SHARED DISPLAYS AND TEAM PERFORMANCE

Cheryl A. Bolstad
Mica R. Endsley
SA Technologies Inc., Marietta, Georgia

ABSTRACT

In this study we present a model of team Situation Awareness (SA) and two experiments designed to test some aspects of the model. Specifically we tested the use of shared mental models and shared displays as a means of enhancing team (SA). While it has been hypothesized that shared displays and shared mental models (in conjunction with one another) would assist team members in performing joint tasks, this hypothesis has never been empirically evaluated. In the second study, we expanded our evaluation of shared displays to include abstracted displays and we varied the workload and task complexity levels of the task to increase team interaction. 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 and through the use of shared displays, particularly under high workloads.

Key words: situation awareness, shared displays, mental models, team performance, abstract displays

INTRODUCTION

In many complex systems, tasks will often need to be accomplished through the joint efforts of several individuals. When individuals work together they are known as a team. While little is known about the nature and property of teams (Salas, Prince, Baker and Shrestha, 1995) even less is known about ways to improve team performance. In recent years, efforts have been made to evaluate team behavior, improve team performance and to train team activities (e.g. Caldwell, and Everhart, 1998; Cannon-Bowers, Salas and Converse, 1993), however, future research is still needed to understand team processes.

Essentially, in order to perform their tasks, members of the team needs to have a certain level of team SA. Overall, team SA can be conceived as "the degree to which every team member possesses the SA required for his or her responsibilities" (Endsley, 1995). Team members need to posses a shared understanding of the situation with regard to their shared SA requirements to develop effective team performance.

Team Model of Situation Awareness

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 process has been described in a model of team SA as coming about as a function of four components (Endsley and 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.

(2) Shared SA Devices - the devices available for sharing this information, which can include direct communication (both verbal and nonverbal), shared displays or a shared environment. As nonverbal communications 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.

Overview

The two experiments described in this study evaluated two components of this model: the use of shared SA devices and shared SA mechanisms as a means of forming team SA. In the first study, the presence and absence of both shared mental models and shared displays was manipulated. In the second study, we expanded our evaluation of shared displays to include abstracted displays and we varied the workload and task complexity levels of the task to increase team interaction.

EXPERIMENT 1

Method

Participants. Thirty-two participants (mean age = 21.72) served as subjects in this research They were tested in pairs for a total of 16 teams.

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. Half of the teams received training in the other team member's job (Shared Mental Models) and half did not (Non-Shared Mental Models).

Task. The Theatre Defense task incorporates activities by two individuals: an Intelligence Officer and an Air Commander who each have separate, but inter-related tasks. The role of the Air Commander is to protect the home base from incoming aircraft. Targets appear on the radar screen moving towards a central point (the home base). The Air Commander must prioritize these targets 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 by attacking the aircraft or letting it pass through to safety. Reward and penalty points are associated with each aircraft depending on its identification and its type. The Intelligence Officer was supplied with a list of targets and the identifications provided by several different sensors. 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. Once the Intelligence Officer made a decision, this information was passed to the Air Commander who saw the target change colors (indicating its category).

Procedure

Teams were given a handout describing their individual task. Then teams in the Shared Mental Model condition were asked to read each other's job description (cross training) in order to formulate a Shared Mental Model of the joint task. In the Non-shared Mental Model condition participants 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 allowing them the ability to

view the other team member's computer screen while performing the task. In the Non-Shared Display manipulation participants could not view each other or the other team member's displays.

Results

The dependent variables were examined using a 2 by 4 by 5 (Shared Mental Model by Shared Display/Order by Block) ANOVA. All analyses were performed using analysis of variance (ANOVA). Tukey tests were used for post-hoc analysis. We used an alpha level of 0.05 for all analyses.

Mental models. Reward points did not significantly vary across the Shared Mental Model conditions. Mean penalty points were significantly higher in the Non-Shared Mental Model condition (218 points) than in the Shared Mental Model condition (149 points), $F(1,4) = 13{,}82$, $p = 0.021$.

Shared displays. Reward points also did not significantly vary across the Shared Display conditions. However, penalty points did vary significantly across Shared Display condition, $F(3,12) = 6.14$, $p = 0.009$ (see Figure 1). Teams that began without Shared Displays accrued the most penalty points (244 points). They performed significantly better when the Shared Displays were provided in the later trials (147 points). Teams that began with the Shared Display did not perform worse after it was removed however. One interpretation of this data is that the Shared Displays were useful by helping to build up a shared mental model (thus providing residual effects when the Shared Displays were removed).

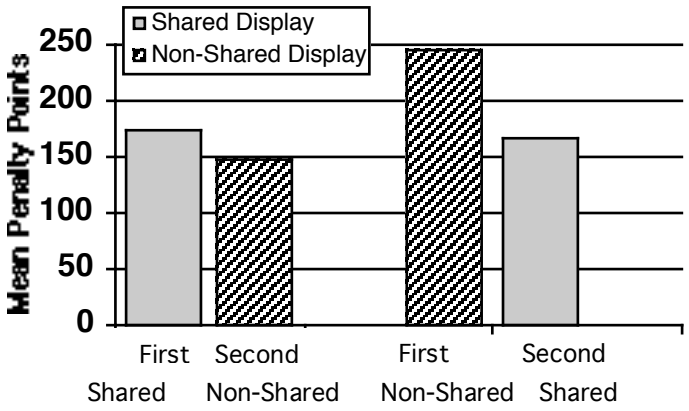

Figure 1. Mean penalty points by shared display condition.

Shared mental models by shared display interaction. There were no significant interaction affects associated with penalty or reward points, however there was a significant Shared Display by Shared Mental Model interaction effect found for decision times. The teams that were given a Shared Mental Model but not a Shared Display first had the fastest classification times (5.47 sec.), 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 (6.37 sec.). 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.

EXPERIMENT 2

In the previous study, the shared display condition provided each team member with a complete replicate of the other team member's display. This may not be the best way to provide shared information to team members, however. An abstracted shared display instead provides only the critical information from the other team member's display, based on an analysis of shared information requirements (Endsley and

Jones, 1997). It is hypothesized that the use of abstracted shared displays might help to build team SA without imposing the extra workload observed with the use of the full shared displays. It is also hypothesized that abstracted displays will help team members to further build up shared mental models. Secondly, we wished to further explore the issues associated with workload level and its affect on team interaction.

Methods

Participants. Thirty-six participants (mean age = 23.19 years) served as subjects for this research. The participants were tested in pairs for a total of 18 teams. Six Teams per Display Condition.

Design. Two factors served as independent variables in the study: Workload Level and Shared Display Type. Workload Level was a within team manipulation. Three workload levels, low, medium and high were set based on the maximum number of aircraft on the display at any one time. Shared Display Type was a between team manipulation. Teams were assigned to one of three display conditions: Non-Shared Displays (verbal interaction only) which served as a control condition, Full Shared Display (similar display type as used in the previous experiment) or Abstracted Shared Display.

Task. Several changes were made to the Theater Defense task for this experiment. First, the number of aircraft on the screen varied. Secondly, including AWACS and two different missile types in the scenarios increased task complexity. Lastly, an abstracted display was created for each team member. The displays were modified to provide each officer with all the needed information from the other team member's display, based on an analysis of shared information requirements.

Procedure

Teams were tested one at a time. In the Abstract Shared Display condition, information regarding the additional abstracted displays were included in the participant's instructions. Teams in the Non-Shared Display condition were not given any information regarding the other team member's task. Teams were not cross-trained, however, they could communicate with one another verbally during the task.

Results

The data was analyzed using a 3 by 3 (Shared Display Type by Workload Level) ANOVA. All analyses were performed using analysis of variance (ANOVA). Tukey tests were used for post-hoc analysis. We used an alpha level of 0.05 for all analyses.

Workload. As expected, both reward, $\underline{F}(2, 153) = 125.34$, $p < 0.001$, and penalty points, $\underline{F}(2, 153)$ 183.68, $p < 0.001$, increased significantly from Workload Level three to Workload Level none.

Shared display. Both the reward points, $F(2,153) = 8.68$, $p < .001$, and penalty points, $F(2,153) = 5.945$, p. = 003, significantly varied across the display conditions. Reward points were lowest (845), and penalty points were highest (349) in the Full Shared Display condition. The Non-Shared and Abstracted Shared Displays were similar in terms of both reward (1069 vs. 1061) and penalty points (276 vs. 232), with a slight (but not significant) improvement in penalty points for the Abstracted Shared Display.

Shared display by workload interaction. The interaction of Shared Display Type and Workload Level was significant for both reward points, $\underline{F}(4, 153) = 2.84$, $p = 0.026$, and penalty points, $\underline{F}(4, 153) = 3.41$, $p = 0.011$. At the Low Workload Level, the number of reward and penalty points did not vary significantly across Shared Display Type conditions (see Figure 2). This indicates that at Low Workload Levels, the presence or type of Shared Displays does not present either a problem or a significant boost to performance. This was not true for the Moderate and High Workload Levels, however. While reward

points were higher in the High Workload conditions, the increases were less for the Full Shared Display condition than for the Non-Shared and Abstracted Shared Display conditions.

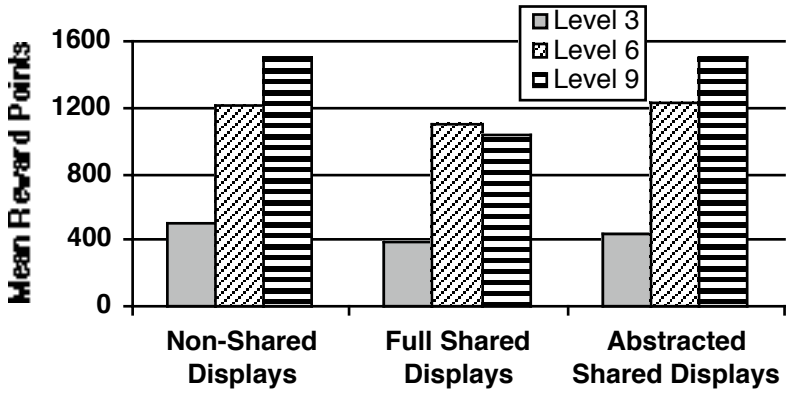

Figure 2. Mean reward points by shared display type and workload level.

As shown in Figure 3, the penalty points were also higher in the Full Shared Display condition at the Highest Workload Level. Penalty points were actually lower with the Abstracted Shared Display at the Moderate and High Workload Levels as compared to the two other Shared Display conditions. Thus, it can be seen that the Full Shared Display created a particular problem at the Higher Workload Levels. The Abstracted Shared Display, on the other hand, allowed penalty reduction at the Higher Workload Levels while allowing an increase in reward points.

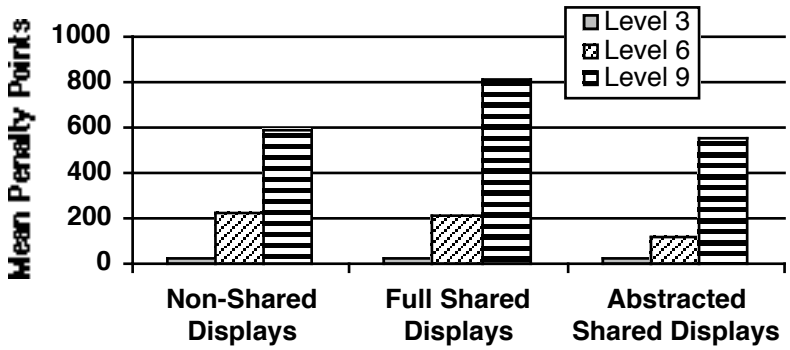

Figure 3. Mean penalty points by shared display type and workload level.

Team Interaction. There was a significant change in the degree to which the Air Commander provided information to the Intelligence Officer in the two Shared Display conditions, $F(2,45) = 13.78$, $p = 0.000$. The Air Commander communicated significantly more information (such as sensor reliability) in the Non-Shared Display condition (22.5) than in either the Full Shared Display (9.6) or Abstracted Shared Display(5.9), in part because the shared displays required less verbal communications.

GENERAL DISCUSSION

This first experiment demonstrated that when members of a team are dependent on one another for successful performance, the presence of a shared mental model helped to improve overall team

performance. The mechanism whereby the shared displays aided performance was not direct as expected. teams actually performed worse with a shared display, however, a residual effect was seen in later trials. After the shared displays were removed, the teams outperformed both their prior performance and other teams that received the non-shared display condition followed by the shared display condition. The combination of no 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.

The second experiment indicates that the way in which people use Shared Displays is actually quite complex and related to both task strategies used and workload level. Overall, when compared to a situation in which no shared display is available, providing Full Shared Displays induced lower reward and higher penalty points overall. However, examination of the data shows that these displays were problematic particularly under high workload levels where the extra information served to hinder performance. As Workload Level increased, the Abstracted Shared Displays proved to be a particular benefit. The use of an abstracted display also seems to decrease the need for team interaction. Teams using abstracted displays had overall lower level of verbal exchanges. These teams may have had enough sufficient information to perform their task.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

While the microworld task created for these tests 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 Shared Mental Models and Shared Displays help improve team performance. These findings add further support to the team SA model developed by Endsley and Jones (1997). Shared Displays help team members to build shared mental models, which lead to improved team performance. These results were further clarified by the second experiment to show that Abstracted Shared Displays are better than Exact Shared Displays particularly under high workload levels. Overall, these studies confirm and expanded on the previous research on mental models and shared displays as a means of providing team SA. However, more research is needed to expand these results to more realistic tasks and battlefield conditions

ACKNOWLEDGEMENTS

This study was supported by a subcontract to Logicon Technical Services for the Air Force Research Laboratory. We would like to thank Gil Kuperman, Robert Stewart, and Michael McNeese for their support and encouragement on this project. Lastly, The authors also wish to acknowledge their appreciation to David Kaber, North Carolina State University, for use of the Multitask simulation and Mark Bolstad for his many hours of support in software development.

REFERENCES

Caldwell, B. S. and Everhart, N. C. (1998). Information flow and development of coordination in distributed supervisory control teams. International Journal of Human-Computer Interaction, 10(1), 51-70.

Cannon-Bowers, J. A., Salas, E., and Converse, S. (1993). Shared mental models in experts team decision making. In N. J. Castellan, Jr. (Ed.), Current Issues in Individual and Group Decision Making, (pp. 221-246). Hillsdale, NJ: Erlbaum.

Endsley, M. R. (1995). Towards a theory of situation awareness. Human Factors, 37(1), 32.64.

Endsley, M. R., and Jones, W. M. (1997). Situation awareness, information dominance, and information warfare (AL/CF-TR-1997-0156). Wright-Patterson AFB, OH: United States Air Force Armstrong Laboratory.

Salas, E., Prince, C., Baker, D. P., and Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. Human Factors, 371(1), 123-136.