Understanding Audio Communication Delay in Distributed Team Interaction

Impact on Trust, Shared Understanding, and Workload

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***Abstract*—Distributed teams are geographically separated and may need to rely on networked communication technologies (e.g., audio or video conference, email) to mediate their interaction. A limitation of these networked communication technologies is that they generate transmission delays that result from network congestion or routing issues. For the purposes of this research we focus on verbal communication over audio and video technologies and define communication delay as the time interval between a team member speaking a message (sender) and when it is rendered on the other side (receiver). Communication delay in distributed settings is an important and challenging problem, particularly in air traffic control, and space and military operations, where communication and information sharing are paramount to team success. The goal of this research is to better understand the effect of communication delays on team collaboration and team processes to maximize distributed team performance.**

Keywords—distributed teams; team communication; delay; team process; digital communication; networked communication technology

I. Introduction

Work teams are increasingly turning to distributed teams that are separated either geographically or spatially whereby members are linked together only through information communication technology. Subsequently, distributed teams rely heavily on various networked communication technologies such as audio or video conferencing, email, and chat to support work activities or share information. While these technologies facilitate remote interaction, networked communication is often subject to delays or lag. This may hinder effective communication, which is a key component for successful team performance. Several factors can create a context for communication delays to occur including, the power of the computing machines, type of data being transmitted (voice, video, or data), distance that messages must travel, and the current level of network traffic or congestion [1]. Although some delays, such as those experienced in cell phone conversations are rather tolerable, data from field tests of advanced communications networks for future military operations demonstrated one-way communication delays of up to 1.8 seconds, with longer delays in multi-hop situations and satellite communications [2]. While it is possible to reduce some delays by increasing the available bandwidth or by making more efficient use of existing bandwidth [3]; it may not be feasible to completely eliminate the delay associated with all distributed situations [4]. In the present study, we selected audio communication delay lengths based on data from Army field tests of networked communication technologies [2]. Video technology were selected for their potential to provide richer social interactions [5] that may, in turn, lessen the effect of delay.

II. Hypotheses

Hypothesis 1: Increases in communication delay will result in faster task completion times, but lower task accuracy (shared understanding), less information shared, lower team member trust, technology trust, and team member satisfaction scores, and increased mental workload.

Hypothesis 2: Social cues, provided by a video of team members will lessen the effect of delay such that accuracy will be higher, more information will be shared, team member trust, technology trust, and satisfaction scores will be higher, and mental workload will be lower than audio only conditions.

III. Experimental Design

A 2 x3 repeated measures design was used. Independent variables were type of communication technology (audio, video) and delay length (0, 800 ms, 1600 ms). Delay lengths were based on results from field research of network technologies and SME input [2]. Treatment conditions were counterbalanced. Objective measures were: task completion time, task accuracy (shared understanding), and the percentage of factoids shared. Subjective measures were: mental workload [6], interpersonal trust [7], trust in technology [8], and team member satisfaction [9].

IV. Experimental Method

Sixty volunteers were recruited from the civilian population at Aberdeen Proving Ground. Participants worked in a team (dyad) and performed a task called the Experimental Laboratory for Investigating Collaboration, Information

Sharing, and Trust (ELICIT). ELICIT [10] is a computer-based multiplayer intelligence environment in which participants assume the roles of networked intelligence analysts whose goal is to uncover an anticipated adversary attack. Each team member received four types of factoids that represent information about the anticipated attack: who factoids provide information about the likely actors involved, what factoids describe the target, where factoids describe the place, and when factoids describe the month, day and time of the attack. Each team member received different factoids and used audio and/or video technology to verbally share factoids and work toward a solution. Audio and video communication for each team member was delayed using the DelaySystem Audio and Video Delay System (Allen Avionics, Inc.). Each dyad performed six experimental sessions, plus a training session.

V. Results

Mean task completion time and percentage of factoids shared were analyzed in separate 3 (delay) x 2 (technology) repeated measures ANOVAs, with an alpha level of .05. Results showed that technology did not significantly affect task completion time or the percentage of factoids shared. However, results showed that delay significantly affected both task completion time $F(2,58) = 4.24$, $p = 0.02$, partial $eta^2 = 0.13$ (Fig. 1), and the percentage of factoids shared $F(2,58) = 3.39$, $p = 0.04$, partial $eta^2 = 0.11$ (Fig. 2). Post hoc analysis with Bonferroni correction showed that the mean task completion time for the 800 ms delay length (M = 14.1, SD = 3.31) was significantly longer ($p = 0.03$) than the 0 ms delay condition (M = 12.87, SD = 3.48). No other significant effects were found. Post hoc analysis of the percentage of factoids shared failed to reach significance with a Bonferroni correction. Percent accuracy data were analyzed using a Friedman nonparametric ANOVA with no significant effects of delay or technology.

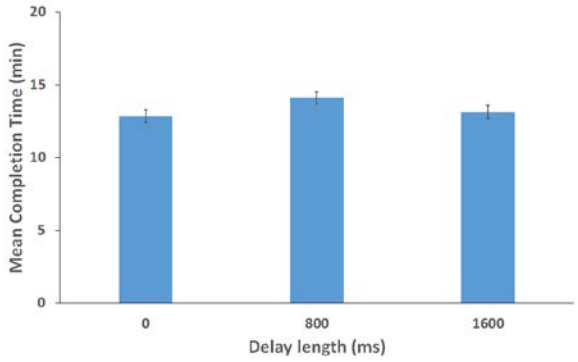

Fig. 1. Mean task completion time (SEM)

Overall mental workload scores from each team member on the NASA TLX were averaged to arrive at a team rating of mental workload, and analyzed with a repeated measures ANOVA. There were no significant effects of delay or technology on ratings of overall workload. However, analysis of the TLX subscales showed that frustration ratings were affected by delay $F(2,58) = 3.41$, $p = 0.04$, partial $eta^2 = .11$ (Fig. 2), with significantly higher ratings at the 1600 ms delay (M = 52.17, SD = 75.57) than the no delay (M = 37.83, SD = 63.17) condition (Fig. 3). No effects of delay or technology were found for the other TLX subscales. Repeated measures ANOVAs performed on the technology trust, interpersonal trust, and satisfaction data showed no significant effects of delay or technology and no significant interaction effects.

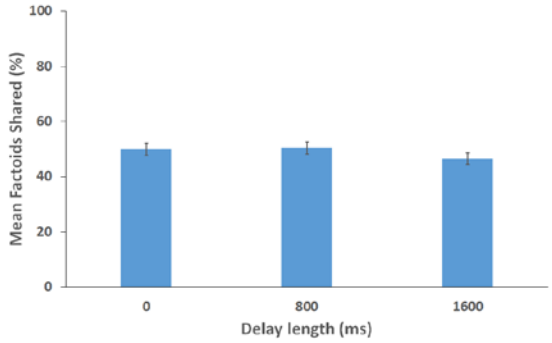

Fig 2. Mean percent of factoids shared (SEM)

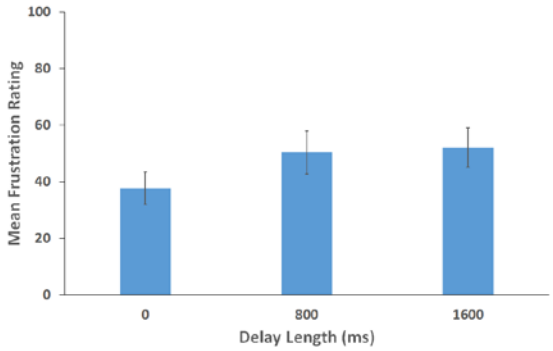

Fig 3. Mean TLX frustration rating (SEM)

VI. Discussion

Results indicated that Hypothesis 1 was partially supported: For the longer 1600 ms delay, teams shared significantly less information compared to the 800 ms delay, and rated their frustration significantly higher than no delay, which is not surprising given that delays are inherently stressful and where possible, people tend to avoid them. What is surprising is that even though the 1600 ms delay led to increased ratings of frustration, this was not reflected in lower team satisfaction, lower team trust, and lower trust in technology scores. These results suggest that team members did not blame the communication technology or their partner for the stressful interactions, but considered it a part of working remotely and found a way to work together in spite of the delay, which may also have impacted task accuracy as team solutions were accurate 95% of the time. Although the solution to each factoid set was not given until all experimental trials were complete, team members may have felt confident enough in their solutions that trust and satisfaction were not affected. There are two potential explanations for these results. First, since participants were recruited from the same laboratory, they may have shared a collective orientation based on their affiliation with the same organization, thereby reducing uncertainty in their interactions, and enabling them to work together to solve the adversary attack. Although not measured in the current

experiment, this is an important finding which may be pertinent for temporary or ad hoc distributed teams where there often isn't an existing connection or affiliation between team members and there is little time for trust to develop. Second, participants were "experienced" with communication technology as reported on a demographic survey and likely had encountered delays in the past (i.e., cell phone delays) and may have been able to compensate for the delay to accomplish their mission.

With respect to task completion time, results were contrary to our expectation; teams actually took longer to complete the task with the 800 ms delay compared to no delay, but no other significant differences found. When delays are present, turn-taking among team members takes longer, with more interruptions and repeated information which necessarily equates to longer task completion times. However, we hypothesized that the delay would increase the effort required to perform the task and would disrupt interactions such that teams would solve the task prematurely [11]. It appears that the 800 ms delay disrupted communication enough to produce a difference in task completion time, although not in the expected direction, so perhaps longer delays would have aligned better with our expectations. In addition, task accuracy (shared understanding) was not affected by the delays suggesting that team members were somehow able to still manage the situation and accomplish their mission. For example, team members may have used a more efficient strategy when delays were present such as synthesizing information before it was shared. Although, we would expect a subsequent increase in mental workload or effort and a decrease in satisfaction, neither of which was supported by the data. This could be due to their prior experience with technology as mentioned previously. Further analysis of team member interactions should be done to determine if this was the case. While this helps shed some light on how teams respond to delays in distributed collaboration, further research should extend these findings to include more complex situations such as concurrent tasks being performed, diverse team composition, and possibly time pressure, to better understand how team members manage their interactions when delays are present.

In Hypothesis two, we expected that video technology, with its social cues and support of gaze awareness and gestures [5] would lessen the effects of delay, however, results showed that technology did not affect performance or subjective measures. Evidence for teams using the video was provided during post-experiment interviews as they noted that the visual cues helped them assess their partner's status. So, video may have benefitted their interaction (i.e., timing of communication) but may not have been captured in the current experiment. In general, the existing literature suggests that benefits of video depends on the circumstances surrounding the interaction, the type of task, and team history [12], so perhaps our results may be due to the scripted nature of the ELICIT task, causing team members to focus most of their attention on the factoids pertaining to the adversary attack, instead of the video of their team member, both presented on the same display in front of them.

VII. Follow-on Study

Based on the results of the present study, we propose a second study to explore team composition as another factor that may impact distributed team communication. With traditional boundaries in today's organizations expanding, teams are becoming increasingly diverse. Work team diversity can be beneficial, because demographically diverse workers possess more unique knowledge to draw from which can lead to more creative problem solving. On the other hand, diversity in work teams can create challenges for communicating and managing information, especially in distributed team contexts. Our next study will explore how communication delays affect team member collaboration in distributed teams whose members are demographically diverse.

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