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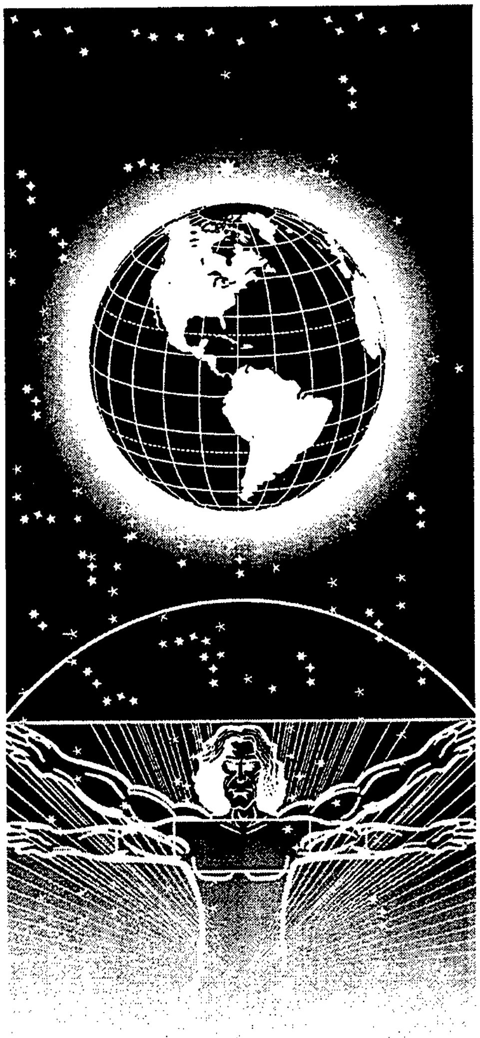

UNITED STATES AIR FORCE RESEARCH LABORATORY

INFORMATION DISSONANCE, SHARED MENTAL MODELS AND SHARED DISPLAYS: AN EMPIRICAL EVALUATION OF INFORMATION DOMINANCE TECHNIQUES

Cheryl A. Bolstad
Mica R. Endsley

SA TECHNOLOGIES
4731 EAST FOREST PEAK
MARIETTA GA 30066

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Human Effectiveness Directorate
Crew System Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

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FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

This study experimentally tested the use of shared mental models and shared displays as a means of enhancing team situation awareness (SA). Teams were tested using a simulation of an aircraft defense task that incorporated features of a distributed team architecture. As hypothesized, the presence of shared displays and shared mental models improved team performance. However, the mechanism whereby the shared displays aided performance was not direct as expected. Teams were initially slower when first given a shared display, but a residual effect was seen in later trials where it aided performance. While shared displays initially slowed team performance in this task, most likely due to extra attention demands, they also provided for the development of shared mental models that greatly enhanced performance after they were removed. The combination of non-shared displays and no mental model was highly detrimental to performance. Teams who experienced this condition first were unable to ever develop very good performance. Overall, we found that effective team performance could be enhanced by providing teams with sufficient information to build a shared mental model of each other's tasks and goals, either through direct instruction, or through provision of shared displays.

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PREFACE

This effort was accomplished under Contract F41624-94-D-6000, Delivery Order 0007 for the Air Force Research Laboratory's Human Effectiveness Directorate, Crew System Interface Division, Information Analysis and Exploitation Branch (AFRL/HECA). It was completed for the prime contractor, Logicon Technical Services, Inc. (LTSI), Dayton Ohio, under Work Unit No. 71841046: "Crew Systems for Information Warfare." Mr. Don Monk was the Contract Monitor. We would like to thank Mr. Gilbert Kuperman (AFRL/HECA), Mr. Robert Stewart (LTSI), and Dr. Mike McNeese (AFRL/HECA) for their support and encouragement to this project.

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INTRODUCTION

Achieving information dominance (ID) in the military battlespace has become a major operational thrust. Defined as "the ability to collect, control, exploit, and defend information while denying an adversary the ability to do the same" (Department of the Air Force, 1995), ID is seen as the key controlling the battle and winning future armed conflicts. "Dominating the information spectrum is as critical to conflict now as occupying the land or controlling the air has been in the past." (General Ronald R. Fogleman (Department of the Air Force, 1995)).

The concept of ID and the issues involved in achieving it have been discussed based on a model of situation awareness (SA) within the context of complex, distributed crews (or military units) as is envisioned in future military operations (Endsley & Jones, 1997). By examining what is known about how people access, assimilate, and interpret information to develop SA and how this fits within the decision making and action cycle, directions for the development of systems to support the goal of ID were established. Achieving ID involves far more than having more data than the enemy. It requires that the data be transformed into the required information in a timely manner for a multitude of forces, each with varied and dynamically changing but inter-related information needs, and properly understood by each within the context of a joint mission. Fulfilling this requirement requires an understanding of SA and the factors that impact it for each of the distributed teams involved, and the way in which these SA needs interact between teams.

In military operations, most actions occur in teams or crews of individuals. Examining SA as it exists within teams and between teams that are involved in achieving a common goal lends an important perspective for the determination of system designs that support the complex inter-related activities of these teams. Team SA has been defined as "the degree to which every team member possess the SA required for his or her responsibilities" (Endsley, 1995). The degree to which team members possess a shared understanding of the situation with regard to their shared SA requirements is an extremely important aspect of team SA. Shared SA can be defined as "the degree to which team members possess the same SA on shared SA requirements." Shared SA can be depicted as the shaded area in Figure 1, where each circle represents the SA requirements of each team member. It is the area where these requirements overlap that constitutes the need for a shared understanding of the situation within a team. Similarly, where the SA requirements overlap between teams, a shared understanding of this information is equally important for the ability of the teams to achieve their goals.

Developing shared SA within a team and between teams can be extremely challenging, especially where those teams are distributed in terms of space, time, or physical barriers. This has been described in the model of team SA as a function of four components (Endsley & Jones, 1997):

(1) Shared SA Requirements - the degree to which the team members know which information needs to be shared, including their higher level assessments and projections (which are usually not otherwise available to fellow team members), and information on team members' task status and current capabilities.

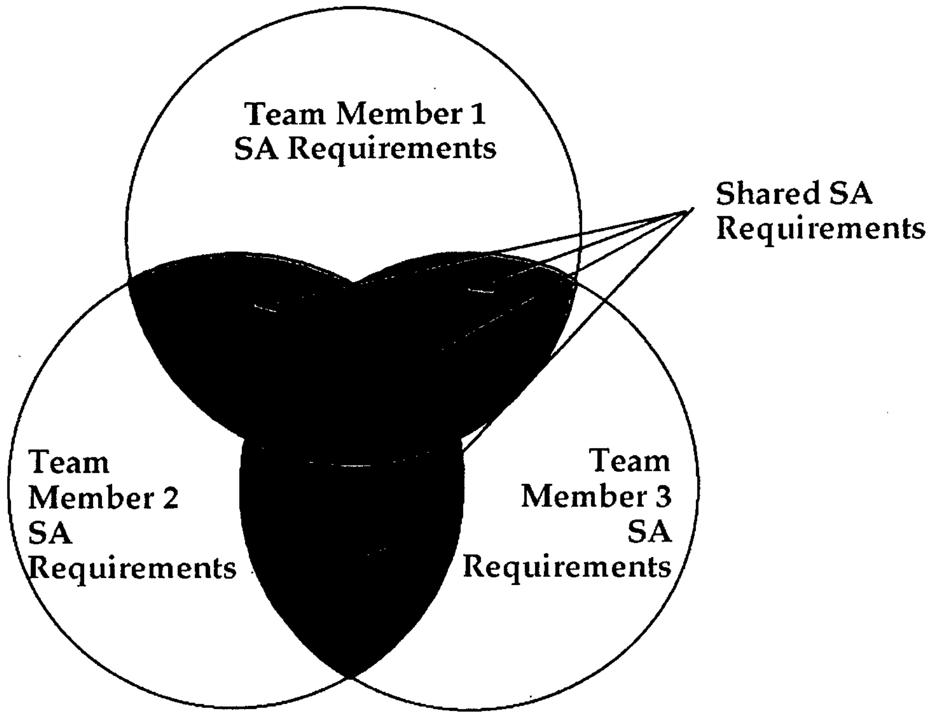

Figure 1. Shared SA Requirements

(2) Shared SA Devices - the devices available for sharing this information, which can include direct communication (both verbal and non-verbal), Shared Displays or a shared environment. As non-verbal communication and a shared environment are usually not available in distributed teams, this places far more emphasis on verbal communication and technologies for creating shared information displays.

(3) Shared SA Mechanisms - the degree to which team members possess mechanisms, such as Shared Mental Models, which support their ability to interpret information in the same way and make accurate projections regarding each other's actions. The possession of Shared Mental Models can greatly facilitate communication and coordination in team settings.

(4) Shared SA Processes - the degree to which team members engage in effective processes for sharing SA information which may include a group norm of questioning assumptions, checking each other for conflicting information or perceptions, setting up coordination and prioritization of tasks, and establishing contingency planning among others.

Objective

The objective of this study was to experimentally test this model of SA using a simulation test-bed that incorporates features of a distributed team architecture, as would be found in a military battlespace. In particular, this effort focused on examining the use of shared battlespace displays and the role of shared mental models. While it has been hypothesized that shared displays and shared mental models would assist team members in performing joint tasks, this hypothesis has never been empirically evaluated.

METHOD

Participants

Thirty four participants served as paid subjects in this research. Two participants (one team) were dropped from the analysis due to their low overall performance (less than three standard deviations below the mean on performance measures). The remaining 32 participants were tested in pairs for a total of 16 teams. The participants (mean age = 21.72 years; range 18 - 36 years) comprised of 10 men and 22 women with an average of 14.9 years of formal education. All but one participant indicated they had normal or better vision. The participants had an average of 6.8 years of computer experience (range 2 - 22), so all were familiar with the general operation of a personnel computer.

Design

Two factors served as independent variables in the study: Shared Mental Models and Shared Displays. Presence or absence of a Shared Mental Model was a between team manipulation, while presence or absence of a Shared Display was a within team manipulation. The use of Shared Displays was counterbalanced across teams. Therefore, half of the teams participated in the task with Shared Displays first, followed by Non-shared Displays. The other half of the teams begun the task without Shared Displays, followed by Shared Displays, as shown in Table 1. Each team completed five ten-minute blocks in each of the two display conditions.

Table 1. Experimental Design

	Shared Mental Model	**Non-shared Mental Model**
Shared Display/ Non-shared Display	Team 1 Team 5 Team 9 Team 17	Team 2 Team 6 Team 10 Team 14
Non-shared Display/ Shared Display	Team 3 Team 7 Team 11 Team 15	Team 4 Team 8 Team 12 Team 16

The effects of the independent variables on the performance of the two decision makers in the Theatre Defense task were examined as dependent variables. The processing outcome (destroyed, passed through, or collided), time to process a target, and reward and penalty points were recorded for the Air Commander. The time to make an identification, correctness of identification, and use of the Air Commander's prioritization order were recorded for the Intelligence Officer. These variables were also used to examine the effects of information dissonance and missing information on decision making under time pressure.

Procedure

Teams were tested one at a time. Prior to performing the Theatre Defense task, each team member was asked to fill out an informed consent sheet as well as a short background questionnaire that asked about formal schooling, age, and computer use. After completion of the questionnaire, team members were given a handout describing their task within Theatre Defense (see Appendix A for the Intelligence Officer's job description and Appendix B for the Air Commander's job description).

Teams in the Shared Mental Model condition were then asked to read each other's job description in order to formulate a Shared Mental Model of the joint task. After reading the instructions, they were given time to ask questions, discuss, and formulate a joint strategy to optimize their performance. In the Non-shared Mental Model condition, participants were given time to ask questions, however, the other team member was not in the room during this period. In this condition, they were only given information regarding their own task and no discussion was allowed between the team members.

In the Shared Display manipulation, the two team members were seated side by side with their computer monitors approximately six inches apart. This placement allowed them the ability to view the other team member's computer screen while performing the task. In the Non-shared Display manipulation, participants were also seated side by side, but they were separated by a barrier and thus could not view each other or the other team member's displays.

Teams completed two ten-minute practice trials. Questions were answered at the completion of each trial. In the Shared Mental Model condition, the team could work on a joint strategy both between practice trials and at the conclusion of the practice. The test consisted of five ten-minute trials in the Non-shared Display condition and five in the Shared Display condition. Participants were given a 15 minute break after each five trial block. In the Shared Mental Model condition, participants were allowed to discuss the task during the break, but not between the trials.

Task

A new task paradigm was created for exploring decision making and SA issues in a team task appropriate for the information warfare environment. The microworld, entitled Theatre Defense, incorporates activities by two individuals: an Intelligence Officer and an Air Commander who each have separate, but inter-related tasks. The two team members work at separate workstations, connected by an ethernet LAN. The role of the Air Commander is to protect the home base from incoming aircraft. Targets (designated by blank boxes) appear on the radar screen moving towards a central point (the home base), as shown in Figure 2. The Air Commander must prioritize these targets (based on range and speed) and request information from the Intelligence Officer on their identity and mission priority. Once an identification has been received from the Intelligence Officer, the Air Commander processes the targets accordingly. The Air Commander must choose which targets to destroy (based on range, speed, and penalty/reward points) and which to let through to the home base (such as friendlies).

Targets included fighters, bombers, and transport aircraft of either friendly or enemy designations, making for a possibility of six categories with a total of 18 different aircraft types. Points were assigned to each category representing the reward points for destroying the aircraft and penalty points for allowing the aircraft to get through to the home base. Reward and penalty points for each category were based on the mission relevance and lethality of the aircraft type. Friendly aircraft had a zero penalty for getting through to home base and a negative reward associated with destroying them. In addition to landing or destroying an aircraft, it was possible for some targets to collide with each other, resulting in the reward and penalty points associated with both aircraft to be recorded. Thus, the Air Commander needed to correctly destroy enemy aircraft that would conflict with friendly aircraft before such a collision occurred.

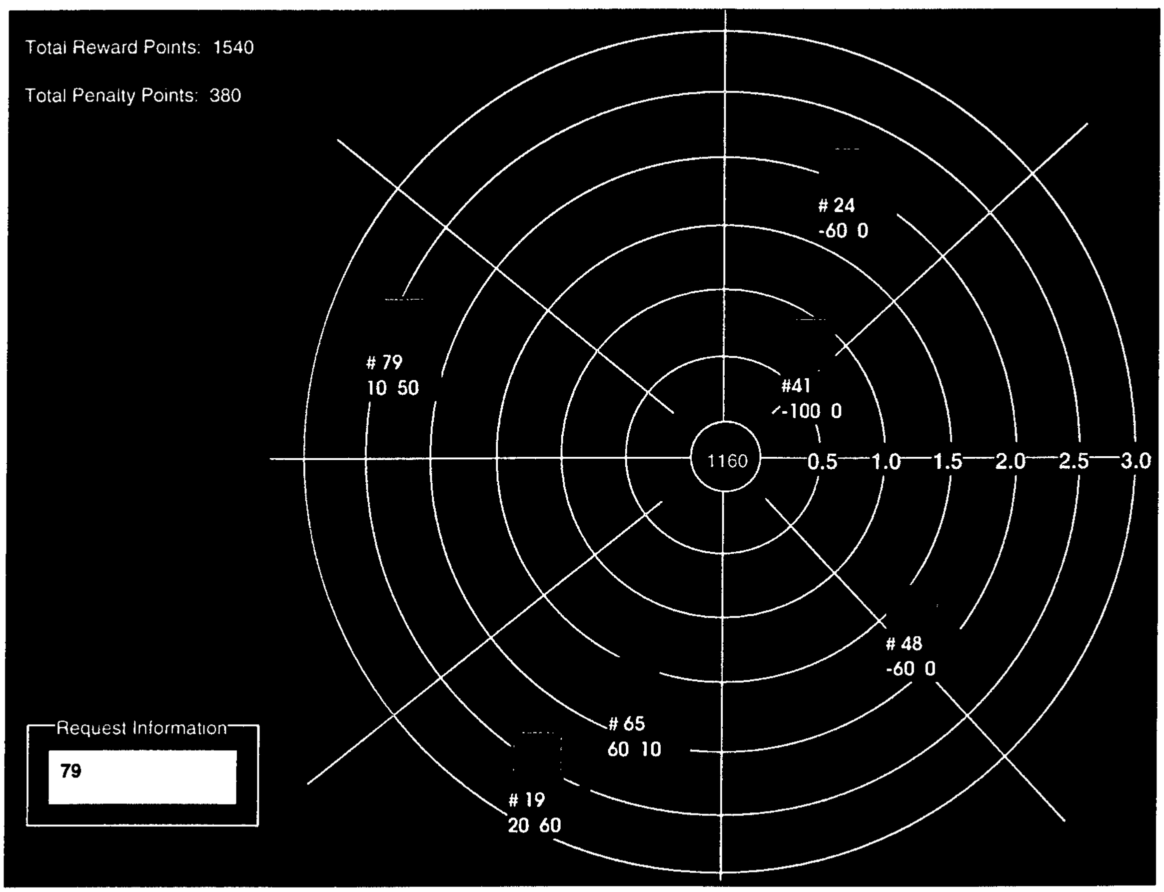

Figure 2. Air Commander Workstation's Screen

The Intelligence Officer was supplied with a list of targets and the identifications provided by several different sensors of varying reliability, as shown in Figure 3. Upon a request from the Air Commander, the Intelligence Officer needed to select the sensor information for that target and make a designation of the target aircraft type and category. Three sensors (A, B, and C) were provided which participants were instructed had reliability rates of 75%, 50%, and 50%, respectively. To represent issues present in the real world, the information from the three sensors was either consistent (1/3 of the cases), partially missing (1/3 of the cases), or dissonant (1/3 of the cases). As decision making in the face of information dissonance was of particular concern, conflicting (dissonant) sensor information was provided for 1/3 of the targets where different sensors indicated the target was of the same category but of two different types (e.g., F18 vs F16) or of two different categories (e.g., F16 vs SU35). The distribution of the dissonant information was distributed across sensor types and reliabilities in order to examine these effects. For instance, in some cases two sensors indicated a friendly and one an enemy, and in other cases two indicated an enemy and one a friendly. Which sensor provided the dissonant information was also counter-balanced across cases to provide for information on the effect of sensor reliability as well as sensor confirmation in making identification decisions.

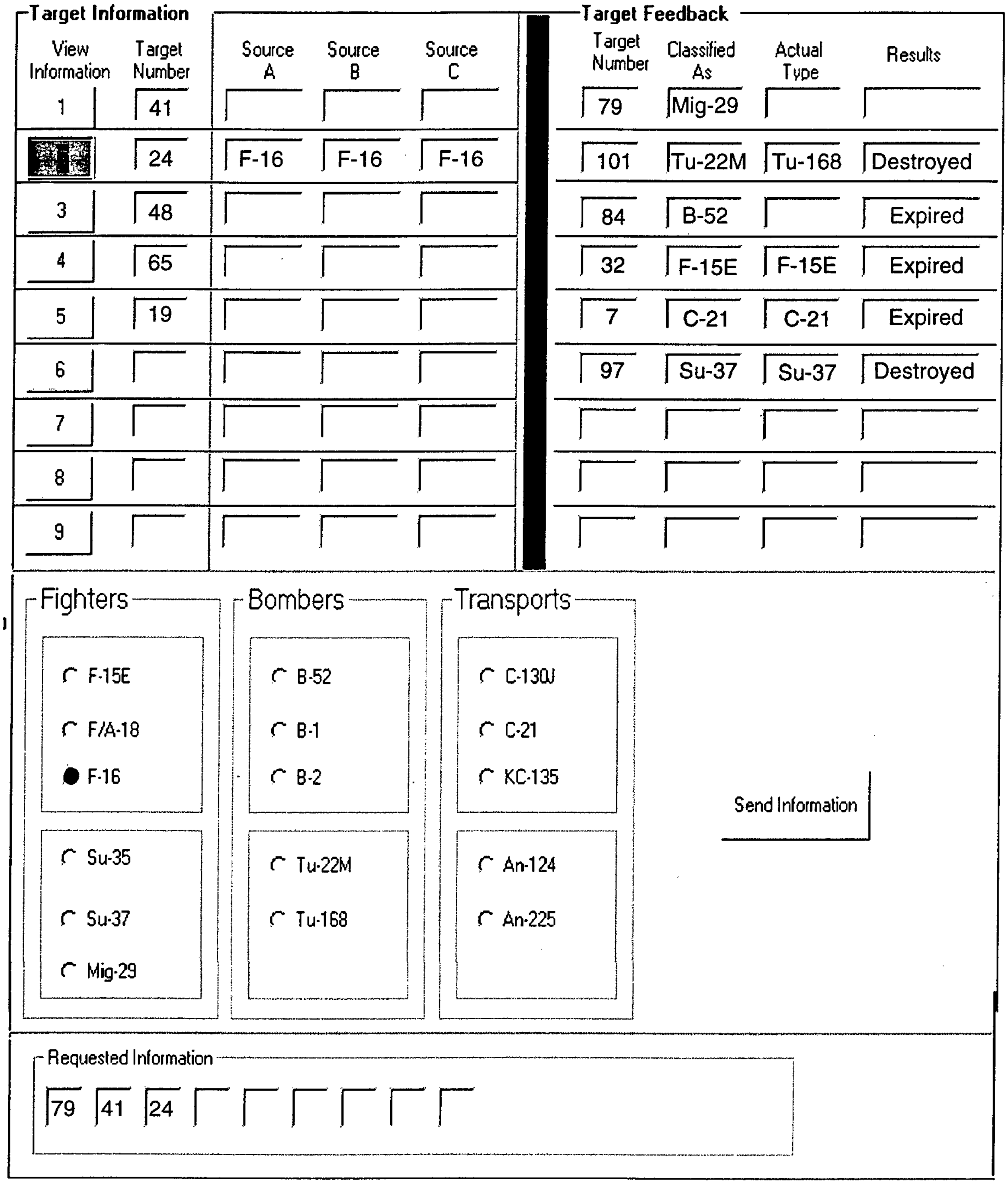

Figure 3. Intelligence Officer's Workstation Screen

Once the Intelligence Officer made a decision, this information was passed to the Air Commander who saw the target change colors (indicating its category) and the reward and penalty points associated with the target. This information was dependent on the Intelligence Officer's identification and therefore may or may not have been correct. However, the points assigned when the target was processed (landed, destroyed or collided) were based on the actual identification of the target. Feedback was provided only after the target was destroyed or allowed to pass through to the home base (as in the real world) to the Intelligence Officer (e.g. F-16 passed through; F-16 destroyed). The Air Commander was also provided with the running point total. Learning therefore was able to take place allowing the team members to develop effective strategies and decision behaviors.

The pace of the task was such that to maximize points, both officers needed to be very strategic about how they prioritized and processed targets. Otherwise a significant number of enemy aircraft would penetrate the air defense and strike the home base or a significant number of friendly aircraft would fall prey to fratricide.

In the Non-Shared Display condition, each officer had only a limited amount of information from the other, in addition to their own display. The Intelligence Officer saw only the prioritization list provided by the Air Commander and the Air Commander saw only the resultant classification provided by the Intelligence Officer.

In the Shared Display condition, each officer also saw the "big picture," showing all the display information of the other officer. Therefore the Intelligence Officer also saw a picture of the Air Commander's radar display which it was hypothesized would help him/her better prioritize and anticipate the prioritization of the targets to be identified. The Air Commander also saw the underlying sensor data generating the target identification. This was hypothesized to lead to a benefit in correct processing of targets. On the other hand, the extra information provided may lead to overload and slow down decision making.

The Shared Mental Model condition was investigated by manipulating the instructions that were provided to each officer. In the Non-Shared Mental Model condition, each team member was provided with only the instructions for their part of the task. In the Shared Mental Model condition, each was also provided with the instructions for the other team member.

The Theatre Defense program was written in Microsoft Visual Basic. It was based on Multitask, a single person control task created by Kaber and Endsley (1997). Theatre Defense was hosted on two separate Pentium based workstations that were connected by an Ethernet LAN. Data for each team member was recorded on their workstation computer.

RESULTS

Scoring

Data was collected from both participants during the trials. In order to facilitate data analysis (as each team produced more than 3,000 separate target entries), summary files were created containing means for the variables of interest for each of the 10 trial blocks. Mean penalty points, mean reward points, and mean decision time to expiration, collision, or attack were calculated for each block for each team. Mean time from target information request to classification, mean target viewing time, the percentage of targets that were requested by the Air Commander at time of classification, and the percentage of targets that were at the top of the Air Commander's request list at the time of classification were also calculated for each block for each team.

Three sets of analysis were conducted. The first examined the effects of Shared Mental Models and Shared Displays on team performance. The second analysis examined the influence of Sensor Performance on decision making, and the final analysis focused in more detail on the effects of the dissonant data. All analyses were performed using analysis of variance (ANOVA). Tukey tests were used for post-hoc analysis. We used an alpha level of .05 for all analyses.

Mental Models and Shared Displays

Penalty points, reward points, decision making time, percentage of targets classified from the request list, and percentage of targets classified from the top of the Air Commander's request list were examined using a 2 by 4 by 5 (Shared Mental Model by Shared Display/Order by Block) ANOVA. Main effects and two-way interactions were included in the model. (As the order of receiving Shared Displays may have had an affect as well as the presence or absence of the Shared Displays, this variable was treated as having four levels in the analysis: Shared Display first, Non-Shared Display second, Non-shared Display first and Shared Display second.)

Penalty Points and Reward Points

Reward points did not significantly vary across the Shared Mental Model and Shared Display conditions. Mean penalty points per block were observed to be higher in the Non-Shared Mental Model condition than in the Shared Mental Model condition, $F(1,4) = 13{,}817$, $p = .021$, as shown in Figure 4. Display type also effected the penalty points, $F(3,12) = 6.14$, $p = .009$, as shown in Figure 5. Teams that started out without Shared Displays accrued the most penalty points. Teams that were provided with Shared Displays and teams that had Non-Shared Displays after a period in which they had been provided with Shared Displays performed better. Therefore, one interpretation of this data is that the Shared Displays were useful by helping to build up a mental model (thus providing residual effects when the Shared Displays were removed). There were no significant main effects of Block or two-way interactions.

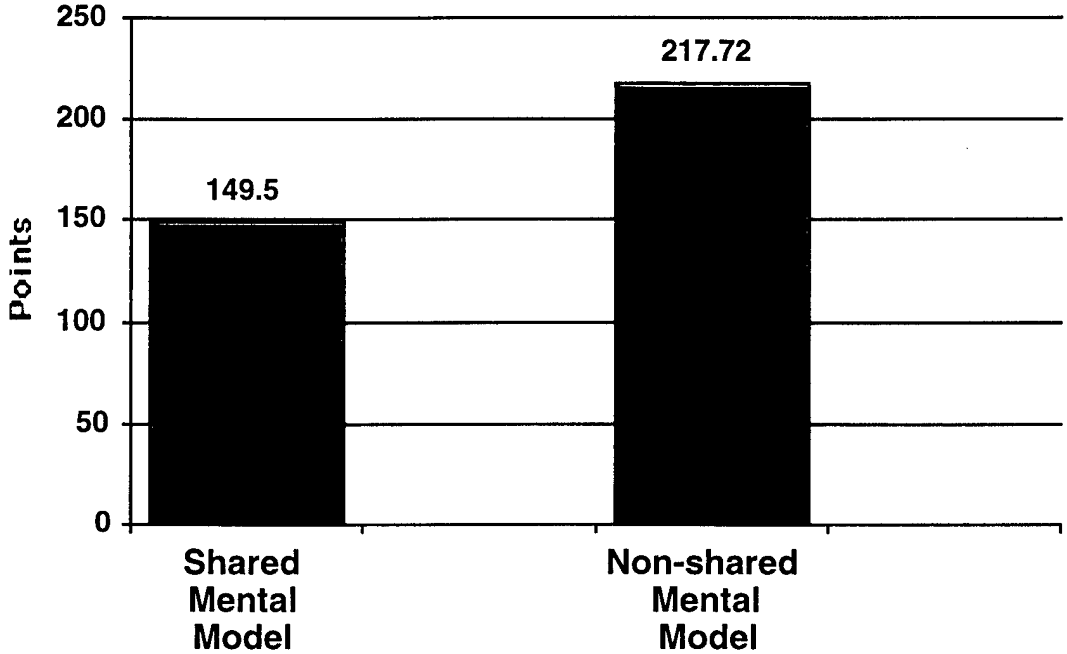

Figure 4: Mean Penalty Points by Shared Mental Model Condition

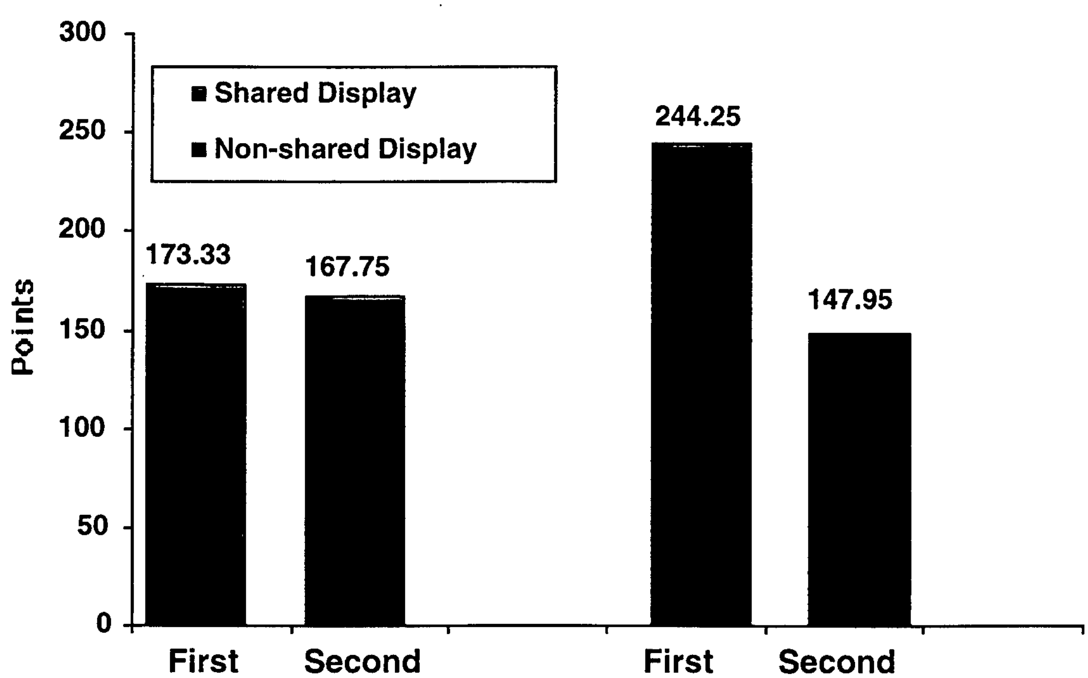

Figure 5: Mean Penalty Points by Shared Display Condition

Decision Time

The time data present an interesting picture. The participants worked together as a team on a time constrained task. Therefore, any time the Intelligence Officer was slower in making identifications limited the amount of time the Air Commander had for making targeting decisions. In the Non-Shared Mental Model condition, the Intelligence Officers were significantly slower at categorizing information than those in the Shared Mental Model condition, $F(1,4) = 54.43$, $p = .002$. This left the Air Commander with less time to attack the targets, $F(1,4) = 90.73$, $p = .001$. Mean time from classification to landing was similarly reduced, $F(1,4) = 10.49$, $p = .032$. This is shown in Figure 6. The presence of Shared Mental Models, therefore, was shown to aid classification performance, leaving more time for the attack decision.

Display type also effected decision time performance. The Intelligence Officers were slower at classifying aircraft, $F(3,12) = 10.36$, $p = .001$, when given a Shared Display than when they had the Non-shared Display condition, as shown in Figure 7. They were the fastest when they did not have the Shared Display after having had the Shared Display first. While having the Shared Display slowed them down slightly, it also allowed them to build up a mental model that helped them after the Shared Display was removed.

Correspondingly, the Air Commanders had less time to process aircraft, with mean time to landing greatest when they did not have the Shared Display after first having the Shared Display condition, $F(3,12) = 49.627$, $p < .001$. This is also the condition where classification time was fastest. The Air Commanders took significantly less time to attack incoming planes, $F(3,12) = 13.392$, $p < .001$, in the Shared Display condition when it came after a Non-shared Display condition, showing a learning effect.

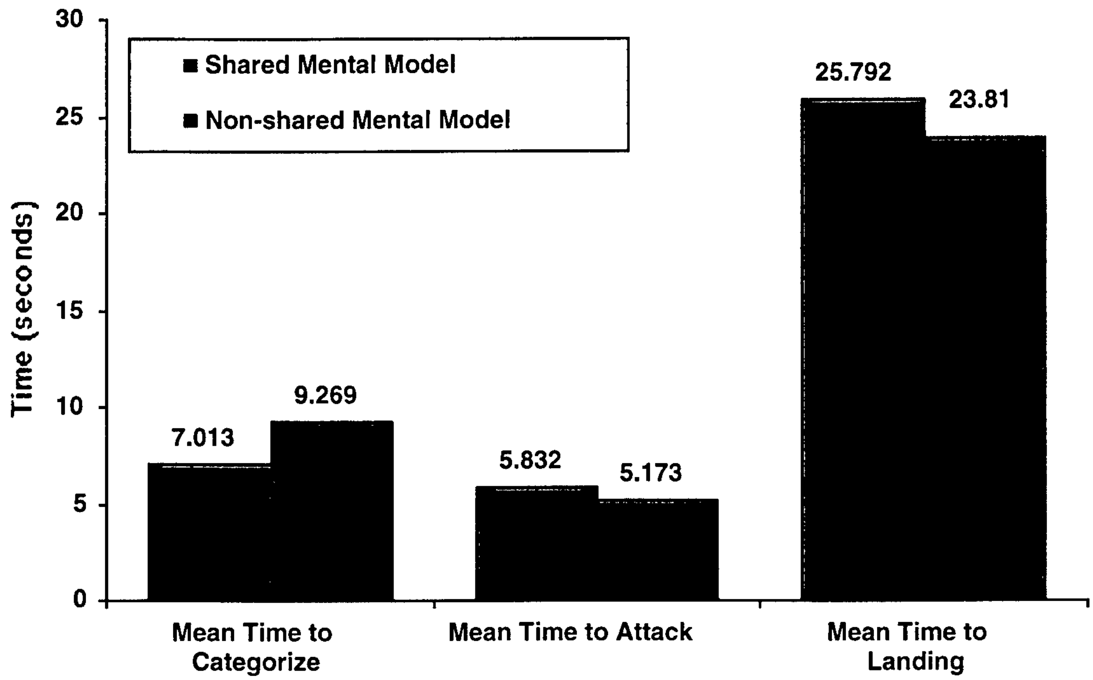

Figure 6: Decision Time by Shared Mental Model Condition

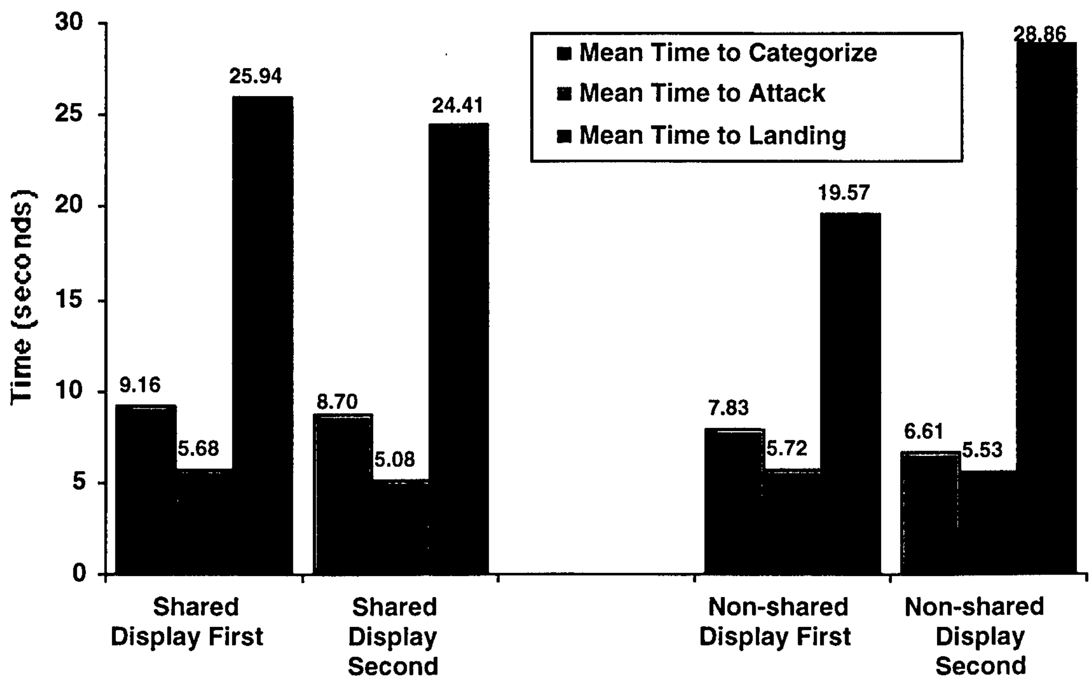

Figure 7: Mean Decision Time by Shared Display Condition

The interaction of Shared Mental Model and Shared Display was significant for both the time it took the Intelligence Officer to classify requested targets, $F(3, 128) = 3.103$, $p = .029$, shown in Figure 8, and the time it took the Air Commander to attack, $F(3, 130) = 2.825$, $p = .041$, shown in Figure 9. As shown in Figure 8, the Intelligence Officer was faster at classifying targets when provided a Shared Mental Model of the Air Commander's task and the Non-shared Display condition. When they did not have a Shared Mental Model, classification time was shortest in the Non-shared Display condition only if it followed the Shared Display condition which compensated for the lack of a Shared Mental Model.

On the other hand, the opposite effect was observed for the Air Commander. The Air Commander had (and used) more time to process and attack incoming planes when the team was given the Shared Mental Model condition, shown in Figure 9. The teams that were given a Shared Mental Model but not a Shared Display first had the fastest classification times (as the Intelligence Officer was not slowed down by looking at the Air Commander's screen) and thus the longest times for processing and attacking by the Air Commander. When the teams had Non-shared Mental Models and Non-shared Displays first, the Intelligence Officer took significantly longer to send over the requested target information, thus leaving the Air Commander with less time to make a decision. It appears from this interaction, that either the presence of a Shared Mental Model or Shared Display first will lead to faster decision making times.

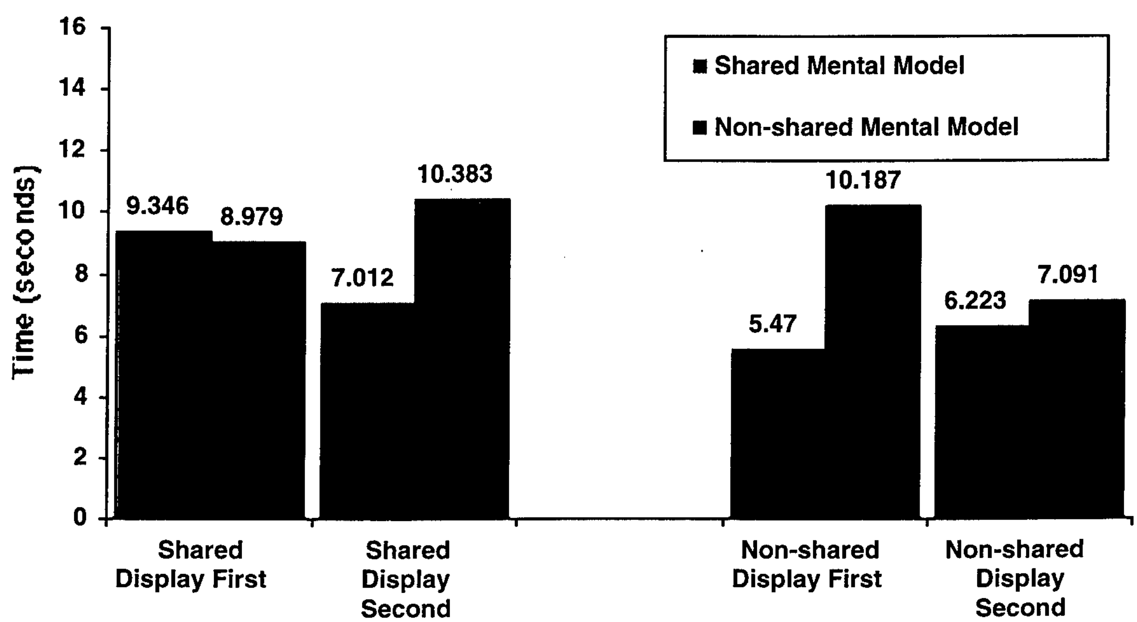

Figure 8: **Mean Classification Time for Shared Display by Shared Mental Model Interaction**

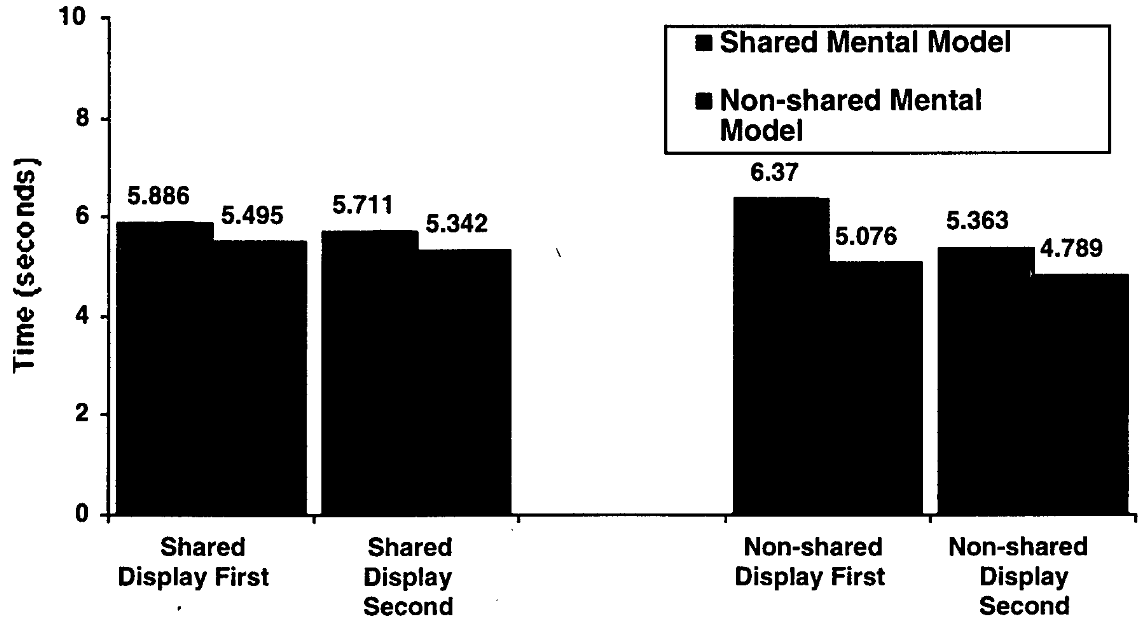

Figure 9: Mean Time to Attack for Shared Display by Shared Mental Model Interaction

Classification of Priority Targets

The degree to which the Intelligence Officer classified targets that the Air Commander had requested was examined as an index of the degree to which the two participants were operating as a team. The percentage of targets classified that were on the request list was significantly effected by Shared Displays, $F(3,12) = 135.289$, $p < .001$. The interaction of Shared Mental Model and Shared Display was also significant for this variable, $F(3,132) = 3.75$, $p = .013$. This effect is shown in Figure 10.

Similarly, the percentage of targets classified that were at the top of the request list (the highest priority) was significantly effected by Shared Mental Models, $F(1,4) = 199.288$, $p < .001$, and Shared Displays, $F(3,12) = 32.613$, $p < .001$. There was also a significant Shared Mental Model by Shared Display interaction for this variable, $F(3,132) = 5.90$, $p = .001$, shown in Figure 11. When Air Commanders were given a Shared Display first and no mental model, they adopted a strategy to request fewer targets during the final five trials (see Figure 10). The Intelligence Officer also sent over fewer of the requested top priority aircraft classifications (see Figure 11) when first given a Shared Display. However, when the teams were not given a Shared Display first, and had no Mental Model, they requested more aircraft and classified more of the high priority aircraft. This may be in part to their inability to adopt a mental model of the joint task and thus the development of a strategy to lower the workload of the other team member.

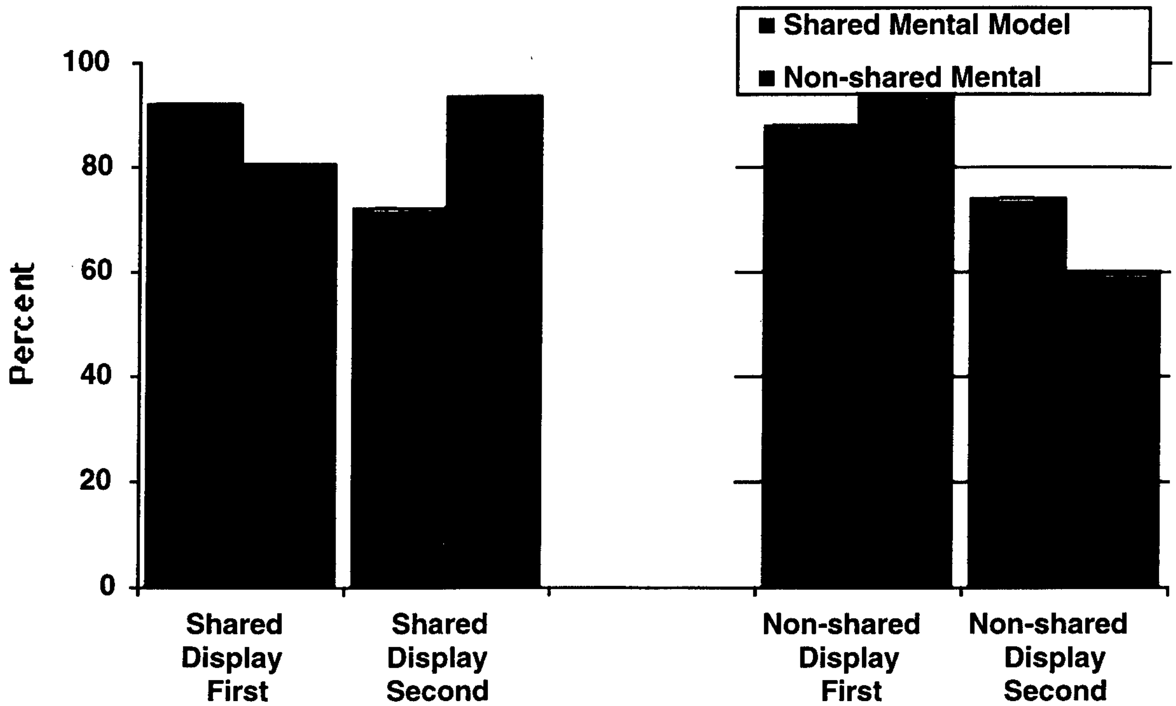

Figure 10: Percent of Targets Classified that were Requested by the Air Commander

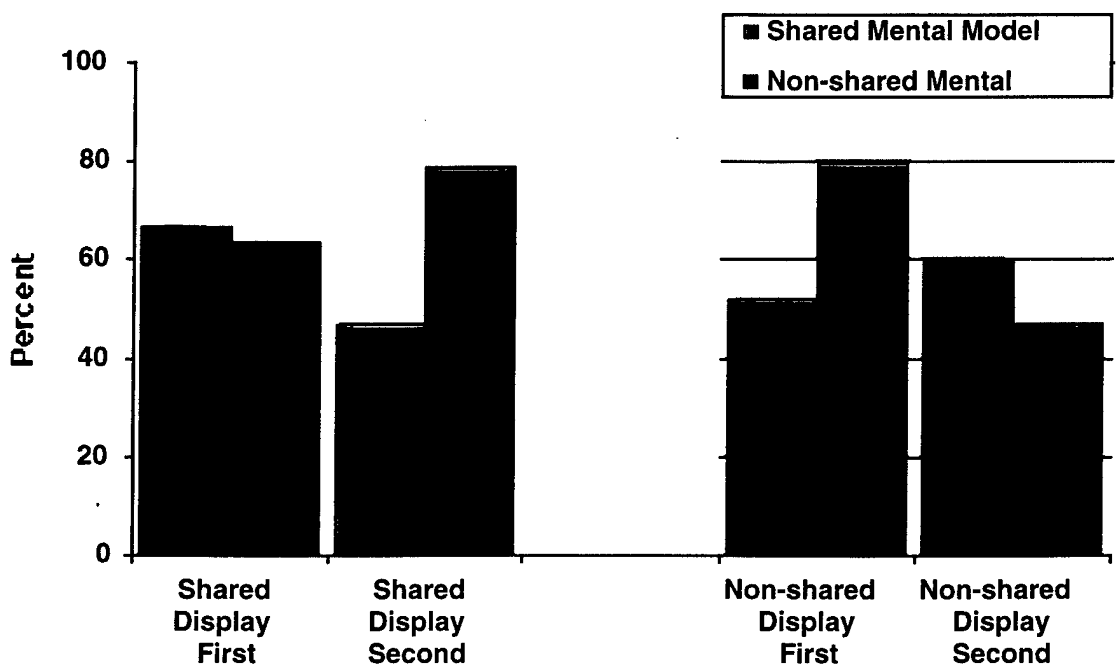

Figure 11: Percent of Targets Classified from the Top of the Request List

Sensor Performance

The second analysis examined the effect of the differing Sensor Performances (all three sensors showing the same information, missing sensor information, or dissonant sensor information) on the performance of the Intelligence Officer. During the study, the Intelligence Officer would view the available sensor information to determine each aircraft's classification. Four Sensor Patterns were presented for missing and dissonant Sensor Performances: Sensor A missing or dissonant, sensor B missing or dissonant, sensor C missing or dissonant, and sensors B and C missing or dissonant from sensor A. A 3 by 4 by 16 (Sensor Performance by Sensor Pattern by Team) ANOVA was performed on both the mean viewing time and correctness of classification by the Intelligence Officer.

Mean viewing time was not significantly effected by any of the variables of interest. It appears that teams did not take longer to make a classification decision based on the differing Sensor Performance types or Sensor Patterns. This may be in part due to the speeded nature of the task which pushes the Intelligence Officer to classify as quickly as possible.

There was a significant main effect of Team, Sensor Performance, and Sensor Pattern on the correctness of the classification, however. Two teams were lower in the percentage of correct classifications, as compared to the remaining 14 teams, $F(15,90) = 7.76$, $p < .001$. However, these teams did surprisingly well in terms of overall points and speed.

Teams incorrectly classified targets with dissonant sensor data more frequently than those with full or missing sensor data, $F(2, 30) = 241.905$, $p < .001$. Surprisingly, missing sensor data was not a problem for classification, although a sensor that showed dissonant data was. The pattern of the dissonant or missing sensor also had an effect, $F(3,45) = 15.47$, $p < .001$. When dissonant or missing data was presented on sensor A (the first and most reliable of the three) or on sensors B and C, the Intelligence Officer incorrectly classified the targets more often.

The Sensor Performance by Sensor Pattern interaction was also significant, $F(6,90) = 13.54$, $p < .001$, making these main effects clearer. The interaction appears to be primarily driven by the dissonant data, as shown in Figure 12, which created a very significant effect on performance when either sensor A or both of the last two sensors (B and C) were dissonant (OXX vs. XOO in Figure 12). Under these conditions, the Intelligence Officer correctly identified the aircraft less than 60% of the time. This finding is due in part to the strategy adopted by most of the Intelligence Officers. They appeared to rely primarily on sensor A as they were told in the task description that this sensor was the most reliable (75% vs. 50%). The effect of missing data in these same positions was negligible, however.

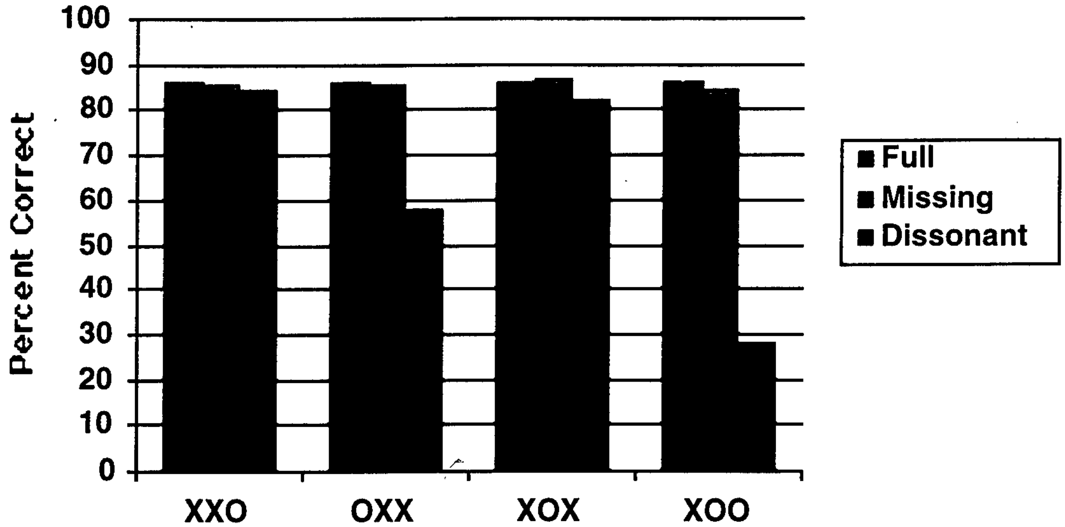

Figure 12. Correctness of Categorization by Sensor Performance and Pattern

Dissonant Data

We conducted a further analysis on the classification performance involving target sets with dissonant sensor data to see if the Intelligence Officers' decision making was effected by the sensor's display of Aircraft Type (fighter, bomber, transport) or Identity of the targets (enemy, friendly, or a combination of both). A 16 x 4 x 3 x 3 (team by Sensor Pattern by Aircraft Type by Aircraft Identity) ANOVA was performed. This analysis also showed the result that the two dissonant data Sensor Patterns shown in Figure 12 led the Intelligence Officers to misclassify aircraft more often than other data patterns, $F(3,45) = 9.64$, $p < .001$. The same two teams that had the lowest percentage of correct classifications overall also had the lowest percentage of targets with dissonant sensor data classified correctly, $F(15,1007) = 28.58$, $p < .001$.

The Identity of the targets did not effect classification performance. The analysis of Aircraft Type revealed that bombers were misclassified slightly more often than fighter or transport aircraft, $F(2,30) = 5.22$, $p = .011$, as shown in Figure 13. The time it took to classify fighters was the longest, $F(2,30) = 9.39$, $p = .001$, as shown in Figure 14. It most likely took longer for classification of fighters as they are the farthest from the send button.

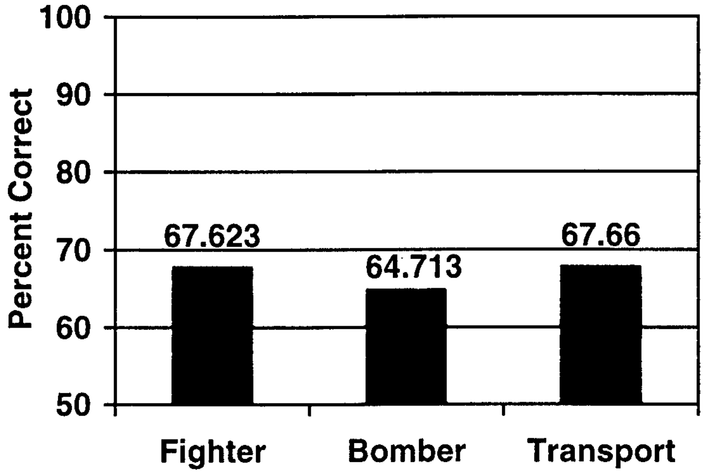

Figure 13. Categorization Performance by Target Type

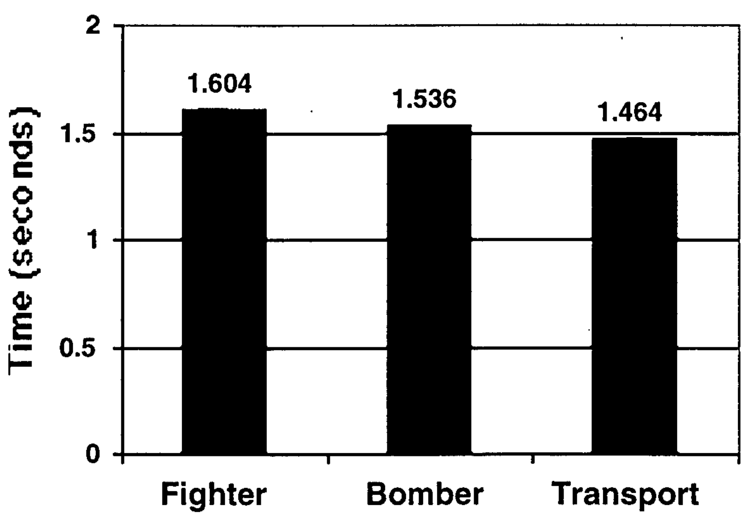

Figure 14. Mean Categorization Time by Target Type

Intelligence Officers also took more time classifying targets with dissonant sensor data when the aircraft involved were friendly aircraft than when they involved enemy aircraft or mixed presentations, $F(2,30) = 5.67$, $p = .008$, as shown in Figure 15. Overall, these data show that dissonant data is more of a problem when the most reliable sensor is effected or more than one sensor is effected, when friendly aircraft are involved, and for certain target types more so than others.

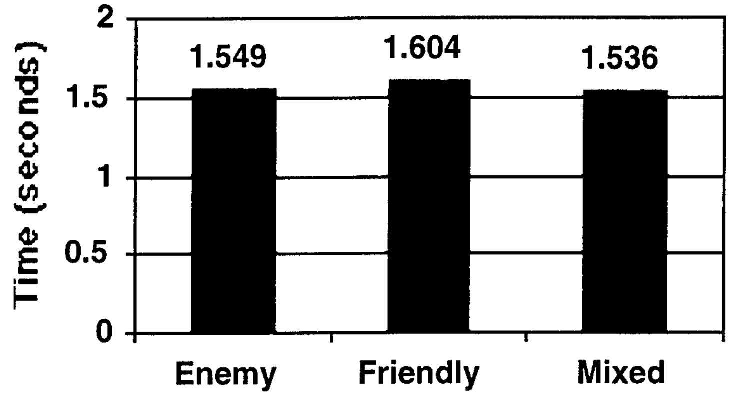

Figure 15. Mean Categorization Time by Target Identification

DISCUSSION

While the microworld task created for this test was somewhat simplified in nature, it was successful in demonstrating that when members of a team are dependent on each other for successful performance, the presence of both a Shared Mental Model and Shared Display help improve team performance. Not only did teams accumulate more penalty points when they did not have a Shared Mental Model, but the Intelligence Officer needed more time to send the requested target information, thus leaving the Air Commander with less time to attack and process incoming aircraft. Clearly the presence of Shared Mental Models, developed through an understanding of the other team member's tasks and goals, was shown to be beneficial in this task.

The mechanism whereby the Shared Displays aided performance was not direct as expected, however. While teams were initially slower when first given a Shared Display, we believe this is due to two factors: they were spending extra time looking at the other person's display, and they may have used more time to develop a mental model of the other person's task. The residual effect of the mental model developed through the Shared Displays could be seen in the second block of trials, after the Shared Display was removed, with significantly lower penalty points and faster classification times. Shared Displays therefore appeared to have a direct affect of slowing performance, due to the demands of processing information in this time critical task, but had an indirect effect of contributing to the development of a Shared Mental Model thus aiding performance in later trials.

The combination of Non-Shared Displays and No Mental Model was highly detrimental to performance. Teams who experienced this condition first were unable to ever develop very good performance. Most likely they developed poor task strategies that were never corrected later-on when Shared Displays were available. Teams that had either Shared Mental Models or the Shared Display first were able to develop fairly effective performance strategies. The best performance came from a combination of Shared Displays and Shared Mental Models followed by removal of the Shared Displays for minimization of distractions.

The analysis of the dissonant sensor data revealed that it is handled quite differently from missing sensor data, although the underlying states of the world may be quite similar. In other words, a case of F16, F16, F18 may actually be the same as the case of F16, F16, no data. The only difference is whether the dissonant sensor's data is displayed or not. Yet, the participants in this study handled these cases quite differently. Missing data was treated as if the errant sensor would have provided the same reading as the other sensors. Dissonant data, however, significantly effected performance, particularly if it occurred on the primary sensor or on more than one sensor.

While the majority of the Intelligence Officers adopted the strategy of relying primarily on sensor A to determine aircraft identity, this strategy did not always return a correct classification. For example, the three sensor displays might show F-16, F-18, F18. In some instances, the aircraft was actually an F-16 and in others an F-18. Therefore, if they relied on sensor A they would be correct half of the time. This is what the data revealed (Figure 12). However, if sensor A's information was missing, the classification was handled very differently. In these cases, the Intelligence officer went with the majority of the sensors and assumed it was the identity provided by sensors B and C. They did not appear to consider the fact that sensor A may report a different aircraft. There appeared to be no loss in confidence by the Intelligence Officer under these cases, as shown by no effect on viewing time.

Even if a team did poorly at classifying targets with dissonant sensor data, (relying on the strategy of always classifying based on sensor A), they could still do well overall as only 30% of the targets in this test involved dissonant sensor data. However, the best team in the study (in terms of combined reward minus penalty points) also had the highest percentage of correctly classified dissonant aircraft, showing that developing effective strategies for dealing with dissonant information is important for performance.

The detailed analysis of the dissonant data revealed that bombers were misclassified more often than fighters or transport aircraft. We are unsure as to why this occurred. The fact that transport aircraft had the fastest classification times may simply be an artifact of the fact that these categories were closest to the Send Information button on the Intelligence Officer's screen (see Figure 3).

Overall, we found that the Theatre Defense task was most difficult for the Intelligence Officer. Overall team performance hinged on the Intelligence Officer's ability to correctly classify the aircraft in a timely fashion. In fact, five of the six highest scoring teams (see Figure 11) adopted a strategy that relied primarily on this team member. In the teams using this strategy, the Intelligence Officer sent over all aircraft classifications as soon as the targets appeared on the screen, basically ignoring the Air Commander's requests. In the Shared Mental Model condition, these teams had the Air Commander send over only those targets that had to be immediately classified, such as those on a collision path. In the Non-shared Mental Model condition, the Intelligence Officer sent over most targets before the Air Commander even requested them and hence the Air Commander literally gave up requesting target identifications. While this strategy did produce the highest overall points, it was extremely taxing for the Intelligence Officer (high workload) and very mundane (boring and low workload) for the Air Commander. If more targets (the maximum in this study was six at a time) were to appear on the screen at the same time, however, this strategy would break down as the Intelligence Officer would be completely overloaded.

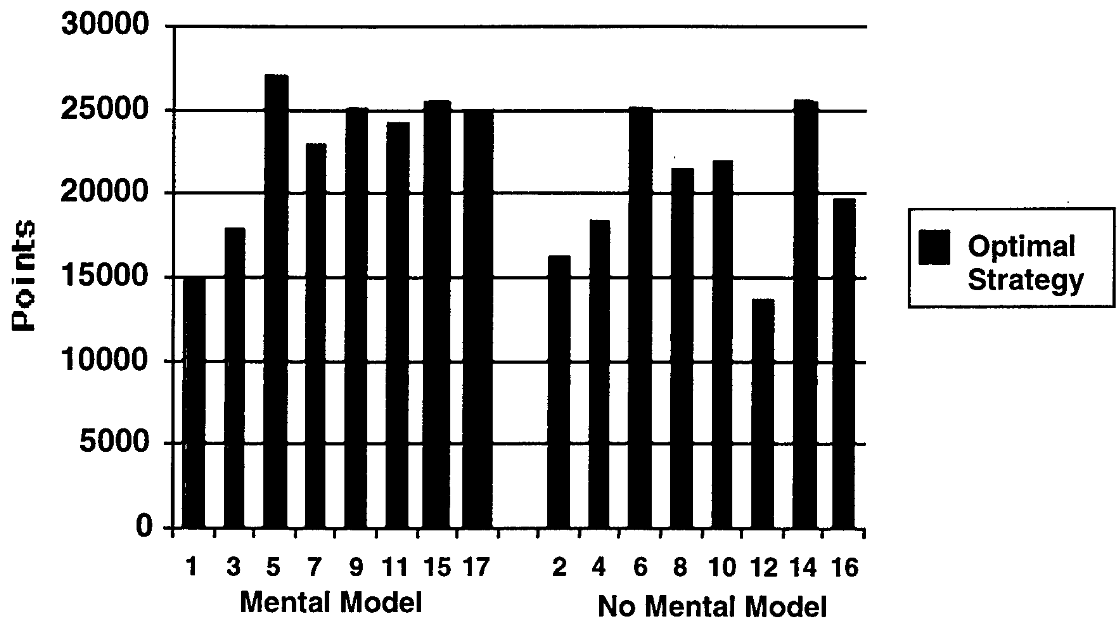

Figure 16: Total Team Points (Reward - Penalty)

CONCLUSIONS AND RECOMMENDATIONS

In conclusion this study supported the hypothesis that effective team performance could be enhanced by providing teams in an information based task with sufficient information to build a shared mental model of each other's tasks and goals. These shared mental models could be developed through either sharing of task related information or through the provision of shared displays. Contrary to expectations, the use of shared displays did not directly aid performance. In some ways, it hindered performance in this task due to the extra time required to process the information. This result may be different in a less time pressured task, however, and should be researched further.

This study also supplied information on the effects of dissonant and missing data on decision making. These results should be viewed with considerable concern, as dissonant and missing data may often be present in battlefield situations. Participants in this study appeared to ignore the potential consequences when a sensor's data was not shown, treating it as if its output were the same as the other sensors. If that sensor showed another value that was different than the other sensors, however, this had a considerable effect on classification performance, particularly if a high reliability sensor or multiple sensors were involved.

It is possible that the participants in this task, not being actual military officers, may not be representative of what would actually happen in the field. Recent research on a similar task with experienced aircraft pilots, however, found that dissonant data significantly effected the probability of attacking a target identified by the primary sensor as an enemy when the dissonant data showed a friendly aircraft (seeking to avoid fratricide), but not when it showed another enemy aircraft (Banbury, Selcon, Endsley, Gorton, & Tatlock, 1998). These experienced military pilots also treated missing sensor data as if it were in accord with the classification provided by the primary sensor. Thus, they too were insensitive to the fact that the missing data was equally likely to indicate a friendly as an enemy in accordance with the primary sensor classification. This result was present across various levels of sensor reliability.

These findings would tend to confirm the findings of the present study, indicating that treatment of missing and dissonant data is a significant problem. More research is needed to find methods of improving performance under such conditions. As it is unlikely that sensor performance will always be perfect, the effects of conflicting or missing data on decision behavior should be carefully considered when making design decisions regarding which data to present.

Overall, the development of team situation awareness was shown to enhance team performance. The findings of this study need to be further explored in relation to more complex tasks involving multiple teams as well as single teams. Relatively little is currently know about the effects of various display and organizational factors on the development and support of team situation awareness in complex tasks that involve battlefield stresses and conditions. More research is needed to extend these findings to more realistic conditions.

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Appendix A : Intelligence Officer Job Description

Overview

In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of Air Commander or Intelligence officer. Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The Air Commander will be viewing these aircraft on a display similar to a radar screen. The Intelligence officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 5 trials of approximately 10 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 5 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Intelligence Officer

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Western Europe. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards a U.S. base in N. Africa. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to provide the air commander at this N. African base with target identification information on these incoming aircraft.

You will be providing requested target information. You will be shown a list of aircraft target numbers that are within this base's airspace. It is your job to decide on target identifications and to send this information to the air commander.

You may see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports, and enemy transports. There are a total of

18 different kinds of aircraft that are in use by friendly and enemy forces as shown in the table below.

Plane Categories	Types
Friendly Fighters	F/A-18 F-15E F-16
Friendly Bombers	B-52 B-1 B-2
Friendly Transports Enemy Fighters	C-130J C-21 KC-135 Mig-29 Su-35 Su-37
Enemy Bombers	Tu-22M Tu-168
Enemy Transports	An-124 An-225

Your station contains a set of head phones and the information screen that is shown on the following page. Targets whose ID are requested are shown in the box at the bottom of the screen labeled 'Requested Information' in order of priority. You need to monitor this section of your screen as the target numbers will be continually changing as targets land, are destroyed, or appear in your air space.

You will have access to sensor data about these targets. The screen will display each sensors best assessment of the target's ID, which may not always be correct. It is up to you to determine the true aircraft identification, so use your best judgment. You can access sensor data for a target by clicking on the 'View Information' button that corresponds to the target number or by pressing the number on the keyboard that corresponds to the button number on the screen. However, you may only see sensor data for one target at a time.

The sensors are labeled 'Source A', 'Source B', and 'Source C'. Sensor A is reliable 75% of the time, Sensor B is correct 50% of the time and Sensor C is correct 50% of the time. Remember to use these reliabilities when determining target identification. Be aware that not all sensors may report information on a particular target. For instance, Sensors B and C may have information on the first target requested, but not sensor A. Thus, you may have to make your decision on partial information.

Once you have viewed the sensor data, you need to indicate the aircraft's identification by selecting the aircraft type on the middle part of your screen. All the possible aircraft are listed there. After you have selected an ID, click on the 'Send Information' button to send this information to the air commander.

The right side of your information screen will provide you with information regarding the outcome of the battle. It will display the aircraft number and its actual ID as well as the final result for the plane; destroyed, got through, or collided. This feedback will give you information regarding your classification of the aircraft. If you misclassified a plane, the "Classified As" and "Actual Type" box will display two different airplanes and the text will appear in red. If you correctly classified an aircraft, the text will appear in blue. If the plane was not classified prior to resolution, it will appear in green text. Use this information to help you better identify the aircraft. There will be a delay between making your ID and receiving this feedback, as true ID and disposition cannot be determined until the plane has either landed or been destroyed.

Sensor data for aircraft will continually appear on your information screen until the testing time is up. Thus, you could potentially process hundreds of planes in the 10 minutes allotted for task. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can.

Appendix B: Air Commander Job Description

Overview

In this study we are interested in understanding how individual and team decision making occurs in the warfare environment. Unlike the wars fought in the earlier part of this century, future battles will have individuals working together that are separated by great distances, such as continents. Thus, the transfer and understanding of information between teams will be critical to mission success.

During this task you will be asked to make decisions that are similar to ones faced by individuals during a military operation. You will be assigned to either the position of air commander or Intelligence officer. Your battle ground is the air space over your home base. You will be working together to defeat the enemy. It is the air commander's job to ensure that the home base is protected from enemy aircraft. The air commander will be viewing these aircraft on a display similar to a radar screen. The Intelligence officer's job entails providing the air commander with information on these same aircraft that are detected by the sensors. Your success will depend upon how well the overall team performs.

This task is hosted on two separate computer workstations. You will be asked to sit at one of these workstations while wearing a set of headphones. We will first begin with a training period followed by 5 trials of approximately 10 minutes each. You may request a break at any time between trials and you will be given a 15 minute break during the middle of the test. This will be followed by a second test period of 5 more trials. If you have any questions regarding the following task instructions please ask them before the testing begins. You will get to practice before testing begins and may also ask questions during practice.

Air Commander

The United States has just learned that Ikestan attacked a U.S. base in the middle east. The president has ordered all military personnel in the surrounding areas to be on alert for possible attacks. You are stationed at an air base in Tenya, N. Africa, which has been put on alert. A few hours after the initial attack you are instructed to report to your post as enemy aircraft are making their way towards your base. Aircraft have been sent to intercept and destroy these incoming planes. It is your job to protect your base from enemy aircraft strikes while allowing your planes to land safely.

Your success is determined by the number of reward and penalty points you accrue. You will want to maximize your reward points and minimize your penalty points. In order to do this, you will need to determine which aircraft are friendly and which are enemy and what type of aircraft they are. At the same time, you will need to prioritize incoming targets based upon their range from your home base and speed to determine which aircraft are the most critical at any one time. You will request aircraft identity information from the Intelligence officer (who is at an airbase in Western Europe) to support this prioritization decision.

Point assignments have been made for each type of aircraft representing the reward points for destroying the aircraft and the penalty points for allowing the aircraft to land at your home base. The points are based on the mission relevance and lethality of the aircraft. For example, transports can carry many personnel and therefore could present a great threat if they land at a U.S. base, while the loss of a U.S. transport would be a devastating blow to our forces. Friendly aircraft have a zero penalty for getting through to home base (you would want them to safely land at home) and a negative reward associated with destroying it (you would not want to destroy your own planes). Enemy aircraft, however, have both positive reward and penalty points.

In addition, it is possible for some targets to collide with one another. If two friendly aircraft collide, no points are accrued for this. If two enemy aircraft collide the highest reward points of the two aircraft are given. However, if a friendly and an enemy aircraft collide, you receive double the penalty points of the enemy aircraft. Therefore, it is in your best interest to destroy enemy aircraft before they collide with friendly planes.

You will see 6 different types of aircraft: friendly fighters, enemy fighters, friendly bombers, enemy bombers, friendly transports, and enemy transports. There are a total of 18 different kinds of aircraft that are in use by friendly and enemy forces. Below is a table of these aircraft, their color appearance on your radar screen once identified, and their associated reward and penalty points.

Plane Categories	Types	Color	Reward Points	Penalty Points
Friendly Fighters	F/A-18	Blue	-20	0
	F-15E	Blue	-40	0
	F-16	Blue	-60	0
Friendly Bombers	B-52	Green	-50	0
	B-1	Green	-80	0
	B-2	Green	-100	0
Friendly Transports	C-130J	Turquoise	-120	0
	C-21	Turquoise	-140	0
	KC-135	Turquoise	-150	0
Enemy Fighters	Mig-29	Red	60	10
	Su-35	Red	80	20
	Su-37	Red	100	10
Enemy Bombers	Tu-22M	Orange	10	50
	Tu-168	Orange	20	60
Enemy Transports	An-124	Yellow	50	60
	An-225	Yellow	50	60

You will view the aircraft on a radar screen, similar to that shown on the following page. Your home base is at the center of the screen. The aircraft will appear from outside the radar and travel inward towards your home base. It is your job to let the friendly aircraft land at the base, but the enemy aircraft must be destroyed before reaching the base. An aircraft will get through if left alone (it will land on its own). To destroy an aircraft, use the computer mouse to click on it once. This gives the command to launch missile defense resources against the target. The target will turn a light violet color to indicate that it has been targeted.

Initially, all aircraft appear as white squares. Below each square is the aircraft target number and its speed. In order for you to determine what type of aircraft is on your radar, you must request this information from the Intelligence officer. This is done by typing the aircraft's number in the request box in the lower left corner of the radar screen. All you need to do is type in each number followed by the return key. The Intelligence officer will receive and process your information. It's identity will be shown by the color of the square on your radar screen (ex. blue for friendly fighters). The aircraft number will remain the same, but the penalty points for the identification that has been made will appear below the target number. This may or may not be correct depending on the accuracy of the ID. You must decide what to do with each aircraft, either processing it (destroying it) or letting it land at the base. At all times during this task, your total reward and penalty points are shown at the top left corner of your radar screen.

Aircraft will continually appear on your radar screen until the testing time is up. Thus, you could potentially process hundreds of planes in the 10 minutes allotted for each session. Please be aware that this task moves quickly. We want you to work as quickly and as accurately as you can. These instructions may seem a bit confusing, so we will start with several training sessions to help clarify your task.

Appendix C: ANOVA Results

AIR COMANDER DATA

Penalty Points

DEP VAR: PPOINTS N: 158 MULTIPLE R: 0.501 SQUARED MULTIPLE R: 0.251

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	44.844	1	44.844	9.525	0.002
SHARED DISPLAY	66.161	3	22.054	4.685	0.004
BLOCK	19.941	4	4.985	1.059	0.380
SHARED DISPLAY*MENTAL MODEL	14.169	3	4.723	1.003	0.394
SHARED DISPLAY*BLOCK	43.099	12	3.592	0.763	0.687
MENTAL MODEL*BLOCK	12.982	4	3.246	0.689	0.601
ERROR	612.014	130	4.708		

POST-HOC ANALYSIS
TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	44.844	1	44.844	13.817	0.021
ERROR	12.982	4	3.246		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	66.161	3	22.054	6.140	0.009
ERROR	43.099	12	3.592		

Reward Points

DEP VAR: RPOINTS N: 158 MULTIPLE R: 0.352 SQUARED MULTIPLE R: 0.124

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	33.624	1	33.624	1.201	0.275
SHARED DISPLAY	54.952	3	18.317	0.654	0.582
BLOCK	50.064	4	12.516	0.447	0.774
SHARED DISPLAY*MENTAL MODEL	89.768	3	29.923	1.069	0.365
SHARED DISPLAY*BLOCK	192.786	12	16.065	0.574	0.860
MENTAL MODEL*BLOCK	83.721	4	20.930	0.747	0.561
ERROR	3640.215	130	28.002		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	33.624	1	33.624	1.606	0.274
ERROR	83.721	4	20.930		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	54.952	3	18.317	1.140	0.372
ERROR	192.786	12	16.065		

Time to Landing

DEP VAR: TIMEEXP N: 155 MULTIPLE R: 0.642 SQUARED MULTIPLE R: 0.413

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	127.472	1	127.472	5.043	0.026
SHARED DISPLAY	1613.447	3	537.816	21.277	0.000
BLOCK	71.741	4	17.935	0.710	0.587
SHARED DISPLAY*MENTAL MODEL	159.188	3	53.063	2.099	0.104
SHARED DISPLAY*BLOCK	130.047	12	10.837	0.429	0.949
MENTAL MODEL*BLOCK	48.630	4	12.157	0.481	0.750
ERROR	3210.135	127	25.277		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	127.472	1	127.472	10.485	0.032
ERROR	48.630	4	12.157		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	1613.447	3	537.816	49.627	0.000
ERROR	130.047	12	10.837		

Time to Collision

DEP VAR:TIMECOLL N: 153 MULTIPLE R: 0.502 SQUARED MULTIPLE R: 0.252

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	120.532	1	120.532	3.667	0.058
SHARED DISPLAY	597.270	3	199.090	6.056	0.001
BLOCK	251.047	4	62.762	1.909	0.113
SHARED DISPLAY*MENTAL MODEL	52.465	3	17.488	0.532	0.661
SHARED DISPLAY*BLOCK	289.357	12	24.113	0.734	0.716
MENTAL MODEL*BLOCK	78.293	4	19.573	0.595	0.667
ERROR	4109.015	125	32.872		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	120.532	1	120.532	6.158	0.068
ERROR	78.293	4	19.573		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	597.270	3	199.090	8.257	0.003
ERROR	289.357	12	24.113		

Time to Attack

DEP VAR: TIMEATT N: 158 MULTIPLE R: 0.547 SQUARED MULTIPLE R: 0.299

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	16.832	1	16.832	24.887	0.000
SHARED DISPLAY	10.561	3	3.520	5.205	0.002
BLOCK	0.150	4	0.038	0.056	0.994
SHARED DISPLAY*MENTAL MODEL	5.732	3	1.911	2.825	0.041
SHARED DISPLAY*BLOCK	3.155	12	0.263	0.389	0.966
MENTAL MODEL*BLOCK	0.742	4	0.186	0.274	0.894
ERROR	87.921	130	0.676		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	16.832	1	16.832	90.729	0.001
ERROR	0.742	4	0.186		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	10.561	3	3.520	13.392	0.000
ERROR	3.155	12	0.263		

Intelligence Officer Data

Mean Time from View to Send

DEP VAR:VIEWTIME N: 159 MULTIPLE R: 0.379 SQUARED MULTIPLE R: 0.144
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	0.950	1	0.950	1.205	0.274
SHARED DISPLAY	1.223	3	0.408	0.517	0.671
BLOCKS	1.815	4	0.454	0.575	0.681
SHARED DISPLAY*MENTAL MODEL	1.270	3	0.423	0.537	0.658
SHARED DISPLAY*BLOCKS	9.494	12	0.791	1.003	0.450
MENTAL MODEL*BLOCKS	2.430	4	0.608	0.770	0.546
ERROR	103.322	131	0.789		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.950	1	0.950	1.564	0.279
ERROR	2.430	4	0.608		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	1.223	3	0.408	0.515	0.679
ERROR	9.494	12	0.791		

Mean Time from Requested to Send

DEP VAR:REQUESTT N: 156 MULTIPLE R: 0.466 SQUARED MULTIPLE R: 0.217
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	182.174	1	182.174	10.841	0.001
SHARED DISPLAY	131.326	3	43.775	2.605	0.055
BLOCKS	48.955	4	12.239	0.728	0.574
SHARED DISPLAY*MENTAL MODEL	156.449	3	52.150	3.103	0.029
SHARED DISPLAY*BLOCKS	50.633	12	4.219	0.251	0.995
MENTAL MODEL*BLOCKS	13.389	4	3.347	0.199	0.938
ERROR	2150.863	128	16.804		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	182.174	1	182.174	54.427	0.002
ERROR	13.389	4	3.347		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	131.326	3	43.775	10.375	0.001
ERROR	50.633	12	4.219		

Requested Targets

DEP VAR: REQUEST N: 160 MULTIPLE R: 0.431 SQUARED MULTIPLE R: 0.186
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	0.000	1	0.000	0.003	0.955
SHARED DISPLAY	1.309	3	0.436	5.852	0.001
BLOCKS	0.017	4	0.004	0.059	0.994
SHARED DISPLAY*MENTAL MODEL	0.838	3	0.279	3.747	0.013
SHARED DISPLAY*BLOCKS	0.039	12	0.003	0.043	1.000
MENTAL MODEL*BLOCKS	0.039	4	0.010	0.132	0.970
ERROR	9.845	132	0.075		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.000	1	0.000	0.024	0.885
ERROR	0.039	4	0.010		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	1.309	3	0.436	135.289	0.000
ERROR	0.039	12	0.003		

Targets Classified from the Top of the Request List

DEP VAR: TOP N: 160 MULTIPLE R: 0.427 SQUARED MULTIPLE R: 0.182

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
MENTAL MODEL	0.477	1	0.477	5.566	0.020
SHARED DISPLAY	0.394	3	0.131	1.532	0.209
BLOCKS	0.074	4	0.019	0.216	0.929
SHARED DISPLAY*MENTAL MODEL	1.519	3	0.506	5.902	0.001
SHARED DISPLAY*BLOCK	0.048	12	0.004	0.047	1.000
MENTAL MODEL*BLOCKS	0.010	4	0.002	0.028	0.998
ERROR	11.320	132	0.086		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: MENTAL MODEL
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.477	1	0.477	199.288	0.000
ERROR	0.010	4	0.002		

TEST FOR EFFECT CALLED: SHARED DISPLAY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.394	3	0.131	32.613	0.000
ERROR	0.048	12	0.004		

Target Information View Time

DEP VAR: VIEWTIM N: 192 MULTIPLE R: 0.728 SQUARED MULTIPLE R: 0.530
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
TEAM	2488.740	15	165.916	1.060	0.404
COVERAGE	305.081	2	152.541	0.975	0.381
SENSOR	474.968	3	158.323	1.012	0.391
TEAM*SENSOR	7006.098	45	155.691	0.995	0.496
TEAM*COVERAGE	4679.487	30	155.983	0.997	0.484
COVERAGE*SENSOR	936.454	6	156.076	0.998	0.432
ERROR	14081.700	90	156.463		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: COVERAGE
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	305.081	2	152.541	0.978	0.388
ERROR	4679.487	30	155.983		

TEST FOR EFFECT CALLED: SENSOR
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	474.968	3	158.323	1.017	0.394
ERROR	7006.098	45	155.691		

Correct Classifications

DEP VAR: CORRECT N: 192 MULTIPLE R: 0.901 SQUARED MULTIPLE R: 0.811
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
TEAM	4.820	15	0.321	7.758	0.000
COVERAGE	3.863	2	1.931	46.623	0.000
SENSOR	1.884	3	0.628	15.156	0.000
TEAM*SENSOR	1.826	45	0.041	0.980	0.520
TEAM*COVERAGE	0.240	30	0.008	0.193	1.000
COVERAGE *SENSOR	3.366	6	0.561	13.544	0.000
ERROR	3.728	90	0.041		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: COVERAGE
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	3.863	2	1.931	241.905	0.000
ERROR	0.240	30	0.008		

TEST FOR EFFECT CALLED: SENSOR
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	1.884	3	0.628	15.470	0.000
ERROR	1.826	45	0.041		

Dissonant Data Analysis

Prioritizer Target Information View Time

DEP VAR:VIEWTIME N: 1144 MULTIPLE R: 0.181 SQUARED MULTIPLE R: 0.033
ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SENSOR PATTERN	1.600	3	0.533	1.237	0.295
ID	3.545	2	1.772	4.111	0.017
CATEGORY	3.763	2	1.881	4.364	0.013
SENSOR PATTERN*ID	0.705	6	0.117	0.273	0.950
ID*CATEGORY	1.310	4	0.328	0.760	0.551
SENSOR PATTERN *CATEGORY	3.226	6	0.538	1.247	0.279
SENSOR PATTERN*ID*CATEGORY	2.072	12	0.173	0.400	0.964
ERROR	477.657	1108	0.431		

Correct Classifications (no team)

DEP VAR: CORRECT N: 1151 MULTIPLE R: 0.481 SQUARED MULTIPLE R: 0.231

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SENSOR PATTERN	76.463	3	25.488	105.248	0.000
ID	0.803	2	0.401	1.658	0.191
CATEGORY	0.817	2	0.409	1.687	0.185
SENSOR PATTERN*ID	1.266	6	0.211	0.871	0.515
ID*CATEGORY	0.447	4	0.112	0.461	0.764
SENSOR PATTERN*CATEGORY	0.547	6	0.091	0.376	0.894
SENSOR PATTERN*ID*CATEGORY	0.956	12	0.080	0.329	.984
ERROR	270.016	1115	0.242		

Correct Classifications (with team analysis)

DEP VAR: CORRECT N: 1151 MULTIPLE R: 0.850 SQUARED MULTIPLE R: 0.722

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
TEAM	41.559	15	2.771	28.582	0.000
SENSOR PATTERN	76.449	3	25.483	262.888	0.000
ID	0.807	2	0.404	4.164	0.016
CATEGORY	0.809	2	0.405	4.173	0.016
SENSOR PATTERN*ID	1.259	6	0.210	2.165	0.044
SENSOR PATTERN*CATEGORY	0.554	6	0.092	0.953	0.456
SENSOR PATTERN*TEAM	118.993	45	2.644	27.279	0.000
ID*CATEGORY	0.440	4	0.110	1.134	0.339
ID*TEAM	10.407	30	0.347	3.579	0.000
CATEGORY*TEAM	2.323	30	0.077	0.799	0.771
ERROR	97.614	1007	0.097		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: SENSOR PATTERN
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	76.449	3	25.483	9.637	0.000
ERROR	118.993	45	2.644		

TEST FOR EFFECT CALLED: ID
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.807	2	0.404	1.164	0.326
ERROR	10.407	30	0.347		

TEST FOR EFFECT CALLED: CATEGORY
TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	0.809	2	0.405	5.224	0.011
ERROR	2.323	30	0.077		

Prioritizer Target Information View Time

DEP VAR:VIEWTIME N: 1144 MULTIPLE R: 0.659 SQUARED MULTIPLE R: 0.435

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
TEAM	171.337	15	11.422	40.914	0.000
SENSOR PATTERN	1.772	3	0.591	2.115	0.097
ID	3.762	2	1.881	6.738	0.001
CATEGORY	3.779	2	1.889	6.768	0.001
SENSOR PATTERN*ID	0.659	6	0.110	0.393	0.884
SENSOR PATTERN*CATEGORY	3.258	6	0.543	1.945	0.071
SENSOR PATTERN*TEAM	13.327	45	0.296	1.061	0.366
ID*CATEGORY	1.332	4	0.333	1.193	0.312
ID*TEAM	9.954	30	0.332	1.188	0.224
CATEGORY*TEAM	6.036	30	0.201	0.721	0.865
ERROR	279.183	1000	0.279		

POST-HOC ANALYSIS

TEST FOR EFFECT CALLED: SENSOR PATTERN

TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	1.772	3	0.591	1.994	0.128
ERROR	13.327	45	0.296		

TEST FOR EFFECT CALLED: ID

TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	3.762	2	1.881	5.669	0.008
ERROR	9.954	30	0.332		

TEST FOR EFFECT CALLED: CATEGORY

TEST OF HYPOTHESIS

SOURCE	SS	DF	MS	F	P
HYPOTHESIS	3.779	2	1.889	9.390	0.001
ERROR	6.036	30	0.201		

GLOSSARY

ANOVA	Analysis of Variance
ID	Information Dominance
SA	Situation Awareness