Characteristics

The first level of detail included all eye movement characteristics (fixations, saccades, blinks, and pupil). The general visual scanning variables used in the analyses are the mean values of a 5-minute interval (Table K-7). Table K-8 presents the percentage of time spent on fixations, saccades, and blinks. Each 5-minute interval contained approximately 426 fixations. On average, the participants spent 78% of the time in fixations. The average fixation duration was 560 ms. During fixations, small eye movements occurred that resulted in average area coverage of 0.67 square inch (435 mm^2). The participants' eyes moved in saccades approximately 17% of the time. The saccades lasted an average of 120 ms. The mean distance traveled between two fixations was 3.30 inches (77.19 mm). The mean pupil diameter was 5.87 mm. On average, participants blinked 81 times per 5-minute interval. Blinks accounted for 7% of the time. The mean blink duration was 250 ms. During closure of the eyelids, the eye can still travel. The distance traveled within a blink was 9.18 inches (23.32 mm).

Table K-7. General Visual Scanning Variables (n=864)

Variable Label	Mean	SD	Units
Fixation Number	426.00	50.00	
Fixation Mean Duration	560.00	78.00	ms
Fixation Area Mean	0.67	0.12	inch^2
Visual Efficiency	0.82	0.04	
Total Fixation Time	235.00	20.00	second
Saccade Number	431.00	55.00	
Saccade Mean Duration	120.00	19.00	ms
Saccade Mean Distance	3.30	0.59	inch
Eye Motion Workload	4.76	1.09	inch/sec
Total Saccade Time	50.00	10.00	second
Pupil Mean Diameter	5.87	1.07	mm
Pupil Motion Workload	0.05	0.03	mm/sec
Blink Number	81.00	31.00	
Blink Mean Duration	253.00	132.00	ms
Blink Mean Distance	9.18	4.02	inch
Total Blink Time	21.34	15.03	second

Note that the mean 5-minute interval data formed the basis for the calculation of the percentage of time. The total of the percentage spent on fixations, saccades, and blinks therefore does not add to 100 percent due to inherent rounding error (K-8).

Table K-8. Total Fixation, Saccade, and Blink Time (sec.)

Variable Label	Mean	SD	Percent
Total Fixation Time	234.68	20.12	78.23
Total Saccade Time	49.81	10.31	16.60
Total Blink Time	21.34	15.03	7.11

Correlations

Considering the correlations between general eye movement related variables, the number of saccades is not included in the inferential statistical analysis. With a correlation coefficient of 0.99 between the number of saccades and the number of fixations, these two variables represented the same phenomenon. Table K-9 presents the correlations among general eye movement-related variables. What is striking about the table of correlations is the apparent independence of the various measures. Given the integrated nature of vision, it would not have been surprising to see more redundancy in these measures.

Table K-9. Correlations Between General Eye Movement Related Variables

	Saccade Number	Saccade Mean Duration	Saccade Mean Distance	Eye Motion Workload	Blink Number	Blink Mean Duration	Blink Mean Distance	Pupil Number	Pupil Mean Diameter	Pupil Motion Workload	Fixation Number	Fixation Mean Duration	Fixation Area Mean	Visual Efficiency
Saccade Number	1	-0.1	-0.35	0.06	0.47	-0.29	-0.1	0.77	0.19	-0.18	0.99	-0.17	-0.03	-0.13
Saccade Mean Duration		1	0.6	0.48	-0.28	0.19	0.3	-0.21	0.25	0.51	-0.12	-0.4	-0.16	-0.74
Saccade Mean Distance			1	0.76	-0.2	0.17	0.3	-0.42	0.14	0.15	-0.35	-0.34	-0.26	-0.49
Eye Motion Workload				1	-0.08	-0.16	0.19	-0.26	0.2	0	0.02	-0.57	-0.38	-0.66
Blink Number					1	-0.09	-0.11	0.37	-0.11	-0.11	0.48	-0.11	0.13	0.08
Blink Mean Duration						1	0.07	-0.35	-0.15	0.15	-0.28	-0.15	-0.13	-0.22
Blink Mean Distance							1	-0.19	0.14	0.04	-0.08	-0.25	-0.1	-0.3
Pupil Number								1	0.2	-0.18	0.79	0.38	0.31	0.34
Pupil Mean Diameter									1	-0.1	0.18	-0.06	-0.04	-0.13
Pupil Motion Workload										1	-0.16	-0.23	-0.08	-0.34
Fixation Number											1	-0.16	-0.04	-0.1
Fixation Mean Duration												1	0.49	0.81
Fixation Area Mean													1	0.45
Visual Efficiency														1

Scene Plane Fixations

The second level of eye movement data included fixations, broken down by the scene plane on which they rested. Table K-10 and Table K-11 present the scene plane scanning variables and the distribution of total fixation times across scene planes respectively. The participants fixated 58% of the total time or 75% of the fixation time on the radarscope. The mean duration of the radarscope fixations was 620 ms. Participants spent only 0.5% of the total time or 0.6% of the fixation time on fixations on the ATWIT device. The mean ATWIT fixation duration was 610 ms. Fixations on the flight strip bay accounted for 2.2% of the total time or 2.9% of the fixation time. The mean duration of flight strip bay fixations was 320 ms. Participants fixated on the keyboard/mouse Area for 17% of the total time or 21.7% of the fixation time. The mean duration of the keyboard/mouse area fixations was 450 ms.

Table K-10. Scene Plane Visual Scanning Variables (n=864)

Variable Label	Mean	SD	Units
Radarscope Number	290.96	53.13	
Radarscope Mean Duration	620.00	110.00	ms
Radarscope Total Duration	175.46	26.62	seconds
ATWIT Number	2.84	2.75	
ATWIT Mean Duration	610.00	410.00	ms
ATWIT Total Duration	1.49	1.00	seconds
Flight Strips Number	19.03	21.31	
Flight Strips Mean Duration	320.00	130.00	ms
Flight Strips Total Duration	6.74	9.20	seconds
Keyboard/Mouse Number	113.16	42.70	
Keyboard/Mouse Mean Duration	450.00	98.00	ms
Keyboard/Mouse Total Duration	51.00	20.57	seconds

Note that the amount of time spent looking at the ATWIT device was on average 1.5 seconds per 5-minute interval (Table K-11).

Table K-11. Cumulative Fixation Duration for the 4 Scene Planes: Radarscope, ATWIT Panel, Flight Strip Bay, and Keyboard Mouse Area

Variable Label	Mean	SD	Percent Total Time	Percent Fixation Time
Radarscope Total Duration	175.46	26.62	58.48	74.76
ATWIT Total Duration	1.49	1.00	0.50	0.64
Flight Strips Total Duration	6.74	9.20	2.25	2.87
Keyboard/Mouse Total Duration	51.00	20.57	17.00	21.73

The correlations between the number and duration of fixations on different scene planes were low. The highest correlation occurred between the mean duration of fixations on the flight strip bay and the duration of fixations on the keyboard area (*r* =.35). The distribution of the fixations across the scene planes therefore did not seem to follow a fixed pattern.

Radarscope Fixations

The third and most detailed level of analysis focused on object fixations on the Plan View Display. The main information display in air traffic control is the PVD or radarscope. The objects of fixations on the PVD were data blocks, CA/LA, other statics (airports, fixes, VORs, etc.), preview area, system area, and the tablist area. The researchers calculate the mean duration, number of fixations, and the total duration for each of these categories. The researchers also expressed the total duration in percentage of the total time, percentage of the total fixation

time, and percentage of the total fixation time on the radarscope. Table K-12 presents the number and duration of the fixations on radarscope objects. Table K-12 presents the overall mean fixation durations and their standard deviations.

The participants spent on average 92% of their time on the radarscope looking at aircraft data blocks. On average, ATCSs looked at the aircraft representations on the radarscope 251 times in a 5-minute interval, or roughly 50 times-per-minute. The average fixation duration on aircraft representations was 660 ms. The CA/LA area accounted for a negligible small percentage of the fixated time (visited approximately once every 20 minutes). ATCSs looked at CA/LA with average fixation duration of only 30 ms. ATCSs rested their gaze on static objects in 2% of the time fixated on the radarscope. In a 5- minute interval, 8 of the participants' fixations rested on static objects. The average duration of these fixations was 150 ms. Participants fixated on the preview area in 2% of the time of the radarscope fixations. The participants looked at the preview area an average of approximately six times every 5 minutes. The mean duration of the fixations on the preview was on average 150 ms. ATCSs fixated on the system area 2% of the time of the radarscope fixations (visited an average of approximately 9 times). The fixations on the systems area lasted 380 ms. Lastly, ATCSs fixated on the tab list in a negligible small percentage of the time of the radarscope fixations (visited on average of three times per 5 minutes). The fixations on the tab list lasted 160 seconds.

Table K-12. Radarscope Objects

Variable Label	Mean	SD	Units
Data Block Mean Duration	660.00	130.00	Ms
Data Block Number	250.72	59.56	Frequency
Data Block Total Duration	161.07	33.99	Seconds
CA/LA Mean Duration	30.00	110.00	Ms
CA/LA Number	0.23	0.81	Frequency
CA/LA Total Duration	0.07	0.27	Seconds
Other Statics Mean Duration	150.00	170.00	Ms
Other Statics Number	8.34	17.24	Frequency
Other Statics Total Duration	2.86	6.71	Seconds
Preview Mean Duration	400.00	320.00	Ms
Preview Number	5.67	7.22	Frequency
Preview Total Duration	2.69	3.95	Seconds
System Mean Duration	380.00	220.00	Ms
System Number	8.78	8.89	Frequency
System Total Duration	3.92	4.95	Seconds
Tab list Mean Duration	160.00	280.00	Ms
Tab list Number	1.54	3.16	Frequency
Tab list Total Duration	0.64	1.56	Seconds

Table K-13 clearly shows that the most important elements on the radarscope were aircraft. On average, aircraft fixations constituted 92% of the fixation time on the radarscope.

Table K-13. Cumulative Fixation Duration on Objects on the Radarscope

Variable Label	N	Mean	SD	Percent Total Time	Percent Fixation Time	Percent Radarscope Fixation Time
Aircraft Total Duration	864	161.07	33.99	54.00	69.00	92.00
CA/LA Total Duration	864	0.07	0.27	0.00	0.00	0.00
Other Statics Total Duration	864	2.86	6.71	1.00	1.00	2.00
Preview Total Duration	864	2.69	3.95	1.00	1.00	2.00
System Total Duration	864	3.92	4.95	1.00	2.00	2.00
Tab list Total Duration	864	0.64	1.56	0.00	0.00	0.00

ATWIT

Equipment failure caused the loss of data for one simulation scenario. For this simulation, the researchers substituted the overall mean value for the ATWIT variables for each interval. The data set used for the descriptive statistics contained 96 observations. The ATWIT ratings showed a trend as a function of interval number (Table K-14), reflecting the buildup of traffic during the first 10-15 minutes of the scenarios.

Table K-14. ATWIT Ratings as a Function of Simulation Interval (n=96)

	Interval	Low Load		High Load			
		Means	SDs	Means	SDs	Means	SDs
No Noise	1	1.50	1.84	1.67	0.70	1.58	1.38
	2	2.00	2.57	3.67	2.35	2.83	2.58
	3	2.25	2.03	4.83	2.57	3.54	2.63
	4	3.13	2.49	4.67	1.97	3.90	2.35
	5	3.38	2.58	4.38	2.04	3.88	2.36
	6	3.92	2.12	4.79	2.13	4.35	2.15
	7	3.75	2.31	4.92	2.24	4.33	2.33
	8	1.67	1.90	5.21	2.52	3.44	2.84
	9	2.17	3.03	5.50	2.87	3.83	3.37
Noise	1	1.13	0.34	1.42	1.84	1.27	1.32
	2	1.54	0.72	2.63	2.46	2.08	1.88
	3	2.08	1.89	3.79	2.32	2.94	2.26
	4	2.50	1.96	5.50	2.13	4.00	2.53
	5	2.33	1.31	6.67	1.95	4.50	2.74
	6	2.67	1.99	6.71	2.05	4.69	2.86
	7	2.38	2.04	6.33	2.43	4.35	2.99
	8	2.46	1.98	5.38	2.34	3.92	2.60
	9	3.13	2.92	3.67	3.31	3.40	3.10
	1	1.31	1.32	1.54	1.38	1.43	1.35
	2	1.77	1.88	3.15	2.44	2.46	2.28
	3	2.17	1.94	4.31	2.48	3.24	2.46
	4	2.81	2.24	5.08	2.07	3.95	2.43
	5	2.85	2.09	5.52	2.29	4.19	2.56
	6	3.29	2.13	5.75	2.28	4.52	2.52
	7	3.06	2.26	5.63	2.42	4.34	2.66
	8	2.06	1.96	5.29	2.41	3.68	2.72
	9	2.65	2.99	4.58	3.20	3.61	3.23

The ATWIT latencies showed a similar increase at the onset of a scenario, although the effect was not as pronounced as in the ATWIT ratings themselves (Table K-15).

Table K-15. ATWIT Latencies as a Function of Simulation Interval (n=96)

	Interval	Low Load		High Load			
		Means	SDs	Means	SDs	Means	SDs
No Noise	1	3.13	3.99	2.75	1.57	2.94	3.01
	2	4.75	5.30	3.79	5.30	4.27	5.27
	3	3.33	4.21	5.13	6.47	4.23	5.47
	4	6.13	5.97	4.42	4.78	5.27	5.42
	5	5.00	6.07	2.88	4.18	3.94	5.27
	6	3.83	4.40	3.38	4.27	3.60	4.30
	7	4.79	5.73	2.83	3.71	3.81	4.88
	8	4.29	5.24	4.46	5.08	4.38	5.11
	9	5.50	6.84	6.29	7.09	5.90	6.90
Noise	1	2.54	1.53	2.96	3.94	2.75	2.96
	2	2.67	2.35	4.29	5.47	3.48	4.25
	3	4.54	4.42	5.42	6.37	4.98	5.44
	4	4.88	4.55	4.54	6.20	4.71	5.38
	5	4.96	5.09	4.21	5.21	4.58	5.11
	6	4.46	4.94	4.88	5.71	4.67	5.29
	7	4.13	4.32	3.50	5.34	3.81	4.81
	8	4.92	4.76	3.13	4.18	4.02	4.53
	9	5.42	6.32	6.33	6.98	5.88	6.60
	1	2.83	3.01	2.85	2.97	2.84	5.17
	2	3.71	4.19	4.04	5.34	2.97	4.14
	3	3.94	4.31	5.27	6.35	3.88	4.82
	4	5.50	5.29	4.48	5.48	4.78	3.81
	5	4.98	5.54	3.54	4.72	4.60	4.82
	6	4.15	4.64	4.13	5.05	5.44	4.20
	7	4.46	5.03	3.17	4.56	4.99	4.80
	8	4.60	4.96	3.79	4.65	5.38	5.89
	9	5.46	6.51	6.31	6.96	4.26	6.72

Performance Measures

The data reduction and analysis (DRA) program reduced the simulator data files, the simulation pilot command files, the push-to-talk (communication), and the ATWIT files to a set of 41 variables. These variables were divided into Conflict, Complexity, Error, Communications, and Task Load variables.

Conflicts

The DRA module calculated the number and duration of standard, terminal, longitudinal, and parallel conflicts. The DRA module originally reduced data of experiments with IFR aircraft ILS approaches only. In the current experiment, however, both IFR and VFR aircraft and visual approaches were present. These variables are indicators of how close a ATCS works traffic. They are not the number of times an ATCS violated separation requirements.

Table K-16 summarizes the means and standard deviations for the conflict related variables. On average, there were 3.2 standard conflicts per 45-minute simulation. These conflicts lasted approximately 4 minutes and 20 seconds. Terminal Conflicts occurred 1.6 times per scenario for a total of about 1 minute and 20 seconds. Less than one longitudinal conflict occurred per scenario, on average lasting less than 50 seconds. No Parallel Conflict Information was recorded. The number of recorded Between Sector Conflicts was approximately 5.5 per 45-minute scenario. The cumulative Duration of Between Sector Conflicts within a scenario was approximately 5 minutes and 45 seconds. The Closest Point of Approach was less than 2800 feet with a Horizontal Separation of less than 2200 feet and a vertical separation of less than 480 feet. The aircraft Proximity Index during this experiment averaged almost 27.5.

Table K-16. Mean and SDs of DRA Variables Related to Task Load as a Function of Task Load and Visual Noise

		Low Load		High Load			
		Means	SDs	Means	SDs	Means	SDs
No Noise	No Standard Conflicts	2.21	1.44	0.83	1.05	2.76	1.77
	Dur Standard Conflicts	222.42	629.98	150.33	482.71	180.94	449.88
	No Terminal Conflicts (3/500)	0.29	0.46	0.17	0.38	0.48	0.68
	Dur Terminal Conflicts (3/500)	8.17	15.35	3.38	10.24	19.40	41.23
	No Longitudinal Conflicts	0.46	0.78	0.33	0.48	0.74	1.00
	Dur Longitudinal Conflicts	36.83	69.92	17.75	27.06	44.42	68.58
	No Between Sector Conflicts	2.63	2.24	3.33	1.17	4.21	2.66
	Dur Between Sector Conflicts	147.00	141.04	169.67	130.98	282.28	225.95
	Closest Point of Approach (Feet)	4393.92	5804.33	3728.83	5299.35	2595.69	4473.78
	CPA Horizontal Separation	4223.00	5900.05	3563.75	5385.99	2358.60	4567.23
	CPA Vertical Separation	556.42	306.32	493.17	275.18	516.99	229.31
	Aircraft- Proximity- Index (0-100)	19.54	26.67	28.08	29.32	22.02	20.09
Noise	No Standard Conflicts	3.32	1.92	6.79	3.54	3.81	3.97
	Dur Standard Conflicts	139.46	114.57	523.67	436.68	337.00	492.87
	No Terminal Conflicts (3/500)	0.67	0.81	5.25	2.29	2.71	3.04
	Dur Terminal Conflicts (3/500)	30.64	54.53	306.63	190.18	155.00	203.05
	No Longitudinal Conflicts	1.03	1.12	1.50	1.18	0.92	1.07
	Dur Longitudinal Conflicts	52.01	67.84	77.71	72.60	47.73	62.09
	No Between Sector Conflicts	5.79	2.04	10.21	2.70	6.77	4.04
	Dur Between Sector Conflicts	417.56	215.03	648.67	181.86	409.17	288.38
	Closest Point of Approach (Feet)	797.45	678.83	599.63	318.23	2164.23	4036.38
	CPA Horizontal Separation	494.20	749.25	430.79	276.28	1997.27	4091.36
	CPA Vertical Separation	477.56	101.86	395.83	207.43	444.50	246.03
	Aircraft- Proximity- Index (0-100)	24.50	10.02	37.75	32.41	32.92	30.96
	No Standard Conflicts	1.52	1.43	5.05	3.32	3.29	3.10
	Dur Standard Conflicts	186.38	556.39	331.56	370.71	258.97	475.89
	No Terminal Conflicts (3/500)	0.23	0.42	2.96	2.87	1.60	2.46
	Dur Terminal Conflicts (3/500)	5.77	13.13	168.63	196.47	87.20	160.88
	No Longitudinal Conflicts	0.40	0.64	1.26	1.16	0.83	1.03
	Dur Longitudinal Conflicts	27.29	53.33	64.86	70.71	46.07	65.09
	No Between Sector Conflicts	2.98	1.80	8.00	3.25	5.49	3.64
	Dur Between Sector Conflicts	158.33	135.13	533.11	229.02	345.72	265.46
	Closest Point of Approach (Feet)	4061.38	5508.40	698.54	533.90	2379.96	4243.76

Complexity

The average system activity was 16. The average number of altitude changes was approximately 25 per scenario. A 45-minute simulation contained approximately 28 heading changes. ATCSs instructed aircraft to change their speeds less than two times per scenario. Table K-17 summarizes the means and standard deviations for complexity related variables.

Table K-17. Means and SDs of Complexity Related Variables as a Function of Task Load and Visual Noise

		Low Load		High Load			
		Means	SDs	Means	SDs	Means	SDs
No Noise	Average System Activity	4.56	0.90	13.19	2.68	7.47	4.10
	Number of Altitude Changes	19.42	5.46	17.79	5.58	25.32	10.01
	Number of Heading Changes	19.88	10.12	18.71	6.57	28.39	14.50
	Number of Speed Changes	2.17	1.97	0.29	0.55	1.80	1.72
Noise	Average System Activity	10.37	3.99	36.15	6.94	24.67	12.71
	Number of Altitude Changes	31.22	10.11	30.29	11.07	24.04	10.73
	Number of Heading Changes	36.90	13.27	43.71	15.39	31.21	17.22
	Number of Speed Changes	1.43	1.37	2.92	3.05	1.60	2.54
	Average System Activity	8.88	4.79	23.26	14.18	16.07	12.77
	Number of Altitude Changes	18.60	5.52	30.76	10.50	24.68	10.34
	Number of Heading Changes	19.29	8.46	40.30	14.63	29.80	15.90
	Number of Speed Changes	1.23	1.72	2.18	2.46	1.70	2.16

Error

The error-related variables contributed relatively little to insight in the performance of the ATCSs in this study. The simulation pilots did not execute missed approaches. The ATCSs nor did not issue hand-offs outside the sector boundary. The number and duration of turns and holds were extremely low. Interestingly enough, the DRA found an average of five Start Point Delays with an average Start Point Delay Duration of 35 seconds. Most likely, this was due to delays in the simulation software because the current study did not contain aircraft that needed a manual release. ATCSs did not have the option to hold traffic at the airport as a tool to control traffic flow. Table K-18 summarizes the means and standard deviations for error related variables.

Table K-18. Mean and Standard Deviation of Error Related Variables

Variable	Mean	SD
No Missed Approaches	0.00	0.00
No Hand-offs Outside Boundary	0.00	0.00
No Turn/Hold Delays	0.10	0.30
Dur Turn/Hold Delays	5.59	23.05
No Start Point Delays	5.00	2.27
Dur Start Point Delay	35.67	208.80

Communications

The average number of ATCS messages per simulation run was approximately 36, and the number of pilot keystrokes totaled about 480. Table K-19 summarizes the means and standard deviations for communications-related variables.

Table K-19. Mean and Standard Deviation of Communications-Related Variables

Variable	Mean	SD
No Ground-to-Air Contacts	4.11	28.05
Dur Ground-to-Air Contacts	18.07	115.00
No ATCS Messages	35.76	17.07
No Pilot Message Key Strokes	479.36	213.29

Task Load

The average number of aircraft handled was approximately 26. The cumulative time ATCSs had aircraft under control averaged almost 19,800 seconds or 5 hours and 30 minutes. The aircraft under control flew an average of a cumulative distance of 1600 miles. On average, the number of arrivals, departures, and accepted hand-offs were 5.5, 7.5, and 10.5, respectively. Aircraft arrived every 2 minutes and 40 seconds and departed every 6 minutes and 30 seconds. Table K-20 summarizes the means and standard deviations for task load-related variables.

Table K-20. Mean and Standard Deviation of Task Load-Related Variables

Variable	Mean	SD
No Aircraft Handled	26.36	8.01
Time Under Control	19734.51	7330.47
Distance Flown	1624.06	3404.61
No Completed Flights	7.61	2.00
No Arrivals	5.56	3.07
Ave Arrival Interval (Seconds)	221.32	133.54
No Departures	7.36	2.63
Ave Departure Interval (Seconds)	390.34	155.98
No Hand-offs Accepted	10.46	3.77
Hand-off Accept Delay Time	0.00	0.00

Appendix L
Detailed Results of Selected Statistical Analyses

Table L-1. MANOVA Results for General Post-Scenario Questions

Effect	Wilk's' Lambda	*F*	Num DF	Den DF	*p* < .05
Load x Visual noise	.413	2.663	8	15	.0486
Load	.021	89.261	8	15	.000
No Visual noise	.041	44.301	8	15	.000
Visual noise	.078	22.082	8	15	.000
Visual noise	.370	3.191	8	15	.025
Low Load	.531	1.658	8	15	.190
High Load	.414	2.659	8	15	.049

Table L-2. Load and Visual Noise Interaction on General Post-Scenario Questions

Ques #	Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
1	Realism	1	1.168	1.168	0.650	.429
2	Representativeness	1	4.175	4.175	2.150	.157
3	ATWIT Interference	1	0.200	0.200	0.590	.452
4	Oculometer Interference	1	0.830	0.830	0.790	.383
5	Simulation Pilot Performance	1	2.625	2.625	3.110	.092
7	Working Hard?	1	12.676	12.676	9.240	.006
8	Control Quality	1	7.353	7.353	8.190	.009
13	Difficulty	1	11.908	11.908	11.210	.003

Table L-3. Effect of Task Load on Individual General Post-Scenario Questions

Ques #	Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
1	Realism	1	5.709	5.709	2.370	.138
2	Representativeness	1	28.144	28.144	8.170	.009
3	ATWIT Interference	1	3.234	3.234	9.900	.005
4	Oculometer Interference	1	0.858	0.858	0.530	.473
5	Simulation Pilot Performance	1	5.100	5.100	6.590	.018
7	Working Hard?	1	349.285	349.285	296.660	.000
8	Control Quality	1	29.739	29.739	14.440	.001
13	Difficulty	1	400.941	400.941	263.880	.000

Table L-4. MANOVA Results for Post-Scenario SA Related Questions

Effect	Wilk's' Lambda	*F*	Num DF	Den DF	*p* < .05
Visual noise	.552	3.863	4	19	.018
Load	.316	10.308	4	19	.000
Load x Visual noise	.668	2.366	4	19	.089

Table L-5. Effect of Task Load on Individual SA Related Post-Scenario Questions

Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
Overall SA	1	37.816	37.816	25.190	.000
Current ACFT Location SA	1	48.525	48.525	42.980	.000
Projected ACFT Location SA	1	41.690	41.690	32.850	.000
Potential Violations SA	1	22.224	22.224	13.030	.002

Table L-6. Effect of Visual noise on Individual SA Related Post-Scenario Questions

Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
Overall SA	1	4.062	4.062	3.950	.059
Current ACFT Location SA	1	6.905	6.905	5.460	.029
Projected ACFT Location SA	1	6.374	6.374	5.830	.025
Potential Violations SA	1	13.358	13.358	14.630	.001

Table L-7. MANOVA Results of Post-Scenario TLX Items

Effect	Wilk's' Lambda	*F*	Num DF	Den DF	*p* < .05
Load x Visual noise	.545	2.363	6	17	.076
Load	.060	45.175	6	17	.000
Visual noise	.518	2.633	6	17	.054

Table L-8. Effect of Task Load on Individual TLX Items in the Post-Scenario Questionnaire

Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
Mental Demand	1	328.716	328.716	222.270	.000
Physical Demand	1	150.211	150.211	41.910	.000
Temporal Demand	1	242.671	242.671	99.950	.000
Performance	1	15.394	15.394	8.720	.007
Effort	1	44.425	44.425	23.840	.000
Frustration	1	170.274	170.274	80.050	.000

Table L-9. MANOVA Results for Mean and Maximum ATWIT Ratings

Effect	Wilk's' Lambda	*F*	Num DF	Den DF	*p* < .05
Load x Visual noise	.702	4.453	2	21	.024
Load	.159	55.738	2	21	.000
No Visual noise	.093	102.960	2	21	.000
Visual noise	.330	21.304	2	21	.000
Visual noise	.988	0.129	2	21	.879
Low Load	.849	1.861	2	21	.180
High Load	.856	1.767	2	21	.195

Table L-10. Univariate Interaction of Load and Visual Noise on ATWIT Mean and Maximum

Load x Visual noise	DF	Type III SS	Mean Square	*F*	*p* < .05
ATWIT Mean	1	1.960	1.960	3.690	.068

ATWIT Maximum	1	29.739	29.739	9.190	.006

Table L-11. Univariate Effect of Task Load on ATWIT Mean and Maximum

Load	DF	Type III SS	Mean Square	*F*	*p* < .05
ATWIT Mean	1	110.405	110.405	92.370	.000
ATWIT Maximum	1	136.728	136.728	18.520	.000

Table L-12. MANOVA Results on General Eye Movement Characteristics

Effect	Wilk’s' Lambda	*F*	Num DF	Den DF	*p* < .05
Load x Visual noise	.617	2.239	5	18	.095
Visual noise	.900	0.409	5	18	.836
Load	.350	6.680	5	18	.001

Table L-13. Effect of Task Load on General Eye Movement Characteristics

Variable	DF	Type III SS	Mean Square	F	p < .05
Number of Fixations	1	186469.740	186469.740	4.240	.051
Mean Fixation Duration	1	0.004	0.004	2.170	.155
Mean Fixation Area	1	0.059	0.059	19.540	.000
Visual Efficiency	1	0.001	0.001	0.890	.357
Mean Saccade Duration	1	0.000	0.000	0.160	.692
Mean Saccade Distance	1	0.407	0.407	4.310	.050
Eye Motion Workload	1	0.217	0.217	0.590	.451
Number of Blinks	1	119114.555	119114.555	3.040	.095
Mean Blink Duration	1	0.000	0.000	0.000	.960
Mean Blink Distance	1	4.224	4.224	0.610	.442
Mean Pupil Diameter	1	0.215	0.215	0.920	.347
Pupil Motion Workload	1	0.000	0.000	0.440	.516

Table L-14. MANOVA Results on Scene Plane Fixation Characteristics

Effect	Wilk’s' Lambda	F	Num DF	Den DF	p < .05
Load x Visual noise	.251	14.200	4	19	.000
Visual noise	.639	2.700	4	19	.063
Low Load	.460	5.580	4	19	.004
High Load	.415	5.070	5	18	.005
Load	.110	38.490	4	19	.000
No Visual noise	.213	17.595	4	19	.000
Visual noise	.119	26.596	5	18	.000

Table L-15. Effect of Task Load and Visual Noise Interaction on Scene Plane Fixations

Variable	DF	Type III SS	Mean Square	*F*	*p* < .05
Radarscope Fixations	1	248482.300	248482.300	15.620	.001
Radarscope Mean Duration	1	0.026	0.026	17.490	.000
Flight Strip Bay Fixations	1	25091.170	25091.170	14.720	.001
Flight Strip Bay Mean Duration	1	0.001	0.001	0.460	.504
ATWIT Fixations	1	15.583	15.583	0.110	.742
ATWIT Mean Duration	1	0.008	0.008	0.450	.508
Keyboard Area Fixations	1	19481.580	19481.580	1.060	.316
Keyboard Area Mean Duration	1	0.021	0.021	8.520	.008

Table L-16. MANOVA Results on Radarscope Fixations

Effect	Wilk's' Lambda	*F*	Num DF	Den DF	*p* < .05
Load x Visual noise	.151	19.198	5	17	.000
Visual noise	.157	14.320	6	16	.000
Load	.151	15.034	6	16	.000

Table L-17. Interaction Effects of Task Load and Visual Noise for Radar Object Related Fixations

Variables	DF	Type III SS	Mean Square	*F*	*p* < .05
System Area Fixations	1	5273.824	5273.824	10.540	.004
System Area Mean Duration	1	0.017	0.017	2.920	.102
Static Object Fixations	1	--	--	--	--
Static Object Mean Duration	1	0.059	0.059	12.910	.002
Tab List Fixations	1	1633.818	1633.818	20.850	.000
Tab List Mean Duration	1	0.117	0.117	6.470	.019
Preview Area Fixations	1	1997.909	1997.909	4.100	.055
Preview Area Mean Duration	1	0.008	0.008	1.000	.329
Aircraft Fixations	1	948841.000	948841.000	46.850	.000
Aircraft Mean Duration	1	0.059	0.059	28.220	.000

Table L-18. Effects of Task Load for Radar Object Related Fixations

Variables	DF	Type III SS	Mean Square	*F*	*p* < .05
System Area Fixations	1	12947.480	12947.480	22.380	.000
System Area Mean Duration	1	0.188	0.188	44.090	.000
Static Object Fixations	1	69790.560	69790.560	47.500	.000
Static Object Mean Duration	1	0.005	0.005	0.600	.448
Tab List Fixations	1	30.168	30.168	0.780	.386
Tab List Mean Duration	1	0.067	0.067	1.740	.201
Preview Area Fixations	1	10293.770	10293.770	13.700	.001
Preview Area Mean Duration	1	0.001	0.001	0.110	.742

Aircraft Fixations	1	621127.500	621127.500	11.760	.002
Aircraft Mean Duration	1	0.006	0.006	1.790	.194

Table L-19. Repeated Measures Analysis Results VFR X Condition Interaction for General Eye Movement Characteristics

Variables	Wilk’s' Lambda	*F*	Num DF	Den DF	$p < .05$
Number of Fixations	.833	0.400	4	8	.804
Average Fixation Duration	.541	1.698	4	8	.243
Average Fixation Area	.713	0.806	4	8	.555
Visual Efficiency	.491	2.076	4	8	.176
Average Saccade Duration	.305	4.558	4	8	.033
Average Saccade Distance	.438	2.567	4	8	.119
Eye Motion Workload	.582	1.436	4	8	.307
Number of Blinks	.649	1.082	4	8	.426
Average Blink Duration	.460	2.351	4	8	.141
Average Blink Distance	.900	0.224	4	8	.918
Pupil Diameter	.463	2.319	4	8	.145
Pupil Motion Workload	.463	2.319	4	8	.145

Table L-20. Main Effect of the Presence of VFR Intrusions on Eye Movement Variables

Effect: VFR	Wilk’s' Lambda	*F*	Num DF	Den DF	$p < .05$
Number of Fixations	.845	2.018	1	11	.183
Average Fixation Duration	.984	0.179	1	11	.681
Average Fixation Area	.898	1.247	1	11	.288
Visual Efficiency	1.000	0.000	1	11	1.000
Average Saccade Duration	.939	0.714	1	11	.416
Average Saccade Distance	.976	0.271	1	11	.613
Eye Motion Workload	.952	0.552	1	11	.473
Number of Blinks	.844	2.031	1	11	.182
Average Blink Duration	.920	0.951	1	11	.350
Average Blink Distance	.976	0.273	1	11	.612
Pupil Diameter	.850	1.935	1	11	.192
Pupil Motion Workload	.731	4.053	1	11	.069

Table L-21. Effect of Radarscope Objects on Fixation Duration

Effect	Wilk’s' Lambda	*F*	Num DF	Den DF	$p < .05$
Objects	.018	239.810	4	18	.000
Load	.717	8.300	1	21	.009
Visual noise	1.000	0.000	1	21	1.000
Objects x Load	.356	8.158	4	18	.001
Objects x Visual noise	.894	0.534	4	18	.713
Load x Visual noise	.392	32.521	1	21	.000
Objects x Load x Visual noise	.557	3.573	4	18	.026

Appendix M
Other Analyses Opportunities

The combined oculometry and simulator data sets lend themselves to other forms of analyses. For example, for each fixation this data point included the targets that were within a circle with a 2 inch radius. Researchers can calculate a transition probability (or Markov) matrix, when choosing targets closest to the fixation. This matrix represents the probability that target B follows target A and vice versa. SA studies have suggested that ATCSs group the aircraft in their airspace. If the visual scan reflects this grouping, the Markov matrix will reflect this. Ellis (1986) suggested that experts are likely to scan a display in a stratified random manner, resulting in a symmetrical Markov matrix. It is interesting, that these analytical techniques were developed for stationary objects. In our facility, the objects are moving targets linking the fixations with the objects.

Data on each fixation also contains information on its coordinates. Researchers can calculate the number of fixations per segment and the number of transitions between segments by breaking up the radarscope into polar coordinates. TRACON ATCSs will indicate that they scan inside out, that is from the center of the radarscope (the airport) to the edge of the radarscope. They explain this by pointing at the fact that the airport is the sink of the problem, all arriving aircraft will converge to that point and all departing aircraft will appear at that point. By starting to solve problems in the center of the scope, the ATCS starts at most likely the highly congested point. Using a Markov matrix based on polar coordinate segments, researchers visualize the probabilities of moving from one segment to the next. If inside out scanning exists, this will result in increased probabilities for transitions from segments that are closer to the airport or center of the radarscope than for segments that are more distant.

Others (Credeur et al., 1993; Hilburn & Parasuraman, 1996[1]) have used a division of the radarscope in sections and looked at transitions between these sections. The division of the radarscope in sections is arbitrary. Hilburn and Parasuraman used a grid consisting of squares to calculated the entropy in the visual scene of ATCSs and found a structured scan. By basing his divisions purely on radarscope location, this result should not be a surprise. After all, the airspace structure includes airways and approach patterns. It will therefore be less likely that fixation transitions occur between areas where no structural elements exist and areas that contain structural elements. A study by Credeur et al. (1993) provides a better approach. This study used transitions between structural elements.

The division of the airspace in sections in reality assigns fixations to bins based on the location on the radarscope. There are alternatives that do not use the fixation location. The alternative methods may shed more light on cognitive processes used by ATCSs during visual sampling of the information available on the radarscope. By dividing fixations by the object fixated upon,

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[1] Dynamic Decision aiding in air traffic control: A bio-behavioral analysis. B. Hilburn and R. Parasuraman, 1996, Vivek, *9*, (1), 30-38.

researchers obtain the structure in the visual scan between objects. This has the potential to reveal scanning strategies or grouping of objects used by ATCSs.

Researchers base another potentially useful division of fixations on the distance between subsequent fixations. By creating bins based on inter-fixation distances, one can reveal the tightness of the visual scan. A high number of transitions between or within bins that represent short distances could indicate closed loop control in the visual system. Transitions between long distance bins would indicate situations where local feedback cannot be used. This would indicate higher level cognitive processes often thought to exist in open loop control.

Finally, one of the goals of the visual scanning research program is to develop measures that quantify the nature of visual scanning patterns. Few, if any, studies have addressed a crucial point necessary to develop such measures. Structure in a visual scan does not reveal if the ATCS created a situation that allowed efficient acquisition of information available on the radarscope. To do so, one needs to express the information on the radarscope as a function of time and investigate if the ATCS picked up the available information in an efficient way. In other words, visual scanning efficiency creates a situation that allows for maximal information pickup.

The ATCS scans not only the radarscope, but flight strips and communication channels as well. In the current study, researchers recorded ATCS-pilot communications. Some ATCSs are under the impression that ATCSs conduct auditory and visual scanning simultaneously, i.e., while looking at one aircraft an ATCS talks to the pilot of another. By transcribing the ATCS-pilot communications and synchronizing the messages with the fixation information, verification of this impression is possible. In case aircraft at which ATCSs looked strongly correlate with aircraft to which ATCSs talked, processing is not parallel. If, on the other hand, no correlation exists, this would indicate that ATCSs were talking to aircraft at which they were not looking. Communications and visual scanning would then happen in parallel.

Knecht, Smit, and Hancock (1996) have used risk indices, calculated from separation requirements and actual separation between aircraft, to look at actions taken by pilots to prevent loss of separation. Similar indices can be developed for ATCSs and visual scanning variables can then be compared to different risk levels.

The study examined the differences in terms of number of fixations and fixation durations. Researchers identified objects on the radarscope by type, e.g., aircraft, airports, VORs, etc. The object group of aircraft can be further broken down into arrivals, overflights, and departures, or VFR and IFR aircraft. Fixation duration contains information about the processing time that provides insight into the complexity of processing related to different aircraft types.

During the experiments and during demonstrations audiences ask questions like “Can better eye movements be taught?” A highly skilled visual scan evolves from years of experience. Another approach taken by researchers, called the “optimal controller,” states that the “optimal controller” samples displays economically without compromising risk issues. For example, when two aircraft close in on one another one would need to sample more often when the aircraft grows closer. If, giving sampling of these two aircraft too much priority, the risk of conflicts occurring between other aircraft not sampled increases. The optimal controller would sample optimally. Then researchers are able to compare visual scanning information recorded from ATCSs with the performance of a non-existing optimal controller. Research in this area frequently requires the use of an oculometer to understand differences between optimal and operational control. In an operational setting one would target adaptive support systems based on what ATCSs are most likely to miss compared to an optimal ATCS model.

Appendix N
Recommendations

1. Modify the data reduction module to incorporate both VFR and IFR rules.
   Rationale: The data reduction module at the RDHFL does not distinguish between VFR and IFR aircraft.

2. Modify the data reduction module to calculate ATCS performance based on ATCS responsibility, not on position symbol only.
   Rationale: Currently the data reduction module assumes aircraft carrying a position symbol belongs to a particular ATCS. Aircraft carrying the ATCS position symbol as well as other aircraft inside the ATCS airspace are the ATCS responsibility.

3. Investigate the effect of an intrusion alert, warning the ATCS of aircraft entering Class C airspace.
   Rationale: Verbal reports during this experiment on aircraft intrusions into Class C airspace indicated that ATCSs did miss some of the intrusions. Their eye movement characteristics did not change during the 5-minute intervals that included these events. The features of the representation of these aircraft did not differ from aircraft under normal control.

4. Investigate the efficiency of ATCS visual information acquisition.
   Rationale: Increasing task load and introducing visual noise affected eye movement characteristics as evident from scene plane and radarscope object data. Eye movement characteristics by themselves do not provide insight into how ATCSs acquire information.

5. Investigate how the ATCS uses fixation time on aircraft representations.
   Rationale: The data indicated that ATCSs spend the most fixation time on aircraft representations. The question remains as to how the ATCS uses this time. The aircraft representation (radar return, vector line, and data block) contains more information than any of the other objects. Does the ATCS spend more time acquiring this information, or is the increase in fixation time due to an increase in higher level cognitive processing?

6. Investigate if ATCSs acquire all aircraft information during a single fixation.
   Rationale: One assumption is eye movements force a sequential acquisition of information. With an increase in expertise, ATCSs develop high levels of automation in the acquisition of visual information. How much information ATCS can acquire during one fixation remains unknown.

7. Investigate ATCS visual information processing in the parafoveal and the peripheral field of view.
   Rationale: Some researchers have shown that cognitive load and experience affects the amount of information collected from a fixation. If experience increases the functional field of view, how much of the radarscope can the ATCS process in a single fixation?