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13. ABSTRACT (Maximum 200 words)
The objective of this project is to train graduate students in conducting research in human factors and ergonomics issues related to aviation. Numerous research projects have been completed within this project. They have focused on: (1) an investigation of causal factors related to problems with sutuation awareness among pilots and air traffic controllers, (2) investigatins of automated compensation for enhancing performance in teleoperations task under operator/system control axis misalignment with both static and dynamic misalignments, (3) an investigation of level of automation effects on human performance, situation awareness and workload, (4) an investigation of adaptive automation and level of control on human performance, situation awareness and workload under dual task conditions, and (5) an investigation of cue characteristics related to errors in situation awareness comprehension. Each of these projects provided the AASERT fellows with extensive experience in studying critical issues related to human performance in aviation, and each has resulted in new research that significantly advances scientific knowledge in each of these areas.

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Augmentation Award for Training in Aviation Human Factors & Ergonomics
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Objective

The objective of this project is to train graduate students in conducting research in human factors and ergonomics issues related to aviation.

Status of Effort

Two students were supported under this grant.

David B. Kaber: Graduated with a Ph.D in Industrial Engineering - August, 1996. GPA 3.95/4.0

Dissertation: The effect of level of automation and adaptive automation on performance in dynamic control environments

Debra G. Jones: Graduated with a Ph.D. in Industrial Engineering - December, 1996. GPA 3.96/4.0

Dissertation: The effect of cue type on situation awareness

Research Conducted by AFOSR Student Fellows

Numerous research projects have been completed within this project. They have focused on: (1) an investigation of causal factors related to problems with situation awareness among pilots and air traffic controllers, (2) investigations of automated compensation for enhancing performance in teleoperations task under operator/system control axis misalignment with both static and dynamic misalignments, (3) an investigation of level of automation effects on human performance, situation awareness and workload, (4) an investigation of adaptive automation and level of control on human performance, situation awareness and workload under dual task conditions, and (5) an investigation of cue characteristics related to errors in situation awareness comprehension. Each of these projects provided the AASERT fellows with extensive experience in studying critical issues related to human performance in aviation, and each has resulted in new research that significantly advances scientific knowledge in each of these areas.

Accomplishments/Findings

The following studies were completed under this grant.

(1) Investigation of causal factors related to problems with situation awareness among pilots and air traffic controllers

Situation Awareness (SA) is a crucial factor in effective decision making in the dynamic flight environment. Consequently, an understanding of the types of SA errors that occur in this environment is beneficial. This study used reports from the Aviation Safety Reporting System (ASRS) to investigate the types of SA errors that occur in aviation and causal factors associated with their occurrence.

The errors were classified into one of three major categories: Level 1 (failure to correctly perceive the information), Level 2 (failure to comprehend the situation), or Level 3 (failure to project the situation into the future). Of the errors identified, 78% were Level 1 SA errors, 17% were Level 2 SA errors, and 5% were Level 3 SA errors. Level 1 SA errors occurred when relevant data was not available, when data was hard to discriminate or detect, when a failure to monitor or observe data occurred, when presented information was misperceived, or when memory loss occurred. Level 2 SA errors involved a missing/or incomplete mental model, the use of an incorrect mental model, over-reliance on default values, and miscellaneous other factors. Level 3 errors involved either an over-projection of current trends or miscellaneous other factors. These results provided indication of the types and frequency of SA errors that occur in aviation and an indication of factors that lead to problems in SA along with their respective frequencies.

This research provides significant new insight into the types of problems pilots have with situation awareness, and the types of factors that lead to SA errors. As situation awareness has been found to be a causal factor in 88% of aircraft accidents, these results are particularly important to the goal of improving safety and decreasing accidents in aircraft both in military and civilian aviation. The data will be used to determine remedial techniques for improving SA within each causal factor category.

(2) <u>Investigations of automated compensation for enhancing performance in teleoperations task under operator/system control axis misalignment with both static and dynamic misalignments</u>

The first study examined the effect of automatic compensation for misalignment between display and controller orientation on teleoperation. Teleoperation tasks are common in aviation for activities such as satellite maneuvering in space or the operation of aircraft drones for example. In a telemanipulation scenario gross misalignments may arise between operator viewing direction and controller orientation due to changing system (end-effector) or operator positions. It remains to be clarified as to whether humans can adapt to such visual-motor non-compliance through experience. An experiment was conducted to test a means of providing automated compensation for misalignments between display and controller rotations relieving human operators of the need to learn or adjust for alternate motor mappings. Subjects were asked to perform a telemanipulation task involving tracking of a randomly moving target. Performance was recorded under various misalignments of the controller (from 0 to 180 degrees in each direction) with and without automated compensation. Results indicate significant improvements in operator performance through use of automatic compensation under misalignments involving both the controller and display (such as encountered in situations where the human operator moves about a fixed teleoperator). When only the controller is misaligned (such as encountered in situations where the teleoperator moves about a fixed human operator and the human moves his or her head to maintain display orientation), human operators are able to adjust internally, and the automated compensation actually degraded performance.

This study was followed by a second study which replicated the first, but was expanded to examine the effect of dynamically changing orientations of the human operator or the display as opposed to the fixed misalignments examined in the first study. Teleoperations are often performed under such positional disturbances which may be brought on by movement of the operator or teleoperator. An experiment was conducted in which subjects were required to perform teleoperation involving tracking an irregularly moving target on a computer display using a cursor linked to a joystick while they, or the display, were continuously rotated in a clockwise or counter-clockwise direction. Performance was recorded under different rates of rotation, with and without automated compass compensation for the misalignment. Results indicate that significant improvements in operator task accuracy were achieved with the compass for situations in which the teleoperator was rotated (leading to misalignments of the display and controller), however not in the situation in which the misalignments were brought on by the rotation of the human operator (leading to misalignments of the controller alone). Thus, the second study supported the findings of the first study under dynamic misalignment conditions.

These two studies provide significant new data providing an understanding of what misalignment conditions cause problems for human operators in teleoperations tasks and showing considerable benefit to the use of automated compensation under some conditions. These results are applicable to a range of situations encountered by the Air Force in which human operators may control dynamic objects that are separate from them (e.g. drones, mobile robots, etc...) or in which they need to operate the dynamic control of objects while moving themselves (e.g. operating on satellites in space).

(3) Investigation of level of automation effects on human performance, situation awareness and workload.

Automation has become wide spread in aviation, both in the cockpit and the ground. Accompanying the use of automation, a noted trend towards out-of-the-loop performance errors has occurred. Historically, the pilot has been expected to maintain a monitoring role over automation, intervening when necessary. Their ability to do so when functioning in such a role is quite limited, however. An out-of-the-loop performance problem results in which humans have a significant reduction in their ability to detect system errors and perform tasks manually in the face of system failures. This problem has been shown to be largely due to a loss of situation awareness that occurs under automated conditions. Furthermore, such systems tend to be very difficult for human operators to control and understand in real-time due to the increased level of complexity associated with most automated systems.

This project investigated the use of intermediate levels of automation in which the human operator maintains a greater degree of control as a means of improving situation awareness and avoiding the out-of-the loop syndrome associated with full automation of tasks. A ten level taxonomy of Level of Automtion (LOA) was developed that delineates different levels of automation as a function of which roles are assigned to the human operator and which are assigned to the machine. The taxonomy was developed to incorporate functions that needed to be performed across a wide range of systems, including teleoperations and robotics. The four major role types were defined as: Monitoring (sensing and observing information), Generating (producing options for control performance), Selection (choosing which option to implement) and Implementing (actually performing the task). The ten levels of automaton were formed on the basis of allocating each role to the human, computer or shared between the human and computer. They include (1) Manual control, (2) Action support, (3) Batch processing, (4) Shared control, (5) Decision support, (6) Blended decision making, (7) Rigid system, (8) Automated decision making, (9) Supervisory control , and (10) Full automation.

A study was conducted using a simulation that incorporated multiple tasks to be processed with different relevance to the assigned goals, multiple goals, and high task demands under limited time resources. The simulation required users to develop complex strategies for optimizing system performance along multiple goals simultaneously. The study revealed that overall performance was greatly improved by LOA that provided computer aiding in the Implementation role of task execution. Decrements in overall performance were observed, however, with LOA that incorporated joint human-computer Generation of options, as compared to purely manual Generation. The use of computer or joint human-computer Selection of options did not significantly affect overall performance, compared to human Selection. (Joint Monitoring was necessary across almost all levels of control). When the automation failed, and human operators were required to jump-in and assume manual control, their ability to do so was significantly better when human functioning in the Implementation role had been present. Time to recover and performance during manual control immediately following the failure was worse at LOA that incorporated advanced process planning in the queuing of targets (Batch Processing and Automated Decision Making). Reductions in workload and corresponding improvements in operator situation awareness were observed with higher LOA that incorporated joint human- computer or computer Selection of options to implement.

This study represents a unique contribution to the study of automation in aviation, both in terms of the LOA taxonomy developed and in terms of the findings of the study regarding which aspects of a task benefit most from automation (or may be degraded by automation). As automation is becoming an increasing part of many aviation systems (including commercial and military cockpits, air traffic control and ground control), expanding from simply performing tasks or control functions to providing decision guidance and highly cognitive functions (through artificial intelligence and expert systems, for instance), these findings are particularly germane. These results are directly applicable to design decisions regarding which tasks automation should perform and how such systems should interact with human operators.

(4) Investigation of adaptive automation and level of automation on human performance, situation awareness and workload under dual task conditions.

This study expanded on the previous study investigating the effects of level of automation (LOA) to include an investigation of adaptive automation (AA) and dual-task conditions. Most automation does not function all the time, but rather at different times control may be passed to human operators for particular tasks. Intermittent periods of transfer of control may serve to improve human performance by keeping the operator in-the-loop. Effective strategies for merging control from multiple sources need to be developed and for transitioning control from machines to humans.

This study examined several AA partitioning strategies in which the percentage of the time the task was automated was varied (0%, 20%, 40%, 60% and 100%) in addition to 6 LOAs selected as representative based on the earlier study (Manual, Batch Processing, Shared Control, Blended Decision Making, Supervisory Control and Full automation). In addition, a secondary gage monitoring task was employed as previous studies have indicated that automation complacency may only occur when the operator is dual tasked. The earlier LOA study found that SA was surprisingly high under high levels of automation (contrary to previous findings), possibly due to the fact that subjects had not other task to perform other than monitoring the automation. Therefore, a secondary task was added to test this hypothesis and see if SA is indeed negatively affected by automation mostly under vigilance and dual-task conditions, both factors which are characteristic of tasks in the aviation domain.

The results of this study generally confirmed the findings of the previous study in relation to the effects of LOA on performance, workload and situation awareness. The insertion of the secondary guage monitoring task did not substantially change the results of the study across LOA; performance on this task mapped to the ratings on the subjective workload measure indicating it reflected a measure of cognitive resources available in each condition as would secondary task workload measure. Situation awareness was best under manual control, full automation, and shared control.

While AA partioning strategies had a significant effect on subject performance with performance improving as percentage of time the task was automated, LOA was a much stronger driving factor in affecting human performance in this task. The AA strategy used, however, was the primary factor driving subjective workload and workload as measured by the secondary guage monitoring task. AA strategey did not significantly affect operator situation awareness.

The results of this study act to both confirm the results of the previous study and to expand upon them based on more realistic dual-task and vigilance conditions and to examine the impact of AA strategies. These results are particularly important for the design of automated systems in a wide variety of aviation applications including cockpits and air traffic control.

(5) <u>Investigation of cue characteristics related to errors in situation awareness comprehension</u>

Situation awareness (SA) errors have been linked to a large majority of accidents and incidents involving human error in aviation. In some poor SA can lead to accidents, loss of life, and/or poor mission performance. In other cases poor SA can be recovered from prior to a major performance error occurring. A significant question exists as to how does an operator may realize his or her SA is off-the-mark, allowing for activities to regain SA, while in some cases the person may continue with poor SA oblivious to information that should point out his or her erroneous situation model.

Two types of events may occur. When some piece of data is perceived it may be misinterpreted and integrated with the existing mental model to yield a misrepresentation of the situation. In other cases, it may indicate that the operator's mental model is in error and a new mental model is selected allowing the operator's SA to be in line with the actual situation. An inappropriate choice can easily sabotage SA efforts for quite some time. It is hypothesized that different types of cues may be more likely to call to the operator's attention that they have inaccurate SA. Schema bizarre cues are expected to be more likely to be recognized that schema irrelevant cues. The presence of unexpected cues (per the mental model) is also expected to be more likely to be noticed than the absence of expected cues.

An experimental study was conducted for testing these hypotheses within the context of a high fidelity air traffic control simulation. It engaged 12 subjects who were all experienced controllers in ATC traffic scenarios which included three types of errors that would induce an incorrect mental model: incorrect aircraft ID on flight strip, incorrect flight plan on flight strip, and pilot communication error. Cues were then introduced according to the above taxonomy (schema bizarre, schema irrelevant, schema unexpected, and absense of schema expected) that should indicate to the controller that an error had been made that needed correction. (All scenarios and cues were developed through a subject matter expert to ensure fidelity and accuracy.)

The study found that schema bizarre cues were detected and the error discovered more frequently than schema irrelevant cues, conforming to the hypothesis. Schema unexpected cues were not detected more frequently than the absense of expected cues, however. In investigating the many cases where subjects did not discover that an error had been made (65% of all cases), it appears that majority involved a representational error. The subjects detected the cue, but made assumptions to explain it way so as to be consistent with the orignal (but erroneous mental model). Very often these explanations were quite far fetched and subjects did not tend to check their assumptions.

This study represents a novel attempt to address methods for improving SA based on schema theory. Its results should be applicable to a wide range of systems in which people rely on SA for performance, including aircraft and air traffic control. The study revealed significant difficulties in correcting incorrect mental models that underly SA, but that schema bizarre cues were the most likely to result in a correction being made.

Personnel Supported

Graduate Students: David Kaber
Debra Jones

Publications

Jones, D. G. (1996) The effect of cue type on situation awareness. Doctoral Dissertation. Lubbock, TX: Texas Tech University.

Jones, D. G. and Endsley, M. R. (1996) Sources of situation awareness errors. Aviation, Space and Environmental Medicine. 67(6), 507-512.

Kaber, D. B. (1996) The effect of level of automation and adaptive automation on performance in dynamic control environments. Doctoral Dissertation. Lubbock, TX: Texas Tech University.

Kaber, D. B., Macedo, J. A. and Endsley, M. R. (1996). Human factors investigation of automated compensation for incongruent display-controller axes in teleoperations: Part II. Dynamic misalignments. In R. Koubek and W. Karwowski (Eds.), Manufacturing Agility and Hybrid Automation (pp. 473-477). Louisville, KY: IEA Press.

Macedo, J. A., Endsley, M. R. and Kaber, D. B. (1996). Human factors investigation of automated compensation for incongruent display-controller axes in teleoperations: Part I. Static Misalignments. In R. Koubek and W. Karwowski (Eds.), Manufacturing Agility and Hybrid Automation (pp. 469-472). Louisville, KY: IEA Press.

Macedo, J. A., Kaber, D. B., Endsley, M. R. and Powanusorn, P. (in review). The effects of automated compensation for incongruent axes on teleoperator performance. Submitted to Human Factors.

Endsley, M. R. and Kaber, D. B. (in review). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Sumitted to Ergonomics.

Interactions/Transitions

a. Meetings and Conferences

Jones, D. G. and Endsley, M. R. (1995, November) Investigation of situation awareness errors. Presentation at the International Conference on Experimental Analysis and Measurement of Situation Awareness, Daytona Beach, Florida.

Kaber, D. B. and Endsley, M. R. (1996, March). Impact of the Level of Automation on Situation Awareness and Performance. Presentation at the 2nd Automation Technology and Human Performance Conference, Cocoa Beach, Florida.

Kaber, D. B. and Endsley, M. R. (1995, November). Level of control effects on aviation related task performance and situation awareness. Poster at the International Conference on Experimental Analysis and Measurement of Situation Awareness, Daytona Beach, Florida.

Kaber, D. B., Macedo, J. A. and Endsley, M. R. (1996, August). Human factors investigation of automated compensation for incongruent display-controller axes in teleoperations: Part II. Dynamic misalignments. Presentation at the Fifth International Conference on Human Aspects of Advanced Manufacturing: Agility & Hybrid Automation, Maui, Hawaii.

Macedo, J. A., Endsley, M. R. and Kaber, D. B. (1996, August). Human factors investigation of automated compensation for incongruent display-controller axes in teleoperations: Part I. Static Misalignments. Presentation at the Fifth International Conference on Human Aspects of Advanced Manufacturing: Agility & Hybrid Automation, Maui, Hawaii.

b. Consulting and Advisory Functions to Labs and Government Agencies

Not applicable to student training grant.

c. Transitions

none

New Discoveries, inventions, patents

none

Honors/Awards

none