REFERENCES

Helmreich, R.L., Klinect, J.R., and Wilhelm, J.A. (this volume). Models of Threat, Error, and Response in Flight Operations. In Jensen, R.S. (Ed.), *Proceedings of the Tenth International Symposium on Aviation Psychology*, The Ohio State University.

Klinect, J.R., Wilhelm, J.A., Helmreich, R. L. (this volume). Threat and Error Management: Data from Line Operations Safety Audits. In Jensen, R.S. (Ed.), *Proceedings of the Tenth International Symposium on Aviation Psychology*, The Ohio State University.

National Transportation Safety Board (1994). *A review of flightcrew-involved, major accidents of US air carriers, 1978 through 1990* (Safety study NTSB/SS-94/10). Washington, DC: author.

University of Texas Crew Research Project Website: www.psy.utexas.edu/psy/helmreich/nasaut.htm

AIR TRAFFIC CONTROLLER RADAR SCANNING UNDER CURRENT AND PROPOSED FREE FLIGHT CONDITIONS

Earl S. Stein, Ph.D. , Ben Willems, MA & Todd Truitt, MS
DOT/FAA William J. Hughes Technical Center
Atlantic City International Airport, New Jersey

ABSTRACT

Using a high fidelity Air Traffic Control simulation and a specially constructed generic en route airspace sector, researchers evaluated air traffic control specialist (ATCS) performance and visual scanning behavior under two control conditions. These included current methods and conditions where ATCSs monitored traffic and intervened with advisories only when necessary. Results indicated that, regardless of condition, controllers spent most available scanning time looking at aircraft representations on the radar. However, measures of situational awareness (SA) declined sharply under high taskload when the controllers were in the passive-monitoring mode. Active involvement is apparently an SA enhancer. Controllers changed their scanning patterns between the active control and passive monitoring conditions. These conditions reflected the worst case scenarios. Future free flight implementation will likely include technological support and controllers in more active roles.

INTRODUCTION

Air Traffic Control (ATC) is a complex system that requires constant monitoring by human operators who are extensively trained and tested. ATCSs must focus their visual attention and yet constantly scan for anomalies in the airspace under their control. When controllers make an error, it is not uncommon for them to say, "I didn't see it."

Recent proposals in airspace management suggest that the role of the ground controller as the primary source of aircraft separation assurance may change (RTCA, 1995). Technology such as the cockpit display of traffic information could shift all or part of the separation responsibility to the cockpit. Current thinking about the future suggests that the controller will remain responsible for separation but that pilots may have considerably more latitude in terms of how they use the available airspace (FAA, 1997). Developers have named the technology and concepts surrounding these proposed changes free flight (FAA, 1998).

Whereas researchers have invested some effort in evaluating the human factors impact on pilots, they have not systematically studied the impact of free flight issues in the ATCS domain. Simulation provides the capability to investigate human performance under novel conditions without placing any aspect of the system at risk. It also permits a closely controlled environment where experimenters can specify weather and wind, two major confounding factors in ATC.

METHOD

Participants

Sixteen full performance level (FPL) ATCSs from 12 Air Route Traffic Control Centers participated in this high fidelity simulation study. 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 years (6-22). Six participants had worked at more than one facility during their ATC career. Using a 10-point scale, 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).

Equipment

The experiment used a single en route ATC workstation driven by ATCoach (UFA, Inc., 1992) real-time simulation software. This provided a high fidelity interactive simulation. A 2,000 by 2,000 pixel, 29" video display unit presented the radarscope plan view display (PVD). A 19in monitor mounted above the PVD displayed a map of the airspace. An Air Traffic Workload Input Technique device (ATWIT) (Stein, 1985) mounted to the immediate left of the PVD within easy reach of the participant allowed input of real time 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.

Participating controllers interacted with live simulation pilots who "flew" the simulated aircraft from consoles in another laboratory experiment room. Pilots under current control procedures responded to clearances and queries as they normally would. When working under free flight conditions, aircraft executed their scripted flight plans without requesting clearances. They responded as appropriate to airspace advisories when the controller was monitoring and believed that the controller should issue such communications. Figure 1 shows the simulation with the occulometer equipment set up and operating.

Figure 1. Radar Position Simulation

An ASL 4000 eye-tracking system collected eye movements and fixation data in real time for post-run analysis. The system known as an oculometer is based on an eye-safe infrared light source, which reflects differentially from the controller's retina and cornea respectively. An electromagnetic head tracker allows the computer to filter out head movements such that the data show eye movements relative to the information displayed.

The oculometer data stream is linked to the flow of simulation displayed targets. This integrated data stream allows determination of point of gaze not only on fixed targets such as terrain features but also on dynamic objects. Experience demonstrates the data block is the most frequently fixated object in a radar display (Stein, 1989; Niessen, Eyferth, & Bierwagen, 1998).

Experimental Design

The experimental design employed a 2 X 2 (Task Load X Involvement) within-subjects design. The ATCSs worked both the practice and experimental scenarios in a counterbalanced order.

Procedure

Each participant controlled four practice and four experimental scenarios. Experimental scenarios required either active control or only monitoring by the participant. Experimental scenarios were of either high or low Task Load. The complexity of the scenario (in terms of anticipated altitude transitions) and rate at which aircraft entered the airspace constituted Task Load. A supervisory controller subject matter expert (SME) developed and pre-tested the scenarios. Additional SMEs reviewed them prior to the experiment. Each scenario began with traffic in the airspace similar to that present after a position relief briefing.

The four practice scenarios had a moderate level of Task Load. These scenarios allowed 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 occurred during each practice scenario.

The two active-involvement scenarios simulated air traffic and procedures similar to a current field setting. One of the scenarios was high Task Load and one was low Task Load. During the high-Task Load scenario, aircraft entered the airspace at an average rate of one per minute. The low-Task Load scenario consisted of aircraft entering the airspace at an average rate of one every 2 minutes. Each active-involvement scenario contained three coordination events.

The two monitoring scenarios approximated conditions similar to an advanced stage (free maneuvering) of free flight. One scenario was high Task Load and the other was low Task Load. Task load varied for monitored scenarios in the same manner as for active-involvement scenarios. During monitored 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. Monitored scenarios also contained three coordination events.

Data Collection

During each simulation, experimenters employed a multi-method multivariate measurement system. This approach included both automated data collection accomplished within the simulation system and manual methods. Participants responded to ATWIT queries

every 5 minutes during each run and completed post-run questionnaires after each simulation.

Once data are collected, researchers conducted a complex data reduction and analysis. Part of this process includes deleting variables that simply do not demonstrate any productive variance. Once this is done, we complete inferential and other analyses as required.

This creates data and analysis products that are well beyond the scope and space available here. The following section summarizes a subset of the data collected. More detail will be provided in a technical report that is currently in preparation (Willems & Truitt, in press).

RESULTS

Studies of this complexity generate a great amount of data, and we can only report a small portion of the results. Therefore, we will focus on significant findings that appeared as the result of active versus monitoring controller involvement and of the impact of task load.

These statistical inferences are based on analyses that employ MANOVA, ANOVA, and, where needed, simple effect analysis and post hoc testing. To save space, we did not report the individual products of these analyses but they will be available in a technical report (Willems and Truitt, in press).

Figure 2 demonstrates the flow of the actual eye movements in terms of time. The saccades are divided by 5-minute time blocks across the scenarios. On average, the saccade durations were longer for intervals 2 to 4 and 6 ($p < .05$).

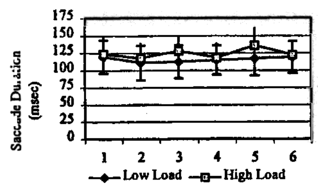

Figure 2. Saccade Duration by Time Interval

Researchers also use fixation duration to evaluate operator behavior. In a radar environment, the controller has to make choices in terms of how to scan for information. In Figure 3, there are differences across different objects and some differences based on level of controller involvement. Fixations are considerably longer on radar returns (RRM) and data blocks (DBM) than they are on the systems area (SYM) and other stationary (STM) objects. Active control conditions significantly ($p < .05$) increased the duration of fixations on the systems area only.

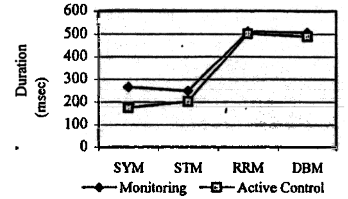

Figure 3. Fixation duration by radar scope object and involvement

The structure in visual scanning captures the probability that a controller will scan objects in a given order. The more structure there is the more predictability. There appears to be an interaction between system load (demand) placed on the operator and level of involvement by the controller. There is an overall trend with less structure under higher load and is most pronounced when a controller is actively working the traffic (see Figure 4).

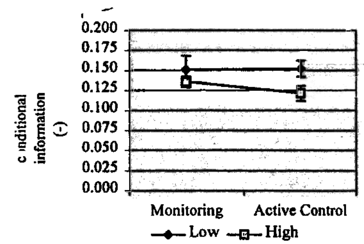

Figure 4. Scanning Structure based on load and involvement

Workload is a recurrent construct that researchers measure and to which they apply most human factors settings. ATWIT is the real time subjective measure that the Federal Aviation Administration William J. Hughes Technical Center Research Development & Human Factors Laboratory uses in most of its simulation studies. Results of the ATWIT data analysis clearly demonstrated that controllers reported higher subjective workload when actively working traffic than when passively monitoring. The difference in perceived workload became most pronounced when the controllers were actively working higher system loads as compared to the conditions under which demand was lighter by design. This is apparent in Figure 5.

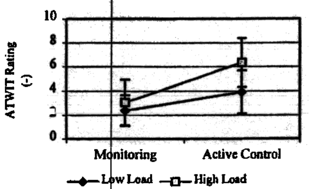

Figure 5. ATWIT mean ratings by load and involvement

Several measurement tools captured information on controller situational awareness. The Situation Presence Assessment Method (SPAM) used real time probes of information that controllers had in front of them. Reaction time served as the principle dependent variable. Figure 6 describes the mean reaction times of participants under conditions of level of involvement and task load.

Under monitoring conditions, it took controllers an average of over twice as long to respond to the SPAM queries, as shown in Figure 6.

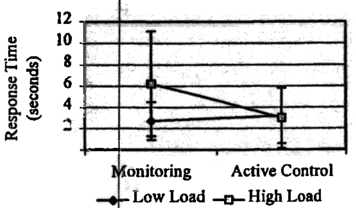

Figure 6. Mean SPAM response time by taskload and involvement.

Whereas there are differences of professional opinion concerning the degree to which memory is or should be part of the SA construct, researchers asked participants what they could remember directly concerning the aircraft under their control (Figure 7).

Participants correctly recalled a greater proportion of the aircraft when they were actively working traffic than when monitoring. Direct recall was also reduced under conditions of higher system demand.

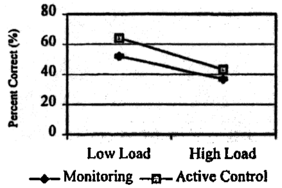

Figure 7. Percent correct recall by load and involvement.

DISCUSSION

It was difficult to select the subsets of analysis that characterize this complex study of controller behavior under diverse control conditions and taskload. There were many interactions between independent variables. The results are based on the lowest levels of analysis from which we can draw some meaningful conclusions.

There were subtle changes in eye movements as seen in Figures 2, 3, and 4. There appeared to be differences in saccade durations, with longer durations during active control conditions in most time segments. This suggests that when actively working traffic, controllers move their eyes more than when just monitoring traffic. It further suggests that when they are less involved they are likely getting into a more methodical and less exploratory scanning routine.

Figure 4 also shows that taskload and involvement interact. When passively monitoring, load does not make much difference in terms of scanning structure. Under low load and monitoring conditions, controller scan patterns have more structure and are basically more predictable. Predictability in scanning is not necessarily a desirable quality because it suggests certain rigidity to the pattern. Under high load and active control, there is less structure, which means that controllers are less predictable in their scanning. One might speculate that this might increase the probability that they see something that would be missed when scanning rigidly, and could be the subject of another study.

Fixation duration is another important visual scanning variable. As seen in Figure 3, ATCSs spend most of their available fixation time on data blocks and radar targets. Because human beings only assimilate

information for transfer to sensory and working memory when fixating, this is not surprising. The data blocks and radar targets are the primary dynamics in using radar to maintain SA. For the most part, the level of involvement did not make any difference concerning radar object fixation times. The only apparent difference were the mean fixation times on the system area with monitoring controllers spending a bit more time there.

Because this project used full mission simulation, we also assessed workload in addition to scanning data. Overall, controllers reported that they were working harder when actively controlling traffic than when monitoring. This suggests that they believed us that, when monitoring, they were not responsible for separation.

We had expected that, even in simulation, it would be difficult to convince controllers to let go of the separation requirements. This is especially true because the current concept for the future is that controllers will remain in charge and remain responsible for separation. To maintain this separation, controllers must stay in the loop and maintain situational awareness.

The results of this study suggest that passive monitoring does reduce controller SA. If response time, as used in the SPAM, is a viable indicator, , then, when monitoring, controllers have less SA. Their response time is almost three times longer than when they are actively working traffic. This is despite the fact that they feel they are working harder when separating aircraft than when simply monitoring traffic. These results support the reaction time data collected with the SPAM queries. Working memory is important in assisting a human operator in staying in the loop of a complex command and control system, and monitoring is not a memory or SA enhancer.

CONCLUSIONS

Human beings are not at their best when placed in situations where they must monitor but do not have control or responsibility. This conclusion is found throughout the literature on human factors and applied psychology. We have seen nothing to refute it here.

This work was undertaken to look at the worst case situations. Controllers had no technology enhancements to help them stay in the loop. However, they were asked to passively monitor but not be responsible if things went wrong. In simulation, they were reluctantly willing to comply. However, it changed how they scanned for information, and it interrupted their processing of information in memory. Fortunately, this worst case scenario will not happen in the real world. Free flight conditions will likely exist with technological support both on the ground and in the air. Further, controllers will continue to maintain separation and will have the latitude to impose structure where needed so that separation will be maintained. This responsibility, the technology, and the latitude will likely keep them focused.

REFERENCES

Niessen, C., Eyferth, K., & Bierwagen, T. (in press). Modeling cognitive processes of experienced air traffic controllers. *Ergonomics*.

FAA (1997, September). *ATS concept of operations for the national airspace system in 2005.* Washington DC: Author

FAA (1998). Free flight phase 1. Retrieved January 4, 1999 from the World Wide Web: http://ffp1.faa.gov/Development.htm

Stein, E. S. (1985). *Air traffic controller workload: An examination of workload probe* (DOT/FAA/CT-TN-84/24). Atlantic City, NJ: DOT/FAA Technical Center.

Stein, E. S. (1989). *Air traffic controller scanning and eye movements in search of information-a literature review* (DOT/FAA/CT-TN 89/9). Atlantic City, NJ: DOT/FAA Technical Center. (NTIS No. ADA 206 709).

RTCA (1995). *RTCA task force 3: Free flight implementation draft final report.* Washington DC: Author

UFA, Inc. (1992). *ATCoach* [Computer Software]. Lexington, MA: UFA, Inc.

Willems, B. & Truitt, T. R. (in press). *Implications of reduced involvement in en route air traffic control* (DOT/FAA/CT/-TN98/37). Atlantic City International Airport, NJ: DOT/FAA William J. Hughes Technical Center.