IMPROVING PERFORMANCE:

SHOULD WE SUPPORT INDIVIDUALS OR TEAMS?

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ABSTRACT

As part of our research program on integration of intelligent agents with human teams, we analyzed the performance of 34 teams (102 subjects) in a target identification task. Teams were assigned to one of four conditions. The control group received no aiding; each agent condition was focused on an alternative strategy: 1) support individual team members by tracking known information; 2) support team communication by automatically passing information to the relevant member; or 3) support team coordination by identifying responsibility for specific data. We found performance improvements for teams across trials under all conditions. Teams using communication and coordination agents performed better on hard targets, although subjects perceived the coordination agent to be the least valuable for teamwork support. Our findings suggest that direct support of teamwork is more beneficial than aiding individual tasks.

INTRODUCTION

Commonly, teams are responsible for complex tasks that require diverse knowledge and coordination of effort. Individual team members or the team as a whole might be aided. Decision aids to support individual performance have received much of the early focus [1]. We are engaged in determining how to effectively incorporate intelligent agents into human teams. Our current research program is focused on systematically exploring alternative strategies for using machine agents in support of team performance. Under a Multi-University Research Initiative (MURI) project, we have developed a framework for examining three distinct approaches. A basic tenet of our model is that the performance of teams, especially in tightly coupled tasks, is believed to be highly dependent on both teamwork skills and individual competencies.

First, individual team members may be supported directly in completion of their own tasks. A second alternative is to introduce the machine agent as a team member with its own subtask. In that case all the issues associated with communication and coordination among team members become relevant [1], [2], [3], [4]. The third option is to support interactions among team members using machine agents (facilitating communication, allocation of tasks, coordination among the human agents, and attention focus) [5]. We are particularly interested in how to support and promote teamwork dimensions [4]. Smith-Jentsch et al. have included several factors for dimensions of team work: 1) Team situation awareness (exploit all available information sources; disseminate information; provide situation updates); 2) Supporting behavior (prompt correction of team errors; provide and request backup when necessary); 3) Communication (proper terminology; complete internal and external reports; brevity and clarity); and 4) Team initiative/leadership (provide feedback to team members; state clear and appropriate priorities). Table 1 shows potential ways to support these four teamwork dimensions.

METHOD

Design

The goal of the study was to examine the impact of alternative agents on communication patterns, data gathering strategies, reliance on (i.e., use of) the intelligent agents, and performance. We used a repeated measures between-subjects design with four conditions: 1) control, 2) individual agent,

Teamwork Dimension	***Ways to Provide Support***
Situation assessment	❑ act as an information provider ❑ ensure the exchange of relevant knowledge among all members ❑ provide a shared representation of the situation for common knowledge ❑ notify people when all available information sources are not being used ❑ notify people when information is currently disable or unreliable
Supporting behaviors	❑ make other's actions and decisions visible to detect potential errors ❑ alert members to potential errors, constraints and conflicts ❑ support self-reflection of the team for self-correcting teams
Communication	❑ alert members to ambiguity ❑ support translation of terminology among various subgroups ❑ serve as a repository for messages between team members
Team leadership/initiative	❑ communicate intent behind commands to allow lower levels of command to meet intent under evolving conditions ❑ communicate priorities and notify members when priorities change

Table 1: Using Agents to Support Teamwork

3) team clipboard agent, and 4) team checklist agent and three trials. We collected process data for communication and data gathering strategies as well as outcome measures of performance (e.g., number of targets processed and number of errors).

Materials

A low fidelity simulation, Tactical Navy Decision Making (TANDEM), was used for our initial team studies (see Figure 1). TANDEM was jointly developed at the Naval Air Warfare Center - -Training Systems Division and the University of Central Florida to provide a simplified tactical decision-making environment. In TANDEM, subjects perform a sequence of time critical information gathering and communications tasks to identify targets then decide whether to shoot or clear each target. This task is real-time, reactive and inflexible. The ambiguity of both the radar targets and the scenario workload can be manipulated [3].

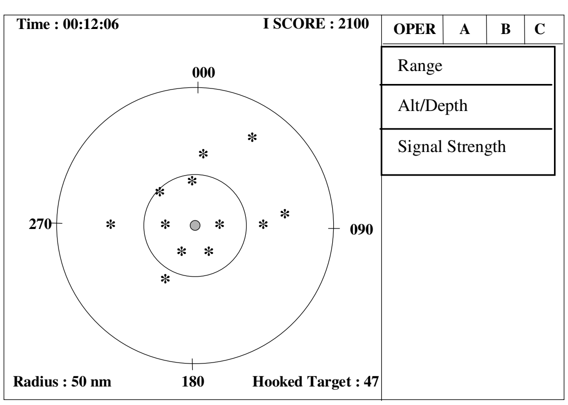

Figure 1: Standard TANDEM environment

Identification tasks and data menus differed for each team member. ALPHA determined if the target was an airplane, surface vessel or submarine. BRAVO determined if it was military or civilian. CHARLIE decided whether the target was peaceful or hostile then acted as the team coordinator by indicating the target type, classification and intent to the system and engaging the target (shoot or clear). There were five pieces of information available for each identification task, with agreement on three required for a positive identification. Each data menu had three of the items pertinent to the position's identification task and several other items that might be needed by other team members.

Ambiguity of the targets was manipulated so the team needed to communicate for identification of roughly two-thirds of the targets. For easy targets, all three pertinent items on the individual's menu agreed. For medium, only two items on the menu agreed so data was required from one or both teammates. For hard targets two items on the menu agreed, but did not provide the correct solution. Subjects had no way of knowing the difficulty level of the targets.

Three agents were designed to investigate different ways of deploying machine agents to support multi-person teams: 1) Individual Agent, 2) Team Clipboard Agent, and 3) Team Checklist Agent. We hypothesized that the Individual Agent should aid the individual task and aid communication among team members by aggregating values. This agent showed all data items available to an individual team member and filled in the values for the data items as the subject selected them from the menu. See Figure 2.

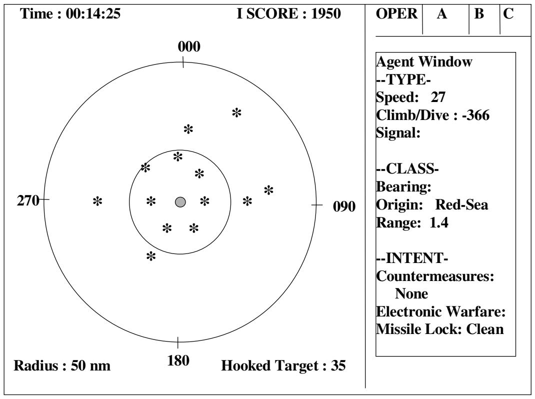

Figure 2: Individual Agent

The Team Clipboard Agent should aid the individual task and aid team communication to a greater degree than the Individual Agent should. This agent aggregated values from all members and automatically passed values as they were selected from the menu to the appropriate team member. See Figure 3. We hypothesized that this agent should reduce verbal communication among team members and reduce communication errors.

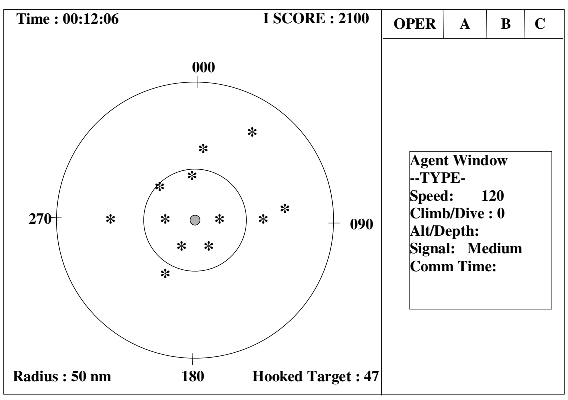

Figure 3: Team Clipboard Agent

The third agent, Team Checklist, should aid team coordination. This agent showed who had access to what data. See Figure 4. For example, all three team members (ALPHA, BRAVO, CHARLIE) had access to speed, but only BRAVO had access to altitude/depth.

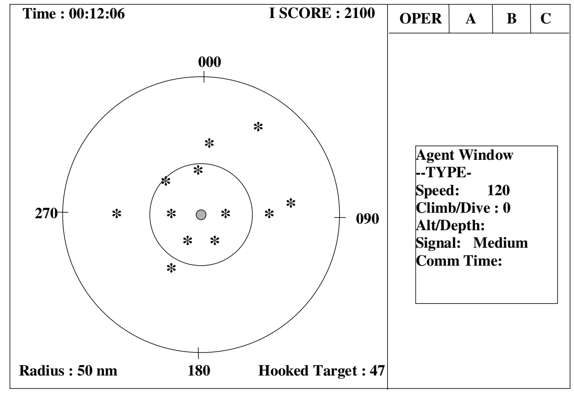

Figure 4: Team Clipboard Agent

Participants

Forty teams of three were recruited for this study (10 teams in each of the four conditions). Subjects were recruited as intact teams, consisting of friends or acquaintances. A variety of subjects participated in the study (ages 13-32; mean age of 20). Each team member had a different identification task to perform and needed to communicate with one another to successfully complete their tasks.

Procedure

Each team participated in a 90-minute session that began with a 15-minute training session in which the TANDEM software and team goals were explained. The team was told to identify as many targets as possible, as accurately as possible during the 15-minute trial. After the training session, the team participated in three 15-minute trials. Each trial included 75 targets. At the conclusion, subjects were asked to complete a brief questionnaire.

RESULTS

The performance data reported in this paper are based on 34 teams, with 8-9 per condition. Five teams were dropped due to problems with the data collection tool. One team from the checklist condition was dropped because of performance problems; they had less than 29% accuracy in target identification. Although participants were diverse (ages 13-32; mean age of 20), there were no significant differences among subject demographics between conditions.

The agent aiding conditions showed a significantly higher number of hard targets correct than in the control condition ($p<.046$). See Figure 5. No other differences were found between all agent conditions and the unaided condition (control) with respect to the performance data (e.g., the type and number of targets hooked and classified, the percentage of targets correctly identified, and the number of times the agents were activated).

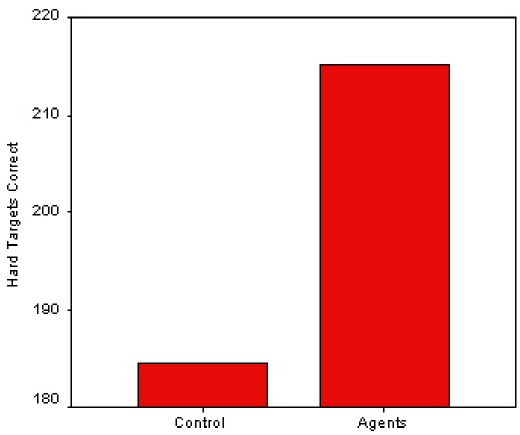

Figure 5: Hard Targets Correct for Control vs. Agent Conditions

As Figure 6 shows, aiding teamwork directly (team clipboard/checklist) proved more effective than supporting team members at their individual tasks despite the reductions in memory load and ready accessibility to parameters for sharing provided by the individual clipboard.

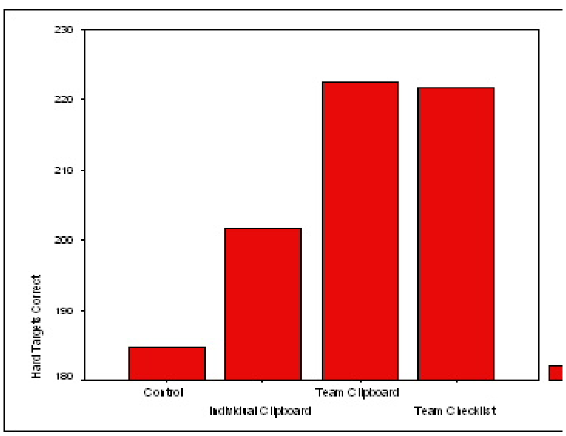

Figure 6: Hard Targets Correct for Each Condition

Learning effects were found across trials for all conditions. An earlier study with a smaller number of teams (N=5) showed additional differences in the agent conditions from the control condition. See Figure 7. Learning effects and effects for target difficulties were also found in this earlier study [6].

Teams hooked equal numbers of easy, medium and hard targets during each trial. In the clipboard condition, teams got more hard targets correct than in the unaided condition ($p<.05$) and spent less time on easier targets than in the unaided condition ($p<.027$). In the checklist condition, teams hooked more hard targets than in the unaided condition ($p<.041$) and teams got more hard targets correct than in the unaided condition ($p<.035$).

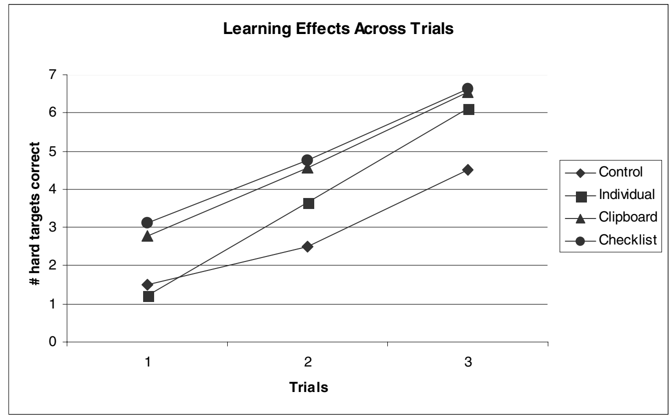

Figure 7: Learning Effects Across Trials for Hard Targets Correct

Self-reported perception of teamwork showed all groups perceived themselves as good teams (rating of 4.5 out of possible 5) based on behaviors such as exchanging information at the appropriate time with teammates, supporting teammates. There was no significant difference among the various team members based on their position (ALPHA, BRAVO, CHARLIE) for either their perception of the effectiveness of the teamwork or the value of the agent. Table 2 shows ratings on the value of the agents by the subjects.

Table 2. Self-reported Ratings of the Value of the Agents for Particular Tasks (ratings 1 to 5, with 5 as highest)

Value	Individual Agent	Clipboard Agent	Checklist Agent
Individual's task	3.8	4.5	1.6
Team Communication	4.0	3.5	1.8
Team Coordination	3.5	3.2	1.8

When subjects were asked to rate the value of the agent to their own task, the checklist agent was rated the lowest. With respect to the value of the agent to the individual's own task, the individual agent rated higher than the checklist agent ($p<= .000$) and the clipboard agent rated higher than the checklist agent ($p=<.000$).

When subjects were asked to rate the value of an agent to the team's communication task, the individual agent was rated the highest, then the clipboard and finally, the checklist agent. The individual agent rated higher than the checklist agent ($p<=.000$) and the clipboard agent rated higher than the checklist agent ($p<=.000$). On this same measure, the individual agent also rated higher than the clipboard agent, but not significantly.

When subjects were asked to rate the value of an agent to the team's coordination task, the individual agent rated highest, but not significantly different than the clipboard agent. Both individual and clipboard agents were rated higher than the checklist agent ($p=.001$) on this measure.

DISCUSSION

Although this study showed little performance enhancement with agent aiding, variations within the teams studied may have obscured the differences among the various agents and the unaided condition. However, the use of an agent appears to help teams integrate, interpret and act upon hard targets with greater speed and accuracy than in the unaided condition. We hypothesize that both the cognitive workload and the communication required to identify and process hard targets are greater than for either easy or medium targets

Although teams using the checklist agent (which aided coordination) performed better on hard targets than those in other conditions, subjects perceived its value in teamwork support less positively. There are several possible explanations for this dislike. The checklist agent allowed the subjects to assign responsibility for each data item and individuals who did not quickly provide information to their teammates could be highlighted. In addition, individuals were not required to request information from a specific teammate. They could broadcast their request for data (e.g., "does anyone have altitude/depth for this target?") to the entire team rather than specifically requesting the data from BRAVO. Therefore, the coordination provided by the Checklist Agent may have been of less use to the teams than directly getting the value.

Subjects' perception of their team's skills may have been affected by their pre-existing friendship relations, potentially casting a "halo effect" on their assessment of team performance. This relationship may have also affected their negative perception of the checklist agent, since it highlighted individuals who were slow in providing information to the team. To investigate team processes objectively, we plan to analyze communication data (number of requests for data, responses, target identifications, and confirmations) in conjunction with performance data. In addition, we are looking at the data gathering strategies for evidence of cognitive models, both of the task and of the team contributions.

Our findings suggest that supporting team task accomplishment results in better overall performance than simply supporting individual tasks. The potential for coordinating human-human interactions through agent systems seems a particularly promising approach because of the high payoff and the reusable and largely domain independent character of the agents' tasks

Additional work will be done to understand the degree to which the various agent-aiding strategies differ, and on which measures and how these differences can support team decision making and performance.

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REFERENCES

[1] E. M. Roth, J. T. Malin, J. T & D. L. Schreckenghost (1997). Paradigms for Intelligent Interface Design. In M. Helander, T. K. Landauer, and P. Prabhu (Eds) Handbook of Human-Computer Interaction, Second Edition, pp. 1177 -1201.

[2] P. M. Jones & C. M. Mitchell (1995). Human-Computer Cooperative Problem Solving: Theory, design, and evaluation of an intelligent associate system. IEEE Transactions on Systems, Man, and Cybernetics. SMC-25(7), 1039-1053.

[3] J. J. Johnston, J. Poirier, and K. A. Smith-Jentsch (1998). Decision Making Under Stress: Creating a Research Methodology. In J. A. Cannon-Bowers and E. Salas (eds.), Decision Making Under Stress: Implications for Individual and Team Training. Washington, DC: American Psychological Association, pp. 39-59.

[4] K. Smith-Jentsch, J. H. Johnston, S. C. Payne (1998). Measuring Team-Related Expertise in Complex Environments. In J. A. Cannon-Bowers and E. Salas (eds.), Decision Making Under Stress: Implications for Individual and Team Training. Washington, DC: American Psychological Association, pp. 61-87.

[5] J. T. Malin, D. L. Schreckenghost, D. D. Woods, S. S. Potter, L. Johannesen, M. Holloway, and K. D. Forbus (1991). Making Intelligent Systems Team Players: Case Studies and Design Issues. Vol. 1: Human-Computer Interaction Design; Vol. 2: Fault Management System cases. (NASA Technical Memorandum 104738). Houston, TX: NASA Johnson Space Center.

[6] T. L. Lenox, L. L. Roberts, and M. Lewis (1997). Human-Agent Interaction in a Target Identification Task, 1997 IEEE International Conference on Systems, Man, and Cybernetics. 2702-2706.