Collaboration Technologies Decrease Reliance on Radio Communication in Simulated Air Battle Management

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Radio has been the dominant collaboration technology in military aviation, but may not be optimal owing to channel overload and static interference. The current study sought to examine how team communication was changed when radio was augmented by text-based chat, a virtual whiteboard, and two ecological resource displays in a simulated air defense task. To accomplish this, twenty-one five-person teams performed the simulation with goals to protect friendly assets, eliminate enemy aircraft, and conduct refueling operations. The joint availability of chat and the whiteboard increased the total number of team communications, but reduced team reliance on radio. Access to a graphical resource display decreased team communications and radio reliance. A content analysis indicated that access to chat and the whiteboard, and to the graphical resource display, allowed teams to communicate more effectively. Overall, these results support the utility of advanced collaboration technologies for enhancing team communication in military settings.

Working in teams is ubiquitous in military aviation. Because of this, the ability to receive, process, and transmit information effectively within and between teams is critical for performance and safety in aviation operations (Alberts & Hayes, 2003; Burke, Stagl, Salas, Pierce, & Kendall, 2006). Historically, radio has been the dominant technology used for team communication in these settings (Vidulich, Bolia, & Nelson, 2004). While effective, radio is limited by serial transmission (e.g., only one person can talk at a time), no archival log (useful for refreshing understanding of past or missed dialogue), static interference, and channel overload. Also, a more general concern is that overreliance on any single communication modality could negatively impact teams responses to dynamic changes in the operational environment (e.g., if radio communications are disrupted or compromised; Alberts & Hayes, 2003).

As alternatives to radio, emerging collaboration technologies, such as email, instant messaging, and virtual whiteboards, have begun to be integrated into military operations (e.g., Heacox, Moore, Morrison, & Yturralde, 2004). The availability of these tools not only alters the ways in which personnel communicate and collaborate, but also composition and proximal location of team members. For example, teams can now be geographically and temporally disbursed, as opposed to constrained to a central location. Based on this, it has been suggested that collaboration technologies will enable a degree of command decentralization, resulting in greater flexibility of military teams (e.g., Alberts & Hayes, 2003).

Utilization of these new collaboration technologies typically entails different costs and benefits for operators. For example, email and chat feature a log of previous communications, allowing users to offload responsibility and workload associated with retention of communication (Berry, 2006). Such technologies also provide for simultaneous and asynchronous communication (Bolstad & Endsley, 2003). A virtual whiteboards allows users to convey information through a spatial medium, potentially enhancing comprehension (e.g., spatial information has been shown to be communicated more effectively through visual, rather than verbal, media; Wickens, Vidulich, & Sandry-Garza, 1984). Finally, emerging collaboration technologies may reduce the need for operator communication. For example, whiteboard displays may increase team situation awareness of ongoing operations, but may also reduce communication regarding those events. Consequently, collaboration technologies that afford operators the ability to represent and transmit information in supplemental modalities may positively impact team performance.

It is also possible that collaboration technologies may increase operator workload if information is not easily accessible, if it creates an additional monitoring burden (Parasuraman & Riley, 1997), or if insufficient practice with the tool is provided (Funke & Galster, 2009). Moreover, new technologies may distract users as they focus on composing messages and monitoring responses instead of engaging in and attending to task goals. This has negative implications for situation awareness, particularly in tasks that are heavily dependent upon visual attention (Funke & Galster, 2009). Finally, these technologies may be perceived unfavorably if composing and transmitting messages is significantly slower than oral communication.
Due to the increasing drive to implement collaboration technologies into command and control environments (Kaufman, 2005), it is vital to evaluate the impact these technologies exert on team performance, communication, and perceived workload. In a recent experiment, Strang and colleagues (under review) asked five-person teams to engage in a simulated air battle management (ABM) task. The task required participants to assume the roles of weapons directors (WDs), sweep operators, and tanker refueling operators while working together in a simulated air defense task to protect friendly assets, eliminate enemy aircraft, and conduct refueling operations under high and low task demands. While engaged in this task, teams were occasionally provided with supplemental decision aids (two types of ecological team resource displays) and communication technologies (chat and a virtual whiteboard). Their results indicated that the graphical resource display increased team performance and reduced workload. Access to chat and the virtual whiteboard did not influence team performance, and had mixed effects on perceived workload (increasing some team members’ workload, while reducing others). Strang and colleagues concluded that new collaborative technologies, and domain-specific, ecologically designed resource displays, may be of benefit to team ABM operations as supplements to radio. However, due to space limitations, the work reported by Strang et al. (under review) did not include a thorough analysis of the communication data that were collected. The purpose of the current manuscript is to examine these data in order to explore how the collaboration technologies that were employed may have altered the quantity and quality of team communications observed in that experiment.

Methods

Participants
Seventy men and 35 women between the ages of 18 and 30 (M = 21.94, SD = 3.16) participated in the experiment. Participants, drawn from local universities and a temporary work agency, were partitioned into 21 five-person teams. Participants provided written informed consent prior to taking part in the experiment; all experimental procedures were approved by an Institutional Review Board prior to data collection. Participants were fiscally compensated for their participation.

Experimental Design
A 2 × 2 × 2 within-subjects design was employed. The factors were task-demands (standard, high), collaboration technology (radio-only, augmented), and resource display (tabular, graphical). Dependent measures included the total number of team communications and the cumulative duration of radio communications. In addition, an analysis was conducted to examine the semantic content of radio communications made by participants.

Apparatus

Workstations. Five computer workstations (one for each team member) located within the same laboratory space were equipped with Dell 1703FPs 17-inch LCD monitors, a standard optical mouse, and a standard keyboard. Oral communication was transmitted and recorded using radio headsets (Sennheiser HD250 Linear II headphones and a Sennheiser HMD 224 microphone) tuned to a universal frequency. To promote use of headsets and microphones, as well as to simulate the auditory constraints of real aviation environments, a 50 kHz pink noise projected at 55 dB was generated in the laboratory. To initiate a radio transmission, participants pushed down a pressure-sensitive foot pedal underneath each workstation. The instantiation and relief of each foot press was recorded, enabling experimenters to record the number and length of each radio transmission.

Tactical Simulation Environment. A simulated air defense task was created using Aptima, Inc.’s Distributed Dynamic Decision-making (DDD) software (version 3.0; MacMillan, Entin, Hess, & Paley, 2004) in which two WDs were responsible for matching friendly fighters with enemy targets, scheduling fighters for refueling and resupply, and communicating action plans to the team. The simulation also featured two sweep operators and a single tanker operator who maneuvered team assets as instructed by WDs, engaged enemy targets, and provided feedback to WDs concerning asset resources (i.e., weapon and fuel status).

The number of enemy targets present in each trial was dictated by the task-demand condition. The standard condition featured four enemy aircraft; the high condition featured six. Each time an enemy aircraft was intercepted and destroyed, a new one would appear. This generation rate of enemy aircraft ensured consistent task-demand in each trial. In addition, trials featured six fast-moving “high-threat” aircraft, which appeared at random intervals. All enemy targets entered the scenario from the right side of the tactical display (the gray zone in Figure 2), and proceeded on a random path to the left (the red zone in Figure 2). As they moved, enemy aircraft could attack fighter and tanker assets, as well as an Air Force base and four infantry units positioned in the red zone.
Team communication. Team communication was manipulated across two levels. In the radio-only condition, participants communicated orally via radio headset. In the augmented communication condition, participants could converse using radio or with two additional collaboration tools: chat and a virtual whiteboard. The virtual whiteboard allowed WDs to generate spatial images that could be distributed in real-time using pre-programmed “drag-and-drop” symbols or “free-hand” (examples appear in Figure 2).

Resource displays. Team resource display was also manipulated across two levels. The tabular display condition provided sweep and tanker operators with access to team weapon and fuel status information in a digital format (Figure 1). The graphical resource display (Figure 1) included the same basic information, but was arranged in a “user-friendly” analog format that was made available to all team members. The graphical display also conveyed additional information by alerting teams to low asset fuel reserves (indicated by a change to an amber colored fuel status), and a black bar indicating the minimum fuel required for each asset to rendezvous with a refueling tanker.

Procedure
Participants completed an eight-hour training session on the day prior to beginning the experiment. During that time, participants were told that the purpose of the study was to evaluate how teams use collaboration technologies in ABM operations. Next, participants were randomly assigned to team positions. Teams then completed fourteen practice trials (ten minutes each) to familiarize themselves with the task and technologies.

Teams returned the next day for the experimental session. Upon arrival, they were assigned an order of presentation for sixteen trials, blocked and counterbalanced across eight unique conditions (representing all combinations of factors). Participants were given a rest period (up to 20 minutes) each time they completed four trials. Sessions were completed in eight hours. All dependent measures were averaged across block prior to inferential analysis.

Results
Following completion of the experiment, audio recordings, chat logs, and whiteboard logs were compiled and examined. When supplemental collaboration tools were available, teams sent an average of 3.61 chat messages and 71.44 whiteboard annotations per trial. These means were tested against zero using one sample t-tests to establish that teams were, in fact, using these tools. Results confirmed significant uses of both chat, t (20) = 5.94, p < .05, and the whiteboard, t (20) = 5.94, p < .05.

To test the effects of the experimental manipulations on team communication, separate 2 (task-demands) × 2 (collaboration technology) × 2 (resource display) within-groups analyses of variance (ANOVAs) were computed for the frequency of team communications and the cumulative duration of radio communications.

Frequency of communication. Main effects of task-demand, F (1, 20) = 5.53, p < .05, η² = .22, collaboration technology, F (1, 20) = 15.62, p < .05, η² = .49, and resource display, F (1, 20) = 13.05, p < .05, η² = .40, were detected. As illustrated in Figure 3, teams increased their frequency of communication in the high task-
demands condition compared to the standard condition. Teams also communicated more in the augmented collaboration technology condition compared to the radio-only condition, which was driven by utilization of the virtual whiteboard since radio communications declined substantially in this condition. Finally, teams communicated more when they had access to the tabular, as compared to the graphical, resource display.

![Resource Display Collaboration Technology Task-demand](image)

**Figure 3.** Mean frequency of team communication for each task condition.

**Duration of radio communication.** Main effects of collaboration technology, $F(1, 20) = 35.86, p < .05, \eta^2_p = .64$, and resource display, $F(1, 20) = 10.92, p < .05, \eta^2_p = .35$, were detected. These results indicate that the availability of the graphical resource display ($M = 387.28$ s, $SE = 22.75$ s) caused a decrease in the duration of communications compared to the tabular display ($M = 426.40$ s, $SE = 23.03$ s). In addition, duration was less in the augmented condition ($M = 364.10$ s, $SE = 24.06$ s) than in the radio-only condition ($M = 449.58$ s, $SE = 22.38$ s).

**Radio communication content analysis.** A subset of all radio communications between participants were hand-transcribed (four trials from each team, 84 trials total). From this set, 10 trials from each experimental condition (80 trials total) were selected at random for a content analysis that resulted in a database of 11,661 transcribed communications. The categorization scheme for coding these communications was developed specifically for this experiment (Table 1).

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Example Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarification / Confirmation</td>
<td>Statements either complying with or clarifying an order or request.</td>
<td>“Copy that.”</td>
</tr>
<tr>
<td>Coordinate</td>
<td>Statements which reflect planning, back-up behavior, or assisting teammates, but which were not directives for action.</td>
<td>“I need some help down here.”</td>
</tr>
<tr>
<td>Directive – Maneuver / Attack</td>
<td>Statements concerning maneuvering fighters or tankers, or intercepting enemy aircraft.</td>
<td>“Intercept MiG 227 at G6.”</td>
</tr>
<tr>
<td>Directive – Resupply</td>
<td>Statements tasking assets for refueling or resupply.</td>
<td>“Restock and refuel your fighters.”</td>
</tr>
<tr>
<td>Resource Status Request</td>
<td>Questions concerning asset fuel or weapons loadings.</td>
<td>“Who has low fuel?”</td>
</tr>
<tr>
<td>Resource Status Update</td>
<td>Statements providing information about fuel or weapons loadings.</td>
<td>“I’ve got 1 minute of fuel left.”</td>
</tr>
<tr>
<td>Simulation Dynamics</td>
<td>Statements or questions concerning the nature or functions of the DDD simulation environment</td>
<td>“You have to right click to bring up the menu.”</td>
</tr>
<tr>
<td>Situation Update</td>
<td>Statements or questions concerning scenario events and developments.</td>
<td>“There are still two MiGs at I5.”</td>
</tr>
<tr>
<td>Social / Emotive</td>
<td>Statements which reflected emotion, social interaction, or performance feedback.</td>
<td>“Good job!”</td>
</tr>
</tbody>
</table>
Using this protocol, two judges independently classified the transcribed radio communications into the prescribed categories. Inter-rater reliability of the judges was deemed sufficient (proportion of overall agreement = .82; Cohen’s kappa = .77, p < .05; Ubersax, 2000; Cohen, 1960). The percentage of radio communications in each category for each condition is presented in Table 2.

Table 2. Percentage of radio communications by category as a function of task condition.

<table>
<thead>
<tr>
<th>Category</th>
<th>Radio-Only Comm.</th>
<th>Augmented Comm.</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tabular Display</td>
<td>Graphical Display</td>
<td>Tabular Display</td>
</tr>
<tr>
<td></td>
<td>Stand. High</td>
<td>Stand. High</td>
<td>Stand. High</td>
</tr>
<tr>
<td>Directive – Maneuver / Attack</td>
<td>26.17 32.09</td>
<td>42.23 38.25</td>
<td>25.43 18.77</td>
</tr>
<tr>
<td>Situation Update</td>
<td>26.33 20.70</td>
<td>18.91 22.19</td>
<td>30.93 24.92</td>
</tr>
<tr>
<td>Clarification / Confirmation</td>
<td>20.51 16.96</td>
<td>17.19 17.42</td>
<td>14.61 21.03</td>
</tr>
<tr>
<td>Resource Status – Update</td>
<td>9.68 11.00</td>
<td>4.95 6.32</td>
<td>8.11 13.18</td>
</tr>
<tr>
<td>Social</td>
<td>2.58 2.90</td>
<td>3.03 3.16</td>
<td>3.00 5.49</td>
</tr>
<tr>
<td>Resource Status – Request</td>
<td>5.44 6.42</td>
<td>.96 .31</td>
<td>5.01 6.72</td>
</tr>
<tr>
<td>Simulation Dynamics</td>
<td>.88 .68</td>
<td>.76 .57</td>
<td>1.60 1.63</td>
</tr>
<tr>
<td>Coordinate</td>
<td>1.65 .92</td>
<td>1.10 .74</td>
<td>2.60 1.23</td>
</tr>
</tbody>
</table>

*a* Categories are presented in their order of predominance, from largest to smallest, in the complete 11,661 item data set.

*b* Indicates the prevalence of communications in each category from the complete data set, collapsed across experimental conditions to facilitate cross-condition comparisons.

As can be observed in the table, access to the virtual whiteboard and chat in the augmented communication conditions resulted in decrements in the percentage of radio communications classified as directive – attack, consistent with the types of communication the whiteboard was designed to convey. Utilization of these tools also resulted in an increase in the percentage of situation update communications. This suggests that access to chat and the whiteboard may have supported team situation awareness by providing increased opportunities to discuss task strategies. Access to the graphical resource display resulted in a relatively substantial decrease in radio communications classified as resource status – update and resource status – request, which is also consistent with the information conveyed by the display, and an increase in directive – attack communications, indicating that the display allowed participants to better manage critical resources and intercept enemy aircraft. Substantial differences in communication were not observed with manipulation of trial task demands, suggesting that demands did not impact the types of communication participants engaged in.

**Discussion**

The purpose of the current manuscript was to explore the influence of a pair of collaboration technologies and team decision-aids on the quality and quantity of team communications in a simulated air defense task. Results indicated that changes in task demands, the availability of the graphical resource display, and access to supplemental collaboration technologies altered the dynamics of team communication in this task.

With regard to the effects of task demands, results indicated that high demand caused an increase in the number of team communications. This is not surprising given that participants were tracking and responding to an increased number of enemy aircraft in that condition. Though task demands and collaboration technologies did not interact in the current experiment, it is possible that under “real-world” circumstances, the ability to offload communication to additional media, such as chat or whiteboard, may prevent radio overload and increase team effectiveness when task demands are high.

Findings related to the effects of the resource displays clearly favored the utility of the graphical display since it decreased the total number and duration of team communications, and those reductions allowed teams to more fully focus on intercepting enemy aircraft, rather than on resource management. When these findings are paired with those of Strang et al. (under review), which showed that the graphical display also reduced perceived
workload and improved team performance, it suggests that such a monitor may be a very useful tool for ABM operations. It is also worth noting that the graphical display was developed from feedback the authors received provided by subject matter experts (Russell et al., 2009).

Finally, the joint availability of chat and the virtual whiteboard caused an increase in the total number of team communications, but decreased the duration of radio communication. This seems to imply that the tools were effective for reducing reliance on radio while simultaneously increasing overall team communication. Interestingly, these findings might explain why Strang et al. (under review) found that the additions of chat and whiteboard resulted in an increase in perceived workload for some team members (WDs), but not others (sweep operators). Specifically, since only WDs needed to monitor all communications, given their important role in issuing commands, an increase in overall communication across multiple modalities may have led to perceptions of increased workload. However, sweep operators, who had fewer responsibilities, may have found the advantages of chat and whiteboard useful and manageable. These results illustrate that, under varying circumstances, some team members may be benefitted by the availability of collaboration technologies while others are unchanged (or hindered) by the same tools. This suggests that teams may be better served by adaptive collaboration technologies, which may be tailored to the needs of individual team members and roles (Baldwin, 2003). By allowing team members (or an automated decision aid) to flexibly and dynamically alter the functionality of these tools, it may be possible to maximize team performance while minimizing associated negative outcomes. Determining the nature and behavior of such tools is likely to be a fruitful area of future research.

References


