Implications of Reduced Involvement in En Route Air Traffic Control

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16. Abstract

The expansion of the National Route Program will allow airlines to be more flexible in filing and amending flight plans. This may result in a change in the role of the air traffic control specialist from direct control to a position with more monitoring responsibilities. This change may result in a reduction of situation awareness, memory and vigilance. This experiment investigated the effect of moving a controller from the current active control to a monitoring position. It examined the effect of the change in involvement and task load by measuring eye movements, workload, situation awareness, system performance, controller performance ratings, organization of information in memory, and responses to questionnaires. Controllers received training on a generic en route airspace, the Genera High sector, during four practice simulations of 40 minutes each. They then worked four 30-minute experimental scenarios. Results indicated that controllers showed a less structured scanning pattern under high task load and active involvement conditions. Measured workload correlated well with traffic volume. Under monitoring conditions, controllers perceived lower workload. Controller situation awareness was lower under monitoring conditions and decreased further with an increase in task load. Controllers perceived that their situation awareness did not change between active control and passive monitoring. The decrease in situation awareness warrants careful examination of the need for training and assistance of controllers for situations where they no longer function in the current active control position.

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Table of Contents

Table of Contents (Cont.)

List of Illustrations

Figures Page

Tables Page

Executive Summary

In the current en route Air Traffic Control (ATC) system, the ATC Specialist (ATCS) has primary responsibility for safe and efficient traffic flow. The expansion of the National Route Program (NRP) will allow airlines more flexibility in filing and amending flight plans. The increased flexibility for the airlines will likely move the ATCS away from direct control to a managerial position. Programs like the NRP may make the ATCS a monitor that ensures that aircraft adequately separate themselves. Researchers and ATCSs have voiced concern about the change from active control to a more monitoring role. These concerns include a reduction in situation awareness (SA), memory, and vigilance.

This experiment placed ATCSs at two levels of involvement. At one end, they controlled traffic as they normally would in the field. At the other level, they monitored traffic, but did not actively control or communicate with aircraft. For both levels of involvement, we conducted simulations with moderate and high traffic load.

The simulated sector was generic. It was easy to learn, but it still enabled the experimenters to create complex scenarios. The generic airspace had the advantage that ATCSs from anywhere within the continental United States could participate. Using ATCSs from several Air Route Traffic Control Centers may make results more applicable. The study investigated the effect of the change in involvement and task load by measuring eye movements, workload, SA, system performance, ATCS performance ratings, organization of information in memory, and responses to questionnaires.

The results of this study are varied. The changes in involvement and task load did not affect eye movement characteristics, although they did influence the structure in the visual scanning pattern. Measures that capture eye movement characteristics (e.g., the number and duration of blinks and fixations) did not change. The probability that a controller fixates objects in a particular order is an indication of the structure of the visual scan. Using these transition probabilities, we found that the structure in the visual scan changed as a function of involvement and load. The experiment may have been too short to alter well-rehearsed scanning behavior to change eye movement characteristics. It is clear that the ATCSs looked longer per glance at aircraft than any other object.

Measured workload correlated well with traffic volume. In addition, workload actually decreased when ATCSs monitored instead of actively controlled traffic. They had less to do, and the measures reflected this. In this study, ATCSs received a relief briefing as they would in the field. Analysis of the data revealed that workload was lower during the first 5 minutes than subsequent 5-minute intervals.

The ATCS SA, as measured by the response time to SA-related questions, was lower under monitoring conditions than under active control. Under active control, the level of traffic load did not influence SA, but, under monitoring conditions, a higher traffic load led to a sharp decrease in SA. This is a critical finding with potential implications for future training.

Two observers rated the ATCSs performance under active control conditions. The observers indicated that the ATCSs provided adequate ATC information under both levels of traffic load.

The observers felt that the quality of prioritization suffered from the increase in traffic load. In the observers' opinion, the ATCS SA was lower under high traffic load. A change in load did not affect the quality of communications nor did it affect the safe and efficient flow of traffic. Interestingly, the observers found that an increase in traffic load reduced the ATCS exhibited knowledge of the letters of agreement and standard operating procedures. It is likely that, under the increased pressure of a higher traffic load, the ATCSs were less capable in applying their knowledge.

To assess how ATCSs organize information in memory, we asked the ATCSs to place data blocks back to the position that represented the last screen update of the simulation. The current study did not reveal changes in memory organization across levels of involvement and traffic load. However, the percentage of data block positions correctly recalled under active control was higher than under monitoring.

After each simulation, the controllers filled out a questionnaire. Their responses indicated that they perceived active control scenarios to be more difficult and more realistic. The ATCSs perceived that their SA did not suffer from the change in involvement. They indicated that their SA for aircraft positions and potential violations was not as good under high traffic load conditions for both active control and monitoring conditions.

The expected changes in programs like the NRP may move the ATCS to a situation that will fall somewhere between the current, active control situation and the simulated, monitoring situation of this study. The results indicated that, although perceived workload was less under monitoring conditions, the objective SA measures showed that ATCS SA declines substantially. The fact that the ATCS may not have been aware of the reduction in SA suggests that a monitoring situation without SA enhancers is not a good idea.

Although our experiment was too brief to alter eye movement characteristics, the visual scanning patterns showed changes. These small changes, after only a brief exposure to work as a monitor, may suggest changes in eye movement characteristics while monitoring for longer periods. Changes in visual scanning are an indication of visual information retrieval strategies. The altered SA, in combination with a change in information retrieval strategies, warrants careful examination of the need for training and assistance for situations where the ATCS is no longer in active control.

1. Introduction

The current air traffic control (ATC) system will undergo significant changes in equipment and procedures in the near future (Federal Aviation Administration (FAA), 1996, 1997). The proposed changes will affect the role of current ATC Specialists (ATCSs). One of the significant proposed changes is the implementation of the expansion of the National Route Program (NRP). Some ATCSs refer to the NRP expansion as Free Flight (Smith et al., 1998). Within the FAA, Free Flight is now an accepted term where airlines and pilots obtain more freedom in amending flight plans. In Free Flight, the ATCSs function may involve more monitoring with less direct control. Ground- and satellite-based navigational aids such as the Traffic Alert and Collision Avoidance System (TCAS), global positioning systems (GPS), the Wide Area Augmentation System (WAAS), and Automatic Dependent Surveillance-Broadcast (ADS-B) will make Free Flight possible. Implementation will involve three levels that include free scheduling, free routing, and free maneuvering (FAA, 1996). The implementation of Free Flight as described by RTCA (1995) is significant because the ATCS will do more monitoring as opposed to active control under the current system. Each subsequent stage may reduce the active role of the ATCS. The transition from active control to monitoring could have a significant impact on ATCS behavior and performance in general.

1.1 Background

The primary responsibility for the separation of aircraft in the current en route ATC system belongs to the ATCS. A number of tools help the ATCS maintain separation between aircraft including the plan view display (PVD) and the flight progress strip (FPS). These tools assist the ATCS in developing and maintaining an understanding of the current and future air traffic situation. Using specific knowledge of the current situation and general knowledge of ATC, the ATCS manages air traffic within a sector. In the current ATC system, the ATCS plays an active role. Pilots must follow all ATCS instructions and assigned flight plans. Pilots can make deviations (e.g., changes in heading, altitude, and route) only with the approval of the ATCS or in an emergency.

The implementation of Free Flight as conceived years ago moved the ATCS from an active participant in the separation of aircraft to a monitor that ensures that aircraft adequately separate themselves. In Free Flight, the ATCS may become an air traffic manager. Therefore, it was important to examine how such a transition will affect ATCS behavior and performance.

Hopkin (1988) has argued that active participation in memory and understanding is more important than researchers thought in the past. He suggested that it is necessary to preserve the interaction between an operator and the task at hand. One way to do this is to require the performance of an additional task while monitoring to compensate for the lack of active involvement. The additional task would keep the operator “in the loop.” It should serve to help maintain relevant knowledge about the current situation.

A number of studies support Hopkin’s (1988) interaction hypothesis. For example, Held and Freedman (1963) and Slamecka and Graf (1978) demonstrated that memory is better for something that you do yourself than for something done for you. Conversely, a series of studies challenged Hopkin’s interaction hypothesis (Albright, Truitt, Barile, Vortac, & Manning, 1994;

Vortac, Edwards, Fuller, & Manning, 1994; Vortac, Edwards, Jones, Manning, & Rotter, 1993). These studies focused primarily on the impact of removing flight progress strips rather than on Free Flight. However, they supported the view that the reduction of workload can improve or maintain cognitive functioning despite an associated reduction of active interaction with the task at hand.

Vigilance is another concern when reducing the amount of active ATCS involvement. When operators perform a task for any length of time, especially when monitoring a situation, it is difficult to sustain an optimal level of focused attention (Parasuraman, 1986). The vigilance decrement is the inability to remain focused. Many simulated and operational radar/sonar monitoring studies have provided evidence for a vigilance decrement (Baker, 1962; Colquhoun, 1977; Schmidtke, 1976; Thackray, Bailey, & Touchstone, 1979; Thackray & Touchstone, 1989). However, a vigilance decrement usually occurred only after a considerable amount of time (e.g., 2 hours). Other research has shown the evidence for the occurrence of a vigilance decrement after only a short period (Stern, Boyer, Schroeder, Touchstone, & Stoliarov, 1994). Additionally, vigilance decrements may vary as a function of load (Stern et al.; Thackray et al.). Regardless of the results of past vigilance research in monitoring behavior, the ATC system has a responsibility for public safety. Researchers should not ignore issues like vigilance decrement as a possible consequence of Free Flight implementation.

Free Flight could diminish the amount of active involvement of the ATCS. Diminished active involvement may affect cognitive processing of information and vigilance. Because of these concerns, one must consider how to assess the potential impact of the original concepts of free flight.

1.2 Objective

This study assessed the impact of a change in load and level of involvement on the behavior and performance of ATCSs. We assessed if ATCSs can maintain their awareness (or picture) when their level of direct involvement declines. In addition to participant questionnaires and objective and subjective performance measures, we examined ATCS behavior and cognitive processing through the assessment of eye movements, situation awareness (SA), and memory.

In the current study, Full Performance Level (FPL) en route ATCSs operated in a simulated, generic, en route environment. Simulation offers complete situational control and measurement during a simulated traffic scenario.

2. Method

For convenience, we have presented the appendixes in the following manner: A-C (Airspace-related), D-F (Questionnaires), G (Participant Instructions), H-N (Detailed result tables), and O and P (Coordination events and situation presence assessment method (SPAM) queries).

2.1 Participants

Sixteen FPL ATCSs from 12 Air Route Traffic Control Centers (ARTCCs) within the United States served as voluntary participants. All participants were non-supervisory, full-time FPL ATCSs. None of the participants was on medical waiver or in a staff position at the time of the experiment. Eleven participants had normal vision and five had corrected-to-normal vision. The mean age of the participants was 37.3 years (29-53). They were FPLs for a mean of 9.3 years (2.5-17) and had worked in their current facility for 10.9 mean years (6-22). Six participants had worked at more than one facility during their ATC career. The participants worked air traffic for an average of 11.7 months out of the previous 12 months. Using a 10-point scale, the participants rated their current skill level as 8.2 (6-10), stress level during the past several months as 5.6 (3-9), motivation to participate in the study as 8.9 (6-10), and their current state of health as 8.8 (5-10).

2.2 Experimental Staff

Three human factors specialists (HFSs) conducted the study. One of the HFSs started and ended the simulations, conducted the SPAM measurements, and issued between sector coordination requests. The second HFS provided ATCSs with the Post-Scenario Questionnaires (PSQs), instructed ATCSs on how to use instruments, and started the Recall procedure. The third HFS performed the eye movement measurements and data analysis.

Two subject matter experts (SMEs) participated in the study. Both SMEs were active supervisory controllers in ARTCCs. During the simulations, the two SMEs conducted an over-the-shoulder (OTS) evaluation of controller performance and recorded the correct answers to question asked as part of the SPAM.

Three simulation pilots entered commands into the simulator and read back clearances in response to ATCS instructions. Engineering support staff at the FAA William J. Hughes Technical Center Research Development and Human Factors Laboratory (RDHFL) monitored the simulations and ensured proper function of equipment and software.

2.3 Materials

2.3.1 Airspace

The airspace used for the experiment was Genera Center High (Guttman, Stein, & Gromelski, 1995). Genera Center High (Figure 1), hereafter referred to as Genera sector, is a synthetic airspace sector developed to be representative of a high altitude, en route sector. Genera sector and its related elements are easy to learn while still allowing for considerable complexity. Jetways, fixes, intersections, and airports have simple names for ease of memorization. Appendix A contains the Genera sector Standard Operating Procedures (SOPs), and Letter of Agreement (LOA) with Charlie Center. Appendix B contains a description of Genera sector airspace.

2.3.2 Scenarios

Each participant controlled four practice and four experimental scenarios. The complexity of the scenario and rate at which aircraft entered the airspace constituted load. The development of scenarios occurred in close consultation with an SME to ensure the desired levels of complexity and realism. Each scenario began with traffic in the airspace similar to that present after a position relief briefing.

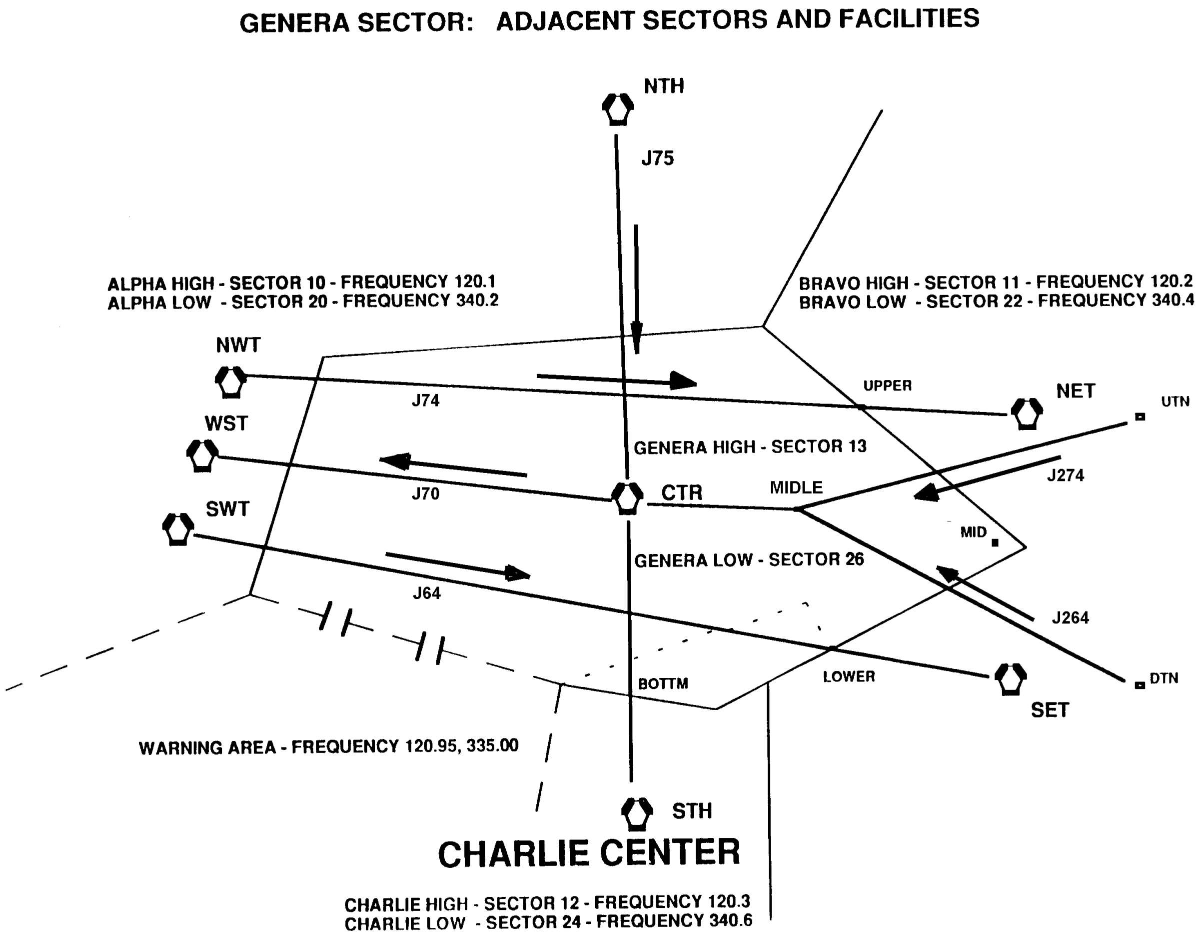

Figure 1. Genera Center high sector map.

The four practice scenarios had a moderate level of load. These scenarios allowed the participants to become familiar with the airspace and equipment used during the experiment. During practice scenarios, aircraft entered the airspace at the rate of about 1.5 every 2 minutes. Each practice scenario lasted 40 minutes. Four coordination events (Appendix O) occurred during each practice scenario. We simulated coordination events by ringing the landline. When the ATCS answered the landline, one of the experimenters responded with a between-facility coordination message (e.g., “This is Tech Center, requesting higher for USA6255”).

The four experimental scenarios consisted of two active control and two monitoring scenarios. The two Active Control (A) scenarios simulated air traffic and procedures similar to a current field setting. One of the scenarios was High Load (HL) and one was Low Load (LL). During the HL scenario, aircraft entered the airspace at an average rate of one per minute. The LL scenario consisted of aircraft entering the airspace at an average rate of about one every 2 minutes. Each A scenario contained three coordination events.

The two Monitor Control (M) scenarios approximated conditions similar to an advanced stage (free maneuvering) of Free Flight. One scenario was HL and the other was LL. Load varied for M scenarios in the same manner as for A scenarios. During M scenarios, aircraft traversed the airspace without assistance from the ATCS. Aircraft had flight plans and navigated through the airspace to avoid conflicts with other aircraft. Data block updates and handoffs took place automatically. M scenarios also contained three coordination events.

2.4 Equipment

2.4.1 Hardware

2.4.1.1 Oculometer and Headtracker

An Applied Science Laboratories (ASL) series 4000 oculometer recorded eye movements. The ASL 4000 oculometer compensates for head movement by using a magnetic tracker (The Bird™, Ascension Technologies Corporation).

2.4.1.2 Console Configuration

The experiment used a single en route ATC workstation. A 2,000 by 2,000 pixel, 29" video display unit presented the radarscope PVD. A 19" monitor mounted above the PVD displayed a map of the airspace. An Air Traffic Workload Input Technique (ATWIT) device (Stein, 1985) mounted to the immediate left of the PVD within easy reach of the participant allowed input of workload ratings. The workstation had a full flight strip bay to the right of the PVD, an en route keyboard, and a trackball with three buttons. A landline allowed interfacility and intrafacility communications. A software program implemented an electronic version of the Quick Action Keys (QAKs) and Computer Readout Device (CRD) in the upper right hand corner of the PVD. To activate a QAK, the participant had to move the cursor to the appropriate QAK and depress the left button on the trackball. The center button on the trackball allowed the participant to make entries on (or slew on) an aircraft. The right trackball button served as a home key that would return the cursor to the center of the PVD when pressed.

2.4.1.3 Communications Configuration

The communication system linked us with the ATCS, SMEs, and simulation pilots. We could communicate with the simulation pilots and SMEs without distracting the participant. The participants made transmissions by depressing a handheld thumb switch.

2.4.2 Software

ATCoach (UFA, Inc., 1992) software simulated the air traffic scenarios. ATCoach is a high fidelity, dynamic ATC simulator that enabled a realistic design and control of airspace and scenarios.

The Data Reduction and Analysis (DRA) program reduced simulation data provided by ATCoach and integrated the data with information about the airspace and communication-events data. The output of the DRA for en route simulations contained detailed information on conflicts, complexity, errors, communications, and load. The DRA provided summary data for the entire simulation or specific intervals.

2.5 Design and Procedure

2.5.1 Experimental Design

The main experimental design employed a 2 X 2 (load X involvement) within-subjects design. The ATCSs worked the practice and experimental scenarios in a counterbalanced order. Each participant worked one of eight condition orders for both the practice and experimental scenarios. We counterbalanced the four practice scenarios for presentation order. The ATCSs worked the four experimental scenarios in an order counterbalanced for condition only.

Experimental scenarios required either A or M control by the participant. Experimental scenarios were of either HL or LL. The questions that relate to changes in performance and behavior are as follow:

a. Does scanning behavior differ across experimental conditions?

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

c. Do SME ratings differ across scenarios?

d. Do responses to PSQs differ across scenarios?

e. Do performance scores differ across task load levels?

2.5.2 Dependent Measures

To evaluate the effect of changes in load and level of involvement on ATCS performance and behavior, we collected data on eye movements, workload, SA, and performance. The following subsections introduce the variables collected in the respective data sets.

2.5.2.1 Eye Movements

The variables calculated to characterize eye movements were fixations, saccades, blinks, and pupil size. To characterize the visual-scanning pattern, we calculated measures of conditional information or structure. Section 3.1 provides a detailed description of the background, results, and discussion of the eye movement measurements used in this study.

2.5.2.2 Air Traffic Workload Input Technique

An ATWIT device (Stein, 1985) recorded response latencies (e.g., times to respond) and workload ratings during all conditions. The participant made a rating on the ATWIT device every 5 minutes. Before each rating, a tone alerted the participant who then had 20 seconds to make a workload rating. The participants used a scale of 1 (low workload) to 10 (high workload). ATWIT is a reliable and relatively unobtrusive on-line measure of subjective workload. Section 3.2 provides a detailed description of the background, results, and discussion of ATWIT ratings and response latencies.

2.5.2.3 Situation Present Assessment Method

The experiment used the SPAM (Durso et al., 1995). We presented six queries (Appendix P) during each experimental scenario at a rate averaging one every 5 minutes. We presented the queries using a simulated landline. During each scenario, half of the queries related to conceptual information regarding the present situation, and half of the queries related to conceptual information regarding future information. For example, a present query was, "Which aircraft currently has a higher altitude, USA335 or TWA790?" A future query was, "Which aircraft will reach the MIDLE intersection first, SWG321 or AAL123?" No two queries asked about the same aircraft. Each particular scenario dictated the order of present versus future query types. We developed the queries in consultation with an SME and based them on information considered relevant and meaningful to the participant. We recorded the time it took the participant to answer the landline, then read them the query, and recorded their answers. The SMEs independently scored each response as correct or incorrect. Section 3.3 provides a detailed description of the background, results, and discussion of the SPAM.

2.5.2.4 Real Time Objective Performance

The experimental conditions included several objective and subjective performance measures referred to as the Real Time Objective Performance (RTOP). The RTOP provided a means to assess ATCS skill and strategy. These measures were meaningful only in the A condition. The data reduction module can break down performance data by conflicts, complexity, error, communications, and load. Analyses involved only a subset of these performance variables. Section 3.4 provides a detailed description of the background, results, and discussion of the performance measures.

2.5.2.5 Subject Matter Expert Ratings Forms

All experimental scenarios involved both subjective and objective SME ratings. Two SMEs made ratings independently on ratings forms (Appendix C). The SMEs provided on-line performance ratings using the rating forms developed by Sollenberger, Stein, and Gromelski (1996). They derived the OTS items from the standard, on-the-job-training, evaluation form (FAA Form 3120-25) normally used during training. Section 3.5 provides a detailed description of the background, analysis, and discussion of the rating forms.

2.5.2.6 Recall

After each experimental scenario, the participants recalled the contents of the airspace as it existed when the scenario ended. They were to associate data blocks with the respective beacon returns as quickly and accurately as possible. The exercise involved all data blocks associated with aircraft that were in the airspace or otherwise under their control. They were to guess if they were not certain about a response.

Using the same display that served as the PVD, the participants saw a representation of the airspace including beacon returns, vector lines, and leader lines for each aircraft located in their exact position as when the scenario ended. A bin at the bottom of the display contained the data blocks involved in the exercise in random order. Using the trackball, the participant selected a data block from the bin. They placed the data block with the beacon return to which they believed it belonged. Dark gray squares indicated areas in which to place data blocks. They used the left trackball button to select and place the data blocks. The participants used as much time as needed to complete the task. Software recorded selection, placement times, and response accuracy for each data block. Section 3.6 provides a detailed description of the background, results, and discussion of the Recall measures.

2.5.2.7 Questionnaires

The experiment included questionnaires to solicit demographic information and opinions from the participants. We used three self-administered questionnaires adapted from Willems, Allen, and Stein (in press).

a. The Entry Questionnaire (Appendix D) collected information about the participants. It included items relating to ATCS experience, skill, stress, motivation, and health.
b. The PSQ (Appendix E) solicited information from the participants about each particular scenario. It included items relating to realism, difficulty, and performance for a particular scenario. Section 3.7 provides a detailed description of the background, results, and discussion of the PSQ measures.
c. The Post-Experimental Questionnaire (PEQ) (Appendix F) obtained general opinions from each participant regarding the experiment as a whole.

2.5.3 Procedure

2.5.3.1 Weekly Schedule of Events

Experimenters collected data from two participants each week. ATCS #1 arrived on Tuesday morning and finished the last simulation on Wednesday morning. ATCS #2 went through the same schedule, abut started Wednesday afternoon and finished Thursday afternoon. Table 1 depicts the schedule for this collection procedure.

2.5.3.2 Training

Training consisted of classroom and practical hands-on training. The participant and the experimental staff were present for the training sessions.

With an SME, we conducted the classroom instruction. First, we obtained verbal consent and then informed the ATCS of the right to withdraw from the experiment at any time. The participant then completed the entry questionnaire, and we provided initial information about the schedule of events. We showed the participant the oculometer to be worn during all scenarios and instructed that we would record all activities on videotape. The SME briefed the participant on the equipment used during the study (i.e., ATCoach, the Soft Computer Readout Device (SCRD), trackball, and landline) and the Genera sector, SOPs, and LOAs.

Table 1. Weekly Schedule of Events

Tuesday		Wednesday		Thursday	
Time	**Event**	**Time**	**Event**	**Time**	**Event**
8:30	Welcome & Entry Q ATCS#1	8:00	Sim Review	8:15	Sim Review
9:00	Sector & Equipment Briefing	8:15	Exp. scenario 2	8:30	Practice scenario 4
10:00	Break	9:15	Break	9:15	Break
10:15	Practice scenario 1	9:30	Exp. scenario 3	9:30	Exp. scenario 1
11:00	Break	10:30	Break	10:30	Break
11:15	Practice scenario 2	10:45	Exp. scenario 4	10:45	Exp. scenario 2
12:00	Lunch	11:45	Exit Q & Debrief	11:45	Lunch
13:30	Practice scenario 3	12:30	Lunch	13:00	Exp. scenario 3
14:15	Break	13:00	Welcome & Entry Q ATCS#2	14:00	Break
14:30	Practice scenario 4	13:30	Sector & Equipment Briefing	14:15	Exp. scenario 4
15:15	Break	14:30	Break	15:15	Break
15:30	Exp. scenario 1	14:45	Practice scenario 1	15:30	Exit Q & Debrief
16:30	Data backup	15:30	Break	16:00	Data backup
		15:45	Practice scenario 2		
		16:30	Break		
		16:45	Practice scenario 3		
		17:30	Data backup		

After the classroom instruction, the participant engaged in hands-on training. A very simple air traffic scenario (five aircraft) started. The participant then activated all of the functions of the SCRD and displays. These functions included the flight plan readout, route readout, J-ring, data block updates (temporary and assigned altitude updates, vector-line length changes, leader-line length changes), and data block handoff and acceptance. We demonstrated how the landline worked. Once the participant understood how to use all of the workstation functions, we explained the function of the oculometer.

Each participant engaged in four 40-minute practice scenarios. We gave instructions pertaining to the ATWIT device (Appendix G). The participant wore the oculometer during all practice scenarios to acclimate to its presence. Two SMEs independently completed the rating forms during all practice scenarios. After each scenario, we removed the oculometer, and the participant completed a PSQ. To give the participant some experience in using the human-computer interface, we introduced the recall procedure at the end of the fourth practice scenario.

2.5.3.3 Data Collection

Experimental data collection began after completion of the fourth practice scenario. Before each experimental scenario, the participant received instructions about the specific condition (A or M), the ATWIT device, the SPAM, and the recall procedure.

Before A conditions, the participant received instructions to control traffic as normally in the field. Before M scenarios, the participant received instructions to simply monitor the traffic. During M conditions, the participant could perform all functions that were normally available. The instructions for the M conditions were intentionally vague to see how the participant would behave during monitoring.

Researchers informed the participants that the ATWIT device emits a brief tone every 5 minutes. When the tone sounded, the participant had 20 seconds to press a number on the touch-sensitive screen indicating the current level of workload. A selection of 1 would indicate the lowest level of workload, and a 10 would indicate the highest level of workload. If the participant did not make a selection within 20 seconds of the alerting tone, the software automatically assigned a rating of 10.

The participant was also aware that SPAM used only one landline during the scenarios and that this landline served all coordination purposes between the participant and adjacent sectors or centers. At various times, a call came over the landline from the “Tech Center.” An intermittent tone over a loudspeaker next to the ATCS workstation indicated an incoming landline call. Once the participant answered the landline by pressing a key on the communications panel, we asked a SPAM forced choice question. The participant had to answer the query as quickly and accurately as possible.

The presentation of the query did not interrupt the scenario, and the participant could use all available information to answer the question. Each scenario included six queries that occurred at approximately 5-minute intervals. In addition to the six queries, we made three other landline calls that required a coordination of activity from the participant. Coordination and queries intermingled to prevent the participant from expecting a query each time there was an incoming landline call. Finally, the participant received instructions about the recall procedure at the end of the scenario.

After we gave all instructions and answered any questions, calibration of the oculometer began. We placed the oculometer on the participant’s head, and a calibration screen consisting of 17 numbered dots appeared on the monitor. Following our instruction, the participant had to hold as still as possible while looking at each dot in turn. We then tested the quality of the calibration by having the participant look at a subset of the 17 dots. If the calibration was poor, we recalibrated the oculometer. If the calibration was acceptable, the experimental scenario began.

We began each experimental scenario with a short count down over the communication system. On our cue, the participant touched the start button on the ATWIT device, and the simulation pilots started the scenario. An SME sitting to the left of the participant gave the participant a position relief briefing. The briefing lasted about 30 seconds during which time the simulation pilots did not make any calls to the participant. While the position relief briefing took place, the second SME sitting to the right of the participant near the FPS bay updated the FPS markings. Once the briefing was complete, the participant took full control of the scenario. Both SMEs remained in the room in order to complete the rating form and score the SPAM queries. Each experimental scenario lasted 30 minutes.

The recall procedure took place at the end of the scenario. The participant continued to wear the oculometer during the recall procedure. We instructed that the participant would see a representation of the airspace as it appeared when the scenario ended. All radar returns, vector lines, and leader lines appeared in their respective and proper positions as when the scenario ended. We informed the participant that the program had placed data blocks for all aircraft that were in the airspace or otherwise under control at the end of the scenario in a bin at the bottom of the display. The participant was to place each data block back into its proper position as quickly and accurately as possible. The participant could use as much time as needed to complete the recall procedure.

After the participant signaled that the recall was complete, we removed the oculometer, and the participant completed the PSQ. The next scenario began after a break of approximately 15 minutes. We continued the procedure until the participant completed all four experimental scenarios.

After completion of the experimental scenarios, we all returned to the classroom where the participant completed the PEQ. We then debriefed the participant by further explaining the motivation behind the experiment and answered any questions about the experiment.

3. Data Set Specific Analyses, Results, and Discussions

To keep the background, results, and discussion related to a specific data set in close proximity of one another, we report them under Subsections 3.1 through 3.7. We conducted multivariate analyses of variance (MANOVAs) for ATWIT ratings, performance measures, eye movements, and questionnaires. We tested the Wilks' Λ statistic using a level of $p < .05$. We reported the equivalent F statistic. If the results of the MANOVA were statistically significant ($p < .05$), we performed univariate analyses of variance (ANOVAs) to determine which of the dependent variables were significantly different across experimental conditions. We based the significance of an ANOVA result on an adjusted alpha level using the following formula:

$\text{alpha(overall)} = 1\text{-}(1\text{-alpha(individual)})^{n}$ where n is the number of variables

or:

$\text{alpha(individual)} = 1\text{-}(1\text{-alpha(overall)})^{1/n}$

We reported the adjusted alpha level with each analysis. If the result of an ANOVA was statistically significant, we performed appropriate post hoc tests to determine which conditions were responsible for the significance. Figure 2 depicts an example of the analysis process.

Other researchers have used a more lenient approach when investigating the effects of manipulation on dependent variables by not adjusting the alpha level. Such an approach may inflate the overall alpha level but allows researchers to investigate trends in the data. In the current study, we follow such an approach to investigate trends.

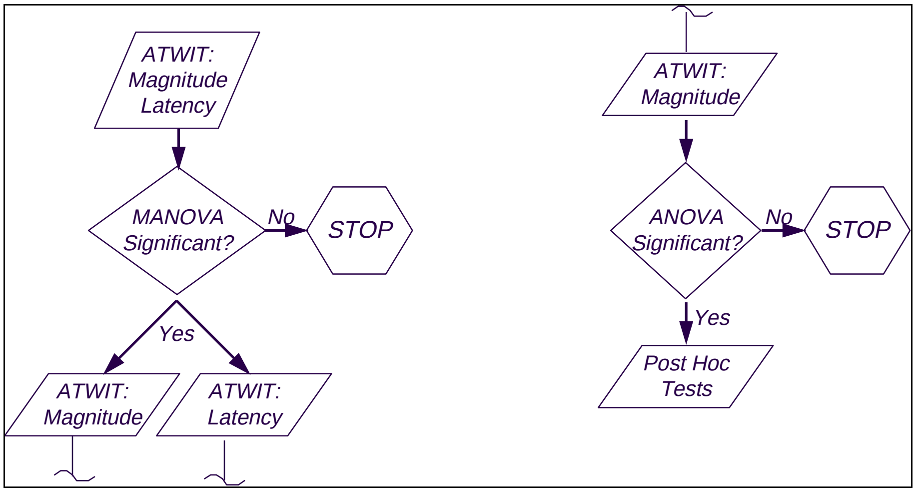

Figure 2. Statistical analysis.

3.1 Eye Movements

3.1.1 Background

Researchers have used eye movements previously to examine behavior within the context of ATC. Stein (1992) defined visual scanning as "a systematic and continuous effort to acquire all necessary visual information in order to build and maintain a complete awareness of activities and situations which may affect the ATCSs area of responsibility" (p. 3). Researchers recognized eye movements as a useful measure for ATC as early as 1975 (Karston, Goldberg, Rood, & Sulzer, 1975). Issues of complexity, cost, and intrusiveness have resulted in few ATC studies using eye movements as a dependent measure (Stein, 1989).

Stein (1992), for example, compared experience (FPL vs. Developmental), taskload (LL vs. HL), and oculometer use (Yes vs. No) in a high fidelity, simulated Terminal Radar Approach Control (TRACON) environment. Results showed that busier ATCSs had shorter and more frequent saccades, and FPLs tended to make more fixations than did Developmentals. Compared to controlling air traffic without the oculometer, wearing the oculometer resulted in more conflicts for the Developmentals but fewer conflicts for the FPLs.

Stein (1992) used three measures of eye movements that are relatively unique: visual efficiency, eye motion workload, and pupil motion workload. Visual efficiency was the proportion of scanning time spent in fixations. Eye motion workload was the average degrees each second that the eyes moved during the course of each scenario. Pupil motion workload was the cumulative difference between pupil diameters for each pair of successive fixations. Results of the experiment found a significant relationship between eye motion workload and performance ratings. Specifically, performance ratings decreased as eye motion workload increased. Stein suggested that the eye motion workload measure is more sensitive to changes in performance than mean number of fixations or saccades alone. Overall, Stein's study provided support for the usefulness of eye movements as a measure of ATCS behavior.

Stern et al. (1994) used eye movement measures and examined the effects of time. They made the important point that looking does not imply seeing, understanding, or remembering. One must extract information from a display and store that information for later use. Stern and colleagues also hypothesized that missed signal detection may be attributed partly to what they termed gaze control inefficiencies (e.g., increases in rates of eye blink, eye closures, saccades, and head movement). Furthermore, using a hypothesis similar to that proposed by Bills (1931), he suggested that blocks (i.e., microsleep or daydreaming) result in attention being diverted away from the primary task. The operator must then attempt to inhibit attending to irrelevant or distracting parts of the environment and maintain focused attention. He proposed that eye movements should reflect any development of eye gaze inefficiency.

In their experiment, Stern et al. (1994) had the participants monitor a low-fidelity radar display simulation. The participants watched for untracked aircraft (aircraft without an associated data block), loss of altitude information from the data block (inoperative transponder), and separation conflicts (aircraft at same altitude). They used electro-oculography in conjunction with a variety of performance measures. Results showed a significant effect of time for numerous eye blink measures such as blink rate, eye-closing duration, 50% window duration, blink flurries, and percent of blinks that were part of a flurry. Additionally, they found a significant decrease in saccade rate and an increase in fixation duration. All of these effects supported the hypothesis than decrements in attention occur over time. This present study used measures related to the characteristics of fixations, saccades, blinks, pupil size, and measures that integrate the eye movement and simulator data.

3.1.2 Results

Appendix H contains detailed information related to visual scanning variables and analysis results. Section H.1 presents the visual scanning variables (Table H-1) and a detailed description of these variables. In Section H.2, Tables H-2 through H-23 contain the full results of the inferential statistical analyses. In Section H.3, Tables H-24 through H-62 contain the results of the descriptive statistics.

3.1.2.1 General Eye Movement Characteristics

Two types of MANOVAs examined changes in visual scanning. The first MANOVA addressed visual scanning differences across scenarios and was a 2 X 2 (involvement X load) repeated measures analysis. The second MANOVA addressed the differences across 5-minute intervals and was a 2 X 2 X 6 repeated-measures MANOVA (involvement X load X interval). For a detailed break down of the dependent variables by load and involvement, see Table 2 and Appendix H.

The analyses of the eye movement data covered four areas. First, the analysis of general eye movement characteristics involved the investigation of the effect of the manipulation of the independent variables on the characteristics of fixations, saccades, blinks, and pupil size. These are basic visual scanning variables. Second, the analysis of fixations across scene planes focused on how the manipulation of the independent variables altered the number and duration of

Table 2. Variables Used to Assess General Eye Movement Characteristics

Variable	Characteristic	Tables in Appendix H
Saccades	Duration, distance, and eye motion workload	H-24 to H-26
Fixations	Number, duration, area, and visual efficiency	H-27 to H-30
Dwells	Number, duration, and area	H-31 to H-33
Blinks	Number and duration	H-34 and H-35
Pupil	Diameter and pupil motion workload	H-36

fixations for each scene plane. Third, the analysis of fixations across radarscope objects looked at manipulating the independent variables on object-based fixation characteristics. Finally, the analysis of the conditional information indices investigated how manipulation of the independent variables alters the structure in the visual scan. Analysis on scenario-based summary variables investigated the effects of manipulation of load and involvement, whereas 5-minute interval-based analyses further investigated the effect of time.

General eye movement characteristics included variables without regard for the scene plane or object at which the ATCS looked (Table 2). The analyses did not include visual efficiency, eye motion workload, and pupil motion workload because an earlier study (Willems et al., in press) demonstrated that these variables were not sensitive to the level of manipulation used in this experiment.

3.1.2.1.1 Scenario-Based Analyses

Using the saccade duration and distance and the fixation number, duration, and distance, the results of the MANOVA indicated that increasing load significantly altered the eye movement characteristics (Table H-2). None of the individual dependent variables related to eye movements showed a significant effect of load or involvement manipulation (Table H-3). However, this is applied research. Using a $p < .01$ and MANOVA is a very conservative approach. Many researchers prefer going directly to ANOVAs and using $p < .05$ as the region for rejecting the null hypothesis. This may produce more significant findings, which reflect Type I error, but it lowers the risk of missing significant differences that should be addressed (Type II error). These are treated below as trends or indicators, whereas others may interpret them as significant differences.

At an alpha level of $p < .05$, the saccade duration showed a trend towards an increase under HL, A conditions (Figure 3). See Table H-24 for a detailed breakdown of saccade duration by load and involvement.

The changes in load and involvement affected none of the other general eye movement characteristics ($p < .01$). Tables H-24 through H-33 present a detailed breakdown of saccade duration and distance, eye motion workload, fixation number, duration, and area, visual scanning efficiency, and dwell number, duration, and area by load and involvement. Note that the analyses only included saccade duration and distance and fixation number, duration, and area.

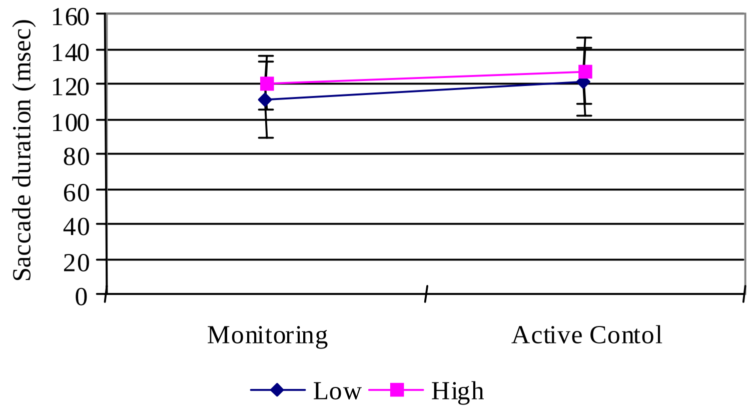

Figure 3. Means and standard deviations of saccade duration by load and involvement.

The second MANOVA indicated that involvement significantly affected the variables often associated with workload and cognitive activity (Table H-4). To maintain an overall alpha level of $p < .05$, the adjusted alpha level was $p < .017$.

None of the individual dependent variables showed an effect of the load or the involvement manipulation (Table H-5). Tables H-34 through H-36 present a detailed breakdown of blink number and duration and pupil diameter by load and involvement.

3.1.2.1.2 Interval-Based Analyses

MANOVAs on interval summary variables investigated the effect of time. The MANOVAs focused on fixation, saccade, and blink and pupil related variables, respectively. For a detailed break down of the dependent variables by load, involvement, and time, see Tables H-24 through H-43.

The MANOVA on fixation-related variables included fixation number, duration, and area and indicated that time significantly affected fixation characteristics (Table H-6). With three dependent variables used in the multivariate analysis, the adjusted alpha level to maintain an overall alpha level of .05 was .017.

The subsequent ANOVAs indicated that time significantly affected all fixation-related variables used in the multivariate analysis (Table H-7). There was a trend visible for the interaction between the effects of load and time on the number of fixations. The fixation duration showed a trend towards an effect of load and marginally for an interaction between the effects of involvement and time. The following paragraphs discuss the effects of time in more detail.

Time significantly affected the number of fixations [$F(1, 15) = 13.825$, $p < .01$)]. Tukey's post hoc HSD test revealed that the number of fixations during the first 5 minutes of the simulations was significantly higher than during subsequent intervals. There was a trend towards an interaction between the effects of load and time. Figure 4 shows that the number of fixations depends on time.

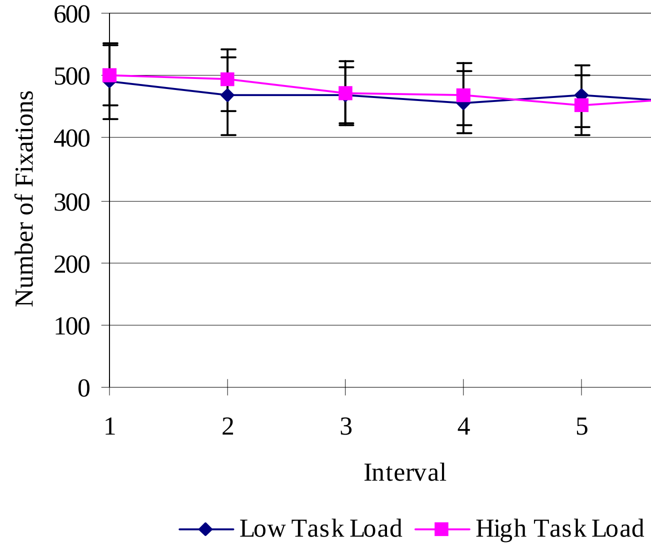

Figure 4. Number of fixations by time and load.

The time also significantly affected the fixation duration [$F(1, 15) = 19.004$, $p < .01$]. Tukey's post hoc HSD test indicated that the fixation duration was significantly shorter during the first 5 minutes of the simulations. There was a trend towards an interaction between the level of involvement and the time (Figure 5). The fixation durations were longer during monitoring than during active control in all but the first 5-minute interval.

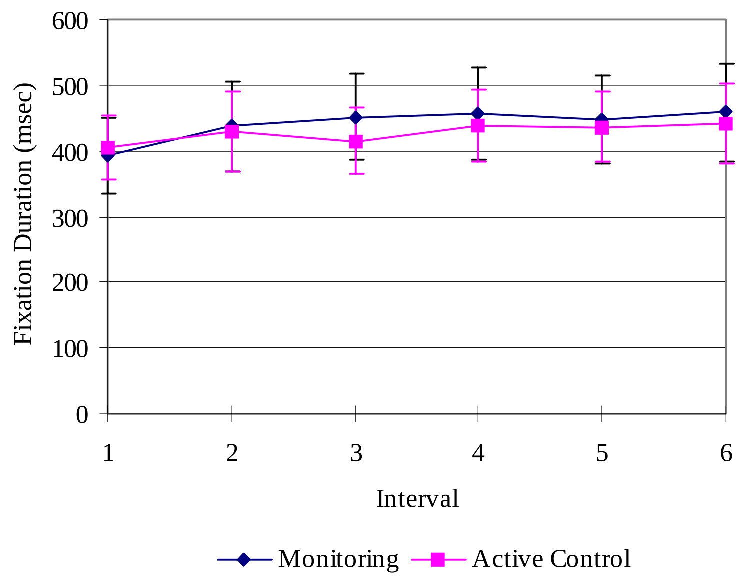

Figure 5. Fixation duration by involvement and time.

Finally, time affected the fixation area significantly [$F(1, 15) = 7.496$, $p < .01$]. Post hoc Tukey HSD tests showed that fixations were more stable (as indicated by a smaller area covered due to small eye movements) in the first 5 minutes of the scenarios than in subsequent 5- minute intervals (Figure 6).

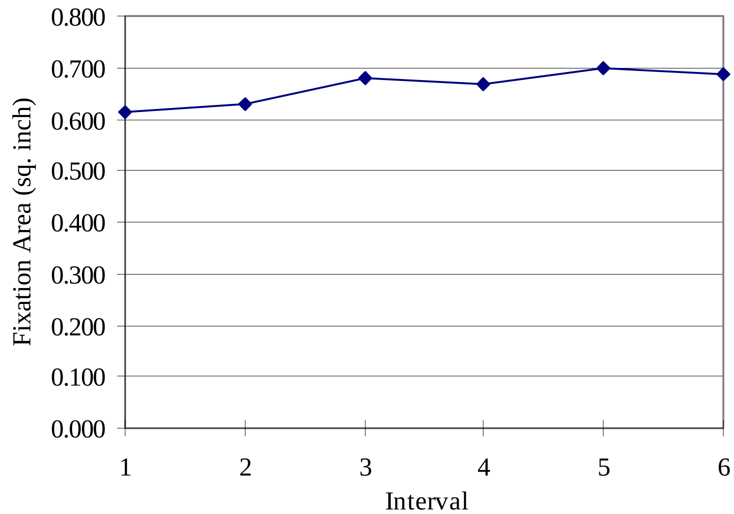

Figure 6. Fixation area by time.

The MANOVA on saccade characteristics included saccade duration and distance and indicated an interaction of the effects of load, involvement and time. It is of little practical value, however, to describe the simple effects of the 3-way interaction. Due to the 3-way interaction, one should investigate the simple main effects and the simple 2-way interactions. To study simple effects, one holds one of the independent variables at a constant level and looks at the main effects and the 2-way interactions of the other independent variables. The reason for investigating the 5-minute intervals is to look at the time dependency of the effects of the two main independent variables, load, and involvement, on the dependent variables. The analysis of simple effects of time investigated the time dependency under each of the four conditions involving load and involvement. The effect of time was significant under the LL, A condition only. Load manipulation significantly affected saccade characteristics during intervals 3 through 5, whereas involvement had an effect during intervals 2 through 4 (Table H-8). To maintain an overall alpha level of .05 for the ANOVAs on saccade duration and distance, the adjusted alpha level was .025.

A 3-way interaction existed for saccade duration (Table H-9). It is of little practical use to describe the simple effects of the 3-way interaction, and we focused on the simple effects of time (Figure 7 and Figure 8). The effect of time was significant during the LL, A, and the HL, M conditions. Load manipulation significantly affected the saccade duration during intervals 3 and 5. Manipulation of involvement affected the saccade duration during intervals 2 through 4 and interval 6. Saccade durations were longer on average for A condition during those segments. Table H-51 displays a detailed breakdown of the values of saccade duration by load, involvement, and time.

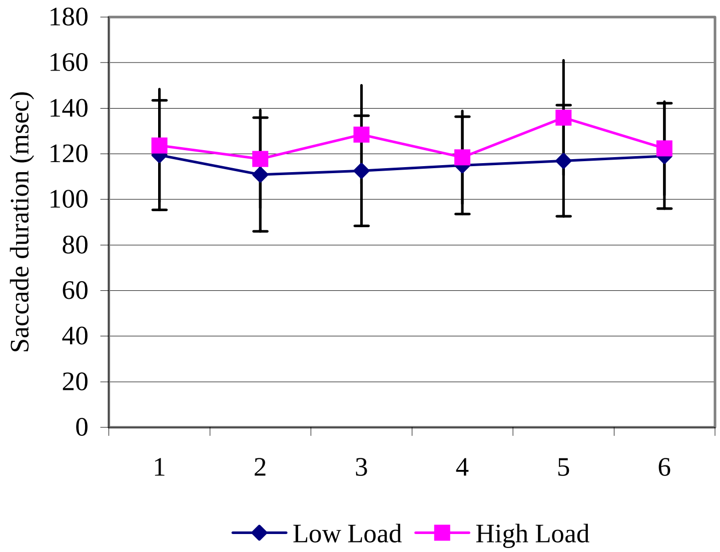

Figure 7. Saccade duration by time and load

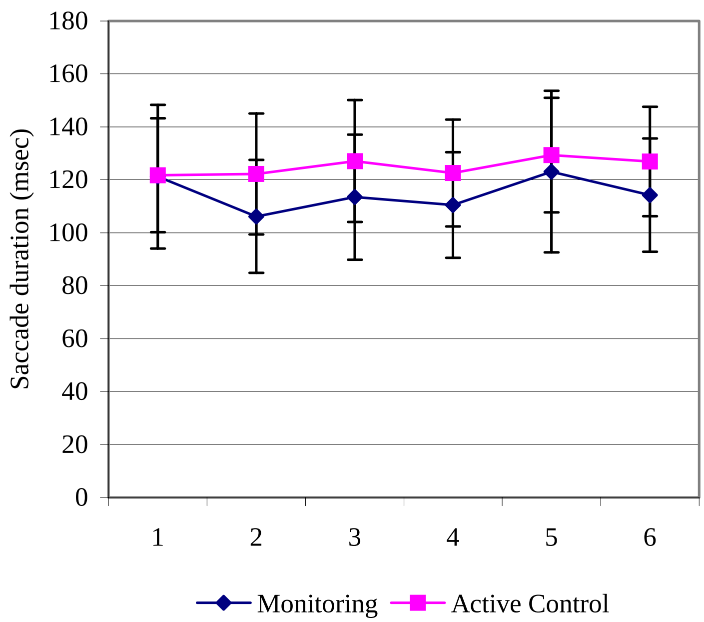

Figure 8. Saccade duration by time involvement.

Only time affected saccade distance (Figure 9, Table H-10). Mean saccade distance changes between intervals, but no trend is visible by time. Keep in mind that the saccade durations were longer during several segments. It appears that ATCSs moved their eyes somewhat slower when actively controlling than when monitoring traffic.

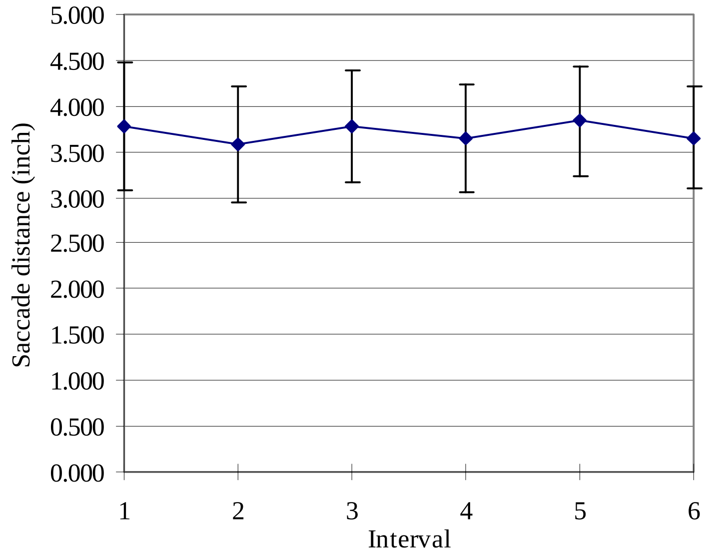

Figure 9. Saccade distance by time.

The MANOVA on blink and pupil characteristics revealed that manipulation of the independent variables did not affect blink number and duration or pupil diameter (Table H-11).

The literature on mental workload indicates that the number of blinks and blink duration may be indicators of the amount of cognitive activity. The current results do not seem to agree with what other researchers have found. The ANOVAs on blink number and duration further investigated the effect of load, involvement, and time. The ANOVA on blink duration did not show a significant effect of time. The plots of blink duration by load and time show, however, that there is a clear separation between the means for the two levels of load. This separation is visible for all 5-minute intervals (Figure 10). Therefore, although the ANOVA does not show a significant difference in blink duration due to load, blink duration still may be a valuable indicator of workload given a large enough number of the participants in an experiment.

<u>3.1.2.2 Scene Planes</u>

The introduction of this new independent variable enabled the analyses of the effects of the independent variables on fixation characteristics distributed across scene planes. The additional independent variable to investigate fixation characteristics by scene plane included eight levels: radarscope, flight strip bay, keyboard, track ball, ATWIT, CRD/QAK, map, and landline.

<u>3.1.2.2.1 Scenario-Based Analyses</u>

For the scenario-based analyses, all scene planes defined in the ATCS work environment formed the levels of the scene plane variable. The dependent variables in these analyses were the number and duration of fixations. The analysis was a 2 X 2 X 8 (load X involvement X scene plane) repeated-measures MANOVA.

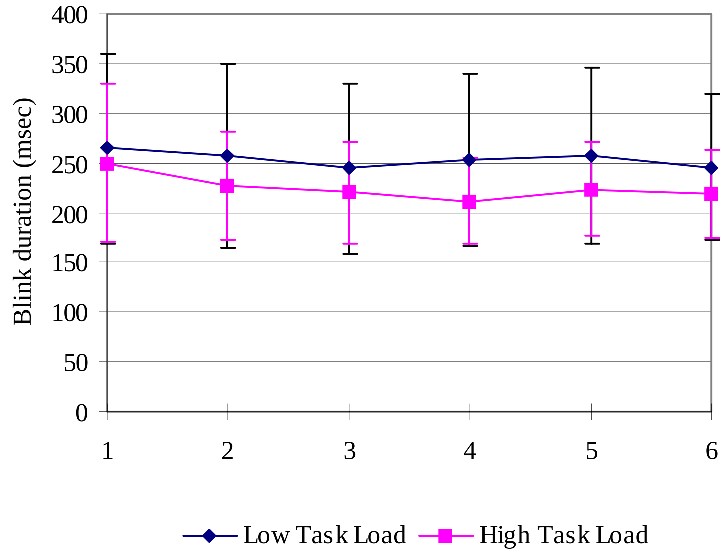

Figure 10. Blink duration by load and time.

None of the independent variables significantly affected the number of fixations (Table H-13). The interaction between the effects of scene plane and involvement on the fixation duration was significant (Table H-14). The simple-effects analyses showed that involvement significantly increased the fixation duration for the CRD/QAK and the map [$F(1, 15) = 33.485$ and $F(1, 15) = 18.707$ respectively, both at $p < .025$, Figure 11]. Tables H-37 and H-38 display a detailed breakdown of the number of fixations and the fixation duration respectively by scene plane by load and involvement.

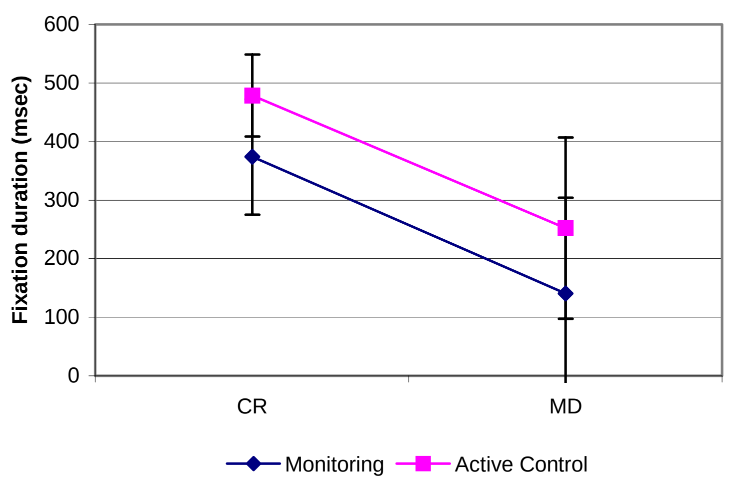

Figure 11. Fixation duration (msec) on the CRD/QAK and the map display by involvement.

3.1.2.2.2 Interval-Based Analyses

The analyses of the effects of time and scene plane on the number and duration of fixations only included the radarscope and flight strip bay as scene planes. The scenario-based analysis had already shown that these two scene planes take up 92% of the number of fixations. The introduction of the time variable increases the number of degrees of freedom needed for further analysis. Limitation of the number of levels of the scene plane variable enabled interval-based analysis. The analysis was a 2 X 2 X 2 X 6 (load X involvement X scene plane X interval) repeated-measures MANOVA.

The MANOVA on the effect of load, involvement, time, and scene plane revealed a 3-way interaction between load, involvement, and time (Table H-15). This interaction does not provide further insight into how the scene plane variable alters the number and duration of fixations. The investigation, therefore, omits the analysis of this interaction. The MANOVA results indicate that the only significant interaction that involves the scene plane variable is between the effects of the scene plane and the time variables [$\Lambda = .027$, $F(10, 6) = 21.454$, $p < .05$]. Univariate analyses of the number and duration of fixations also showed a significant interaction between scene plane and time (Tables H-16 and H-17, respectively). To find differences in fixation characteristics between scene planes is not surprising given the fact that the ATCS priority is on the radarscope. The ATCS furthermore followed the experimental instructions (i.e., the ATWIT device should not interfere with controlling traffic) and, therefore, looked at the ATWIT device only when needed. The simple effects discussed here address the effect of time per scene plane. The interaction between the effects of scene plane and time on the number of fixations per scene plane was significant ($F(1, 15) = 13.036$, $p < .025$).

3.1.2.3 Radar Scope Objects

The radarscope objects included the system area, other static objects, radar returns, and data blocks.

3.1.2.3.1 Scenario-Based Analyses

The MANOVA on the object-based fixations indicated that the load, involvement, and object-independent variables all had significant main effects on the fixation characteristics (Table H-18). The objects used were system area (SY), other static objects (ST), radar return (RR), and data block (DB). The effects of load and involvement were only visible for the fixation duration. The significant effect of object [$\Lambda = .003$, $F(6, 10) = 587.343$, $p < .05$] persisted in the univariate results. ANOVAs on fixation number and duration further investigated the effect of object on fixation characteristics.

The number of fixations varied widely between radarscope objects (Figure 12). A post hoc Tukey HSD test revealed that there was no significant difference between the number of fixations on the system area and other static objects. The number of fixations on the radar returns differed from the number of fixations on the data blocks, the system area, and other static objects. Most fixations had the radar return and the data block as their target. The ATCSs focused only few fixations on the system area and other static objects like airports and intersections. They focused more on data blocks than on radar returns.

Load significantly decreased the fixations duration on the radar scope objects [$F(1, 15) = 22.42$, $p < .05$, Figure 13]. The most pronounced decrease in fixation duration was visible for the fixations on the systems area. Active control also significantly reduced the fixation duration on radarscope objects (Figure 14).

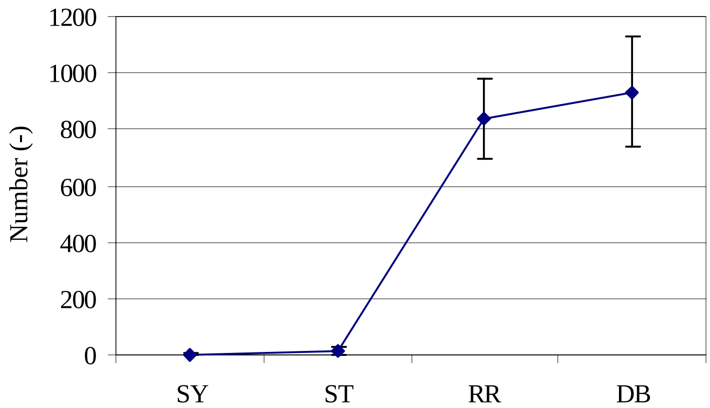

Figure 12. Number of fixations by radar scope object.

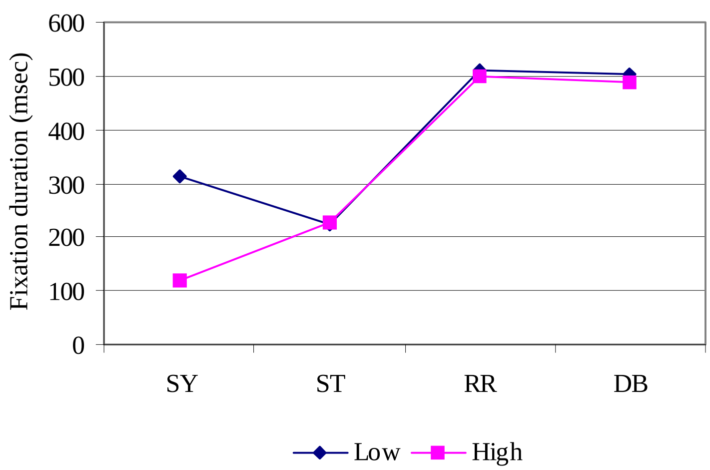

Figure 13. Fixation duration by radarscope objects by load.

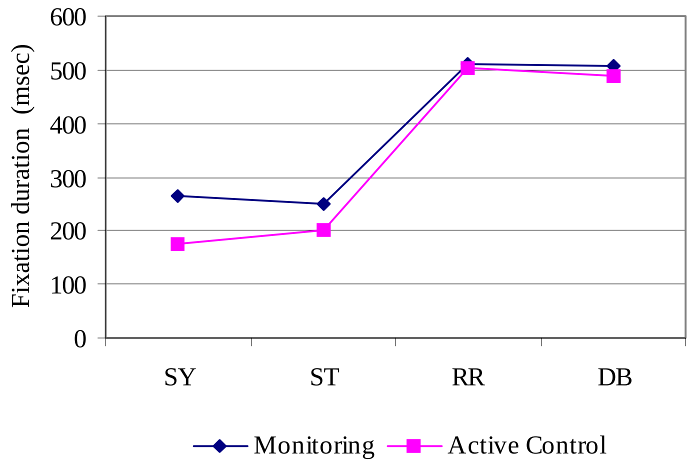

Figure 14. Fixation duration by radarscope object by involvement.

The fixation duration differed significantly depending on the radarscope object on which the ATCS fixated. This result does not come as a surprise. The objects with most relevant and complex information for the ATCS are the radar return and the data block. Figure 15 displays the average fixation durations by radarscope object. The fixation duration on the system area shows a large standard deviation between ATCSs. The number of fixations on the system area is very small in comparison to the number of fixations on the radar returns and data blocks. This may explain some of the variability of the fixation durations. The fixation durations on the radar returns and the data blocks are very similar (i.e., approximately 500 msec). A post hoc Tukey HSD test revealed that the fixation duration divided the four objects into two groups. The first group consisted of the system area and the other static objects with relatively short fixations of approximately 200 msec. The second group consisted of the radar returns and the data blocks with an average fixation duration of 500 msec.

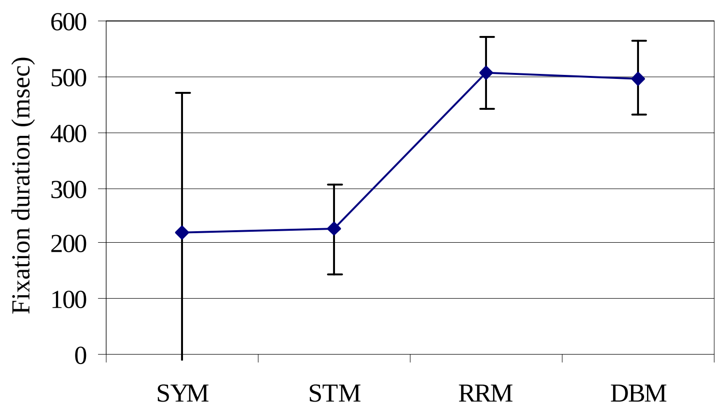

Figure 15. Fixation duration by radar scope object.

3.1.2.3.2 Interval-Based Analyses

The scenario-based analyses had already shown that there were few fixations on other static objects and the system. It had also shown that the duration of fixations on other static objects and the system area were shorter than the fixations on the radar returns and the data blocks. The limited number of fixations on other static objects and the system area would prevent a further breakdown by time. We therefore used the characteristics of fixations on the radar return and the data block as the basis for the interval-based analyses. Given the fact that the aircraft representations carry most of the information relevant to the ATCS, this seems a logical restriction.

We will not discuss interactions or main effects that did not involve the object variable because Section 3.1.2.1.2 presented these results. The object-based analysis of 5-minute interval data singled out fixations on radar returns and data blocks. The MANOVA results (Table H-19) indicated that the effects of load, involvement, and time on fixation characteristics interacted. This 3-way interaction did not involve object variable, and we did not address it further. We have discussed this 3-way interaction effect on fixation characteristics in Section 3.1.2.1.2. The MANOVA results further indicated two 2-way interactions. The first interaction was between load and time. The other interaction involved the effects of involvement and time. We did not discuss these 2-way interactions here because they did not involve the object variable. The main effects of object and time were significant.

The univariate analyses revealed that the main effect of object was significant for the number of fixations [$F(1, 15) = 7.951$, $p < .05$, Tables H-20]. No interactions that involved the object variable reached significance. Section 3.1.2.1.2 presents the effect of time on general fixation characteristics. Therefore, time did not affect the number and duration of fixations on radar returns and data blocks differently.

3.1.2.4 Structure

The probability that an ATCS looks at object B after looking at object A is an indication of the structure or predictability of the visual scan. The transition probability from A to B is the probability of looking at object A followed by looking at object B. These transition probabilities also go by the name of first order Markov elements. The calculation of the conditional information indices uses the probabilities of fixations to fall on two objects in sequence and weighs this with the proportion of fixations on these objects. The conditional information index is an indicator of the level of structure in the visual scan. The conditional information index only looks at a sequence involving two fixations at a time. The indices will have values that increase when the visual scan favors fixations in a certain order. Values closer to zero indicate less structure in the visual scan.

To investigate the existence of preferred sequences of objects, we calculated a conditional information index based on the object target (COB). To investigate the presence of tunnel vision, we calculated a conditional information index based on the distance between fixations (CRA). The probabilities of fixations following fixations that belong to the same distance group form the basis for this measure.

Hilburn, Jorna, Parasuraman, and Byrne (1996) have used entropy in the visual scan based on the transition probabilities between areas on the radarscope. To investigate this approach, we calculated the conditional information index based on the location of the center of the fixation on the radarscope (CBX).

Covering the entire airspace in the visual scan is one of the concerns among ATCSs. We calculated the conditional information index based on the distance between the center of the fixation and the center of the radarscope (CRI). The CRI indicates if ATCSs are more likely to focus on areas at equal distances from the center of the radarscope.

To investigate the effect of load and involvement manipulation, we conducted a 2 X 2 (load X involvement) repeated measures MANOVA. Depending on significant effects of the MANOVA, we conducted ANOVAs on each of the conditional information indices.

The MANOVA showed that load and involvement interacted in their effects on the four conditional information indices [$\Lambda = .156$, $F(4, 12) = 16.172$, $p < .05$, Table H-22. The multivariate simple effects revealed that the effect of load was significant independent of the involvement level [$\Lambda = .306$, $F(4, 12) = 6.816$ for monitoring and $\Lambda = .143$, $F(4, 12) = 17.934$ for active control respectively, both at $p < .05$]. The effect of involvement was only significant under high load conditions [$\Lambda = .104$, $F(4, 12) = 25.734$, $p < .05$].

The COB showed an interaction between the effects of load and involvement (Table H-23). We therefore investigated the simple effects (i.e., the effect of load while holding involvement at either M or A control and vice versa). The effect of load on the structure in the visual scan based on objects was significant under both M and A conditions [$F(1, 15) = 9.947$ and $F(1, 15) = 76.643$ respectively, both at $p < .05$]. The effect of involvement was only significant under high load conditions [$F(1, 15) = 24.556$, $p < .05$].

Figure 16 presents the values for the object-based conditional information index. The structure in the visual scan decreases with an increase in load. Under HL conditions, A control reduces the structure in the visual scan.

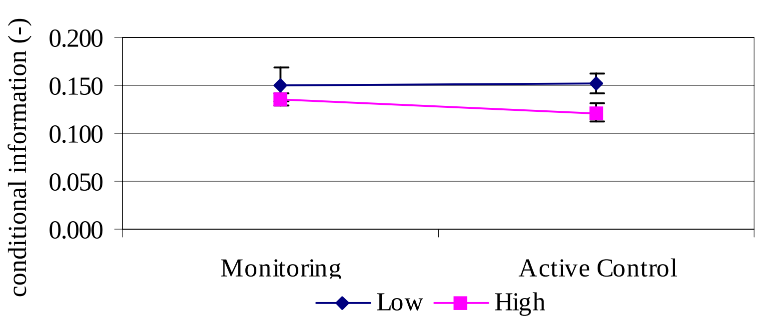

Figure 16. Object-based conditional information index by load and involvement.

The univariate ANOVA indicated that only load had a significant effect on the CRA [$F(1, 15) = 12.802$, $p < .05$]. With an increase in load, the structure increased (Figure 17). Although the CBX indicated that there was more structure in the visual scan when based on position on the radarscope, there was no difference in the CBX due to manipulation of load or involvement levels. The manipulation of load and involvement had no effect on the CRI.

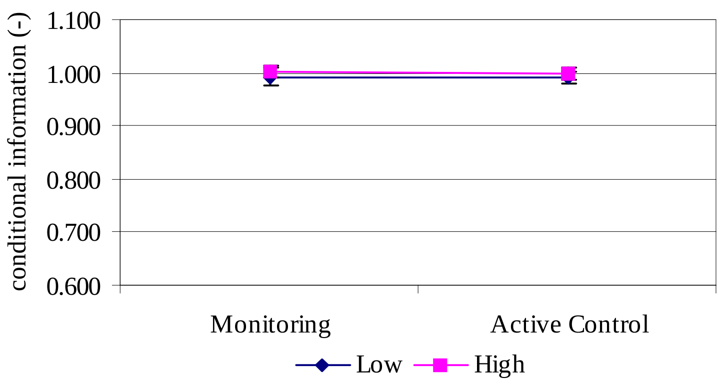

Figure 17. Range-based conditional information index by load and involvement.

3.1.3 Discussion

Manipulation of load and involvement did not affect the general eye movement characteristics significantly. Although the saccades tended to last longer with HL and A control, this is not in correspondence with a saccade distance. The literature on saccade characteristics suggests that saccade duration strongly correlates with saccade distance. The fact that we did not find an effect of the manipulation of our independent variables on saccade distance makes the trend in saccade duration suspect.

Willems et al. (in press) were unable to investigate the effect of time due to a confounding effect of traffic build up in the first 15 minutes of their simulation scenarios. The current study eliminated the confounding effect of traffic build up by providing ATCSs with traffic similar to what they experience during a relief briefing. The data analysis shows that time affects the eye fixation characteristics. During the first 5 minutes of a 30-minute scenario, the ATCS has more fixations that are both shorter and more stable. A possible explanation for this phenomenon is that a considerable amount of verbal information transfer takes place during the relief briefing. The ATCS may not need to retrieve as much information from the radarscope during the first 5 minutes than during subsequent intervals while building an internalized model or picture.

Time affected the saccade duration during LL, A and HL, M conditions only. Although time alters the saccade distance, there is no consistent trend visible towards an increase or a decrease in distance.

The ATCSs spent most of their fixations on the radarscope and the flight strip bay. The A condition increased the duration of fixations on the CRD/QAK and the map significantly. Given the priorities of the ATCSs, it is not surprising to find differences in the number and duration of fixations depending on the scene plane.

Most of the fixations on the radarscope focused on the radar return and the data block. Increasing load resulted in shorter fixations on radarscope objects. Under M conditions, the fixations were shorter than under A conditions. Willems et al. (in press) suggest that longer fixations indicate more cognitive processing. The results, therefore, indicate that, under HL, less processing takes place during a fixation on an individual target than under LL. Similarly, under A conditions, more processing takes place than under M conditions.

To determine the structure in the visual scan, we have used four indices derived from the conditional information index. Ellis and Stark (1986) first introduced the conditional information index. This index indicates the predictability of the visual scan. If the visual scan is completely random, the conditional information index is equal to zero. We can see differences between the conditional information indices depending on what forms the basis for the calculations. If one calculates the transition probabilities between locations on the radarscope, there seems to be more structure in the visual scan. The structure in the airspace is mostly responsible for this result. It indicates that it is very likely that an ATCS searches the radarscope in a pattern based on location on the scope rather than sequences of aircraft or distances between fixations. There is, however, no difference in the radarscope position based on the conditional information index between conditions. Under HL, the distribution of fixations between radarscope objects was more random than under LL. The A condition increased the randomness in the visual scan only under the HL conditions. Under HL, ATCSs were less likely to follow a pattern of fixations based on the distance between fixations.

3.2 Air Traffic Workload Input Technique

3.2.1 Background

In this research, we used the ATWIT to study the ATCS perceived workload. Stein (1985) first introduced ATWIT, which is an online measure that requires ATCSs to indicate, at set times, their perception of their current workload. ATWIT is, therefore, an instantaneous probe that investigates overall perceived workload. Contrary to the NASA Task Load Index (TLX) (Hart & Staveland, 1988), for example, the participants do not need to break down their workload by origin. Another advantage of the ATWIT over post-scenario ratings of workload is that ATWIT asks for input during the simulation instead of relying on ATCS memory during the scenario.

3.2.2 Results

For the analyses of the online workload measure used in this study, we used both the workload rating and the latency. See the tables in Appendix I for details of these analyses. The latency indicates how long it took an ATCS to respond to the ATWIT device. We analyzed ATWIT latencies and ratings with a 2 X 2 X 6 (load X involvement X interval) repeated-measures MANOVA. Significant interactions were found for load X involvement [$F(2, 14) = 24.65$, $p < .05$], load X interval [$F(10, 6) = 6.34$, $p < .05$], and involvement X interval [$F(10, 6) = 15.52$, $p < .05$]. We further investigated the significant interactions with an ANOVA procedure. The first set of ANOVAs examined the load X involvement interaction for ATWIT latency.

The MANOVA on ATWIT rating and latency by load, involvement, and time indicated that the effects of the independent variables interacted in pairs. The 3-way interaction was not statistically significant. Load only affected the ATWIT characteristics under A conditions [$\Lambda = .148$, $F(2, 14) = 40.359$, $p < .05$, Table I-1]. Load affected the ATWIT characteristics throughout the six 5-minute intervals. Involvement affected the ATWIT characteristics under both LL and HL conditions [$\Lambda = .442$, $F(2, 14) = 8.837$ and $\Lambda = .131$, $F(2, 14) = 46.296$ respectively, both at $p < .05$, Table I-1]. Involvement also affected the ATWIT characteristics throughout the six 5-minute intervals.

Figure 18 and Table I-4 present the means and SDs of ATWIT ratings across load, involvement, and time levels. All 2-way interactions were significant for the ATWIT rating. We used simple effects to investigate when ATWIT ratings differed. Although the 3-way interaction was not significant, Table I-4 provides a breakdown of the ATWIT ratings by conditions.

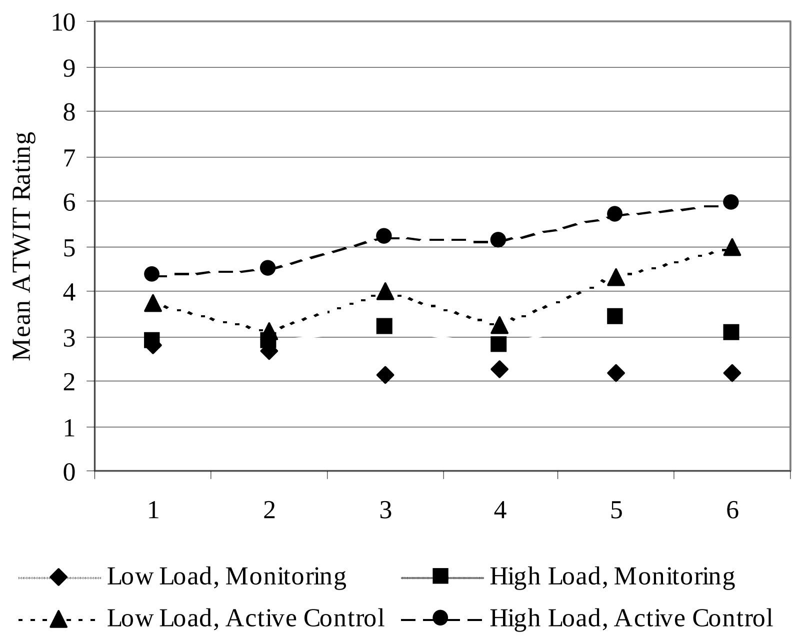

Figure 18. ATWIT ratings by load, involvement, and time.

Increasing load caused an increase in the average ATWIT rating under both M and A conditions [$F(1, 15) = 6.882$ and $F(1, 15) = 74.447$ respectively, both at $p < .05$, Table I-2 and Figure 19]. Active condition scenarios received higher ATWIT ratings than monitoring conditions under LL and HL conditions [$F(1, 15) = 18.855$ and $F(1, 15) = 95.018$ respectively, both at $p < .05$]. The increase in workload estimates due to an increase in load was higher under A conditions than M conditions.

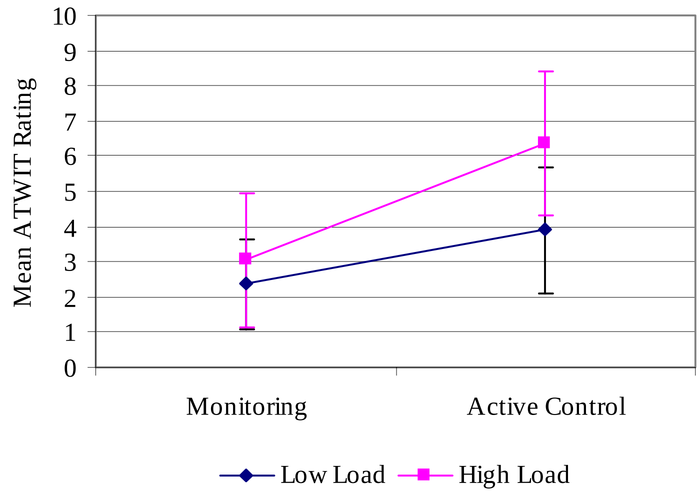

Figure 19. ATWIT ratings: Means and SDs by load and involvement.

The effect of load on the ATWIT rating interacted with the time variable [$F(1, 15) = 4.900$, $p < .05$, Table I-2]. For all intervals, an increase in load led to an increase in perceived workload (Figure 20). As the figure indicates, there was a large variability in ratings between ATCSs. It is also clear that the ATCSs felt that the scenarios were causing only moderate workload.

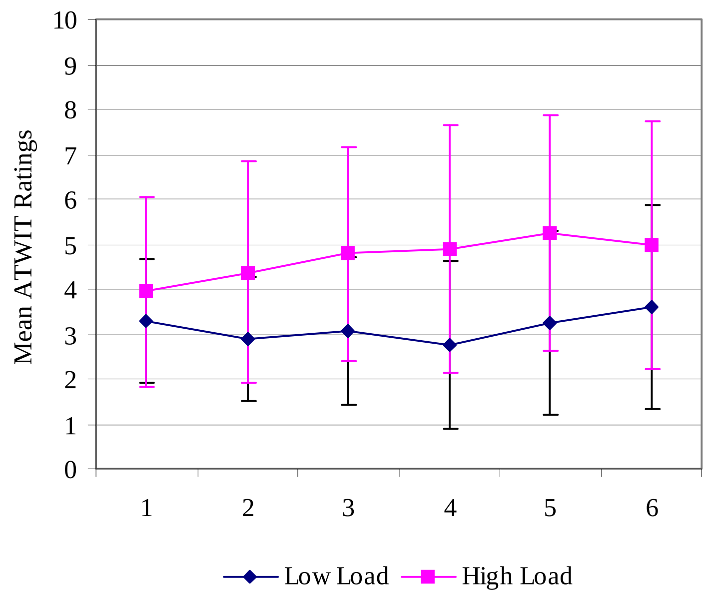

Figure 20. ATWIT ratings: Means and SDs by load and time.

The effect of involvement and time interacted [$F(1, 15) = 13.180$, $p < .05$, Table I-2]. ATCSs rated the perceived workload higher under A conditions. Under M conditions, the workload remained constant over time. Under A conditions, the workload slowly increases over time (Figure 21).

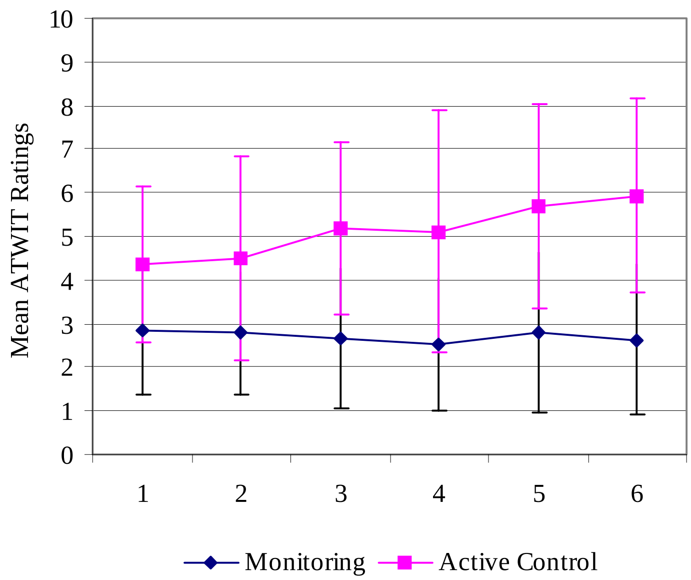

Figure 21. ATWIT ratings: Means and SDs by involvement and time.

Only involvement had a significant effect on the ATWIT latency [$F(1, 15) = 6.574$, $p < .05$, Table I-3]. The ATCSs took longer to respond to the ATWIT under A conditions than under M conditions (Figure 22).

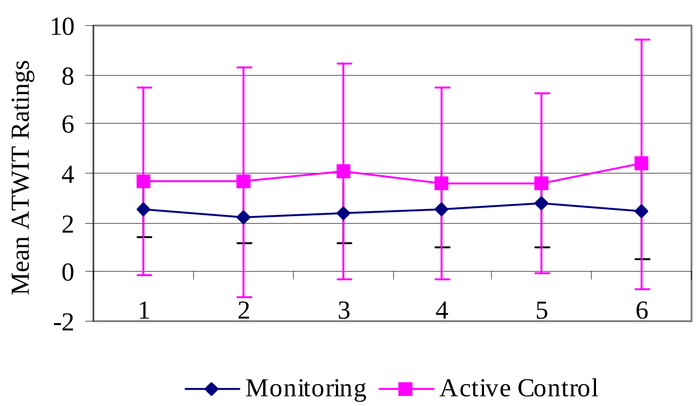

Figure 22. ATWIT latency by involvement and time.

3.2.3 Discussion

ATCSs estimated their workload every 5 minutes. The instructions to the participants were very specific as to how we expected them to respond, emphasizing that the workload estimate should be instantaneous. The instructions also reinforced that estimated workload was not equivalent to load. The instructions provided the participants with clear anchors for several levels of workload, all related to being able to complete the tasks at hand.

The effect of increasing load and changing the level of involvement interacted with time. The participants indicated that their workload was higher under HL. Perceived workload was also higher under A conditions. The ATCSs did not perceive the HL as producing high workload. Even for the HL, A scenario, the average ATWIT rating was approximately 6 on a 10-point scale. During the development of the simulation scenarios, the SME had indicated that this scenario would produce a high workload. There are at least two possible explanations for this result. First, ATCSs often underestimate their workload. The ATCSs have a “can do” attitude that has helped them survive in the current ATC system. Underestimation may have contributed to the lower than expected workload estimates. The ATWIT ratings indicated that ATCSs only perceived a moderate workload. A second explanation may lie in the composition of the generic en route airspace that we used in this experiment. To allow ATCSs to familiarize themselves with the airspace quickly, we built a simple airspace. Although our SME indicated that the load was high, this may have related to the level of traffic more than expected workload due to the combined airspace and traffic load.

Under M conditions, the estimated workload was constant over time. Under A conditions, the estimated workload slowly increased over time. This result would favor the M conditions because it seems to eliminate the effect of time on perceived workload.

3.3 Situation Presence Assessment Method

3.3.1 Background

Unlike eye movements in ATC, a considerable amount of research effort has recently focused on SA in dynamic systems. Although varied definitions have been proposed to capture the essence of SA (Endsley, 1988; Fracker, 1989; Mogford, 1994; Pew, 1994), there is currently no agreed upon definition. Tolk and Keether (1982) thought of it as the ability to envision the current and future disposition of both red and blue aircraft and surface threats. Endsley’s definition of SA is more general and widely cited: “...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p. 3). Regardless of which definition is used, most researchers agree that the perception and understanding of elements in the present situation is an important process in maintaining SA. Furthermore, one must use this information to predict and anticipate future events.

The researchers have also used many different methods to measure how operators develop and maintain SA. The gamut of SA measures includes both subjective and objective techniques. Previously employed measures include physiological measures such as eye movements (Moray & Rotenberg, 1989; Wierwille & Eggemeier, 1993), verbal protocol analysis (Ohnemus & Biers, 1993; Sullivan & Blackman, 1991), retrospective recall (de Groot, 1965; Kibbe, 1988), rating techniques (Reid & Nygren, 1988; Taylor, 1990), memory probes (Endsley, 1988), and on-line queries (Durso et al., 1995). Most of these techniques have demonstrated some degree of validity and usefulness.

The current experiment took place within the realm of a high fidelity, simulated ATC environment. The technique to assess SA was the SPAM (Durso et al., 1995). SPAM provided a means to assess SA without disrupting or otherwise significantly changing the ATC task as performed in the field. Initially validated in an experiment using chess players as the participants, SPAM allowed the presentation of queries using a landline. Thus, the participants answered queries in the SPAM just as they would when coordinating activities between their sector and other adjacent sectors or facilities.

SPAM does not require freezing or stopping the scenario to collect data. Researchers have criticized techniques that assess SA by freezing the simulation like the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988) for its intrusiveness and possible task-altering qualities (Sarter & Woods, 1991). Furthermore, such techniques use memory probes that require the participant to recall information to provide a response. Proportion correct serves as the dependent measure in memory probes like SAGAT. On the other hand, the SPAM technique allows the participants to use all information available to them because it does not freeze the scenario. Rather than assessing memory in and of itself, SPAM assesses the participant ability to find or extrapolate information from the environment and, hence, response time (RT) is the dependent measure. The distinction between SAGAT and SPAM is an important one, especially when considering tasks where memory for verbatim information is not critical and may be detrimental to performance (Bisseret, 1971; Gronlund et al., 1996).

3.3.2 Results

We conducted three separate analyses on the data collected from the SPAM. See the tables in Appendix J for details of these analyses. The first analysis examined the time it took the participants to answer the ringing landline. This landline latency measure served as a secondary workload probe. We investigated the effect of the independent variables and the type of question with a 2 X 2 X 2 (load X involvement X question type) repeated-measures ANOVA.

The ANOVA resulted in a significant load X involvement interaction [$\boldsymbol{F}(1, 47) = 17.47$, $p < .05$]. There was no effect of either load or question type. Simple-effects ANOVAs revealed that the load X involvement interaction was due to load within the A condition [$F(1, 47) = 15.91$, $p < .05$] and involvement within the HL condition [$F(1, 47) = 87.52$, $p < .05$, Table J-1].

The second analysis concerned the time it took us to query the participant. We conducted a 2 X 2 X 2 (load X involvement X question type) repeated-measures ANOVA to ensure that queries were of equal length in all conditions. We found no significant effects (Table J-2). Therefore, the mean length of the queries was equivalent during all conditions. This finding is important because it suggests that the participants did not have more or less time to consider a query during any particular condition.

The third analysis of the SPAM data addressed the main intent of the SPAM measure (e.g., to determine the quality of SA under various conditions). Reaction time to answer the SPAM showed a significant 3-way interaction between load, involvement, and question type [$F(1, 47) = 12.75$, all at $p < .05$, Table J-3]. To interpret the results, we investigated simple effects broken down by type of question.

The simple-effects analysis of the present questions indicated an interaction between load and involvement. To investigate the effects on the RT, we conducted simple-simple analyses where we dealt with three independent variables. We held the first independent variable (the type of question) constant. Subsequently, we held a second independent variable (load or involvement) constant and looked at the effect of the third independent variable. The results indicated that, for the present questions, the effect of load was only significant under M conditions [$F(1, 47) = 20.568$, $p < .05$, Table J-4]. The effect of involvement was only significant under HL [$F(1, 47) = 26.847$, $p < .05$, Table J-4.

The HL, M condition drives the 3-way interaction (Figure 23). The result suggests that the participants maintained an equal level of SA in all conditions except one. When the participants were monitoring a busy scenario, they had relatively worse SA for present information. In fact, it took the participants twice as long to answer queries about present information under the HL, M condition than under the other three conditions. The simple-effects analysis of the future questions revealed no effects of the independent variables on the RT (Table J-5).

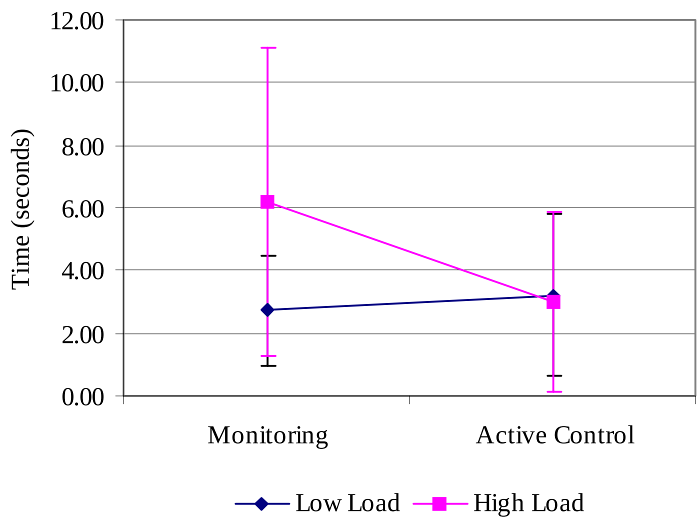

Figure 23. SPAM response time to present questions by load and involvement.

3.3.3 Discussion

The analyses of time to answer the landline indicated that the mean RT to answer the landline in A conditions was longer than in M conditions. In A conditions, mean RT to answer the landline was longer when load was high. Load did not affect mean RT to answer the landline under M conditions. Involvement did not have an effect on mean RT to answer the landline in LL conditions but did have an effect in HL conditions. Under HL, mean RT was longer when the participant was actively controlling the scenario. Assuming that mean RT to answer the landline increases with workload, the results support the finding that workload was higher during A conditions than during M conditions. Additionally, the results support the effectiveness of load manipulations within the A condition in that mean RT was longer under HL than under LL.

We found no significant changes in the mean length of the queries. This finding is important because it suggests that the participants did not have more or less time to consider a query during any particular condition. The results suggest that active participation is important for maintaining SA when load (e.g., scenario complexity) is high.

3.4 Real-Time Objective Performance

3.4.1 Background

In response to the need for new tools to evaluate proposed changes to the ATC system, the FAA has developed methods and measurements in real-time ATC. The DR&A program incorporates the calculations of most of the variables presented by Buckley, DeBaryshe, Hitchner, & Kohn (1983).

3.4.2 Results

This experiment tested the effect of two levels of involvement on ATCS performance and behavior. See the tables in Appendix K for detailed descriptions of the analysis.

During A conditions, the RTOP variables are an indication of ATCS performance related to conflicts, complexity, handoff efficiency, and communications. For the simulation scenarios used for the M conditions, we had recorded traffic controlled by the SME. ATCSs observed these scenarios and answered the landline but did not communicate with the simulation pilots nor did they need to interact with the PVD and CRD. The RTOP variables under M conditions, therefore, merely reflected the performance of the SME that had controlled the recorded traffic. The comparison of the RTOP variables across involvement levels would result in comparing the participant performance with the SME performance. Because the intent of this experiment was to compare performance and behavior of the same ATCS across conditions, we limited the analyses to the comparison between load levels for the A condition only. We investigated the effect of load under the A condition on a subset of the RTOP variables. The variables included in the analysis consisted of three categories: PTT, aircraft changes, and distance and time under control. To obtain information about how load affected ATCS actions per aircraft, we calculated the total number of a particular type of action divided by an estimate of the total number of aircraft handled by the ATCS. For example, the number of altitude changes is calculated as the total number of altitude changes made to an aircraft under control of ATCS A plus the number of changes made under control of ATCS B. This is then divided by the number of aircraft handled by ATCS B. In this manner, we were able to circumvent the problem of finding trivial results due to the changes made in the number of aircraft in the airspace to change the load.

The results indicated that the changes made to an aircraft flight path differed significantly between the LL and HL levels [$\Lambda = .074$, $F(2, 14) = 87.291$, $p < .05$, Table K-2]. The univariate analysis of the number of altitude, heading, and speed changes per aircraft showed that only the number of altitude changes per aircraft increased significantly with load [$F(1, 15) = 14.352$, $p < .05$, Table K-3].

3.4.3 Discussion

After correction for the number of aircraft handled by the ATCSs, there were only minimal differences in variables derived from the DRA between low and high load conditions. The load increase resulted in an increase in the number of altitude changes per aircraft. ATCSs use more control instructions per aircraft to move aircraft through their airspace when load increases. It seems that the increase in load affects ATCS ability to plan. ATCSs, therefore, need to use more control instruction to maintain a safe and expeditious flow of traffic.

3.5 Subject Matter Expert Rating Forms

3.5.1 Background

In our simulations, we use subject matter expertise and knowledge to evaluate the performance of participating ATCSs. To record the evaluations, we used an OTS rating technique developed at the RDHFL. Several other studies have used the OTS form successfully (e.g., Guttman et al., 1995; Sollenberger & Stein, 1995). We adapted the rating form for easier use by the SME. SMEs in our study used a form that contained rating items and anchors and a separate comment sheet. They received training on how to use the evaluation form and how to anchor their ratings.

3.5.2 Results

The following descriptive summary provides an overview of the observer data. Because the M conditions provided little observable behavior for an SME to anchor the ratings, we did not require them to fill out a rating form for these conditions. The tables in Appendix L provide the means and standard deviations for the rating form ratings by load.

3.5.2.1 Providing ATC Information

Load reduced the OTS rating of Providing ATC Information. All three elements of the ATC information section showed a lower OTS rating for the LL conditions (Figure 24).

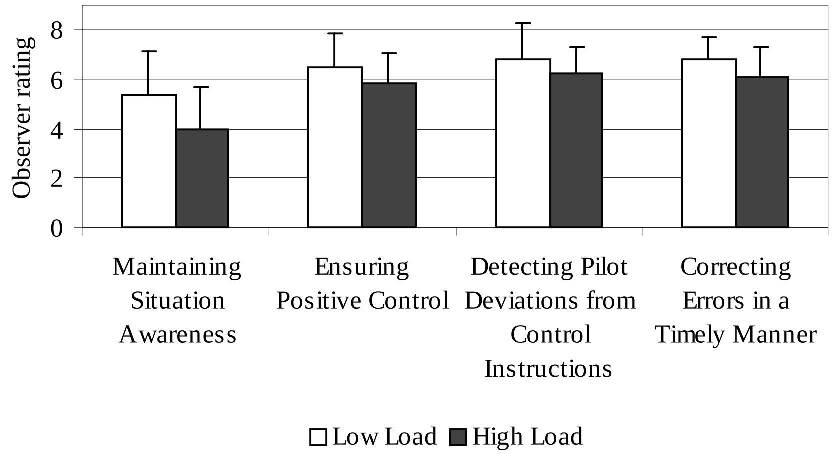

Figure 24. Providing ATC information by load.

3.5.2.2 Prioritizing

The SMEs rated items related to Prioritizing lower with an increase in load (Figure 25). The results showed that ATCSs better organized their actions in order of importance under LL. Raters perceived that ATCSs preplanned control actions less under HL. ATCSs handled control tasks for several aircraft better under LL conditions. With an increase in load, ATCSs flight strip marking decreased.

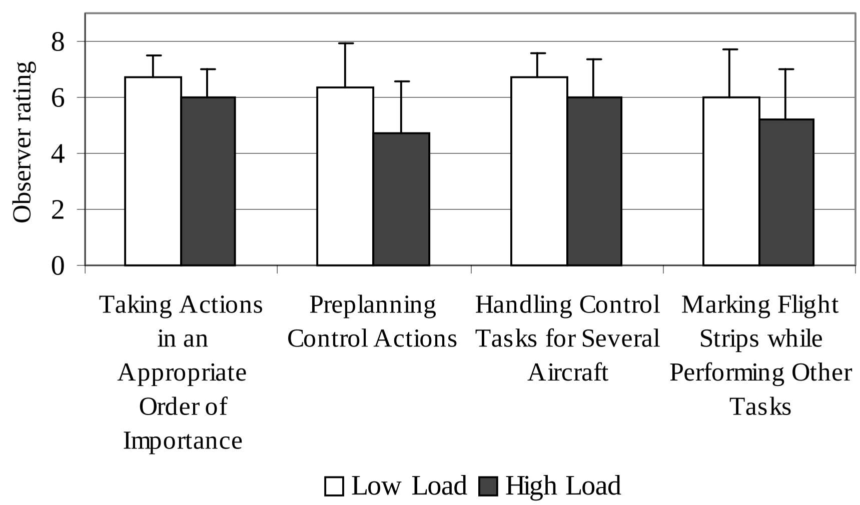

Figure 25. Prioritizing by load.

3.5.2.3 Attention and SA

The SMEs indicated that all items related to ATCSs Attention and SA were lower under HL conditions than under LL conditions (Figure 26).

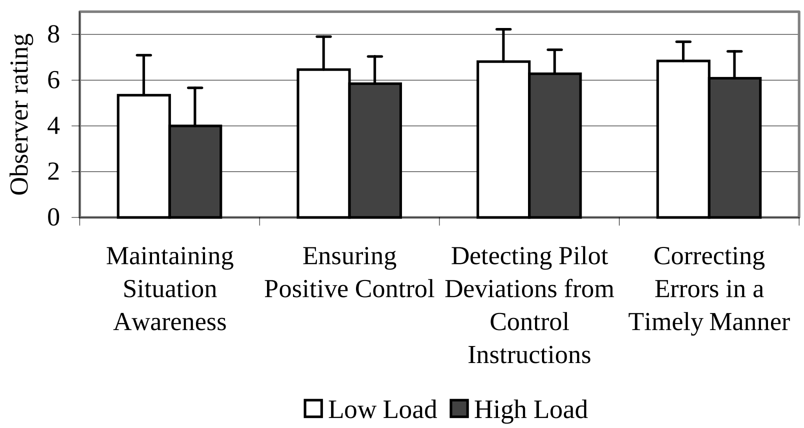

Figure 26. Attention and situation awareness by load.

3.5.2.4 Safe and Efficient Traffic Flow

The SMEs rated the items related to Safe and Efficient Traffic Flow lower under HL conditions (Figure 27). At first glance, it seems that ATCSs efficient sequencing of arrival and departure aircraft does not change with an increase in load.

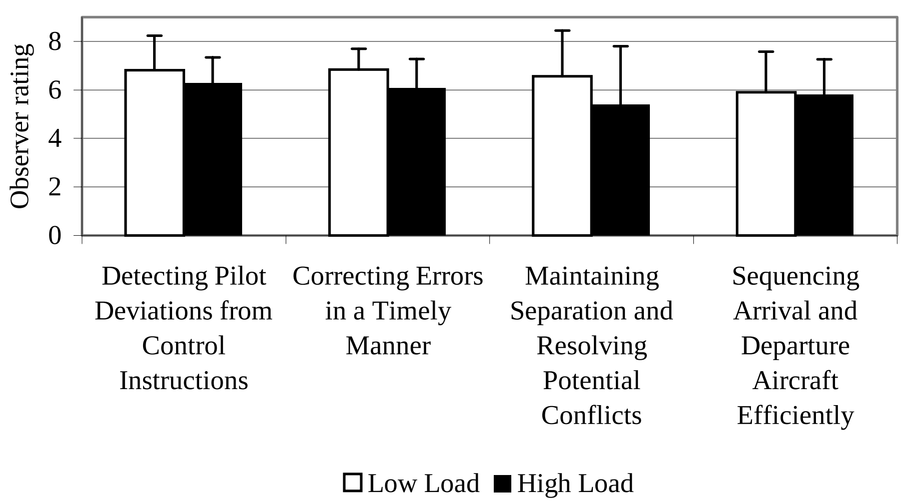

Figure 27. Safe and efficient traffic flow by load.

3.5.2.5 Communications

The SMEs rated most items related to Communications lower under HL conditions (Figure 28). There was a trend visible for a reduction in how clear ATCSs communicated with an increase in load. Load also reduced how well ATCSs listened to pilot readbacks and requests. The increase in load did not seem to affect the use of proper phraseology.

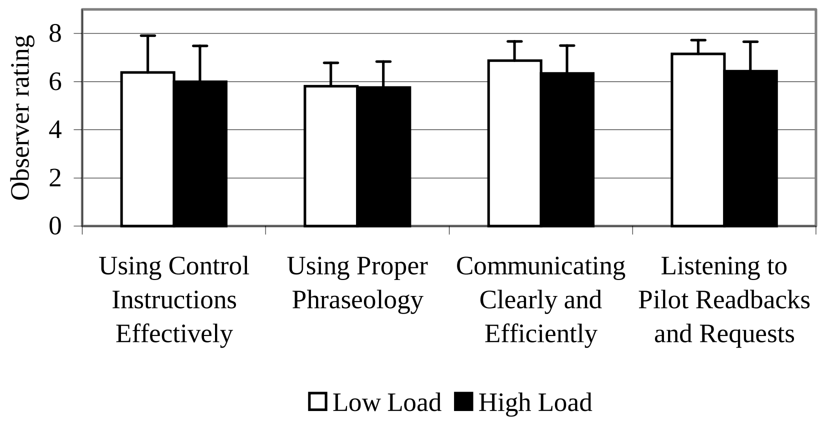

Figure 28. Communications by load.

3.5.2.6 Technical Knowledge

An increase in load affected all items related to Technical Knowledge (Figure 29). The SMEs rated items on knowledge of LOAs and SOPs and aircraft capabilities and limitations lower with increase in load. They indicated that ATCSs used the equipment less effectively with an increase in load.

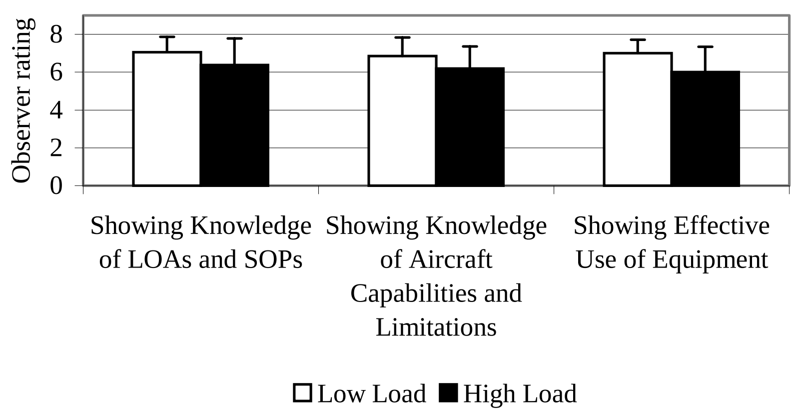

Figure 29. Technical knowledge by load.

3.5.3 Discussion

Both SMEs found that ATCSs provided adequate ATC information under both load conditions. Although the formal analyses did not show an effect of the manipulation of load, the data showed a tendency towards lower ratings of the provision of information under HL. The ATCSs seem to compromise the quality of the information provided to pilots and other ATCSs under HL. Providing this information requires the allocation of some of the ATCS resources. The ATCSs rated the simulations to have only moderate levels of workload. Under higher workload conditions, the ATCS information services may suffer more seriously.

Although the information provided to pilots and other ATCSs did not suffer from an increase in load, ATCSs prioritization did. They organized their actions in a way that conformed less to the level of action priority. This finding went hand in hand with a decrease in the quality of preplanning of control actions with an increase in load. It is likely that, due to a break down in maintaining the bigger picture, ATCSs were less efficient in preplanning their control actions. The loss of efficiency in preplanning control actions in turn may have led to not executing control actions in order of priority.

The rating form data indicated that the increase in load led to a reduction in SA. Increasing load seems to affect the ATCS ability to see the bigger picture, or it causes them to be less aware of the developing situation. In fact, under HL, both raters indicated that the ATCSs had less than average SA. This occurred during scenarios that, according to the ATCSs, caused only moderate workload. The SMEs perceived that ATCSs corrected errors less well under HL.

An ATCS primary responsibility is to maintain safe and efficient traffic flow at all times. The rating form data in the current study indicated that the participants did this for both levels of load.

Our formal analyses showed no difference in the quality of communications as rated by the SMEs by load. There was, however, a trend towards a reduction in the quality of communications because of an increase in load.

The SMEs perceived a reduction in Technical Knowledge with an increase in load. It is not likely that the ATCSs actually had less technical knowledge. Instead, it is more likely that under HL, the ATCSs were less able to apply this knowledge.

Overall, observers rated performance somewhat lower under HL. This is a common finding and may well reflect a component of observer expectations and possible true variance of lower performance under HL. It is not possible to separate these components at this time.

3.6 Recall

3.6.1 Background

The transition to Free Flight can also affect representation in memory. As suggested by Hopkin (1988), the lack of active participation can have adverse effects on the maintenance of information in memory. Several studies have examined the role of memory in ATC. Bisseret (1971) examined ATCS recall across various levels of expertise and load. Results indicated that future states of aircraft were an important aspect of the ATCSs memory representations. Evidence for implicit momentum (Finke, Freyd, & Shyi, 1986; Finke & Shyi, 1988) was found. ATCSs recalled aircraft position as being forward of the actual position. In addition to the importance of future states, recall errors provided evidence that ATCSs stored gist (relative) information in memory as opposed to verbatim information. Gronlund et al. (1996) found that, whereas ATCSs were not very good at recalling specific information such as altitude and speed, they were able to correctly recall the relational associations between aircraft. For example, although the participants could not remember the exact altitude of aircraft A or B, they knew that aircraft A was higher or not at the same altitude as aircraft B.

Gronlund et al. (1996) also examined how ATCSs represent information in memory by looking for evidence of “chunking.” In a procedure similar to that used by de Groot (1965) and Chase and Simon (1973a, b), they examined how ATCSs recalled information over time. With the hypothesis that ATCSs store items with related information in chunks, short bursts of recall activity would indicate chunking because items in the same chunk would cue one another. Longer pauses between recalled items would suggest that the previously recalled item did not serve as a cue for the following item, and memory cues were available from elsewhere (Gronlund & Shiffrin, 1986; Ratcliff & McCoon, 1978).

Means et al. (1988) conducted similar research. They too did not find much evidence for chunking because ATCSs had very few chunks that contained very few aircraft. However, both Means et al. and Gronlund et al. (1996) asked ATCSs to recall the airspace and aircraft by writing the information on a piece of paper. Whereas this method provided some data about what information is most important, neither study was able to fully support the chunking hypothesis. Means et al. asked the participants to circle aircraft that they thought belonged to a group. They based their measure of chunk size solely on the participants subjective perception of what a chunk was. Gronlund et al. used a timing method similar to Chase & Simon (1973a, b) and failed to adequately measure chunk size. In the Gronlund et al. study, it took too long for the participants to recall and write the contents of their memory on the paper map. The long recall times may have resulted in a very insensitive measure of boundaries between chunks, if such chunks existed.

3.6.2 Results

The analysis of the recall data consisted of a 2 X 2 (load X involvement) repeated-measures ANOVA. The tables in Appendix M detail these analyses.

Both load and involvement [$F(1, 12) = 24.77$ and 5.93 respectively, both at $p < .05$, Table M-1] affected the participants ability to recall aircraft at the end of each scenario. There was no significant load X involvement interaction (Figure 30). The participants correctly recalled a greater proportion of aircraft under A conditions than under M conditions. Proportion-correct recall was also greater under LL than under HL.

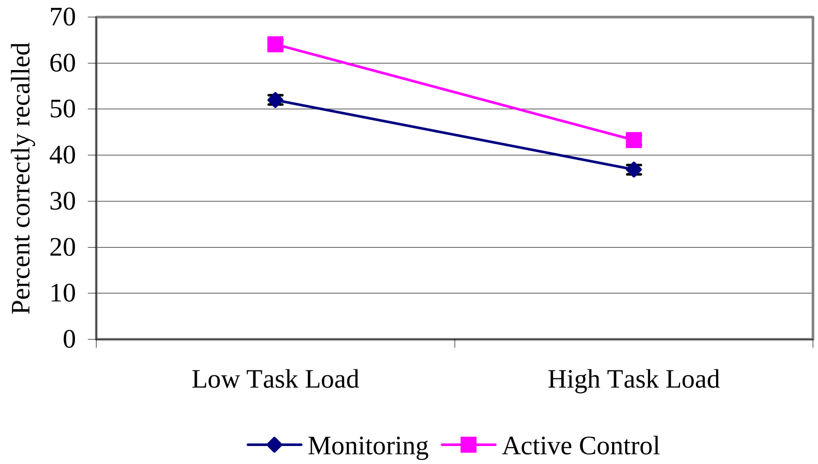

Figure 30. Percent correct recall by load and involvement.

3.6.3 Discussion

The fact that the participants recalled more after being actively involved in a scenario suggests a deeper level of processing. This result concurs with data collected using SPAM (see Section 3.3). When the participants monitored the scenario, they may not have been as motivated to develop complex plans of traffic flow. The participants knew that even if they did devise a plan to control the air traffic in the sector, the pilots would not carry out their plan except by chance. Therefore, active involvement helped the participants to remember additional information that they did not remember under M conditions.

3.7 Post-Scenario Questionnaire

3.7.1 Background

The ATCS responses to the PSQs provided information about several aspects of ATC during a particular simulation scenario.

3.7.2 Results

The PSQ was an important source of data that enabled the participants to provide their opinions about each experimental condition. The tables in Appendix N detail the results of these analyses. We divided the 12 items of the PSQ into 6 groups for analysis: Realism (Items 1 and 2), Workload (Items 6 and 12), Interference (Items 3 and 4), SA (Items 8, 9, 10, and 11), Participant Performance (Item 7), and Simulation-Pilot Performance (Item 5). We analyzed the Realism, Workload, Interference, and SA groups separately. Furthermore, we analyzed the Participant Performance and Simulation-Pilot Performance groups only for a main effect of load within the A condition. We did this because neither participant nor simulation-pilot performance was relevant during M conditions.

3.7.2.1 Realism

We conducted a 2 X 2 (load X involvement) within-subjects MANOVA on Items 1 and 2 of the PSQ, the Realism group. For Item 1, the participant described the realism of the scenario. On Item 2, the participant rated how representative the scenario was of a typical workday. The main effects of load and involvement were not significant nor was the load X involvement interaction (Table N-1). The participants rated conditions in which they actively controlled traffic as not significantly different but more realistic and more representative of a typical workday than M conditions.

Because the multivariate analysis did not reveal any significant effects, no univariate analysis was necessary. To explore trends in the data, we conducted ANOVAs on the individual items and looked for effects that would be significant at a more liberal alpha level of $p < .05$. Tables N-2 and N-3 present the results of the ANOVAs on the questions related to realism and representativeness. ATCSs rated the A control scenarios as more realistic than M scenarios (Figure 31). There was no difference in realism due to a change in load. ATCSs perceived A scenarios to be more representative of a day at work than the M scenarios (Figure 32). There was no effect of load on the perceived representativeness.

3.7.2.2 Workload

We conducted a 2 X 2 (load X involvement) within-subjects MANOVA on Items 6 and 12, the Workload group, of the PSQ. On Item 6, the participants described how hard they worked during the scenario. For Item 12, the participants described the difficulty of the scenario. We found a significant load X involvement interaction [$F(2, 14) = 9.30$, $p < .05$, Table N-19], therefore we conducted simple-effects MANOVAs for the independent variables manipulated within load (A vs. M) and involvement (HL vs. LL). Load demonstrated a significant effect within A conditions [$F(2, 14) = 36.01$, $p < .05$], but there was no significant effect of load within M conditions (Table N-3). The participants rated the HL scenario as more difficult than the LL scenario when they were actively controlling traffic. Conversely, load during M conditions did not significantly affect the participant ratings of scenario difficulty. We expected this result because the participants did not have to make control decisions during M conditions. They made few keyboard and QAK entries, and communications occurred only when coordinating with adjacent sectors and facilities. We also found a significant effect of involvement within both LL and HL conditions [$F(2, 14) = 13.81$ and 25.99, $p < .05$, Table N-4]. The participants rated the A conditions as more difficult than M conditions regardless of load. Again, this is not surprising because the participants performed fewer physical and verbal activities during M conditions. Because the omnibus MANOVA was significant, we conducted a separate ANOVA on each item of the Workload group. An adjusted alpha level of $\alpha = .0253$ determined if a result was significant.

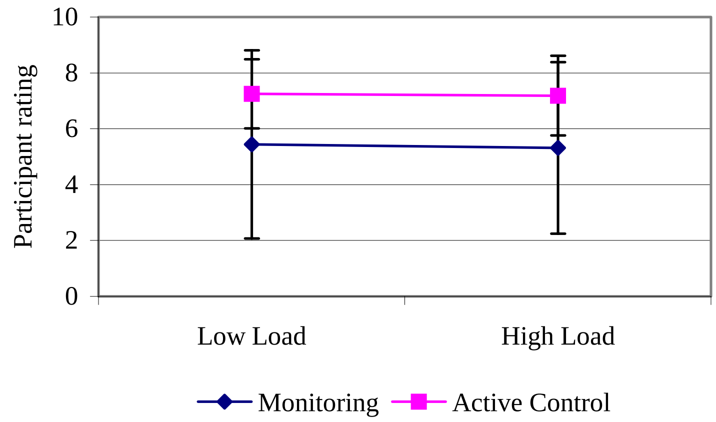

Figure 31. Realism by load and involvement.

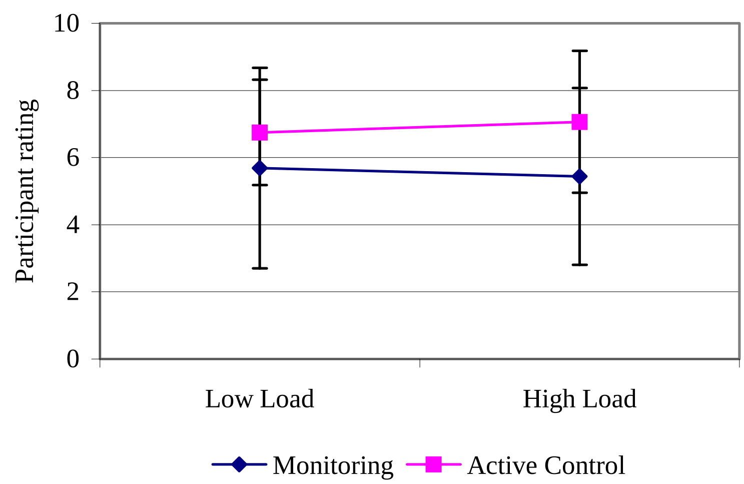

Figure 32. Representativeness by load and involvement.

For Item 6, we found a load X involvement interaction [$F(1, 15) = 10.65$, $p < .05$, Table N-5]. Item 6 showed a significant simple effect of load within the M conditions. It showed a significant simple effect for load within A conditions [$F(1, 15) = 39.68$, $p < .05$, Table N-5]. The simple effects of involvement within both LL and HL [$F(1, 15) = 18.77$ and 47.59, $p < .05$, Table N-5] were also significant. The participants made the same ratings on average after M conditions regardless of load. Compared to M conditions, the participants made higher ratings after A conditions regardless of load (Figure 33).

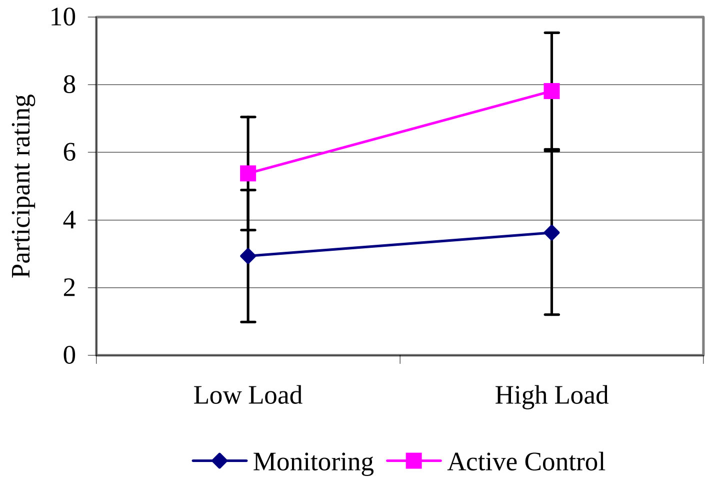

Figure 33. Working hard by load and involvement.

For Item 12, the difficulty of the scenario, we found a significant load X involvement interaction [$F(1, 15) = 5.21$, $p < .05$, Table N-6]. Item 12 showed a significant simple effect of load within the M conditions. It showed a significant simple effect for load within A conditions [$F(1, 15) = 23.82$, $p < .05$, Table N-6]. The simple effects of involvement within both LL and HL conditions [$F(1, 15) = 11.04$ and 47.59, $p < .05$, Table N-6] were also significant. The participants made the same ratings on average after the M conditions regardless of load. Compared to the M conditions, the participants made higher ratings after the A conditions regardless of load (Figure 34).

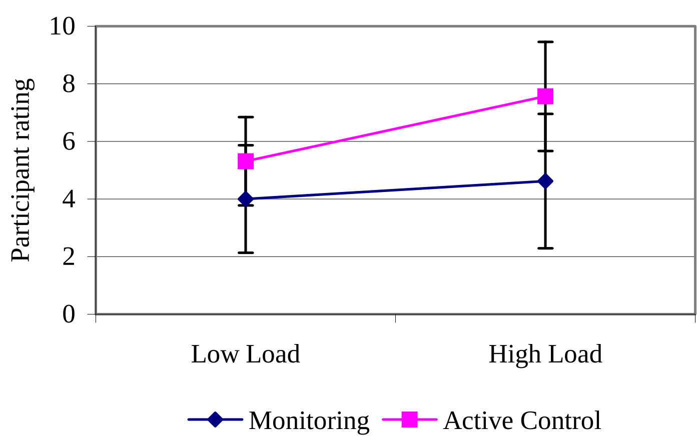

Figure 34. Difficulty by load and involvement.

3.7.2.3 Interference

Before conducting a formal analysis on the interference of the ATWIT device and the oculometer, we emphasized that the rating of the level of interference of both these devices was very low (on average, rated below 4 on a 10-point scale). To test if the participants perceived any interference from either device, a 2 (load) X 2 (involvement) within-subjects MANOVA was conducted on Items 3 and 4, the Interference group, of the PSQ. On Item 3, the participants described how much the ATWIT device interfered with controlling traffic. For Item 4, the participants described how much the oculometer interfered with controlling traffic. Significant effects were found for load and involvement [$F(2, 14) = 7.98$ and 7.47, respectively, both at $p < .05$, Table N-7]. The load X involvement interaction was not significant. The participants reported that there was more interference from the ATWIT and the oculometer during HL conditions and during A conditions. Because the omnibus MANOVA was significant, we conducted a separate ANOVA on each item of the Workload group. An adjusted alpha level of $\alpha = .0253$ determined if a result was significant.

A 2 X 2 (load X involvement) repeated-measures ANOVA was conducted on Item 3 of the PSQ. We found significant effects of both load and involvement [$F(1, 15) = 17.01$ and 12.42, respectively, both at $p < .05$, Table N-8]. The load X involvement interaction was not significant. The ATWIT device interfered more with controlling traffic under A conditions than under M conditions. An increase in load increased the interference of the ATWIT device and more so under A control (Figure 35).

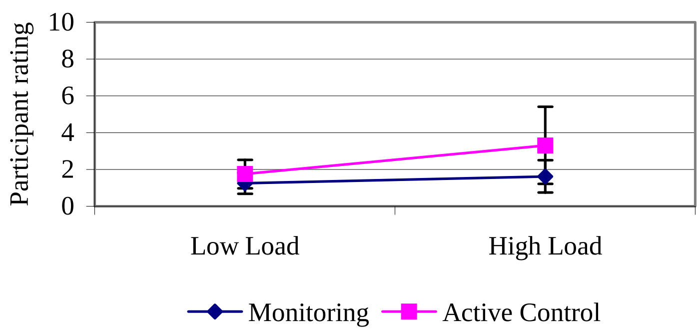

Figure 35. ATWIT interference by load and involvement.

3.7.2.4 Situation Awareness

We conducted a 2 X 2 (load X involvement) within-subjects MANOVA on Items 8, 9, 10, and 11, the SA group of the PSQ. On Item 8, the participants described their overall SA during this scenario. For Item 9, the participants described their SA for current aircraft location. On Item 10, the participants described their SA for projected aircraft locations. The participants also rated their SA for potential violations, Item 11. We found significant effects for the load X involvement interaction [$F(4, 12) = 4.38$, $p < .05$, Table N-9].

Because of the significant load X involvement interaction, we conducted simple-effects MANOVAs. There was no significant effect of load during M conditions. Load did have a significant effect during A conditions [$F(2, 14) = 8.37$, $p < .05$, Table N-9]. There was no significant effect of involvement during LL conditions, but there was a significant effect of involvement during HL conditions [$F(2, 14) = 4.92$, $p < .05$, Table N-9]. Because of the significant omnibus MANOVA, we conducted separate 2 X 2 (load X involvement) ANOVAs for each of the four items.

Item 8, which asked about overall SA, yielded no significant results (Table N-10). There was a trend visible for the interaction between the effects of load and involvement (Figure 36).

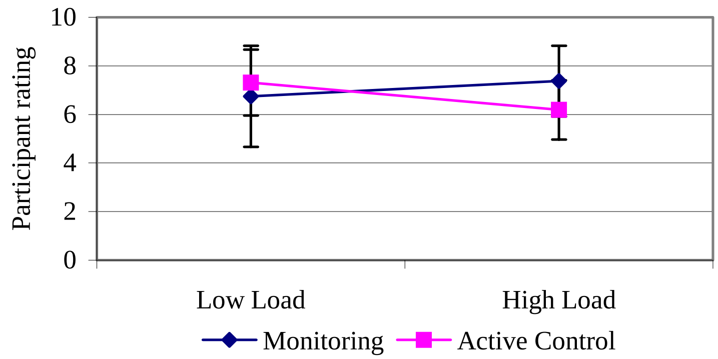

Figure 36. Overall SA by load and involvement.

Item 9, SA for current aircraft locations, showed a significant effect of load [$F(1, 15) = 22.70$, $p < .05$, Table N-11]. The ATCSs rated the perceived SA for current aircraft locations higher under LL than under HL. Although the interaction between load and involvement did not reach significance, there is a trend visible as displayed in Figure 37. The perceived heightened awareness for current aircraft positions under LL, A conditions, is responsible for the main effect of load. Under HL, a change in involvement does not alter the perceived SA for current aircraft positions.

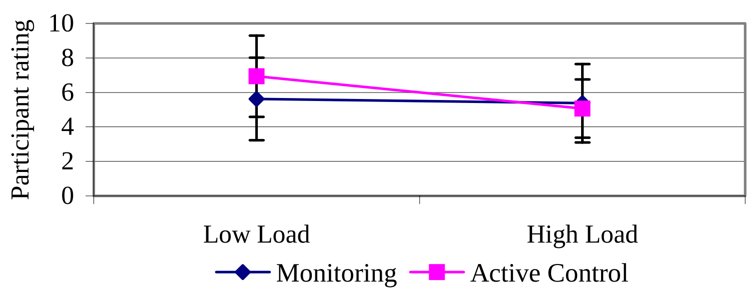

Figure 37. SA for current aircraft position by load and involvement.

Item 10, SA for projected aircraft locations, showed a significant effect of load [$F(1, 15) = 8.72$, $p < .05$, Table N-12]. The ATCSs felt that they were less aware of future aircraft positions under HL than they were under LL conditions (Figure 38).

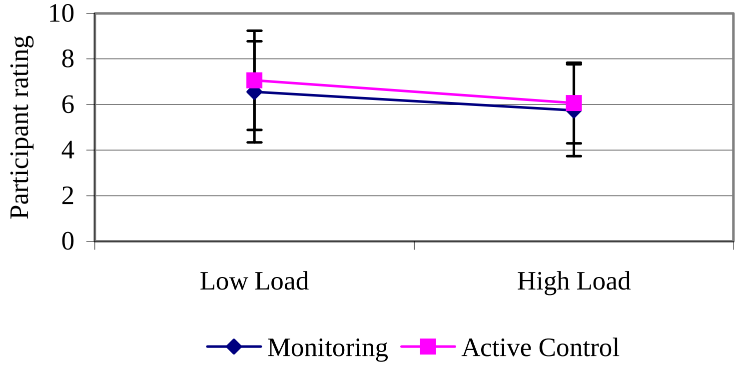

Figure 38. SA for projected aircraft positions by load and involvement.

Item 11, SA for potential violations, showed a significant effect of load [$F(1, 15) = 13.25$, $p < .05$, Table N-13]. Under HL, ATCSs felt they had lower SA for potential violations (Figure 39).

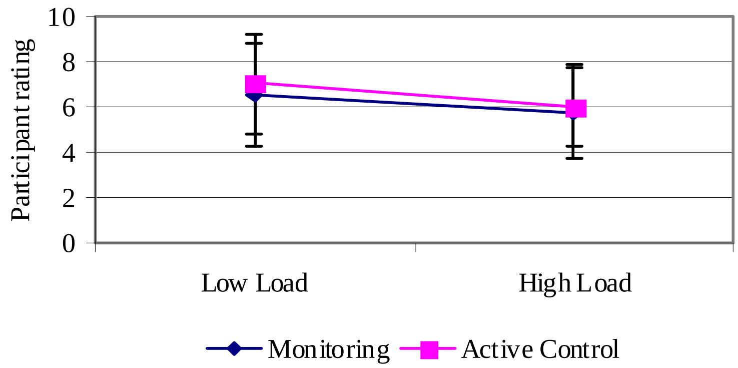

Figure 39. SA for potential violations by load and involvement.

<u>3.7.2.5 Participant Performance</u>

On Item 7, the participants described how well they controlled traffic during the scenario. Because this question only applied to the A condition, we conducted a 1-way ANOVA to assess the potential effect of load on responses to this item. We found a main effect of load [$F(1, 15) = 13.50$, $p < .05$, Table N-14] indicating that the participants felt they performed better under LL conditions (Table N-25).

3.7.2.6 Simulation Pilot Performance

The participants rated simulation pilot performance on Item 5. Because the simulation pilots were only present in the A conditions, we performed a 1-way ANOVA to determine if the participants rated the simulation pilots differently across load. The lack of any significant difference suggested that the simulation pilots performed equally well across the A conditions.

3.7.3 Discussion

The ATCSs rated the A scenarios as more realistic than the M scenarios. The participants may have given slightly higher ratings to the A condition because they typically control air traffic in an active manner and seldom, if ever, serve only as a monitor[1].

The ATCSs indicated that the A scenarios were more difficult than the M scenarios, although the effect of involvement did interact with load. ATCSs rated the HL scenarios to be more difficult than LL scenarios.

The participants did not think that the oculometer was more intrusive in one condition than another. However, some participants did report that it was easier to forget about the oculometer when they were actively engaged in the situation at hand. We can contrast the oculometer with the ATWIT device because the ATWIT device requires physical activity and decision making from the participant where the oculometer does not. Therefore, there is no reason for the oculometer to interfere differently depending on experimental conditions. The statistical results support such a hypothesis.

The analysis of the individual SA items on the PSQ indicated that the participants thought that the various conditions did not affect their overall SA. However, the participants felt that their SA for current and projected aircraft location and SA for potential violations were better under LL conditions. The participants did not perceive a difference in their SA between A and M conditions. The absolute mean ratings suggest that the participants perception of their SA and their measured level of SA may not necessarily agree. Both SPAM and Recall tests showed lower SA for the M condition, whereas perceived SA did not significantly change.

The expected perceived effect of involvement on the perceived SA was not present. The ATCSs rated the SA for potential violation in general better than their SA for current or projected aircraft positions. This finding corresponds well with the notion that the ATCS mostly store gist type or relative information. To be aware of aircraft-specific positional information is more difficult in this case than of potential violations (information about relations between aircraft).

4. General Discussion

The current experiment investigated the effect of changing the level of involvement on the ATCS participants. The ATCSs may move from the active situation of the current NAS to an environment where involvement will be more like a monitor than a controller. This study

[1] En route ATCSs may serve as a monitor during OTS training or during recertification.

exposed the participants to the two ends of the spectrum of involvement. On one end, the ATCSs carried out business as usual. The ATCS was in control and pilots followed control instructions. In the other situation, pilots maneuvered their aircraft without control instructions, and there was no pilot-ATCS communication.

To investigate the effect of the change of involvement of the controller, we employed five data sets (rating form and RTOP results were only applicable under A conditions). We have provided brief discussions of the results for each data set separately. Here, we will provide insight into how the removal of control affected ATCS behavior and performance in general. We will focus on how involvement affected the ATCS behavior and performance. The specific discussions on each data set address the effects of load and time.

4.1 Workload

Perceived workload was higher under A conditions. Under M conditions, the estimated workload was constant over time. Under A, on the other hand, the estimated workload slowly increased over time. However, lower workload may not necessarily be a desirable goal, depending on other effects. Overall, ratings of workload were low to moderate. This is not unusual in a population like ATCSs, who have a great deal of experience. It takes a great deal to move them beyond a moderate workload rating.

4.2 Situation Awareness

The SPAM asks the participants questions about present and future situations. The time to answer a question is an indicator of how quick a participant can access relevant information. A change in the level of involvement did not affect answers to questions about future situations. However, ATCS involvement did affect the ability to answer questions related to the present situation. Under A conditions, the time to answer the queries about the present situation was equal for LL and HL scenarios. Under M conditions, the increase in load almost doubled the time to answer the questions. The SPAM does not probe memory. All information necessary to answer the questions is available on the radarscope. The fact that, under M conditions, the ATCS takes longer to answer the SPAM queries is an indication that SA suffers from reduced involvement. This is contrary to the beliefs of those that suggest that a monitoring situation will free cognitive resources. Freeing cognitive resources would allow the ATCS to direct more resources to keep an up-to-date picture of the situation. The current results are more in line with earlier findings that working memory for something that you have done yourself is better than something that someone does for you.

The PSQ asked the ATCSs about their opinion on their SA for aircraft positions and potential violations. The ATCSs indicated that, although an increase in load reduced their SA for aircraft positions and potential violations, the reduction of involvement did not affect their SA. This is in sharp contrast with the findings from the objective measure of SA. Therefore, although the ATCS may not be aware that the SA is suffering when monitoring traffic, the actual SA is not as good under M conditions as it is under A conditions. Increased automation or changes in the NAS that will place the ATCS in a monitoring position may give the ATCS a false feeling of having good SA, whereas SA has already diminished. Counter measures to assist the ATCS in maintaining an accurate SA may be necessary when changes in the NAS require the ATCS to become a monitor.

4.3 Eye Movements

The general characteristics of eye movements did not change by load or involvement. The effect of time, on the other hand, affected the number and the duration of fixations. During the first 5 minutes of the simulations, the ATCSs scanned for information with more and shorter fixations than during the rest of the simulation time. A possible explanation is that the ATCSs received a relief briefing at the start of the simulation. The ATCSs, therefore, merely verified the correctness of the information in the beginning of the simulation. Other studies have shown that several categories of fixations exist. Carmody, Nodine, and Kundel (1981) distinguish surveying (short duration) fixations and evaluating (long duration) fixations in radiologists scanning X-rays. The need to acquire all information related to the current situation only becomes critical once the state of the airspace has changed considerably. When the ATCS moves into a state of information acquisition and monitoring instead of verification and monitoring, the duration of fixations increases, and the number of fixations decreases.

Fixation area tended to increase over time. The first 5 minutes showed more stable fixations than subsequent 5-minute intervals. There are several possible explanations for this finding. First, during the relief briefing, the ATCS receives specific information about particular aircraft and may focus on these aircraft while digesting the information. Fixations will not fall within clusters of aircraft, and small adjustments may not be necessary. After the ATCS takes over control, these changes and fixations become less stable. An alternative explanation is that the visual system shows signs of fatigue. Although research has shown that eye movements can continue for long periods without showing signs of fatigue, the number of glissades, or slipping into or out of a fixation, increase with fatigue. Our algorithm to calculate fixation onset and area may have captured glissades as well, thereby increasing the average fixation area with an increase in the number of glissades.

The effects of the manipulation of load and involvement only became apparent during analyses of fixation characteristics broken down by scene planes and radarscope objects. Most fixations landed on the radarscope, followed by the flight strip bay and the QAK/CRD. Fixations on the map and the QAK/CRD were shorter under M than under A conditions. The ATCSs had little need for both QAK/CRD and the map under M conditions and spent less time retrieving information from these displays. During A conditions, the ATCSs used the QAK/CRD as both a data entry and data display tool when assigning altitudes, and so on. Under M conditions, the QAK/CRD was merely there, and the ATCSs only looked at it briefly to verify data entry for data block movement, not for control actions. Therefore, monitoring does change how controllers use displays.

The ATCSs focused most of their fixations on the radar returns and the datablocks. In addition to the increased number of fixations on these two objects, these fixations were considerably longer than fixations on any of the other objects or scene planes.

To explore the structure or predictability in the visual scan of the ATCSs, we developed four indices based on “conditional information” (Ellis, 1986). These indices investigated the distribution of radarscope fixations across the radarscope (location and distance from the radarscope center), across objects, and broken down by inter-fixation distances. Although the radarscope location-based index showed the highest level of structure, it did not change significantly with a change in our conditions. The fact that this index showed higher levels of structure may stem from the existence of structure in the airspace. One would expect that the values for this index would decrease when the structure in traffic flow is less apparent, as would be the case in Free Flight. The index that focused on structure in the visual scan based on distance from the center of the radarscope did not reveal an effect of load or involvement manipulation either. In the current en route experiment, the ATCSs did not have a “sink” like the main airport often encountered in TRACON environments. One would expect more structure in the ATCSs visual scan based on this index due to the structure of the TRACON airspace. It is more likely that a fixation on a part of the TRACON high traffic area will follow by a fixation on another high traffic area.

Load affected the structure in the visual scan when based on target objects. Although the structure was low, an increase in load reduced the predictability of the visual scan. The reduction in scanning structure due to active involvement was only apparent under HL. The ATCSs seemed to scan the radarscope in a more random fashion when the complexity increased and they actively controlled traffic. The way the ATCSs distribute their attention across radarscope objects does not alter when their task is to monitor traffic. Therefore, the ATCSs are less likely to adapt their scanning behavior with a change in the traffic situation.

Our final index investigated how likely it was that fixations with particular inter-fixation distances follow one another in a fixed pattern. The results show that this is more likely to happen under HL. This does not necessarily mean that the ATCSs are more likely to suffer from tunnel vision. It could mean that it is more likely that a fixation with a short inter fixation distance often follows a fixation with a long inter-fixation distance. More detailed analyses of the transition probability matrix that focuses on the likelihood that fixations with short inter fixation distances follow one another would allow the determination of the occurrence of tunnel vision.

When we removed active control from the ATCS, we expected a change in eye movement characteristics. Under monitoring conditions, the expected need for information is less. Consequently, one would expect that the fixation duration and frequency would decrease. When the ATCSs are no longer actively changing the state of the aircraft in the airspace, the need to evaluate the current state and the outcome of actions no longer exists. The need for evaluation-type fixations of longer duration would decrease. With the loss of the bigger picture, the ATCS would be less likely to look for information in an open-loop fashion guided by higher level goals. This would result in a scanning pattern that more relies on local feedback of the events on the radarscope. The local feedback in the visual scanning pattern ought to lead to a larger statistical dependency expressed in more structure or higher values of the conditional information indices in monitoring. The visual scan showed less structure under active control than under monitoring conditions. Scanning for information in the open-loop fashion by definition means less structure.

We suspect that during monitoring, ATCSs establish a stimulus-driven scan that is more structured. Interestingly enough, the manipulation of the level of involvement did not change the eye movement characteristics.

The literature explains these findings. It takes a considerable amount of practice to teach the visual system something until it becomes automatic. Automaticity in visual information processing implies rapid, parallel processing. Once a person learns a task, until automaticity occurs, the task at hand requires very little cognitive resources. This type of task performance is quite common among domain experts. The characteristics of the structure in the visual scan after automaticity sets in, contrary to the training process itself, are visible early on. Within 30 minutes for simple stimuli, the parameters that establish the visual scanning pattern will emerge (Moray, 1986). In the current experiment, we removed the ATCS active involvement in the task at hand. The presentation format of the display elements, however, remained the same. This resulted in information acquisition behavior that did not change (e.g., the eye fixation durations and frequencies remained relatively constant). The structure in the visual scan, on the other hand, did show effects of the change in involvement as indicated by the changes in the conditional information indices.

Willems et al. (in press) modeled the home sector of a group of TRACON ATCSs. The ATCSs had worked their airspace for several years and were quite familiar with the traffic patterns. This familiarity may have led the ATCSs to develop efficient visual information acquisition processes that have increased the visual lobe size (the area of the visual field that an ATCS can efficiently use to retrieve information). Although fixation durations are longer, ATCSs process more information in the periphery. The increase in visual lobe size makes it easier to combine information about several aircraft. The more advanced integration of information about several aircraft in a single-eye fixation would result in more efficient scanning patterns. The ARTCC ATCSs participating in the current study worked an unfamiliar airspace and did not have the advantage of working that airspace for many years. Consequently, the peripheral processing of information could not take advantage of background knowledge learned from experience resulting in a smaller functional field of view and less information to absorb at a time. The reduction in information-per-fixation, in turn, would lead to shorter fixation durations and more fixations.

In the TRACON environment, the ATCSs did not have the option to extend the leader lines that connect the radar return and the data block. The data block and the radar return were in close proximity of one another. For the ATCSs that are very familiar with the aircraft representation, this allows them to absorb all information relevant for a given aircraft in a single fixation. The fact that this single fixation now can pick up more information will necessitate a longer duration for information retrieval. In the ARTCC environment, the ATCSs seemed to keep the data blocks at a larger distance from the radar return. To foveate all information for a single aircraft, the ATCSs may require two fixations instead of one. Less information retrieval takes place for each of these fixations, leading to shorter fixations.

An ATCS in the TRACON airspace faces a lack of structure compared to the structured airspace of the ARTCC environment. The ARTCC ATCS can fall back on a large number of assumptions based on where an aircraft is within the airspace. The amount of information that the ATCS needs to retrieve for a given aircraft in the ARTCC environment may be less than in the TRACON environment. The reduction of the amount of information that the ATCS retrieves by using assumptions stored in long term memory will lead to shorter retrieval times and, therefore, shorter fixation durations.

The ATCSs have several types of fixations. When reading general information, the ATCS will perform just like any other reader. The ATCS visual scanning system, however, must have developed a level of automaticity that a non-ATCS does not have. The longer fixations on aircraft are an indication of that. The controller is picking up relevant information from an aircraft representation. The ATCS does that faster than non-ATCSs. The TRACON data block alone consists of call signs, computer IDs, altitude, and speed (4 items). The radar return and everything attached to that consists of the position symbol, vector line, and history trace (3 items). That could take up to 7 fixations if the ATCS would scan for information in a sequential manner (no automaticity or parallel processing). Just to prepare for the next saccade takes about 75 msecs. At least the same amount of time is needed for the acquisition of simple information from scenes such as photographs. If we omit the time to process the information to decide where to jump to next, the visual system needs 150 msecs to get the information and to move on to the next spot. That times seven would give us a little over one second to visit all elements of the aircraft representation. With processing of the information, the controller does this in a little over 600 msecs. In addition, the ATCS may do that not for just one aircraft but for other aircraft that are in the parafoveal (an area of between one and three degrees of visual angle outside of the center of fixation) and near peripheral areas of the retina).

Now, within these longer fixations on aircraft, one can still distinguish between surveying and evaluating fixations. Surveying fixations are shorter and are likely terminated when the controller decides at the feature level that this does not contain relevant information (the state of the aircraft is not changed or the aircraft does not pose a potential problem). Those fixations are probably less that 350 msec. During evaluating fixations, the controller is really picking up information far beyond the feature level. The ATCS looks at that aircraft for a purpose and composes the overall picture of the state of that aircraft. Those fixations are quite long, more in the order of 500 msecs and over.

5. Conclusions

The current experiment placed the ATCSs in a monitoring situation. Changes in airspace management may move the ATCS to a situation that will fall somewhere between the current, active control situation and the simulated monitoring situation of this study. The results indicate that, although perceived workload is less under monitoring conditions, the objective SA measures show that ATCSs SA declines substantially when the ATCS no longer actively controls traffic. The fact that the ATCS may not be aware of the reduction in SA suggests that system designers must seriously consider how they are going to keep controllers involved. Although our experiment may have been brief, the visual scanning patterns showed changes. These small changes after only a brief exposure to work as a monitor may be an indication of changes in eye movement characteristics when the ATCS will work in a monitoring role for longer periods. Changes in the characteristics of eye movements are an indication of visual information retrieval strategies. The altered SA, in combination with a change in information retrieval strategies, warrants careful examination. It implies a need for training and assistance of the ATCSs in situations where they are no longer in active control.

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Acronyms

A	Active Condition
ADS-B	Automatic Dependent Surveillance-Broadcast
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
ASL	Applied Science Laboratories
ATC	Air Traffic Control
ATWIT	Air Traffic Workload Input Technique
CRD	Computer Readout Device
DRA	Data Reduction and Analysis
FAA	Federal Aviation Administration
FL	Flight Level
FPL	Full Performance Level
FPS	Flight Progress Strip
GPS	Global Positioning System
HFS	Human Factors Specialist
HL	High Load
LL	Low Load
LOA	Letter of Agreement
M	Monitoring Condition
MANOVA	Multivariate Analysis of Variance
NRP	National Route Program
OJT	On-the-Job Training
OTS	Over-the-Shoulder
PEQ	Post-Experimental Questionnaire
PVD	Plan View Display
PSQ	Post-Scenario Questionnaire
QAK	Quick Action Key
RDHFL	Research Development and Human Factors Laboratory
RTOP	Real Time Objective Performance
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SCRD	Soft Computer Readout Device
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SPAM	Situation Present Assessment Technique
TCAS	Traffic Alert and Collision Avoidance System
TRACON	Terminal Radar Approach Control
VOR	Very High Frequency Omnidirectional Range
WAAS	Wide Area Augmentation System

Appendix A

Genera Center Standard Operating Procedures and Letters of Agreement

U. S. Department of Transportation

Federal Aviation Administration

GENERA ARTCC

SUBJ: GENERA CENTER STANDARD OPERATING PROCEDURES (SOP)

1. PURPOSE: This Order transmits ZGX Genera Center Standard Operating Procedures.

2. DISTRIBUTION: This Order is distributed to facility managers, staff offices, NATCA, NAGE, control room personnel, and the facility library at Genera ARTCC.

3. EFFECTIVE DATE: July 20, 1995

4. TEAM POSITION RESPONSIBILITIES: En route sector team responsibilities are contained in FAA Order 7110.65, chapter 2, section 10, paragraphs 2-130.

a. Flight Data Position shall:

(1) Prepare strips displaying red routings or red coordination symbols.

(2) Prepare strips for aircraft that will proceed to special use airspace for which an operational count is authorized.

(3) Place strips above the sector suspense/active bayheader and sequence strips by time, when appropriate, with the earliest time at the bottom of the bay.

(4) Forward a copy of the Traffic Management message to the ASIC/CIC. The ASIC/CIC shall be responsible for hand carrying or verbally notifying the appropriate sector(s).

b. Radar Position shall:

(1) Recognize sector saturation and employ procedures to prevent or alleviate this problem.

c. Transfer of Radar Identification.

(1) Data blocks displaying verified MODE C information may be used to accomplish altitude coordination. Assigned altitude shall be reflected in the data block either as a temporary altitude or as a final altitude.

(2) Resolve all potential conflicts prior to dropping full data blocks. Full data blocks shall be displayed on all aircraft within the confines of your airspace.

5. AUTONOMOUS OPERATIONS IN FACSFACGAT WARNING AREAS:

a. Information.

(1) Warning areas in Genera Center area are established with a designated using agency and an ATC point of contact.

(2) The authorize representatives for activation and coordination of the subject warning areas are as follows:

(a) W500 (Hotwater)..................................Plumber Control

(3) Genera Center controllers should allow entry to W500 at point Boill (depicted on Annex) at FL280 and departure from point Finis at FL290, unless otherwise coordinated.

6. GENERA CENTER SPECIAL USE AIRSPACE INTRUSION/SPILL OUT PROCEDURES:

(1) FAA or pilot requests to transit special use airspace to avoid weather do not have priority over military operations being conducted in special use airspace. The decision to release special use airspace to the FAA rests solely with the using agency.

(2) Whiskey Alert Procedures.

(a) The phrase “Whiskey Alert” shall be used when spill in or spill out from a MOA, ATCAA, restricted area, or warning area has not been coordinated or approved in advance and the spill in/spill out is imminent.

1. SECTOR 10................ALPHA HIGH

This sector shall include all airspace from FL240 and above.

a. Standard Operating Procedures

(1) Aircraft filed into the Genera High Sector:

(a) Landing UTN shall be cleared NWT.J74.UPPER.UPPER1 or NTH.J75.J74.UPPER.UPPER1 at or below FL370.

(b) Landing DTN shall be cleared SWT.J64.LOWER.LOWER1 or NTH.J75.LOWER.LOWER1 at or below FL370

(c) Eastbound overflight traffic will not be cleared via J70 eastbound.

(d) Southbound overflight traffic form NTH will be established on J75 or direct STH at or above FL330.

(e) Aircraft operating between the Alpha High sector and the Genera High sector will be at even altitudes south and westbound; odd altitudes north and eastbound.

2. SECTOR 11................BRAVO HIGH

This sector shall include all airspace from FL240 and above.

a. Standard Operating Procedures

(1) Aircraft filed into the Genera High Sector:

(a) Departing UTN shall be cleared UTN.UPTWN1.MIDLE.J70 with release for climb.

(b) Departing DTN shall be cleared DTN.DNTWN1.MIDLE.J70 with release for climb.

(c) Overflight traffic will be established direct MIDLE at a point 20NM east of MIDLE.

(2) Aircraft operating between the Bravo High Sector and Genera High Sector will be at even altitudes south and westbound; odd altitudes north and eastbound.

3. GENERA HIGH SECTOR

This sector shall include all airspace from FL240 and above, excluding that airspace delegated to ZCX, FL270 and above.

a. Standard Operating Procedures

(1) Aircraft filed into the Alpha High Sector:

(a) At or above FL240 may be cleared MIDLE direct WST flight plan route.

(b) Genera Sector shall ensure that aircraft filed over WST with the same destination will be in-trail of each other regardless of altitude.

(2) Alpha High Sector shall deliver arrivals to UTN and DTN at or below FL 370.

(3) Aircraft operating between the Genera High Sector and the Alpha High Sector will be at even altitudes south and westbound; odd altitudes north and eastbound.

(4) Aircraft filed into the Bravo High Sector:

(a) Landing UTN shall be cleared via the UPPER1 arrival to cross UPPER at FL250.

(b) Landing DTN shall be cleared via the LOWER1 arrival to cross LOWER at FL240.

(c) Eastbound overflight traffic shall be established on J64 or J74.

Genera Center Letter of Agreement

Subject: Inter-Center Procedures

Purpose. This agreement establishes Inter-Center procedures between Charlie ARTCC and Genera ARTCC and is supplementary to the procedures in the Air Traffic Control Handbook.

Effective Date. July 20, 1995.

Responsibilities. This agreement covers coordination procedures, altitude assignments, route assignments, delegation of airspace, and coordination/notification procedures of special use airspace. Deviation from procedures outlined in this agreement made by either facility may be made only after coordination, which completely defines responsibility in each case.

Procedures.

Route Assignments.

Traffic entering the Genera High sector shall be established on J75 at or prior to the common Center boundary, with the following exception:

Aircraft at FL270 and above shall be established on J75 prior to the ZGX/ZCX center boundary southbound.

Altitude Assignment.

Aircraft on J75 shall be cleared northbound at odd altitudes and southbound at even altitudes.

Aircraft entering the Charlie High or Low sectors shall be at an assigned altitude designated by the hemispheric altitude for direction of flight.

Aircraft entering the Genera High or Low sectors shall be at an assigned altitude designated by the hemispheric altitude for direction of flight.

Appendix B

Genera Center Airspace

Genera sector controls traffic within its boundaries from 24,000 feet (flight level (FL) 240) and above. All airways within the airspace are one-way airways. Two airways, J64 and J74, move traffic from west to east. One airway, J70, moves traffic from east to west, and one airway, J75, moves traffic from north to south. There are eight Very High Frequency Omnidirectional Range (VOR) navigational beacons associated with Genera sector: CTR, Center; NTH, North; NET, Northeast; SET, Southeast; STH, South; SWT, Southwest; WST, West; and NWT, Northwest. There are four intersections associated with the airspace: UPPER, LOWER, MIDLE, and BOTTM. Of these VORs and intersections, only CTR and MIDLE are within the airspace. Three airports are of relevance to Genera sector: UTN, Uptown Airport; MID, Midtown Airport; and DTN, Downtown Airport. Genera sector lies between three sectors. On the west side lies Alpha sector. To the east lies Bravo sector. Both Alpha and Bravo sectors are from the same ARTCC. To the south lies one sector from another ARTCC, Charlie Center, and an area of restricted airspace called Hotwater or W500. Below the Genera High sector is Genera Low, which controls traffic from FL 230 and below. Although the airspace map depicts an altitude shelf, the present experiment did not use this shelf.

Aircraft had standard arrival and departure procedures. Aircraft landing at UTN had to cross the UPPER intersection at FL 250. Aircraft landing at DTN had to cross the LOWER intersection at FL 240. Genera sector did not control aircraft landing at MID. The ATCS responsible for aircraft in Genera sector had control for climb (e.g., without coordination from adjacent sectors) for aircraft departing from all three airports. However, permission to turn aircraft not within the confines of Genera sector required coordination with the appropriate sector. Aircraft travelling to the same destination airport required at least 5 NM in-trail separation, regardless of altitude.

Appendix C

Observer Rating Form, Instructions, and Rating Criterion

OBSERVER RATING FORM

Observer Code _________ Date _________

Participant:

Scenario:

INSTRUCTIONS

This form is designed to be used by supervisory air traffic control specialists to evaluate the effectiveness of controllers working in simulation environments. SATCSs will observe and rate the performance of controllers in several different performance dimensions using the scale below as a general-purpose guide. Use the entire scale range as much as possible. You will see a wide range of controller performance. Take extensive notes on what you see. Do not depend on your memory. Write down your observations. Additional pages are provided for your comments. Please indicate category number to which you are referring. You may make preliminary ratings during the course of the scenario. However, wait until the scenario is finished before making your final ratings and remain flexible until the end when you have had an opportunity to see the entire available behavior. At all times please focus on what you actually see and hear. This includes what the controller does and what you might reasonably infer from the actions of the pilots. Try to avoid inferring what you think may be happening. If you do not observe relevant behavior or the results of that behavior, then you may leave a specific rating blank. Also, please write down any comments that may help improve this evaluation form. Do not write your name on the form itself. Your identity will remain anonymous, as your data will be identified by an observer code known only to yourself and the researchers conducting this study. The observations you make do not need to be restricted to the performance areas covered in this form and may include other areas that you think are important.

Assumptions: ATC is a complex activity that contains both observable and unobservable behavior. There are so many complex behaviors involved that no observational rating form can cover everything. A sample of the behaviors is the best that can be achieved, and a good form focuses on those behaviors that controllers themselves have identified as the most relevant in terms of their overall performance. Most controller performance is at or above the minimum standards regarding safety and efficiency. The goal of the rating system is to differentiate performance above this minimum. The lowest rating should be assigned for meeting minimum standards and for anything below the minimum since this should be a rare event. It is important for the observer/rater to feel comfortable using the entire scale and to understand that all ratings should be based on behavior that is actually observed.

SCALE	QUALITY	SUPPLEMENTARY
1	**Least Effective**	Unconfident, Indecisive, Inefficient, Disorganized, Behind the power curve, Rough, Leaves some tasks incomplete, Makes mistakes
2	**Poor**	May issue conflicting instructions; Does not plan completely
3	**Fair**	Distracted between tasks
4	**Low Satisfactory**	Postpones routine actions
5	**High Satisfactory**	Knows the job fairly well
6	**Good**	Works steadily, Solves most problems
7	**Very Good**	Knows the job thoroughly, Plans well
8	**Most Effective**	Confident, Decisive, Efficient, Organized, Ahead of the power curve, Smooth, Completes all necessary tasks, Makes no mistakes

I - 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 appropriate aircraft and airspace separation
   - detecting and resolving impending conflicts early
   - recognizing the need for speed restrictions and wake turbulence separation

2. Sequencing Arrival, Departure, and En Route Aircraft Efficiently .. **1 2 3 4 5 6 7 8**
   - using efficient and orderly spacing techniques
   - maintaining safe arrival and departure intervals that minimize delays
3. Using Control Instructions Effectively/Efficiently **1 2 3 4 5 6 7 8**
   - providing accurate navigational assistance to pilots
   - issuing economical clearances that result in need for few additional instructions to handle aircraft completely
   - ensuring clearances use minimum necessary flight path changes
4. Overall Safe and Efficient Traffic Flow Scale Rating **1 2 3 4 5 6 7 8**

II - MAINTAINING ATTENTION AND SITUATIONAL AWARENESS

5. Maintaining Situational Awareness... **1 2 3 4 5 6 7 8**
   - avoiding fixation on one area of the radar scope when other areas need attention
   - using scanning patterns that monitor all aircraft on the radar scope
6. Ensuring Positive Control.. **1 2 3 4 5 6 7 8**
   - tailoring control actions to situation
   - using effective procedures for handling heavy, emergency, and unusual traffic situations
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
   - ensuring pilot adherence to issued clearances
8. Correcting Errors in a Timely Manner **1 2 3 4 5 6 7 8**
   - acting quickly to correct errors
   - changing an issued clearance when necessary to expedite traffic flow
9. Overall Attention and Situation Awareness Scale Rating.............. **1 2 3 4 5 6 7 8**

III - 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

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

12._Handling Control Tasks for Several Aircraft **1 2 3 4 5 6 7 8**
    - shifting control tasks between several aircraft when necessary
    - communicating in timely fashion while sharing time with other actions

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

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

IV - PROVIDING CONTROL INFORMATION

15a. 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

15b. 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

16. Providing Coordination... **1 2 3 4 5 6 7 8**
    - providing effective coordination
    - providing timely coordination
    - using proper point-out procedures
    - performing hand-off procedures properly

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

V - TECHNICAL KNOWLEDGE

18. Showing Knowledge of LOAs and SOPs **1 2 3 4 5 6 7 8**
    - controlling traffic as depicted in current LOAs
    - controlling traffic as depicted in current SOPs

19a. Showing Knowledge of Aircraft Capabilities and Limitations **1 2 3 4 5 6 7 8**
    - using appropriate speed, vectoring, and/or altitude assignments to separate aircraft with varied flight capabilities
    - issuing clearances that are within aircraft performance parameters

19b. Showing Effective Use of Equipment.. **1 2 3 4 5 6 7 8**

- updating of data blocks
- using equipment capabilities

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

VI - COMMUNICATING

21. Using Proper Phraseology.. **1 2 3 4 5 6 7 8**
    - using words and phrases specified in the 7110.65
    - using phraseology that is appropriate for the situation
    - using minimum necessary verbiage
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
    - ensuring clearance delivery is complete
    - speaking with confident, authoritative tone of voice

23. Listening to Pilot Readbacks and Requests **1 2 3 4 5 6 7 8**
    - correcting pilot readback errors
    - acknowledging pilot or other controller requests promptly

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

Number	**Comments**

Appendix D
Entry Questionnaire

Instructions: Please complete the form below. All responses will be kept confidential and your anonymity is guaranteed.

1.	What is your age?		_________ years		
2.	Are you wearing corrective lenses during this experiment?		☐ Yes	☐ No	
3.	How long have you been an FPL controller?		_________ years		
4.	How long have you worked at your current facility?		_________ 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 list other facilities you have worked at:				
8.	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: __________				
9.	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: __________				
10.	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: __________				

11. Please circle the number that best describes your current **state of health**	not healthy	1 2 3 4 5 6 7 8 9 10	extremely healthy
Comments:			
12. 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:			

Appendix E

Post-Scenario Questionnaire (PSQ)

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
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
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
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
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
6.	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
7.	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
8.	Please circle the number that best describes **overall situation awareness** during this scenario	extremely poor	1 2 3 4 5 6 7 8 9 10	extremely well
9.	Please circle the number that best describes your **situation awareness for current aircraft locations** during this scenario.	extremely poor	1 2 3 4 5 6 7 8 9 10	extremely well
10.	Please circle the number that best describes your **situation awareness for projected aircraft locations** during this scenario.	extremely poor	1 2 3 4 5 6 7 8 9 10	extremely well
11.	Please circle the number that best describes your **situation awareness for potential violations** during this scenario.	extremely poor	1 2 3 4 5 6 7 8 9 10	extremely well
12.	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

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

Appendix F

Post-Experimental Questionnaire

1.	Please circle the number that best describes **how realistic the simulations** were. **Comments:**	extremely unrealistic	1	2	3	4	5	6	7	8	9	10	extremely realistic
2.	Please circle the number that best describes **how representative the scenarios were** of a typical workday. **Comments:**	not representative	1	2	3	4	5	6	7	8	9	10	extremely representativ e
3.	Please circle the number that best describes if the **ATWIT device interfered** with controlling traffic. **Comments:**	no interference	1	2	3	4	5	6	7	8	9	10	extreme interference
4.	Please circle the number that best describes if the **oculometer interfered** with controlling traffic. **Comments:**	no interference	1	2	3	4	5	6	7	8	9	10	extreme interference
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. **Comments:**	extremely poor	1	2	3	4	5	6	7	8	9	10	extremely well
6.	Please circle the number that best describes if the **hands-on training was adequate on day 1**. **Comments:**	not adequate	1	2	3	4	5	6	7	8	9	10	adequate
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**? If it depends on certain factors, what are they? **Comments:**				
10. Please circle the number that best describes your **preference for vertical separation** during the experiment **Comments:**	no vertical separation	1 2 3 4 5 6 7 8 9 10	always vertical separation
11. Please circle the number that best describes your **preference for lateral separation (i.e., "vectoring")** during the experiment. **Comments:**	no vector separation	1 2 3 4 5 6 7 8 9 10	always vector separation
12. Please circle the number that best describes your **preference for speed control** during the experiment. **Comments:**	no speed control	1 2 3 4 5 6 7 8 9 10	always speed control
13. Is there anything about the study that we should have asked or that you would like to comment about? **Comments:**			
Please circle the number that best describes the **importance** of the following **aircraft** information:			
14. Aircraft Call Sign	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
15. Aircraft Type	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
16. Aircraft Beacon Code	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
17. Controller Ownership	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
18. Entry Altitude	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high
19. Entry Airspeed	extremely low	1 2 3 4 5 6 7 8 9 10	extremely high

20. Entry Fix	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
21. Exit Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
22. Exit Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
23. Exit Fix	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
24. Arrival Airport (within sector)	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
25. Departure Airport (within sector)	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
26. Current Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
27. Current Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
28. Current Heading	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
29. Current Aircraft Location	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
30. Most Recently Assigned Altitude	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
31. Most Recently Assigned Airspeed	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
32. Most Recently Assigned Heading	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
33. Aircraft Holding/Spinning	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
34. Aircraft Waiting for Hand-off/Release	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
35. Aircraft Near Exit Fix/Arrival Airport	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
36. 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:												
1. System Clock	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
2. VORs	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
3. Fixes	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
4. Airports	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
5. Restricted Area Boundaries	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
6. Runways	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
7. Sector Boundaries	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
8. Filter Settings	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
9. Future Aircraft List	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

10. Collision Alert	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
11. Aircraft History	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
12. J-Ring	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
13. Route Readout	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
14. Vector Lines	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high

Appendix G

General Instructions

Instructions for Participants (given before calibration of oculometer)

First Experimental Scenario

Privacy Statement
Remember that all data is being collected without any information which could later be used to identify you. Your privacy is protected.

Active Control Instructions (Scenarios 1 & 4)
During this scenario we would like for you to control traffic as you normally would in the field. In addition, you will be making ATWIT ratings and answering questions over the landline. A memory recall procedure will occur after the scenario has stopped.

Monitoring Instructions (Scenarios 2 & 8)
During this scenario you will only have to monitor the air traffic. Although there are no pilot/controller communications, you may utilize all other normal control functions (j-ball, vector lines, route readouts). In addition, you will be making ATWIT ratings, answering questions over the landline. A memory recall procedure will occur after the scenario has stopped.

ATWIT Instructions
One purpose of this research is to obtain an accurate evaluation of controller workload. By workload, we mean all the physical and mental effort that you must exert to do your job. This includes maintaining the "picture," planning, coordinating, decision making, communicating, and whatever else is required to maintain a safe and expeditious traffic flow. Every five minutes the ATWIT device, located to the left of the radar display, will emit a brief tone and ten buttons will appear. The buttons will remain visible for only a limited amount of time. The way you will tell us how hard you are working is by pushing the buttons numbered from 1 to 10 which will appear on the ATWIT.

I will review what these buttons mean in terms of your workload. At the low end of the scale (1 or 2), your workload is low - you can accomplish everything easily. As the numbers increase, your workload is getting higher. Numbers 3, 4, and 5 represent increasing levels of moderate workload where the chance of error is still low but steadily increasing. Numbers 6, 7, and 8 reflect relatively high workload where there is some chance of making errors. At the high end of the scale are numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished.

All controllers, no matter how proficient and experienced, will be exposed at one time or another to all levels of workload. It does not detract from a controller's professionalism when he indicates that he is working very hard or that he is hardly working. Feel free to use the entire scale and tell us honestly how hard you are working. Do not sacrifice the safe and expeditious flow of traffic in order to respond to the ATWIT device. Remember, your workload rating should *not* reflect how much you are working during the course of the scenario. Instead, your rating should reflect how much workload you are experiencing during the instant when you are prompted to make the rating.

Do you have any questions about using the ATWIT device?

SPAM Instructions

A single landline will be used for all coordination purposes during the experiment. In addition to coordination activities, at various times during the scenario you will receive a call over the landline from “Tech Center.” During the call you will be asked a question and will be given two response options. Please answer each question as quickly and accurately as possible. In answering each question you may use any and all information normally available to you including the radar scope and flight progress strips.

Do you have any questions about using answering questions over the landline?

Recall Procedure

After the scenario has been stopped you will perform a memory recall procedure. You will see a representation of the airspace on your display. Within the airspace will be the raw radar returns, vector lines, and leader lines as they appeared when the scenario ended. At the bottom of the display will be a bin containing the data blocks from all of the aircraft that were in your airspace or otherwise under your control when the scenario was stopped. Your task is to move the data blocks from the bin to their respective position in the airspace as quickly and accurately as possible.

To place a data block, select the data block from the bin by using the left button on the trackball. The data block will change color when it is selected. After selecting a data block from the bin, move the cursor to the appropritate position and push the left button to place the data block. Once a datablock has been placed it will change color in the bin (from green to gray). To remove a data block that has already been placed, select the *placed* data block using the left trackball button. Once selected, the data block will be highlighted in the bin. Move the cursor over the highlited datablock in the bin and press the left trackball button. The data block will move back into the bin.

Remember to complete the data block placements as quickly and accurately as possible.

Do you have any questions before we calibrate the oculometer?

Instructions for Participants (given before calibration of oculometer)

Subsequent Scenarios

Privacy Statement
Remember that all data is being collected without any information which could later be used to identify you. Your privacy is protected.

Active Control Instructions (Scenarios 1 & 4)
During this scenario we would like for you to control traffic as you normally would in the field. In addition, you will be making ATWIT ratings and answering questions over the landline. A memory recall procedure will occur after the scenario has stopped.

Monitoring Instructions (Scenarios 2 & 8)
During this scenario you will only have to monitor the air traffic. Although there are no pilot/controller communications, you may utilize all other normal control functions (j-ball, vector lines, route readouts). In addition, you will be making ATWIT ratings, answering questions over the landline. A memory recall procedure will occur after the scenario has stopped.

ATWIT Instructions
One purpose of this research is to obtain an accurate evaluation of controller workload. By workload, we mean whatever physical and mental effort you must exert to maintain safe and expeditious traffic flow. Buttons numbered from 1 to 10 will appear on the screen to your left. Push the button which describes your current level of workload. At one extreme, numbers 1 and 2, represent low workload - you can accomplish everything easily. At the other, numbers 9 and 10 represent a very high workload, where it is likely that you will have to leave some tasks unfinished.

All controllers, no matter how proficient and experienced, will be exposed at one time or another to all levels of workload. It does not detract from a controller's professionalism when he indicates that he is working very hard or that he is hardly working. Feel free to use the entire scale and tell us honestly how hard you are working. Do not sacrifice the safe and expeditious flow of traffic to respond to the ATWIT device. Remember, your workload rating should *not* reflect how much you are working during the course of the scenario. Instead, your rating should reflect how much workload you are experiencing during the instant when you are prompted to make the rating.

Do you have any questions about using the ATWIT device?

SPAM Instructions
You will receive calls over the landline from "Tech Center." During the call you will be asked a question and will be given two response options. Please answer each question as quickly and accurately as possible. In answering each question you will be allowed to use any and all information normally available to you including the radar scope and flight progress strips.

Do you have any questions about using answering questions over the landline?

Do you have any questions before we calibrate the oculometer?

Recall Instructions (given immediately after end of scenario)

In a moment you will see a representation of the airspace. Within the airspace will be the raw radar returns, vector lines, and leader lines as they appeared when the scenario ended. Place the data blocks from the bin in their respective positions in the airspace as quickly and accurately as possible.

Do you have any questions about the recall procedure?

Appendix H

Visual Scanning

H.1 Visual Scanning Variables

The oculometer recorded eye movements during both practice scenarios and experimental scenarios. H-1 provides a summary of the eye movement measures.

Table H–1. Visual Scanning Variables

1. `Conditional information – Aircraft
2. Conditional information – Location
3. Conditional information – Range
4. Conditional information - Tightness
5. Eye motion workload
6. Pupil motion workload
7. Visual efficiency
8. Mean number of fixations
9. Mean duration of fixations
10. Mean fixation area
11. Mean distance of saccades
12. Mean duration of saccades
13. Mean number of dwells
14. Mean dwell area
15. Mean duration of dwells
16. Number of fixations on target
17. Mean duration of fixations on target
18. Number of fixations off target
19. Mean duration of fixations off target
20. Number of Fixations on radar returns
21. Mean duration of fixations on radar returns
22. Number of fixations on data blocks
23. Mean duration of fixations on data blocks
24. Number of fixations on other static objects
25. Mean duration of fixations on other static objects
26. Number of fixations on PVD
27. Mean duration of fixations on PVD
28. Number of fixations on SCRD
29. Mean duration of fixations on SCRD
30. Number of fixations on map
31. Mean duration of fixations on map
32. Number of fixations on flight strips
33. Mean duration of fixations on flight strips
34. Number of fixations on keyboard
35. Mean duration of fixations on keyboard
36. Number of fixations on trackball
37. Mean duration of fixations on trackball
38. Number of fixations on ATWIT
39. Mean duration of fixations on ATWIT

H.1.1 Fixations

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:

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

H.1.2 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

H.1.3 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:

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

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

H.1.4 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 $t_{n,fix\ m}$ is the end (sample n) of the last fixation (fixation m).

Dwell Area:

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

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

H.1.5 Visual Efficiency

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

Visual Efficiency:

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

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

Visual Efficiency:

$$VISEFF = \Sigma FIXDUR / (\Sigma FIXDUR + \Sigma SACDUR)$$

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.

H.1.6 Eye Motion Workload

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

Eye Motion Workload:

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

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:

$$EYEMWL = \Sigma SACDST / TIME$$

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

H.1.7 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

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

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:

$$PUPAW = \Sigma\|PUPDIAM_i - PUPDIAM_{i+1}\|$$

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.

H.1.8 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:

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

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.

H.2. Visual Scanning: Inferential Statistics

Table H–2. MANOVA Results for Saccade Duration and Distance, Fixation Number, Duration, and Area

	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Task Load	.326	4.558	0.674	4.558	5	11	.017
Involvement	.612	1.394	0.388	1.394	5	11	.299
Task Load x Involvement	.874	0.316	0.126	0.316	5	11	.893

Table H–3. ANOVA Results for Eye Movement Related Variables ($p < .01$)

		Means sqr Effect	Means sqr Error	$F(1,15)$	*p*-level
Saccade duration	Load	0.001	0.000	6.034	.027
	Involvement	0.001	0.000	5.958	.028
	Load x Involvement	0.000	0.000	0.152	.702
Saccade Distance	Load	0.066	0.185	0.358	.559
	Involvement	0.053	0.177	0.298	.593
	Load x Involvement	0.177	0.127	1.400	.255
Fixation Number	Load	163248.578	81323.086	2.007	.177
	Involvement	55676.969	82758.891	0.673	.425
	Load x Involvement	25214.367	107323.008	0.235	.635
Fixation Duration	Load	0.004	0.001	3.454	.083
	Involvement	0.001	0.002	0.944	.347
	Load x Involvement	0.000	0.002	0.196	.664
Fixation Area	Load	0.000	0.005	0.044	.837
	Involvement	0.001	0.008	0.075	.787
	Load x Involvement	0.000	0.005	0.021	.887

Table H–4. MANOVA Results for Blink Number, Blink Duration, and Pupil Diameter

	Wilks' Lambda	Rao R Form	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Task Load	.760	1.371	0.240	1.371	3	13	.295
Involvement	.500	4.328	0.500	4.328	3	13	.025
Task Load x Involvement	.873	0.631	0.127	0.631	3	13	.608

Table H–5. ANOVA Results for Visual Scanning Related Workload Indicators ($p < .017$)

		Effect	Error	$F(1,15)$	*p*-level
Blink Number	Load	12064.542	10835.198	1.113	0.308
	Involvement	7295.088	13280.576	0.549	0.470
	Load x Involvement	7553.572	8055.369	0.938	0.348
Blink Duration	Load	0.011	0.003	4.312	0.055
	Involvement	0.002	0.001	3.903	0.067
	Load x Involvement	0.001	0.002	0.870	0.366
Pupil Diameter	Load	0.079	0.160	0.493	0.493
	Involvement	0.347	0.090	3.866	0.068
	Load x Involvement	0.026	0.296	0.088	0.771

Table H–6. MANOVA Results for Fixation Number, Duration, and Area by Load, Involvement and Time

	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.699	1.868	0.301	1.868	3	13	.185
Involvement	.702	1.841	0.298	1.841	3	13	.190
Time	.000	353.723	1.000	353.723	15	1	.042
Load x Involvement	.987	0.056	0.013	0.056	3	13	.982
Load x Time	.006	11.696	0.994	11.696	15	1	.226
Involvement x Time	.014	4.535	0.986	4.535	15	1	.355
Load x Involvement x Time	.055	1.146	0.945	1.146	15	1	.635

Table H–7. ANOVA Results for Interval-Based Eye Movement Related Variables ($p < .017$)

		Means sqr Effect	Means sqr Error	F(df1,2)	df1	df2	p-level
Number	Load	5107.655	3995.906	1.278	1	15	.276
	Involvement	138.047	5709.520	0.024	1	15	.879
	Time	11589.951	838.325	13.825	4	60	.000
	Load x Involvement	400.655	4525.971	0.089	1	15	.770
	Load x Time	2576.260	889.213	2.897	4	60	.019
	Involvement x Time	1718.002	1101.729	1.559	4	60	.182
	Load x Involvement x Time	1292.058	612.508	2.109	4	60	.073
Duration	Load	0.031	0.005	6.187	1	15	.025
	Involvement	0.015	0.009	1.628	1	15	.221
	Time	0.021	0.001	19.004	4	60	.000
	Load x Involvement	0.000	0.008	0.013	1	15	.912
	Load x Time	0.002	0.002	1.164	1	15	.335
	Involvement x Time	0.004	0.002	2.349	4	60	.049
	Load x Involvement x Time	0.001	0.001	1.134	4	60	.350
Area	Load	0.003	0.034	0.083	1	15	.777
	Involvement	0.004	0.049	0.087	1	15	.772
	Time	0.067	0.009	7.496	4	60	.000
	Load x Involvement	0.001	0.029	0.021	1	15	.886
	Load x Time	0.014	0.009	1.523	4	60	.193
	Involvement x Time	0.001	0.006	0.232	4	60	.947
	Load x Involvement x Time	0.009	0.005	1.983	4	60	.091

Table H-8. Saccade Characteristics: MANOVA Results

MANOVA, adjusted alpha=0.0169	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.475	7.733	0.525	7.733	2	14	.005
Interval 1	.936	0.478	0.064	0.478	2	14	.630
Interval 2	.760	2.211	0.240	2.211	2	14	.146
Interval 3	.385	11.177	0.615	11.177	2	14	.001
Interval 4	.622	4.256	0.378	4.256	2	14	.036
Interval 5	.449	8.595	0.551	8.595	2	14	.004
Interval 6	.774	2.044	0.226	2.044	2	14	.166
Involvement	.662	3.568	0.338	3.568	2	14	.056
Interval 1	.967	0.236	0.033	0.236	2	14	.793
Interval 2	.649	3.791	0.351	3.791	2	14	.048
Interval 3	.414	9.906	0.586	9.906	2	14	.002
Interval 4	.621	4.271	0.379	4.271	2	14	.036
Interval 5	.861	1.128	0.139	1.128	2	14	.351
Interval 6	.704	2.949	0.296	2.949	2	14	.085
Time	.078	7.076	0.922	7.076	10	6	.013
Low Load, Monitoring	.177	2.785	0.823	2.785	10	6	.111
Low Load, Active	.019	30.276	0.981	30.276	10	6	.000
High Load, Monitoring	.237	1.932	0.763	1.932	10	6	.217
High Load, Active	.309	1.340	0.691	1.340	10	6	.374
Load x Involvement	.944	0.413	0.056	0.413	2	14	.669
Load x Time	.259	1.718	0.741	1.718	10	6	.262
Involvement x Time	.170	2.920	0.830	2.920	10	6	.101
Load x Involvement x Time	.099	5.459	0.901	5.459	10	6	.025

Table H-9. Saccade Duration: ANOVA Results, Interval Based

Duration	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	0.007	0.001	9.227	1	15	.008
Monitoring	0.005	0.001	4.449	1	15	.052
Active Control	0.002	0.001	1.775	1	15	.203
Interval 1	0.000	0.000	0.924	1	15	.352
Interval 2	0.001	0.000	4.679	1	15	.047
Interval 3	0.004	0.000	14.777	1	15	.002
Interval 4	0.000	0.000	0.877	1	15	.364
Interval 5	0.005	0.001	9.875	1	15	.007
Interval 6	0.000	0.000	1.134	1	15	.304
Involvement	0.009	0.001	6.778	1	15	.020
Low Load	0.007	0.002	3.942	1	15	.066
High Load	0.003	0.001	2.382	1	15	.144
Interval 1	0.000	0.000	0.010	1	15	.923
Interval 2	0.004	0.001	7.494	1	15	.015
Interval 3	0.003	0.000	11.484	1	15	.004
Interval 4	0.002	0.000	9.141	1	15	.009
Interval 5	0.001	0.000	1.206	1	15	.289
Interval 6	0.002	0.000	6.170	1	15	.025
Time	0.001	0.000	4.911	5	75	.001
Low Load, Monitoring	0.000	0.000	2.401	5	75	.045
Low Load, Active	0.001	0.000	4.494	5	75	.001
High Load, Monitoring	0.002	0.000	7.479	5	75	.000
High Load, Active	0.000	0.000	1.871	5	75	.109
Load x Involvement	0.000	0.002	0.255	1	15	.621
Load x Time	0.001	0.000	4.091	5	75	.002
Involvement x Time	0.000	0.000	2.578	5	75	.033
Load x Involvement x Time	0.001	0.000	7.656	5	75	.000

Table H-10. Saccade Distance: ANOVA Results, Interval Based

Distance	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	0.473	1.139	0.415	1	15	.529
Monitoring	1.005	0.974	1.032	1	15	.326
Active Control	0.001	0.822	0.001	1	15	.974
Involvement	0.932	1.097	0.849	1	15	.371
Low Load	1.437	0.481	2.988	1	15	.104
High Load	0.028	1.273	0.022	1	15	.885
Time	0.601	0.141	4.257	5	75	.002
Load x Involvement	0.533	0.656	0.812	1	15	.382
Load x Time	0.331	0.129	2.557	5	75	.034
Involvement x Time	0.147	0.131	1.116	5	75	.359
Load x Involvement x Time	0.291	0.154	1.887	5	75	.107

Table H-12. Fixation Characteristics by Scene Plane : MANOVA Results

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Task Load	.669	3.465	0.331	3.465	2	14	.060
Scene Plane	.000	3090.435	1.000	309.435	14	2	.003
Task Load x Involvement	.981	0.133	0.019	0.133	2	14	.876
Task Load x Scene Plane	.054	2.498	0.946	2.498	14	2	.322
Involvement x Scene Plane	.058	2.326	0.942	2.326	14	2	.341
Task Load x Involvement x Scene Plane	.163	0.731	0.837	0.731	14	2	.713

Table H-13. Number of Fixations by Scene Plane : ANOVA Results

Number	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Task Load	20406.072	10165.386	2.007	1	15	.177
Flight Strip Bay	34929.801	35612.473	0.981	1	15	.338
Keyboard	64983.879	5993.706	10.842	1	15	.005
Track Ball	2.680	251.643	0.011	1	15	.919
ATWIT	44.804	302.532	0.148	1	15	.706
CRD/QAK	24132.621	2069.708	11.660	1	15	.004
Map	192.180	95.695	2.008	1	15	.177
Land Line	554.147	243.046	2.280	1	15	.152
Task Load x Scene Plane	7615.680	12110.361	0.629	6	90	.731
Involvement x Scene Plane	16867.813	13762.795	1.226	6	90	.295
Task Load x Involvement x Scene Plane	10782.088	11363.794	0.949	6	90	.473

Table H-14. Fixation Duration by Scene Plane: ANOVA Results

Duration	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Task Load	0.057	0.019	3.017	1	15	.103
Flight Strip Bay	0.001	0.001	0.891	1	15	.360
Keyboard	0.022	0.006	3.334	1	15	.088
Track Ball	0.370	0.162	2.286	1	15	.151
ATWIT	0.000	0.006	0.063	1	15	.805
CRD/QAK	0.164	0.005	33.485	1	15	.000
Map	0.187	0.010	18.707	1	15	.001
Land Line	0.035	0.017	2.104	1	15	.168
Task Load x Scene Plane	0.004	0.027	0.136	6	90	.995
Involvement x Scene Plane	0.111	0.027	4.142	6	90	.000
Task Load x Involvement x Scene Plane	0.002	0.028	0.074	6	90	.999

Table H–15. Fixation Characteristics by Scene Plane: MANOVA Results, Interval Based

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.519	6.498	0.481	6.498	2	14	.010
Scene	.042	157.927	0.958	157.927	2	14	.000
Load x Involvement	.764	2.167	0.236	2.167	2	14	.151
Load x Time	.403	0.888	0.597	0.888	10	6	.587
Involvement x Time	.096	5.657	0.904	5.657	10	6	.023
Load x Scene	.911	0.683	0.089	0.683	2	14	.521
Involvement x Scene	.909	0.700	0.091	0.700	2	14	.513
Time x Scene	.027	21.454	0.973	21.454	10	6	.001
Load x Time x Scene	.272	1.606	0.728	1.606	10	6	.290
Involvement x Time x Scene	.129	4.058	0.871	4.058	10	6	.050
Load x Involvement x Time x Scene	.178	2.765	0.822	2.765	10	6	.113

Table H-16. Number of Fixations by Scene Plane: ANOVA Results, Interval Based

Number	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	3.255	2515.722	0.001	1	15	.972
Scene	7051866.500	52165.211	135.183	1	15	.000
Load x Involvement	1665.574	1972.219	0.845	1	15	.373
Load x Time	1289.157	563.348	2.288	5	75	.054
Involvement x Time	586.443	600.980	0.976	5	75	.438
Load x Scene	2051.382	5271.664	0.389	6	90	.542
Involvement x Scene	807.317	8940.859	0.090	6	90	.768
Time x Scene	22828.459	1751.238	13.036	30	90	.000
Load x Time x Scene	160.772	1248.355	0.129	30	90	.985
Involvement x Time x Scene	5021.814	1505.616	3.335	30	90	.009
Load x Involvement x Time x Scene	8122.203	1250.881	6.493	30	90	.000

Table H-17. Fixation Duration by Scene Plane: ANOVA Results, Interval Based

Duration	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	df1	df2	*p*-level
Load	0.073	0.006	11.291	1	15	.004
Scene	7.604	0.026	293.290	6	90	.000
Load x Involvement	0.007	0.009	0.788	1	15	.389
Load x Time	0.004	0.003	1.106	5	75	.310
Involvement x Time	0.003	0.002	1.740	5	75	.136
Load x Scene	0.004	0.003	1.106	6	90	.310
Involvement x Scene	0.004	0.003	1.376	6	90	.259
Time x Scene	0.016	0.003	5.727	30	90	.000
Load x Time x Scene	0.007	0.003	2.741	30	90	.025
Involvement x Time x Scene	0.002	0.003	0.870	30	90	.506
Load x Involvement x Time x Scene	0.002	0.003	0.557	30	90	.733

Table H- 18. Fixation Characteristics by Radarscope Object:
MANOVA Results, Scenario Based

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Task Load	.398	10.587			2	14	.002
Task Load x Involvement	.862	1.116			2	14	.335
Task Load x Object	.383	2.686			6	10	.081
Involvement x Object	.491	1.728			2	10	.212
Load x Involvement x Object	.697	0.724			2	10	.641

Table H-19. Fixation Characteristics by Radarscope Object: MANOVA Results, Interval Based

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.755	2.268	0.245	2.268	2	14	.140
Involvement	.824	1.496	0.176	1.496	2	14	.258
Radar Return	.789	1.867	0.211	1.867	2	14	.191
Data Block	.726	2.640	0.274	2.640	2	14	.106
Time	.081	6.851	0.919	6.851	10	6	.014
Object	.482	7.518	0.518	7.518	2	14	.006
Monitoring	.446	8.697	0.554	8.697	2	14	.004
Active Control	.634	4.044	0.366	4.044	2	14	.041
Load x Involvement	.995	0.036	0.005	0.036	2	14	.965
Load x Time	.065	8.584	0.935	8.584	10	6	.008
Involvement x Object	.762	2.189	0.238	2.189	2	14	.149
Time x Object	.278	1.555	0.722	1.555	10	6	.305
Load x Involvement x Time	.036	16.136	0.964	16.136	10	6	.001
Load x Involvement x Object	.909	0.701	0.091	0.701	2	14	.513
Load x Time x Object	.613	0.379	0.387	0.379	10	6	.916
Involvement x Time x Object	.374	1.004	0.626	1.004	10	6	.523
Load x Involvement x Time x Object	.254	1.762	0.746	1.762	10	6	.252

Table H-20. Number of Fixations by Radarscope Object: ANOVA Results

Number	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	718.561	1388.644	0.517	1	15	.483
Involvement	885.017	3852.203	0.230	1	15	.639
Time	2285.364	515.099	4.437	5	75	.001
Object	49889.352	6274.989	7.951	1	15	.013
Load x Involvement	41.054	1699.183	0.024	1	15	.879
Load x Time	498.905	322.769	1.546	5	75	.186
Involvement x Time	1744.968	541.476	3.223	5	75	.011
Load x Object	418.541	914.811	0.458	1	15	.509
Involvement x Object	14356.219	3427.043	4.189	1	15	.059
Time x Object	841.015	819.159	1.027	5	75	.408
Load x Involvement x Time	3377.578	369.996	9.129	5	75	.000
Load x Involvement x Object	49.247	1265.070	0.039	1	15	.846
Load x Time x Object	314.950	455.120	0.692	5	75	.631
Involvement x Time x Object	646.686	555.013	1.165	5	75	.334
Load x Involvement x Time x Object	719.144	306.276	2.348	5	75	.049

Table H-21. Fixation Duration by Radarscope Object: ANOVA Results

Duration	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	0.050	0.011	4.391	1	15	.054
Involvement	0.052	0.030	1.747	1	15	.206
Time	0.040	0.003	12.381	5	75	.000
Object	0.013	0.006	2.256	1	15	.154
Load x Involvement	0.002	0.021	0.074	1	15	.789
Load x Time	0.013	0.005	2.826	5	75	.022
Involvement x Time	0.005	0.004	1.328	5	75	.262
Load x Object	0.001	0.004	0.224	1	15	.643
Involvement x Object	0.003	0.003	1.265	1	15	.278
Time x Object	0.002	0.002	0.854	5	75	.516
Load x Involvement x Time	0.002	0.003	0.661	5	75	.654
Load x Involvement x Object	0.003	0.002	1.172	1	15	.296
Load x Time x Object	0.000	0.002	0.116	5	75	.989
Involvement x Time x Object	0.002	0.002	1.265	5	75	.288
Load x Involvement x Time x Object	0.001	0.002	0.384	5	75	.858

Table H-22. Conditional Information Indices: MANOVA Results

MANOVA, adjusted alpha=0.0126	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.133	19.602	0.867	19.602	4	12	.000
Monitoring	.306	6.816	0.694	6.816	4	12	.004
Active Control	.143	17.934	0.857	17.934	4	12	.000
Involvement	.186	13.158	0.814	13.158	4	12	.000
Low Load	.663	1.527	0.337	1.527	4	12	.256
High Load	.104	25.734	0.896	25.734	4	12	.000
Load x Involvement	.156	16.172	0.844	16.172	4	12	.000

Table H-23. Object-Based Conditional Information Index: ANOVA Results

Duration	Means sqr Effect	Means sqr Error	*F*(df1,2)	df1	df2	*p*-level
Load	0.008	0.000	54.332	1	15	.000
Monitoring	0.002	0.000	9.947	1	15	.007
Active Control	0.007	0.000	76.643	1	15	.000
Involvement	0.001	0.000	6.336	1	15	.024
Low Load	0.000	0.000	0.063	1	15	.806
High Load	0.002	0.000	24.556	1	15	.000
Load x Involvement	0.001	0.000	8.413	1	15	.011

H.3. Visual Scanning: Scenario Based Descriptive Statistics

Table H-24. Saccade Duration: Mean and Standard Deviations by Load and Involvement

Saccade Duration (msec)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	111	22	120	16	116	19
Active Control	121	19	127	19	124	19
	116	21	124	17	120	19

Table H-25. Saccade Distance: Mean and Standard Deviations by Load and Involvement

Saccade Distance (inches)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	3.595	0.525	3.772	0.466	3.678	0.498
Active Control	3.757	0.346	3.716	0.653	3.737	0.514
	3.676	0.445	3.742	0.564	3.708	0.503

Table H-26. Eye Motion Workload: Mean and Standard Deviations by Load and Involvement

Eye Motion Workload (-)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	5.306	1.199	5.822	0.755	5.547	1.033
Active Control	5.715	0.715	5.798	0.929	5.756	0.816
	5.510	0.993	5.809	0.838	5.655	0.926

Table H-27. Number of Fixations: Mean and Standard Deviations by Load and Involvement

Number of Fixations	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	2699	503	2846	281	2768	415
Active Control	2798	299	2859	238	2829	268
	2749	410	2853	255	2799	345

Table H-28. Fixation Duration: Mean and Standard Deviations by Load and Involvement

Fixation Duration (msec)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	441	71	430	52	436	62
Active Control	436	44	416	43	426	44
	438	58	423	47	431	53

Table H-29. Fixation Area: Mean and Standard Deviations by Load and Involvement

Fixation Area (sq. inches)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	0.663	0.186	0.663	0.186	0.663	0.183
Active Control	0.660	0.119	0.653	0.115	0.657	0.115
	0.662	0.154	0.658	0.149	0.660	0.150

Table H-30. Visual Scanning Efficiency: Mean and Standard Deviations by Load and Involvement

Visual Scanning Efficiency (-)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.795	0.051	0.781	0.039	0.789	0.046
Active Control	0.782	0.037	0.765	0.033	0.774	0.035
	0.789	0.045	0.773	0.036	0.781	0.041

Table H-31. Number of Dwells: Mean and Standard Deviations by Load and Involvement

Number of Dwells	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	2481	473	2611	258	2541	387
Active Control	2531	276	2615	265	2573	269
	2506	382	2613	257	2558	329

Table H-32. Dwell Duration: Mean and Standard Deviations by Load and Involvement

Dwell Duration (msec)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	482	79	472	66	477	72
Active Control	489	53	463	58	476	56
	486	66	467	61	477	64

Table H-33. Dwell Area: Mean and Standard Deviations by Load and Involvement

Dwell Area (sq. inches)	Low		High			
	Mean	SD	Mean	SD	Mean	SD
Monitoring	0.777	0.203	0.772	0.188	0.775	0.193
Active Control	0.784	0.128	0.759	0.128	0.771	0.127
	0.780	0.167	0.765	0.156	0.773	0.161

Table H-34. Number of Blinks: Means and Standard Deviations by Load and Involvement

Number of Blinks	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	388	177	393	218	390	194
Active Control	388	157	437	161	413	158
	388	164	417	188	402	175

Table H-35. Blink Duration: Means and Standard Deviations by Load and Involvement

Blink Duration (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	256	58	238	55	248	56
Active Control	254	99	218	43	236	78
	255	80	227	49	241	68

Table H-36. Pupil Diameter: Means and Standard Deviations by Load and Involvement

Pupil Diameter (mm)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	6.440	0.839	6.548	0.985	6.491	0.896
Active Control	6.628	0.931	6.658	0.847	6.643	0.876
	6.534	0.877	6.607	0.900	6.569	0.881

Table H-37. Number of Fixations by Scene Plane by Load and Involvement

Number of Fixations by Scene Planes	Scene Plane	Low		High			
		Means	SD	Means	SD	Means	SD
Monitoring	RSN	1808	423	1898	308	1850	370
	FSN	713	362	769	275	739	320
	KBN	48	75	52	52	50	64
	TBN	8	12	10	14	9	13
	ATN	23	9	23	6	23	8
	CRN	78	39	67	46	73	42
	MDN	10	13	3	6	7	11
	LLN	13	13	24	37	18	27
Active Control	RSN	1839	247	1868	170	1854	209
	FSN	721	232	660	226	691	227
	KBN	87	100	145	133	116	119
	TBN	3	4	15	26	9	19
	ATN	29	32	20	7	25	23
	CRN	96	32	130	83	113	64
	MDN	10	10	10	14	10	12
	LLN	12	12	11	11	12	11
	RSN	1823	341	1882	241	1852	296
	FSN	717	299	711	251	714	275
	KBN	67	89	101	112	84	101
	TBN	6	9	13	21	9	16
	ATN	26	23	21	6	24	17
	CRN	87	36	101	74	94	58
	MDN	10	11	7	11	9	11
	LLN	13	12	17	27	15	21

Table H-38. Fixation Duration (msec) by Scene Plane by Load and Involvement

Number of Fixations by Scene Planes	Scene Plane	Low		High			
		Means	SD	Means	SD	Means	SD
Monitoring	Radar Scope	502	72	492	58	497	65
	Flight Strip Bay	308	51	301	38	305	45
	Keyboard	244	164	226	92	236	133
	Track Ball	305	743	254	274	281	565
	ATWIT	331	86	322	89	327	86
	CRD/QAK	392	105	353	91	374	99
	Map	174	183	103	134	141	164
	Land Line	270	172	263	137	267	154
Active Control	Radar Scope	493	56	479	57	486	56
	Flight Strip Bay	313	28	281	22	297	30
	Keyboard	200	91	195	49	198	72
	Track Ball	141	160	107	79	124	126
	ATWIT	324	82	320	89	322	85
	CRD/QAK	498	79	459	55	479	70
	Map	256	148	249	166	252	155
	Land Line	218	107	219	103	218	103
	Radar Scope	498	64	485	57	492	60
	Flight Strip Bay	310	41	290	32	301	38
	Keyboard	222	132	210	73	216	107
	Track Ball	223	535	176	206	200	408
	ATWIT	328	83	321	88	324	85
	CRD/QAK	445	106	410	90	428	100
	Map	215	169	181	167	198	167
	Land Line	244	143	239	120	242	131

Table H-39. Number of Fixations by Radarscope Object by Load and Involvement

Number of Fixations by Scene Planes	Radar Scope Object	Low		High			
		Mean	SD	Mean	SD	Mean	SD
Monitoring	System Area	4	7	3	5	3	6
	Other Static Objects	19	11	12	14	16	13
	Radar Returns	787	206	827	118	806	169
	Data Blocks	926	258	987	250	955	252
Active Control	System Area	2	2	1	1	1	1
	Other Static Objects	19	12	19	18	19	15
	Radar Returns	867	125	866	98	866	110
	Data Blocks	900	146	924	99	912	123
	System Area	3	5	2	3	2	4
	Other Static Objects	19	11	15	16	17	14
	Radar Returns	827	172	848	107	837	144
	Data Blocks	913	207	954	184	933	196

Table H-40. Number of Fixations by Radar Scope Object by Load and Involvement

Number of Fixations by Radar Scope Objects	Radar Scope Objects	Low		High			
		Means	SD	Means	SD	Means	SD
Monitoring	System Area	4	7	3	5	3	6
	Other Static Objects	19	11	12	14	16	13
	Radar Returns	787	206	827	118	806	169
	Data Blocks	926	258	987	250	955	252
Active Control	System Area	2	2	1	1	1	1
	Other Static Objects	19	12	19	18	19	15
	Radar Returns	867	125	866	98	866	110
	Data Blocks	900	146	924	99	912	123
	System Area	3	5	2	3	2	4
	Other Static Objects	19	11	15	16	17	14
	Radar Returns	827	172	848	107	837	144
	Data Blocks	913	207	954	184	933	196

Table H-41. Fixation Duration by Radarscope Object by Load and Involvement

Fixation Duration by Radar Scope Objects	Radar Scope Objects	Low		High			
		Means	SD	Means	SD	Means	SD
Monitoring	System Area	336	277	185	228	265	263
	Other Static Objects	236	54	265	116	249	88
	Radar Returns	513	74	506	70	510	71
	Data Blocks	514	86	497	57	506	73
Active Control	System Area	291	270	60	108	175	234
	Other Static Objects	213	65	193	71	203	68
	Radar Returns	510	61	493	57	502	58
	Data Blocks	495	58	483	63	489	60
	System Area	313	270	118	183	219	250
	Other Static Objects	224	60	227	100	225	81
	Radar Returns	512	66	499	62	506	64
	Data Blocks	505	73	489	60	497	67

Table H-42. Object-Based Conditional Information Index Object by Load and Involvement

COB	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.151	0.017	0.135	0.007	0.144	0.015
Active Control	0.152	0.010	0.121	0.009	0.137	0.018
	0.151	0.014	0.128	0.011	0.140	0.017

Table H-43. Range-Based Conditional Information Index by Load and Involvement

CRA	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.993	0.017	1.002	0.012	0.997	0.015
Active Control	0.991	0.011	0.998	0.011	0.995	0.011
	0.992	0.014	1.000	0.012	0.996	0.013

H.3.2 Interval - Based

Table H-44. Number of Fixations by Load, Involvement, and Time

Number of Fixations	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	502	58	506	55	504	56
	469	60	500	52	484	58
	468	46	462	53	465	49
	445	44	471	50	458	48
	472	44	444	49	458	48
	458	55	467	53	463	53
	469	53	475	55	472	54
Active Control	481	61	494	44	487	53
	465	65	486	48	475	57
	469	47	482	49	475	48
	467	53	469	51	468	51
	463	54	461	46	462	50
	453	55	464	45	458	50
	466	55	476	47	471	52
	491	60	500	49	496	55
	467	61	493	50	480	57
	469	46	472	51	470	48
	456	49	470	50	463	50
	467	49	453	48	460	48
	455	54	465	48	460	51
	468	54	475	51	472	53

Table H-45. Fixation Duration by Load, Involvement, and Time

Fixation Duration (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	397	66	388	47	393	57
	450	83	425	46	438	68
	464	70	440	62	452	66
	464	78	450	61	457	69
	450	56	445	77	447	66
	475	87	442	57	459	74
	450	76	432	61	441	70
Active Control	412	54	396	43	404	49
	451	62	404	51	428	61
	429	48	401	51	416	50
	447	53	430	57	439	55
	440	50	433	57	437	52
	444	61	438	64	441	62
	437	55	417	55	428	56
	405	60	392	45	399	53
	451	72	414	49	433	64
	446	61	421	59	434	61
	455	66	440	59	448	63
	445	52	439	67	442	59
	459	75	440	60	450	68
	443	66	424	59	434	63

Table H-46. Fixation Area by Load, Involvement, and Time

Fixation Area (inch2)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.607	0.160	0.619	0.146	0.613	0.151
	0.677	0.211	0.589	0.169	0.635	0.194
	0.716	0.226	0.657	0.212	0.687	0.217
	0.685	0.286	0.674	0.165	0.679	0.230
	0.680	0.209	0.735	0.194	0.708	0.200
	0.666	0.199	0.704	0.279	0.685	0.239
	0.671	0.214	0.663	0.199	0.667	0.207
Active Control	0.619	0.142	0.617	0.119	0.618	0.129
	0.626	0.152	0.626	0.120	0.626	0.135
	0.689	0.143	0.660	0.120	0.675	0.131
	0.659	0.132	0.661	0.124	0.660	0.126
	0.691	0.112	0.698	0.174	0.694	0.143
	0.688	0.115	0.688	0.132	0.688	0.121
	0.662	0.133	0.659	0.132	0.660	0.133
	0.613	0.149	0.618	0.131	0.615	0.139
	0.651	0.183	0.608	0.145	0.630	0.166
	0.702	0.185	0.659	0.170	0.681	0.177
	0.672	0.217	0.667	0.144	0.669	0.183
	0.686	0.163	0.717	0.182	0.701	0.172
	0.677	0.159	0.696	0.214	0.686	0.187
	0.666	0.177	0.661	0.169	0.664	0.173

Table H-47. Visual Efficiency by Load, Involvement, and Time

Visual Efficiency (-)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.766	0.063	0.759	0.053	0.763	0.058
	0.806	0.053	0.801	0.032	0.803	0.043
	0.815	0.040	0.781	0.047	0.798	0.046
	0.802	0.043	0.806	0.043	0.804	0.042
	0.810	0.042	0.757	0.056	0.783	0.056
	0.811	0.041	0.784	0.049	0.798	0.046
	0.801	0.050	0.781	0.050	0.791	0.051
Active Control	0.773	0.043	0.762	0.042	0.768	0.043
	0.796	0.047	0.758	0.041	0.778	0.048
	0.780	0.045	0.750	0.036	0.765	0.043
	0.789	0.037	0.769	0.035	0.779	0.037
	0.780	0.038	0.765	0.038	0.772	0.038
	0.772	0.045	0.776	0.040	0.774	0.042
	0.782	0.043	0.763	0.039	0.773	0.042
	0.770	0.054	0.760	0.047	0.765	0.050
	0.801	0.049	0.779	0.042	0.791	0.047
	0.797	0.046	0.766	0.044	0.782	0.047
	0.795	0.040	0.788	0.043	0.792	0.041
	0.794	0.042	0.761	0.047	0.778	0.048
	0.791	0.047	0.780	0.044	0.785	0.046
	0.791	0.047	0.772	0.045	0.782	0.047

Table H-48. Number of Dwells by Load, Involvement, and Time

Number of Dwells	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	462	57	465	55	463	55
	433	61	457	45	445	54
	425	41	422	52	424	46
	409	45	433	45	421	46
	437	47	411	41	424	45
	421	60	429	51	425	55
	431	54	436	51	434	52
Active Control	440	58	450	50	445	54
	421	60	448	54	434	58
	425	47	445	49	434	48
	421	47	426	54	423	50
	420	47	418	51	419	48
	404	55	421	49	412	52
	422	52	435	51	428	52
	451	57	458	52	454	55
	427	60	452	49	439	56
	425	43	433	51	429	47
	415	46	430	49	422	48
	428	47	415	46	421	47
	412	57	425	49	418	54
	426	53	435	51	431	52

Table H-49. Dwell Duration by Load, Involvement, and Time

Dwell Duration (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	432	76	427	61	430	68
	492	94	468	55	480	78
	513	77	486	89	499	83
	510	87	491	74	501	80
	490	65	482	91	486	78
	521	106	486	65	503	88
	492	88	473	75	483	82
Active Control	456	67	441	60	449	63
	506	74	447	67	477	75
	483	67	444	70	464	70
	503	58	479	73	491	66
	494	55	489	80	491	67
	509	77	493	81	501	78
	492	67	465	73	479	71
	444	71	434	60	439	66
	499	84	457	61	479	76
	498	72	465	81	481	78
	506	72	485	72	496	73
	492	59	486	84	489	72
	514	91	490	72	502	82
	492	78	469	74	481	77

Table H-50. Dwell Area by Load, Involvement, and Time

Dwell Area (sq. inches)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.708	0.163	0.724	0.139	0.716	0.149
	0.786	0.222	0.708	0.173	0.748	0.201
	0.847	0.251	0.764	0.228	0.806	0.240
	0.812	0.314	0.776	0.164	0.794	0.247
	0.792	0.236	0.837	0.215	0.815	0.223
	0.782	0.216	0.816	0.293	0.799	0.253
	0.787	0.234	0.771	0.207	0.779	0.221
Active Control	0.721	0.147	0.732	0.126	0.726	0.135
	0.738	0.165	0.721	0.123	0.730	0.144
	0.815	0.157	0.748	0.119	0.783	0.142
	0.790	0.158	0.766	0.159	0.779	0.156
	0.827	0.136	0.824	0.214	0.826	0.175
	0.831	0.111	0.808	0.151	0.820	0.130
	0.787	0.149	0.767	0.153	0.777	0.151
	0.714	0.153	0.728	0.130	0.721	0.141
	0.762	0.194	0.715	0.148	0.739	0.174
	0.831	0.205	0.756	0.179	0.794	0.195
	0.801	0.242	0.771	0.159	0.786	0.204
	0.810	0.189	0.831	0.211	0.820	0.198
	0.807	0.169	0.812	0.229	0.810	0.199
	0.787	0.195	0.769	0.182	0.778	0.189

Table H-51. Saccade Duration by Load, Involvement, and Time

SDUM (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	119	29	123	26	121	27
	107	27	105	15	106	21
	103	20	124	23	113	24
	112	23	109	16	111	20
	106	23	141	28	123	31
	108	19	121	23	114	21
	109	24	120	25	115	25
Active Control	119	19	124	24	122	21
	115	23	130	20	122	23
	121	25	133	20	127	23
	117	20	128	20	123	20
	128	21	131	22	129	22
	129	23	124	19	127	21
	122	22	129	21	125	22
	119	24	124	25	121	24
	111	25	118	21	114	23
	113	24	128	22	120	24
	115	21	118	20	117	21
	117	24	136	25	126	26
	119	23	122	21	121	22
	116	24	124	23	120	24

Table H-52. Saccade Distance by Load, Involvement, and Time

SDIM (inch 2)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	3.686	0.737	3.935	0.829	3.806	0.780
	3.437	0.726	3.533	0.489	3.483	0.614
	3.648	0.636	3.861	0.619	3.754	0.626
	3.683	0.657	3.472	0.475	3.577	0.574
	3.491	0.392	3.974	0.746	3.733	0.635
	3.561	0.504	3.638	0.545	3.599	0.517
	3.584	0.614	3.735	0.644	3.659	0.632
Active Control	3.739	0.456	3.750	0.747	3.744	0.604
	3.554	0.471	3.794	0.789	3.670	0.646
	3.711	0.561	3.902	0.681	3.803	0.619
	3.770	0.465	3.650	0.734	3.712	0.602
	4.003	0.450	3.873	0.673	3.940	0.563
	3.797	0.469	3.596	0.715	3.699	0.600
	3.762	0.486	3.761	0.712	3.762	0.605
	3.712	0.603	3.842	0.781	3.775	0.692
	3.495	0.605	3.663	0.659	3.577	0.632
	3.680	0.589	3.882	0.640	3.779	0.618
	3.728	0.558	3.561	0.614	3.646	0.588
	3.755	0.491	3.924	0.700	3.838	0.604
	3.682	0.493	3.617	0.625	3.650	0.558
	3.675	0.558	3.748	0.677	3.711	0.620

Table H-53. Eye Motion Workload by Load, Involvement, and Time

Eye Motion Workload (inch/sec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	5.724	1.343	6.106	1.183	5.909	1.262
	5.312	1.201	5.839	0.789	5.567	1.041
	5.703	1.097	5.819	0.850	5.761	0.966
	5.567	1.059	5.331	0.871	5.449	0.961
	5.478	0.646	5.819	0.944	5.648	0.814
	5.442	0.969	5.626	0.939	5.534	0.942
	5.537	1.060	5.756	0.942	5.646	1.006
Active Control	5.545	1.164	5.811	1.335	5.674	1.236
	5.433	0.829	6.007	1.244	5.711	1.073
	5.769	1.046	6.221	1.123	5.988	1.090
	5.930	0.836	5.621	0.852	5.780	0.844
	5.973	0.784	5.978	0.950	5.975	0.854
	5.730	0.878	5.554	1.008	5.645	0.931
	5.730	0.928	5.865	1.092	5.796	1.010
	5.635	1.240	5.959	1.248	5.791	1.244
	5.372	1.017	5.923	1.027	5.639	1.051
	5.737	1.054	6.020	1.000	5.876	1.029
	5.754	0.952	5.476	0.859	5.617	0.911
	5.733	0.752	5.899	0.934	5.814	0.843
	5.590	0.919	5.590	0.958	5.590	0.931
	5.636	0.997	5.811	1.018	5.721	1.010

Table H-54. Blink Number by Load, Involvement, and Time

Blink Number	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	67	31	69	39	68	34
	66	28	65	34	66	30
	69	29	63	34	66	31
	67	27	66	40	67	33
	68	27	66	38	67	32
	68	32	65	35	67	33
	68	28	66	36	67	32
Active Control	61	27	73	26	67	27
	60	28	75	25	68	27
	66	30	75	30	70	30
	68	28	70	32	69	29
	63	26	73	33	68	29
	70	27	73	32	71	29
	65	27	73	29	69	28
	64	29	71	33	67	31
	63	28	70	30	67	29
	67	29	69	32	68	30
	68	27	68	35	68	31
	66	26	69	35	68	30
	69	29	69	33	69	31
	66	28	69	33	68	30

Table H-55. Blink Duration by Load, Involvement and Time

Blink Duration (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	278	96	257	86	268	91
	251	78	240	63	245	70
	236	43	234	56	235	49
	247	51	221	44	234	49
	253	61	237	46	245	54
	255	65	229	46	242	57
	254	68	236	58	245	64
Active Control	252	97	242	73	247	85
	263	106	214	43	239	85
	254	113	207	43	231	88
	258	112	203	42	231	89
	262	111	211	48	237	89
	236	81	209	42	223	66
	254	101	214	50	235	83
	265	96	250	79	258	88
	257	92	227	54	242	77
	245	86	221	51	233	71
	253	86	212	43	233	71
	258	89	224	48	241	73
	246	73	219	44	233	62
	254	86	225	55	240	74

Table H-56. Pupil Diameter by Load, Involvement, and Time

Pupil Diameter (mm)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	6.5	0.8	6.5	0.9	6.5	0.8
	6.5	0.9	6.6	1.0	6.5	0.9
	6.4	0.9	6.6	1.0	6.5	0.9
	6.3	0.9	6.6	1.0	6.5	0.9
	6.4	0.9	6.6	0.9	6.5	0.9
	6.4	0.9	6.6	1.0	6.5	0.9
	6.4	0.8	6.6	0.9	6.5	0.9
Active Control	6.6	0.9	6.5	0.9	6.6	0.9
	6.7	0.9	6.6	0.9	6.6	0.9
	6.6	0.9	6.6	0.9	6.6	0.9
	6.6	1.0	6.7	0.9	6.7	0.9
	6.6	1.0	6.7	0.9	6.6	0.9
	6.7	1.0	6.7	0.8	6.7	0.9
	6.6	0.9	6.6	0.8	6.6	0.9
	6.6	0.9	6.5	0.9	6.6	0.9
	6.6	0.9	6.6	0.9	6.6	0.9
	6.5	0.9	6.6	0.9	6.6	0.9
	6.5	0.9	6.7	0.9	6.6	0.9
	6.5	0.9	6.6	0.9	6.5	0.9
	6.5	0.9	6.7	0.9	6.6	0.9
	6.5	0.9	6.6	0.9	6.6	0.9

Table H-57. Number of Fixations on a Target by Load, Involvement, and Time

Number of Fixations on a Target	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	495	62	499	54	497	57
	463	60	495	51	478	58
	461	45	455	54	458	49
	434	49	467	49	450	51
	464	47	439	48	452	48
	450	55	460	53	455	53
	461	55	469	55	465	55
Active Control	479	61	491	44	485	53
	462	65	482	49	472	58
	465	47	478	50	471	48
	461	53	464	51	463	51
	456	53	452	47	454	49
	447	53	452	51	449	51
	462	55	470	50	466	52
	487	61	495	49	491	55
	462	62	488	50	475	57
	463	45	467	53	465	49
	448	52	466	49	457	51
	460	49	446	47	453	48
	449	53	456	51	452	52
	462	55	469	52	465	54

Table H-58. Percentage of Fixations on Target by Load, Involvement, and Time

Percentage of Fixations on Target	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	99	2	99	1	99	2
	99	1	99	1	99	1
	99	1	99	1	99	1
	97	3	99	1	98	2
	98	2	99	1	99	1
	98	2	98	2	98	2
	98	2	99	1	98	2
Active Control	100	0	99	1	99	1
	99	1	99	1	99	1
	99	0	99	1	99	1
	99	1	99	1	99	1
	98	1	98	3	98	2
	99	1	98	6	98	4
	99	1	99	3	99	2
	99	2	99	1	99	1
	99	1	99	1	99	1
	99	1	99	1	99	1
	98	2	99	1	99	2
	98	1	99	2	98	2
	99	2	98	4	98	3
	99	2	99	2	99	2

Table H-59. Duration of Fixations on Target by Load, Involvement, and Time

Fixation Duration on Target (msec)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	404	74	394	48	399	62
	457	87	430	46	444	70
	471	70	447	65	459	68
	477	78	454	61	465	70
	459	58	449	78	454	68
	484	88	450	60	467	76
	458	79	437	62	448	72
Active Control	414	54	399	43	407	49
	455	64	407	52	431	62
	433	48	405	53	419	51
	453	53	435	58	444	55
	447	50	442	60	445	54
	449	58	451	72	450	64
	442	55	423	59	433	58
	409	64	396	45	403	55
	456	75	418	50	438	66
	451	62	426	62	439	63
	464	66	444	59	455	63
	453	54	446	68	449	61
	466	75	450	65	458	70
	450	68	430	61	440	65

Table H-60. Number of Fixations not on Target by Load, Involvement, and Time

Number of Fixations not on Target	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	7	10	7	4	7	7
	6	5	6	3	6	4
	7	6	7	5	7	5
	11	11	4	3	8	9
	8	7	4	3	6	6
	8	10	8	10	8	10
	8	8	6	5	7	7
Active Control	2	2	3	4	3	3
	3	3	3	3	3	3
	4	2	4	4	4	3
	6	4	5	4	5	4
	7	5	9	16	8	12
	6	5	12	28	8	20
	5	4	6	14	5	10
	5	7	5	4	5	6
	5	5	5	3	5	4
	6	5	5	4	5	5
	9	8	4	3	7	7
	8	6	7	12	7	9
	7	8	10	21	8	16
	6	7	6	10	6	9

Table H-61. Fixation Area by Load, Involvement, and Time

Fixation Area (inch2)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	0.607	0.160	0.619	0.146	0.613	0.151
	0.677	0.211	0.589	0.169	0.635	0.194
	0.716	0.226	0.657	0.212	0.687	0.217
	0.685	0.286	0.674	0.165	0.679	0.230
	0.680	0.209	0.735	0.194	0.708	0.200
	0.666	0.199	0.704	0.279	0.685	0.239
	0.671	0.214	0.663	0.199	0.667	0.207
Active Control	0.619	0.142	0.617	0.119	0.618	0.129
	0.626	0.152	0.626	0.120	0.626	0.135
	0.689	0.143	0.660	0.120	0.675	0.131
	0.659	0.132	0.661	0.124	0.660	0.126
	0.691	0.112	0.698	0.174	0.694	0.143
	0.688	0.115	0.688	0.132	0.688	0.121
	0.662	0.133	0.659	0.132	0.660	0.133
	0.613	0.149	0.618	0.131	0.615	0.139
	0.651	0.183	0.608	0.145	0.630	0.166
	0.702	0.185	0.659	0.170	0.681	0.177
	0.672	0.217	0.667	0.144	0.669	0.183
	0.686	0.163	0.717	0.182	0.701	0.172
	0.677	0.159	0.696	0.214	0.686	0.187
	0.666	0.177	0.661	0.169	0.664	0.173

Table H-62. Number of Fixations by Scene Planes by Load, Involvement, and Time

Fixation Number by Scene Planes	Monitoring						Active Control						Collapsed across Involvement					
	Low		High		Collapsed		Low		High		Collapsed		Low		High		Collapsed	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Radarscope	307	85	294	53	301	71	293	44	309	32	301	39	300	67	301	44	301	57
	297	62	349	72	322	71	319	47	301	35	311	42	308	56	325	61	316	58
	330	39	324	44	327	41	303	49	308	41	305	44	316	46	316	43	316	44
	299	47	317	52	308	49	326	48	319	41	323	44	313	49	318	46	316	47
	320	56	286	60	303	60	292	48	311	38	301	44	305	53	299	51	302	52
	336	43	329	55	332	49	306	43	316	24	310	35	320	45	322	42	321	43
	314	58	317	59	315	59	307	47	311	35	309	42	310	53	314	49	312	51
Flight Strip Bay	163	104	184	77	173	91	154	60	136	41	146	52	159	84	160	65	159	75
	136	72	126	57	131	64	107	48	125	49	115	48	121	62	125	52	123	57
	115	46	103	35	109	40	123	43	114	41	118	42	119	44	108	38	114	41
	112	70	124	51	118	60	107	43	87	43	97	43	109	57	106	50	107	53
	119	64	127	46	123	55	127	38	96	47	112	45	123	51	111	49	117	50
	96	62	104	46	100	54	104	47	96	47	100	46	100	54	100	46	100	50
	124	74	128	59	126	66	120	49	109	47	115	48	122	62	118	54	120	58
Keyboard	12	16	7	10	9	13	13	17	21	23	17	20	12	16	14	19	13	17
	14	23	5	7	9	18	14	16	24	22	18	20	14	20	14	19	14	19
	5	10	6	8	5	9	19	25	29	26	23	26	12	20	17	22	15	21
	6	10	8	12	7	11	12	16	29	28	20	24	9	14	19	23	14	20
	6	10	11	12	9	11	13	16	26	22	19	20	10	14	18	19	14	17
	7	12	13	15	10	14	16	17	25	20	20	19	12	15	19	19	15	17
	8	14	8	11	8	13	14	18	26	23	20	21	11	16	17	20	14	19
Track Ball	1	3	1	2	1	3	0	1	1	1	0	1	0	1	1	1	0	1
	1	2	2	4	1	3	1	1	2	3	1	2	1	1	2	3	1	2
	1	2	3	6	2	4	1	1	1	3	1	2	1	1	1	3	1	2
	2	6	3	7	3	7	0	1	2	4	1	3	0	1	2	4	1	3
	1	4	4	7	3	6	1	2	2	3	1	2	1	2	2	3	1	2
	2	2	3	4	2	3	1	1	2	3	1	2	1	1	2	3	1	2
	1	3	3	5	2	5	1	1	2	3	1	2	1	1	2	3	1	2
ATWIT	2	2	2	3	2	3	4	8	1	2	3	6	3	6	2	2	2	5
	5	2	4	2	4	2	5	4	4	2	5	3	5	3	4	2	5	3
	4	2	4	2	4	2	6	8	4	3	5	6	5	6	4	3	5	5
	3	2	4	2	4	2	5	5	4	2	4	4	4	4	4	2	4	3
	4	2	3	2	4	2	4	3	4	1	4	2	4	3	3	2	4	2
	5	3	4	2	5	3	6	6	4	2	5	5	5	5	4	2	5	4
	4	2	4	2	4	2	5	6	3	2	4	5	4	5	4	2	4	4
Soft CRD	12	13	12	9	12	11	12	8	22	17	17	14	12	8	22	17	17	14
	16	11	11	10	13	10	18	9	27	13	22	12	18	9	27	13	22	12
	11	6	15	14	13	11	15	6	24	21	19	16	15	6	24	21	19	16
	16	13	12	13	14	13	13	8	22	15	17	13	13	8	22	15	17	13
	17	14	8	7	13	12	24	10	21	17	23	14	24	10	21	17	23	14
	9	7	10	7	9	7	14	9	17	18	16	14	14	9	17	18	16	14
	14	11	11	10	13	11	16	9	22	17	19	14	16	9	22	17	19	14
Map Diaplay	2	5	1	2	1	4	2	4	1	2	2	3	2	4	1	2	1	3
	0	1	2	5	1	4	1	2	2	3	1	2	1	2	2	4	1	3
	0	1	1	3	1	2	2	2	1	2	2	2	1	2	1	2	1	2
	5	8	0	0	2	6	1	1	3	3	2	2	3	6	1	2	2	5
	3	5	0	1	2	4	2	3	0	1	1	2	2	4	0	1	1	3
	0	1	0	1	0	1	3	4	2	7	3	6	2	3	1	5	2	4
	2	5	1	3	1	4	2	3	2	4	2	3	2	4	1	3	1	4
Land Line	2	3	5	12	4	8	2	3	3	3	2	3	2	3	4	8	3	6
	1	2	2	4	2	3	1	2	1	1	1	2	1	2	2	3	1	2
	2	3	4	5	3	4	2	3	2	2	2	2	2	3	3	4	2	3
	1	2	2	4	2	3	3	2	2	2	2	2	2	2	2	3	2	3
	3	3	4	7	3	6	1	1	2	2	2	2	2	2	3	5	2	4
	4	4	5	7	4	6	4	4	2	4	3	4	4	4	3	5	4	5
	2	3	4	7	3	5	2	3	2	2	2	3	2	3	3	5	2	4

Table H-63. Fixation Duration by Scene Planes by Load, Involvement, and Time

Fixation Duration by Scene Planes (msec)	Monitoring						Active Control						Collapsed across Involvement					
	Low		High		Collapsed		Low		High		Collapsed		Low		High		Collapsed	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Radarscope	456	67	453	56	455	61	473	63	449	59	462	61	465	64	451	56	458	60
	530	94	472	61	502	84	507	72	463	73	486	75	518	83	467	66	494	79
	526	75	494	72	510	74	485	64	467	68	476	65	505	71	481	70	493	71
	521	79	522	71	522	74	502	57	494	73	498	64	511	68	508	72	510	70
	505	56	516	82	511	69	492	75	494	65	493	69	498	66	505	74	502	69
	527	80	503	66	515	73	500	75	503	81	501	77	513	78	503	72	508	75
	510	79	493	71	502	75	493	67	478	71	486	69	502	73	486	71	494	73
Flight Strip Bay	305	51	300	54	303	52	308	36	292	29	300	33	306	43	296	43	301	43
	302	50	321	60	311	55	308	45	273	80	291	66	305	47	297	74	301	61
	307	40	287	49	297	45	315	44	260	36	288	49	311	42	274	44	293	47
	319	126	290	33	304	92	304	31	258	80	281	64	311	89	274	63	293	79
	290	92	278	94	284	92	332	36	267	82	301	70	311	71	273	87	292	81
	300	74	281	49	290	63	298	90	280	50	289	73	299	81	280	49	290	67
	304	76	293	60	298	68	311	51	272	63	292	60	307	64	282	62	295	64
Keyboard	223	252	166	98	195	193	146	111	178	101	162	106	185	196	172	98	178	155
	164	116	128	132	147	124	163	124	181	89	171	107	164	118	154	114	159	115
	143	149	226	153	184	154	154	114	184	48	169	88	149	130	205	113	176	124
	123	146	134	129	128	135	154	135	178	87	165	113	139	139	156	110	147	125
	138	131	199	122	169	128	151	134	180	92	165	115	145	131	190	107	167	121
	246	139	187	143	216	142	202	101	176	84	189	92	223	121	181	115	203	119
	173	165	173	132	173	149	162	119	180	83	170	103	167	143	176	110	172	128
Track Ball	63	87	46	86	55	86	47	94	32	68	40	82	55	90	39	77	47	83
	39	74	51	110	45	92	73	163	81	88	77	130	56	126	66	99	61	113
	38	79	159	261	98	199	48	79	68	110	58	95	43	78	113	202	78	155
	258	783	87	122	172	558	47	87	53	79	50	82	149	549	70	103	110	397
	38	67	186	249	112	195	28	60	58	90	42	76	33	63	122	196	77	150
	116	127	217	388	166	288	77	99	63	85	70	91	96	113	140	287	118	216
	91	327	124	232	108	284	54	101	59	87	56	94	72	240	92	178	82	212
ATWIT	193	151	320	239	254	206	157	151	247	280	201	224	175	149	283	259	227	215
	286	97	444	306	362	234	294	138	317	127	305	131	290	117	381	239	334	190
	350	215	332	172	341	192	324	98	239	135	283	123	337	163	286	159	312	162
	483	363	318	190	401	297	331	126	316	147	324	135	404	275	317	167	361	230
	381	185	464	271	423	232	379	309	362	154	371	243	380	253	413	223	396	237
	368	160	306	144	337	153	337	120	370	324	353	237	352	140	338	248	345	199
	341	224	364	230	352	227	304	182	309	210	306	195	322	204	336	221	329	212
Soft CRD	333	270	303	109	318	206	506	173	448	138	478	157	419	240	376	143	398	199
	350	157	357	166	353	158	490	134	454	104	472	120	420	160	405	144	413	152
	385	193	328	120	357	161	541	149	429	91	487	135	465	186	379	117	423	161
	346	115	331	140	339	126	457	172	469	77	463	133	404	156	400	131	402	143
	370	115	302	177	336	150	511	159	450	157	481	158	443	155	376	180	410	170
	422	240	383	185	402	212	483	193	467	214	475	200	454	216	425	201	440	207
	367	189	334	151	351	171	498	162	453	135	476	151	434	187	393	154	414	173
Map Diaplay	44	123	47	98	45	110	109	176	67	121	89	151	76	153	57	108	67	132
	20	82	35	103	27	91	103	180	98	157	100	167	62	144	66	134	64	138
	71	172	70	131	71	150	158	160	94	191	127	176	116	169	82	161	100	165
	109	160	0	0	55	124	81	167	218	162	147	176	94	161	109	158	102	158
	112	169	19	50	65	131	108	149	29	76	69	124	110	157	24	63	67	127
	51	133	28	81	39	109	137	166	58	125	99	151	95	155	43	105	69	134
	67	143	33	88	50	120	116	164	94	152	105	158	92	156	64	127	78	143
Land Line	217	204	164	185	192	194	115	120	135	141	125	128	166	173	150	162	158	166
	138	160	166	152	152	154	74	117	179	175	125	155	106	142	172	161	138	154
	128	166	251	224	189	204	151	116	168	150	159	131	140	140	209	192	174	170
	106	138	255	262	181	219	215	159	193	145	204	151	162	157	224	211	193	186
	190	213	213	186	202	197	209	219	149	104	180	173	200	212	181	151	191	184
	215	192	229	182	222	184	158	127	146	138	152	130	185	162	188	164	187	161
	166	181	213	199	189	191	154	152	162	141	158	146	160	167	187	174	173	171

Appendix I
Air Traffic Workload Input Technique

I.1 ATWIT: Inferential Statistics

Table I–1. ATWIT: MANOVA Results

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.191	29.692	0.809	29.692	2	14	.000
Monitoring	.674	3.392	0.326	3.392	2	14	.063
Active	.148	40.359	0.852	40.359	2	14	.000
Interval 1	.788	1.888	0.212	1.888	2	14	.188
Interval 2	.379	11.452	0.621	11.452	2	14	.001
Interval 3	.316	15.126	0.684	15.126	2	14	.000
Interval 4	.172	33.801	0.828	33.801	2	14	.000
Interval 5	.128	47.730	0.872	47.730	2	14	.000
Interval 6	.324	14.595	0.676	14.595	2	14	.000
Involvement	.198	28.428	0.802	28.428	2	14	.000
Low Load	.442	8.837	0.558	8.837	2	14	.003
High Load	.131	46.296	0.869	46.296	2	14	.000
Interval 1	.319	14.929	0.681	14.929	2	14	.000
Interval 2	.309	15.651	0.691	15.651	2	14	.000
Interval 3	.255	20.435	0.745	20.435	2	14	.000
Interval 4	.227	23.841	0.773	23.841	2	14	.000
Interval 5	.142	42.264	0.858	42.264	2	14	.000
Interval 6	.175	32.917	0.825	32.917	2	14	.000
Time-on-Task	.081	6.807	0.919	6.807	10	6	.015
Load x Involvement	.221	24.655	0.779	24.655	2	14	.000
Load x Time-on-Task	.086	6.339	0.914	6.339	10	6	.017
Involvement x Time-on-Task	.037	15.518	0.963	15.518	10	6	.002
Load x Involvement x Time-on-Task	.197	2.445	0.803	2.445	10	6	.143

Table I–2. ATWIT Rating: ANOVA Results

ATWIT Rating	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	232.815	5.510	42.257	.000
Monitoring	21.333	3.100	6.882	.019
Active	287.630	3.864	74.447	.000
Interval 1	6.891	1.757	3.921	.066
Interval 2	34.516	1.416	24.382	.000
Interval 3	47.266	1.699	27.820	.000
Interval 4	72.250	2.317	31.187	.000
Interval 5	64.000	1.533	41.739	.000
Interval 6	30.250	1.350	22.407	.000
Involvement	563.086	10.058	55.983	.000
Low Load	112.547	5.969	18.855	.001
High Load	526.688	5.543	95.018	.000
Interval 1	37.516	1.182	31.731	.000
Interval 2	47.266	1.566	30.190	.000
Interval 3	102.516	2.416	42.439	.000
Interval 4	105.063	3.063	34.306	.000
Interval 5	132.250	1.983	66.681	.000
Interval 6	175.563	2.662	65.939	.000
Time-on-Task	5.446	0.772	7.056	.000
Load x Involvement	76.148	1.454	52.372	.000
Load x Time-on-Task	4.471	0.912	4.900	.001
Involvement x Time-on-Task	7.417	0.563	13.180	.000
Load x Involvement x Time-on-Task	2.942	1.154	2.549	.035

Table I-3. ATWIT Latency: ANOVA Results

ATWIT Latency	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	2.344	5.944	0.394	.539
Involvement	168.010	25.555	6.574	.022
Time-on-Task	1.585	7.832	0.202	.961
Load x Involvement	7.594	13.483	0.563	.465
Load x Time-on-Task	19.519	8.385	2.328	.051
Involvement x Time-on-Task	2.860	7.258	0.394	.851
Load x Involvement x Time-on-Task	11.094	9.516	1.166	.334

I.2. ATWIT: 5- Minute Interval Descriptive Statistics Based

Table I–4. ATWIT Rating by Load, Involvement, and Time

ATWIT Rating	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	2.81	1.38	2.88	1.59	2.84	1.46
	2.69	1.45	2.88	1.41	2.78	1.41
	2.13	1.15	3.19	1.87	2.66	1.62
	2.25	1.13	2.81	1.83	2.53	1.52
	2.19	1.28	3.44	2.13	2.81	1.84
	2.19	1.33	3.06	1.98	2.63	1.72
	2.38	1.28	3.04	1.78	2.71	1.58
Active Control	3.75	1.24	5.00	2.07	4.38	1.79
	3.13	1.31	5.88	2.39	4.50	2.36
	4.00	1.55	6.38	1.67	5.19	1.99
	3.25	2.32	6.94	1.81	5.09	2.77
	4.31	2.12	7.06	1.65	5.69	2.33
	5.00	2.13	6.88	2.00	5.94	2.24
	3.91	1.89	6.35	2.03	5.13	2.31
	3.28	1.37	3.94	2.11	3.61	1.80
	2.91	1.38	4.38	2.46	3.64	2.11
	3.06	1.64	4.78	2.38	3.92	2.21
	2.75	1.87	4.88	2.76	3.81	2.57
	3.25	2.03	5.25	2.63	4.25	2.54
	3.59	2.26	4.97	2.75	4.28	2.59
	3.14	1.79	4.70	2.53	3.92	2.32

Table I–5. ATWIT Latency by Load, Involvement, and Time

ATWIT Latency (seconds)	Low		High			
	Means	SD	Means	SD	Means	SD
Monitoring	2.438	1.094	2.688	1.250	2.563	1.162
	2.313	1.014	2.188	1.167	2.250	1.078
	2.250	1.125	2.563	1.315	2.406	1.214
	2.625	1.544	2.438	1.548	2.531	1.524
	3.000	2.033	2.500	1.366	2.750	1.723
	2.688	2.469	2.188	1.109	2.438	1.900
	2.552	1.615	2.427	1.279	2.490	1.454
Active Control	3.063	2.435	4.250	4.851	3.656	3.824
	2.563	2.065	4.750	6.148	3.656	4.646
	2.625	1.544	5.500	5.704	4.063	4.362
	4.250	5.335	2.875	1.360	3.563	3.893
	4.438	4.746	2.688	1.815	3.563	3.645
	4.625	5.340	4.125	4.924	4.375	5.059
	3.594	3.911	4.031	4.522	3.813	4.222
	2.750	1.884	3.469	3.574	3.109	2.857
	2.438	1.605	3.469	4.544	2.953	3.420
	2.438	1.343	4.031	4.337	3.234	3.284
	3.438	3.951	2.656	1.450	3.047	2.978
	3.719	3.665	2.594	1.583	3.156	2.858
	3.656	4.209	3.156	3.647	3.406	3.915
	3.073	3.030	3.229	3.411	3.151	3.222

Appendix J
Situation Presence Assessment Method

J.1. Inferential Statistics

Table J–1. SPAM Latency: ANOVA Results

ANOVA	df Effect	Means sqr Effect	Error	Means sqr Error	*F*(df1,2)	*p*-level
Load	1	82.140	47	26.822	3.062	.087
Monitoring	1	53.130	47	22.895	2.321	.134
Active	1	404.260	47	25.407	15.912	.000
Involvement	1	1029.660	47	16.533	62.278	.000
Low Load	1	80.860	47	22.884	3.533	.066
High Load	1	1324.050	47	15.129	87.520	.000
Type	1	0.220	47	27.139	0.008	.929
Load x Involvement	1	375.250	47	21.480	17.470	.000
Load x Type	1	20.167	47	31.945	0.631	.431
Involvement x Type	1	25.627	47	31.500	0.814	.372
Load x Involvement x Type	1	3.154	47	17.380	0.181	.672

Table J–2. SPAM Query Time: ANOVA Results

ANOVA	df Effect	Means sqr Effect	Error	Means sqr Error	*F*(df1,2)	*p*-level
Load	1	0.454	47	15.756	0.029	.866
Involvement	1	0.023	47	13.802	0.002	.967
Type	1	0.055	47	10.592	0.005	.943
Load x Involvement	1	11.207	47	9.930	1.129	.294
Load x Type	1	0.060	47	10.510	0.006	.940
Involvement x Type	1	13.425	47	9.662	1.389	.244
Load x Involvement x Type	1	22.234	47	10.896	2.041	.160

Table J-3. SPAM Response Time: ANOVA Results

ANOVA	df Effect	Means sqr Effect	Error	Means sqr Error	*F*(df1,2)	*p*-level
Load	1	66.500	47	14.087	4.721	.035
Involvement	1	42.135	47	7.444	5.661	.021
Type	1	4.770	47	11.171	0.427	.517
Load x Involvement	1	50.750	47	11.696	4.339	.043
Load x Type	1	63.700	47	12.692	5.019	.030
Involvement x Type	1	48.025	47	8.517	5.639	.022
Load x Involvement x Type	1	119.038	47	9.340	12.745	.001

Table J-4. SPAM Response Time for Present Questions: ANOVA Results

Simple Effects, Present Questions	df Effect	Means sqr Effect	Error	Means sqr Error	F(df1,2)	p-level
Load	1	130.185	47	13.950	9.332	.004
Monitoring	1	291.904	47	14.192	20.568	.000
Active	1	0.901	47	8.218	0.110	.742
Involvement	1	90.064	47	5.748	15.669	.000
Low Load	1	5.320	47	4.994	1.065	.307
High Load	1	247.363	47	9.214	26.847	.000
Load x Involvement	1	162.619	47	8.460	19.222	.000

Table J-5. SPAM Response Time for Future Questions: ANOVA Results

Simple Effects, Future Questions	df Effect	Means sqr Effect	Error	Means sqr Error	F(df1,2)	p-level
Load	1	0.015	47	12.829	0.001	.973
Involvement	1	0.096	47	10.213	0.009	.923
Load x Involvement	1	7.169	47	12.576	0.570	.454

J.2. Scenario Based Descriptive Statistics

Table J–6. SPAM Response Time by Load, Involvement, and Question Type

Response Time		Low Load		High Load			
		Means	SD	Means	SD	Means	SD
Monitoring	Present	2.71	1.76	6.21	4.91	4.48	4.08
	Future	4.17	3.62	3.80	3.83	3.99	3.71
		3.45	2.93	5.01	4.54	4.23	3.90
Active Control	Present	3.20	2.59	3.00	2.86	3.10	2.72
	Future	3.83	3.49	4.23	3.60	4.03	3.53
		3.51	3.07	3.62	3.29	3.57	3.18
	Present	2.96	2.22	4.61	4.31	3.79	3.52
	Future	4.00	3.54	4.02	3.70	4.01	3.61
		3.48	3.00	4.31	4.02	3.90	3.57

Appendix K
Real Time Objective Performance

K.1. Dependent Variables

Table K–1. System and Performance Measures

Performance Data	
Conflicts:	
No. Conflicts	--
Dur. Conflicts	seconds
Conflict API	--
No. Longitudinal conflicts	--
Closest-point-of-approach (feet)	feet (meters)
Horizontal separation at CPA (feet)	
Vertical separation at CPA (feet)	
Complexity:	
Average System Activity CMAV	--
Altitude Changes	--
Heading Changes	--
No. Speed changes	--
Handoff Efficiency:	
No. Hand-offs outside boundary	--
Communications:	
No. Ground-to-air contacts	--
Dur. Ground-to-air contacts	seconds
No. Pilot message key strokes	--

K.2. Inferential Statistics

Table K–2. DRA Altitude, Heading, and Speed Changes: MANOVA Results

MANOVA, adjusted alpha=0.0169	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.244	13.429	0.756	13.429	3	13	.000

Table K-3. DRA Altitude, Heading, and Speed Changes: ANOVA Results

Effect of Task Load	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Altitude Changes	2.183	0.152	14.352	.002
Heading Changes	0.197	0.071	2.763	.117
Speed Changes	0.078	0.015	5.058	.040

Table K–4. DRA Distance and Time Under Control: MANOVA Results

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.074	87.291	0.926	87.291	2	14	.000

Table K–5. DRA Distance and Time Under Control: ANOVA Results

Effect of Task Load	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Distance	1587.033	24.671	64.328	.000
Time	128552.000	1615.184	79.590	.000

Table K–6. DRA PTT: MANOVA Results.

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.658	3.115	0.342	3.115	2	12	.081

Table K–7. DRA PTT: ANOVA Results

Effect of Task Load	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Number	0.560	0.100	5.597	.034
Duration	7.349	1.252	5.870	.031

K.3. Scenario Based Descriptive Statistics

Table K–8. Number of Altitude Changes: Mean and Standard Deviations by Load.

Number of altitude changes per aircraft	Mean	SD
	Means	SD
Low	1.39	0.42
High	1.91	0.45

Table K–9. Number of Heading Changes: Mean and Standard Deviations by Load

Number of heading changes per aircraft	Mean	SD
	Means	SD
Low	0.55	0.27
High	0.39	0.23

Table K–10. Number of Speed Changes: Mean and Standard Deviations by Load

Number of speed changes per aircraft	Mean	SD
	Means	SD
Low	0.22	0.15
High	0.13	0.13

Appendix L
Subject Matter Expert Rating Form

Table L–1. Providing ATC Information by Load and Involvement

	Providing Essential Air Traffic Control Information		Providing Additional Air Traffic Control Information		Providing Coordination	
	Means	SD	Means	SD	Means	SD
Low Load	6.47	0.80	6.84	0.68	5.28	0.81
High Load	6.06	1.05	6.47	1.08	4.88	1.34
	6.27	0.95	6.66	0.91	5.08	1.12

Table L–2. Prioritizing by Load

	Taking Actions in an Appropriate Order of Importance		Preplanning Control Actions		Handling Control Tasks for Several Aircraft		Marking Flight Strips while Performing Other Tasks	
	Means	SD	Means	SD	Means	SD	Means	SD
Low Load	6.72	0.81	6.34	1.62	6.75	0.84	6.03	1.67
High Load	6.00	1.02	4.72	1.87	6.00	1.37	5.22	1.79
	6.36	0.98	5.53	1.92	6.38	1.19	5.63	1.77

Table L–3. Attention and Situation Awareness by Load

	Maintaining Situation Awareness		Ensuring Positive Control		Detecting Pilot Deviations from Control Instructions		Correcting Errors in a Timely Manner	
	Means	SD	Means	SD	Means	SD	Means	SD
Low Load	5.34	1.75	6.47	1.44	6.81	1.42	6.84	0.85
High Load	4.00	1.67	5.84	1.19	6.28	1.05	6.09	1.17
	4.67	1.83	6.16	1.35	6.55	1.27	6.47	1.08

Table L–4. Detecting Pilot Deviations from Control Instructions by Load

	Detecting Pilot Deviations from Control Instructions		Correcting Errors in a Timely Manner		Maintaining Separation and Resolving Potential Conflicts		Sequencing Arrival and Departure Aircraft Efficiently	
	Means	SD	Means	SD	Means	SD	Means	SD
Low Load	6.81	1.42	6.84	0.85	6.56	1.88	5.91	1.67
High Load	6.28	1.05	6.09	1.17	5.41	2.39	5.81	1.45
	6.55	1.27	6.47	1.08	5.98	2.21	5.86	1.55

Table L–5. Using Control Instructions Effectively by Load

	Using Control Instructions Effectively		Using Proper Phraseology		Communicating Clearly and Efficiently		Listening to Pilot Readbacks and Requests	
	Means	SD	Means	SD	Means	SD	Means	SD
Low Load	6.38	1.54	5.81	0.97	6.88	0.79	7.16	0.57
High Load	6.00	1.48	5.75	1.08	6.34	1.15	6.44	1.22
	6.19	1.51	5.78	1.02	6.61	1.02	6.80	1.01

Table L–6. Showing Knowledge of LOAs and SOPs by Load

	Showing Knowledge of LOAs and SOPs		Showing Knowledge of Aircraft Capabilities and Limitations		Showing Effective Use of Equipment	
	Means	SD	Means	SD	Means	SD
Low Load	7.06	0.80	6.84	0.99	7.00	0.72
High Load	6.38	1.41	6.19	1.18	6.00	1.34
	6.72	1.19	6.52	1.13	6.50	1.18

Table L–7. Showing Effective Use of Equipment by Load

Showing Effective Use of Equipment	Means	SD
Low Load	7.00	0.72
High Load	6.00	1.34
	6.50	1.18

Appendix M
Recall

M.1. Inferential Statistics

Table M–1. Percent Correct Recall: ANOVA Results

	df Effect	Means sqr Effect	df Error	Means sqr Error	F	*p*-level
Load	1	4204.803	12	169.754	24.770	.000
Involvement	1	1109.539	12	186.983	5.934	.031
Load x Involvement	1	104.739	12	241.403	0.434	.523

M.2. Scenario Based Descriptive Statistics

Table M-2. Percent Correctly Placed Data Block by Load and Involvement

Percent Corret	Low Task Load	High Task Load
	Means	SD
Monitoring	51.99	36.85
Active Control	64.07	43.25

Appendix N
Post-Scenario Questionnaire

N.1. Inferential Statistics

N.1.1 Realism

Table N–1. Realism: MANOVA Results

	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.319	14.932	0.681	14.932	2	14	.000
Monitoring	.837	1.366	0.163	1.366	2	14	.287
Active	.163	36.009	0.837	36.009	2	14	.000
Involvement	.233	23.107	0.767	23.107	2	14	.000
Low Load	.338	13.715	0.662	13.715	2	14	.001
High Load	.212	25.988	0.788	25.988	2	14	.000
Load x Involvement	.429	9.300	0.571	9.300	2	14	.003

Table N–2. Realism: ANOVA Results

Realism	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	0.141	0.741	0.190	.669
Involvement	54.391	7.257	7.495	.015
Load x Involvement	0.016	2.349	0.007	.936

Table N–3. Representativeness: ANOVA Results

Representativeness	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	0.016	1.949	0.008	.930
Involvement	28.891	5.357	5.393	.035
Load x Involvement	1.266	1.866	0.678	.423

N.1.2. Difficulty

Table N–4. Diffulty: MANOVA Results

	Wilks' Lambda	Rao R Form 2	Pillai-Bartlett Trace	V	df 1	df 2	*p*-level
Load	.319	14.932	0.681	14.932	2	14	.000
Monitoring	.837	1.366	0.163	1.366	2	14	.287
Active	.163	36.009	0.837	36.009	2	14	.000
Involvement	.233	23.107	0.767	23.107	2	14	.000
Low Load	.338	13.715	0.662	13.715	2	14	.001
High Load	.212	25.988	0.788	25.988	2	14	.000
Load x Involvement	.429	9.300	0.571	9.300	2	14	.003

Table N-5. Working Hard: ANOVA Results

Hard	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	39.063	1.763	22.163	.000
Monitoring	3.781	1.715	2.205	.158
Active	47.531	1.198	39.678	.000
Involvement	175.563	4.329	40.553	.000
Low Load	47.531	2.531	18.778	.001
High Load	140.281	2.948	47.587	.000
Load x Involvement	12.250	1.150	10.652	.005

Table N-6. Scenario Difficulty: ANOVA Results

Difficulty	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	33.063	1.263	26.188	.000
Monitoring	3.125	1.592	1.963	.182
Active	40.500	1.700	23.824	.000
Involvement	72.250	3.783	19.097	.001
Low Load	13.781	1.248	11.043	.005
High Load	69.031	4.565	15.123	.001
Load x Involvement	10.563	2.029	5.205	.038

N.1.3. Interference

Table N-7. Interference: MANOVA Results

MANOVA, adjusted alpha=0.0253	Wilks' Lambda	Rao R Form 2 (4, 12)	Pillai-Bartlett Trace	V (4,12)	df 1	df 2	*p*-level
Load	.467	7.981	0.533	7.981	2	14	.005
Involvement	.484	7.475	0.516	7.475	2	14	.006
Load x Involvement	.695	3.065	0.305	3.065	2	14	.079

Table N-8. ATWIT Interference: ANOVA Results

ATWIT	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	15.016	0.882	17.019	.001
Involvement	19.141	1.541	12.424	.003
Load x Involvement	5.641	1.041	5.420	.034

N.1.4. Situation Awareness

Table N-9. Situation Awareness: MANOVA Results

MANOVA, adjusted alpha=0.0127	Wilks' Lambda	Rao R Form 2 (4, 12)	Pillai-Bartlett Trace	V (4,12)	df 1	df 2	*p*-level
Load	.340	5.824	0.660	5.824	4	12	.008
Monitoring	.531	2.645	0.469	2.645	4	12	.086
Active	.264	8.372	0.736	8.372	4	12	.002
Involvement	.416	4.218	0.584	4.218	4	12	.023
Low Load	.509	2.893	0.491	2.893	4	12	.069
High Load	.379	4.923	0.621	4.923	4	12	.014
Load x Involvement	.406	4.384	0.594	4.384	4	12	.021

Table N-10. Overall Situation Awareness: ANOVA Results

Overall SA	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	1.000	1.667	0.600	.451
Involvement	1.563	3.429	0.456	.510
Load x Involvement	12.250	1.917	6.391	.023

Table N-11. Situation Awareness for Current Locations: ANOVA Results

SA for current locations	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	18.063	0.796	22.696	.000
Involvement	4.000	3.933	1.017	.329
Load x Involvement	10.563	1.763	5.993	.027

Table N-12. Situation Awareness for Projected Locations: ANOVA Results

SA for projected locations	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	13.141	1.507	8.718	.010
Involvement	2.641	4.807	0.549	.470
Load x Involvement	0.141	1.907	0.074	.790

Table N–13. Situation Awareness for Potential Violations: ANOVA Results

SA for potential violations	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Load	30.250	2.283	13.248	.002
Involvement	2.250	3.550	0.634	.438
Load x Involvement	1.000	2.033	0.492	.494

Table N-14. Quality of Control: ANOVA Results

Load	Means sqr Effect	Means sqr Error	*F*(df1,2) 1,15	*p*-level
Quality of Control	18.000	1.333	13.500	.002

N.2. Scenario Based Descriptive Statistic

N. 2.1 Realism

Table N–15. Realism: Mean and SDs by Load and Involvement

Realism	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	5.4	3.4	5.3	3.1	5.4	3.2
Active	7.3	1.2	7.2	1.4	7.2	1.3
	6.3	2.7	6.3	2.5	6.3	2.6

Table N–16. Representativeness: Mean and SDs by Load and Involvement

Representativeness	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	5.69	2.98	5.44	2.63	5.56	2.77
Active	6.75	1.57	7.06	2.11	6.91	1.84
	6.22	2.41	6.25	2.49	6.23	2.43

N. 2.2 Difficulty

Table N–17. Working Hard by Load and Involvement

Working Hard?	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	2.94	1.95	3.63	2.42	3.28	2.19
Active	5.38	1.67	7.81	1.72	6.59	2.08
	4.16	2.17	5.72	2.96	4.94	2.70

Table N-18. Difficulty by Load and Involvement

Difficulty	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	4.00	1.86	4.63	2.33	4.31	2.10
Active	5.31	1.54	7.56	1.90	6.44	2.05
	4.66	1.81	6.09	2.57	5.38	2.32

N. 2.3 Interference

Table N–19. ATWIT Interference by Load and Involvement

ATWIT Interference	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	1.25	0.58	1.63	0.89	1.44	0.76
Active	1.75	0.77	3.31	2.09	2.53	1.74
	1.50	0.72	2.47	1.80	1.98	1.44

Table N–20. Oculometer Interference by Load and Involvement

Oculometer Interference	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	2.31	2.36	2.69	2.33	2.50	2.31
Active	2.56	1.63	3.06	2.26	2.81	1.96
	2.44	2.00	2.88	2.27	2.66	2.13

N. 2.4 Situation Awareness

Table N–21. Overall Situation Awareness by Load and Involvement

Overall SA	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	6.75	2.08	7.38	1.45	7.06	1.79
Active	7.31	1.35	6.19	1.22	6.75	1.39
	7.03	1.75	6.78	1.45	6.91	1.60

Table N–22. Situation Awareness for Current Aircraft Position by Load and Involvement

SA for Current Aircraft Position	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	5.63	2.39	5.38	2.28	5.50	2.30
Active	6.94	2.35	5.06	1.69	6.00	2.23
	6.28	2.43	5.22	1.98	5.75	2.26

Table N–23. Situation Awareness for Projected Aircraft Position by Load and Involvement

SA for Projected Aircraft Position	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	6.56	2.22	5.75	2.02	6.16	2.13
Active	7.06	2.17	6.06	1.77	6.56	2.02
	6.81	2.18	5.91	1.87	6.36	2.07

Table N–24. Situation Awareness for Potential Violations by Load and Involvement

SA for Projected Violations	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	8.06	1.39	6.94	2.32	7.50	1.97
Active	7.94	1.34	6.31	1.92	7.13	1.83
	8.00	1.34	6.63	2.12	7.31	1.89

Table N–25. Quality of Control by Load and Involvement

SA for Projected Violations	Low Load		High Load			
	Means	SD	Means	SD	Means	SD
Monitoring	8.06	1.39	6.94	2.32	7.50	1.97
Active	7.94	1.34	6.31	1.92	7.13	1.83
	8.00	1.34	6.63	2.12	7.31	1.89

Appendix O
Coordination Events

Scenario 1: Active High

Coordination Events
17:30
- Genera High, Bravo High

I need United 422 (*BC 2024)* at flight level 330
- (give initials)

33:00
- Genera High, Charlie High

I need Carnival 11 (*BC 0674)* at flight level 240
- (give initials)

36:30
- Genera High, Bravo High

I need Spirit Wings 2249 (*BC 4655)* at 250 knots.
- (give initials)

Notes:

Scenario 2: Monitoring Low

Coordination Events
19:30
- Genera High this is Genera radio with a NOTAM. Advise when ready to copy.
- Southeast VOR is NOTAMed out of service until further advised.
- (give initials)

36:00
- Genera High this is the Military desk.

Whiskey 500 is active now surface to flight level 430.
- (give initials)

45:00
- Genera High this is the Military desk.

Whiskey 500 is deactivated.
- (give initials)

Notes:

Scenario 3: Practice

Coordination Events
18:30
- Genera High, Charlie Center

I need US Air 891 (*BC 2045)* at flight level 310
- (give initials)

29:00
- Genera High, Alpha High

I need Delta 957 (*BC 2016)* at flight level 330
- (give initials)

45:00 (*as soon as DAL259 is flashed to controller and AMX656 has switched, don't call if AMX656 is outside of boundary)*

- Genera High, Alpha High

Aero Mexico 656 (*BC 0666)* is requesting lower, request control reference Delta 259 (*BC 3742)*.

- (give initials)
- *Don't descend AMX656*

46:00 (*as soon as datablock is flashed to controller)*

- Genera High, Bravo High

Reference Air Shuttle 471 (*BC 2555)*, I incorrectly entered an assigned altitude of 260 in data block, he wants flight level 240.

- (give initials)

Notes:

Scenario 4: Active Low

Coordination Events

19:30

- Genera High, Alpha High.

Request control for US Air 2174 (*BC 4611)*, I need him at flight level 310.

- (give initials)

35:30

- Genera High, Charlie Center.

Kiwi 421 (*BC 3762)* is looking for lower, my control reference US Air 1273 (*BC 2565)*.

- (give initials)
- *Call typist, descend KIA421 to flight level 330*

43:00

- Genera High, Bravo High.

Request US Air 8303 (*BC 4243)* and Critter 505 (*BC 0636)* cross lower at 250 knots.

- (give initials)

Notes:

Scenario 5: Practice

Coordination Events

26:00 (*After COA131 has switched frequency)*

- Genera High, Bravo High

Request control for lower on Continental 131 (*BC 4232)*

- (give initials)
- *Call typist and descend COA131 to flight level 290*

34:00 (*If SJI707 has switched frequency, request control for higher)*

- Genera High, Bravo High

I need Sun Jet 707 (*BC 2033)* at flight level 330

- (give initials)
- *If requested control for higher and it was granted, call typist and climb SJI707 to flight level 330*

41:00 (*as soon as datablock flashed to controller)*

- Genera High, Alpha High

Northwest 1277 (*BC 2023)* is requesting flight level 330

- (give initials)
- *If controller asks "my control for higher?", say "approved"*
- *If controller tells you to climb the aircraft, call typist and climb NWA1277 to flight level 330*

48:00 (*after DAL609 has switched frequency)*

- Genera High, Charlie Center

Request control for lower on Delta 609 (*BC 3733)*.

- (give initials)
- *If controller says "approved", call typist and descend DAL609 to flight level 290*

Notes:

<u>Scenario 6: </u>Practice

Coordination Events

19:00 (*as soon as USA1647 is flashed to controller)*

- Genera High, Alpha High

US Air 1647 (*BC 4654)* and Delta 83 (*BC 2536)* both have assigned speeds of 240 knots indicated

- (give initials)

28:30 (*after USA242 has switched frequency)*

- Genera High, Charlie Center

US Air 242 (*BC 3771)* is requesting flight level 350, my control for descent?

- (give initials)
- *If controller says "approved", call typist and descend USA242 to flight level 350*

41:00 (*as soon as COA1228 is flashed to controller)*

- Genera High, Alpha High

Continental 1228 (*BC 2056)* is requesting flight level 270.

- (give initials)

54:00 (*as soon as USA1680 is flashed to controller)*

- Genera High, Alpha High

US Air 1680 (*BC 2067)* and US Air 656 (*BC 2555)* both have assigned speeds of 235 knots indicated

- (give initials)

Notes:

<u>Scenario 7: </u>Practice

Coordination Events

22:00

- Genera High, Charlie Center

I need Delta 1041 (*BC 0662)* at flight level 310

- (give initials)

31:00

- Genera High, Charlie Center

I need US Air 1269 (*BC 2527)* at flight level 310

- (give initials)

42:00 (*as soon as UAS609 flashes to controller)*

- Genera High, Alpha High

US Air 609 (*BC 2534)* is requesting flight level 290

- (give initials)

- *if controller says “approved” call typist and descend USA609 to flight level 290*

46:15

- Genera High, Alpha High

US Air 1432 (*BC 0617)* is requesting flight level 370, my control reference Aero Mexico 417 (*BC 2565)*

- (give initials)
- *if controller says “approved” call typist and climb USA1432 to flight level 370*

Notes

Scenario 8: Monitoring High

Coordination Events

26:00

- Genera High this is Genera radio with a NOTAM. Advise when ready to copy.
- Northeast VOR is NOTAMed out of service until further advised.
- (give initials)

36:00

- Genera High this is Genera radio with a NOTAM. Advise when ready to copy.
- Runway 18 left 36 right at Uptown, NOTAM closed for mowing.
- (give initials)

42:00

- Genera High, Genera Radio

There is a forest fire reported about 30 miles south of the Center VOR, have any pilots reported it?

- (give initials)

Notes:

Appendix P
Situation Presence Assessment Method Queries

15:30
Will US Air 1650 and Continental 707 be in conflict if no further action is taken, yes or no?
Yes
No
21:30
Will Lifeguard 99 Sierra Fox and American 966 be in conflict if no further action is taken, yes or no?
Yes
No
25:00
Which will reach the Center VOR first, Aeromexico 758 or Carnival 11?
Aeromexico 758
Carnival 11
28:00
Are there any speed conflicts on the J74 airway, yes or no?
Yes
No
32:00
Which is traveling at a faster groundspeed, US Air 992 or Spirit Wings 2249?
US Air 992
Spirit Wings 2249
41:00
Which is at a higher altitude, US Air 153 or Delta 1676?
US Air 153
Delta 1676
15:30
Will Continental 707 and US Air 1650 be in conflict if no further action is taken, yes or no?
Yes
No
21:30
Will American 966 and Lifeguard 99 Sierra Fox be in conflict if no further action is taken, yes or no?
Yes
No
25:00
Which will reach the Center VOR first, Carnival 11 or Aeromexico 758?
Aeromexico 758
Carnival 11
28:00
Are there any speed conflicts on the J74 airway, yes or no?
Yes
No
32:00
Which is traveling at a faster groundspeed, US Air 992 or Spirit Wings 2249?
US Air 992
Spirit Wings 2249
41:00
Which is at a higher altitude, Delta 1676 or US Air 153?
US Air 153
Delta 1676

21:00
Which will leave the airspace first, Delta 1481 or US Air 2934?
Delta 1481
US Air 2934
26:30
Which is traveling at a faster groundspeed, Delta 1190 or Jet Ex 918?
Delta 1190
Jet Ex 918
32:30
Which has a higher altitude, Aeromexico 470 or November 305 Alpha Bravo?
Aeromexico 470
November 305 Alpha Bravo
39:00
Which will reach the Center VOR first, November 4 Mike Delta or US Air 145?
November 4 Mike Delta
US Air 145
43:00
Which is traveling at a slower groundspeed, US Air 124 or Continental 1962?
US Air 124
Continental 1962
46:30
Which will reach the Center VOR first, US Air 41 or November 65 Romeo Charlie?
US Air 41
November 65 Romeo Charlie
21:00
Which will leave the airspace first, US Air 2934 or Delta 1481?
Delta 1481
US Air 2934
26:30
Which is traveling at a faster groundspeed, Jet Ex 918 or Delta 1190?
Delta 1190
Jet Ex 918
32:30
Which has a higher altitude, November 305 Alpha Bravo or Aeromexico 470?
Aeromexico 470
November 305 Alpha Bravo
39:00
Which will reach the Center VOR first, US Air 145 or November 4 Mike Delta?
November 4 Mike Delta
US Air 145
43:00
Which is traveling at a slower groundspeed, Continental 1962 or US Air 124?
US Air 124
Continental 1962
46:30
Which will reach the Center VOR first, November 65 Romeo Charlie or US Air 41?
US Air 41
November 65 Romeo Charlie
24:00
Which will reach the Center VOR first, US Air 1273 or Delta 417?
Delta 417
US Air 1273
30:00
Which is traveling at a faster groundspeed, American 246 or Delta 1033?
Delta 1033

American 246
34:00
Which is traveling at a slower groundspeed, US Air 4095 or Kacki Blue 29?
Kacki Blue 29
US Air 4095
41:00
Which will reach their final altitude first, Delta 1586 or Trans World 1432?
Trans World 1432
Delta 1586
44:00
Which will reach the MIDLE intersection first, Carnival 609 or Critter 1176?
Critter 1176
Carnival 609
47:00
Which has a higher altitude, Air Jamaica 656 or Continental 225?
Continental 225
Air Jamaica 656
19:20
Which has a higher altitude, Delta 1165 or US Air 2174?
Delta 1165
US Air 2174
23:15
Which will reach the Center VOR first, Critter 2250 or Aeromexico 454?
Critter 2250
Aeromexico 454
28:45
Which is traveling at a faster groundspeed, Continental 670 or Carnival 471?
Continental 670
Carnival 471
32:00
Will Lifeguard 1640 and Delta 1165 be in conflict if no further action is taken, yes or no?
Yes
No
37:00
Which should reach their final altitude first, US Air 189 or Continental 670?
US Air 189
Continental 670
41:15
Which has the lower altitude, US Air 1723 or Critter 1658?
US Air 1723
Critter 1658
19:20
Which has a higher altitude, US Air 2174 or Delta 1165?
Delta 1165
US Air 2174
23:15
Which will reach the Center VOR first, Aeromexico 454 or Critter 2250?
Critter 2250
Aeromexico 454
28:45
Which is traveling at a faster groundspeed, Carnival 471 or Continental 670?
Continental 670
Carnival 471
32:00
Will Delta 1165 and Lifeguard 1640 be in conflict if no further action is taken, yes or no?

Yes
No
37:00
Which should reach their final altitude first, Continental 670 or US Air 189?
US Air 189
Continental 670
41:15
Which has the lower altitude, Critter 1658 or US Air 1723?
US Air 1723
Critter 1658