COMMUNICATION PROTOCOLS TO SUPPORT COLLABORATION IN DISTRIBUTED TEAMS UNDER ASYNCHRONOUS CONDITIONS

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The safety and success of future space missions will depend on the ability of crewmembers and Mission Control to collaborate effectively, even when communication between them is delayed. Communication protocols—i.e., structured communication templates—were designed with the goal to facilitate space-ground collaboration under time-delayed conditions. Their effectiveness was assessed in several space-analog simulation studies. **Method:** Astronauts and astronaut-like volunteers received communication training prior to their missions. Missions included 2 to 4 days on which communication with Mission Control was delayed. Surveys were administered throughout the mission asking participants to rate the effectiveness of the protocols and their interactions with Mission Control and in a final survey to provide feedback on individual elements of the communication protocols. **Results and Discussion:** Participants rated the protocols as fairly effective. Their ratings also suggest that the protocols mitigated the negative impacts of communication delay. Participants' ratings of individual protocol elements were generally high but also point to specific training needs and technology requirements.

The safety and success of future space missions will depend on the ability of crewmembers and Mission Control to collaborate effectively, even when communication between them is delayed. As mission travel further from the Earth, space-ground communication will involve significant delays, up to 20 minutes one way for missions to Mars. While the presence of communication delay will require future space crews to operate more autonomously than crews in current operations, the necessity of space-ground collaboration will remain. Unforeseen problems for which crews will need assistance from Mission Control, such as system failures or medical emergencies, may arise. Solutions to mitigating the impact of communication delay that focus on faster transmission technology (e.g., Eadie, Seifalian, & Davidson, 2003) may succeed some day in providing seamless communication but current technology is not able to do so. It is therefore essential to explore solutions that focus on the communication process itself rather than transmission speed. In this paper we describe one such approach. Specifically, we designed communication protocols with the goal to facilitate space-ground collaboration under time-delayed conditions, and assessed their effectiveness during several simulated missions in different space-analog environments.

The challenges of asynchronous communication

Communication delays can have a substantial impact on the efficiency and success of distributed team collaborations (Krauss & Bricker, 1966; Kraut, Fussell, Brennan, & Siegel, 2002), especially those that are complex and time intensive (Olson, G. & Olson, J., 2000). Research examining asynchronous communication in the laboratory and in a space analog showed that transmission delays of 50 seconds and 5 minutes disrupted collaboration in distributed teams, irrespective of the communication medium (voice or text) used (Fischer & Mosier, 2014; Fischer, Mosier & Orasanu, 2013). In addition to the obvious threats inherent in having to wait for responses to potentially time-critical communications, problems with message management and comprehension surfaced when participants failed to tailor their interactions and expectations to the communication delay. Both student and astronaut participants were likely to misapply assumptions and conventions of synchronous discourse to asynchronous conditions, behavior that resulted in unnecessary turns, or worse, in misunderstandings (Fischer & Mosier, 2014).

One of the problems concerned team members' reliance on anaphoric expressions, such as pronouns, in their responses to a preceding contribution by a partner. The use of anaphora rests on the assumption that conversational partners have a shared perspective on their evolving communication, an assumption that may be erroneous when communication is asynchronous. Participants in synchronous communication can and do use anaphora to link their respective contributions, and can trust that the referent of the anaphora is easily identified because related communications by partners are consecutive. However, in asynchronous communication related contributions may be temporally adjacent only for the responding partner while for the other –responded-to—participant unrelated contributions may intervene. Consequently, establishing the correct referent for an anaphoric expression such as "that repair didn't work," or "got it" may be cognitively taxing, if not impossible.

A related issue is proximity bias; that is, the tendency of team members to interpret a communication by a remote partner that immediately followed their own contribution to be their partner's response to it. While this is a feature of synchronous discourse it may not necessarily be true under asynchronous conditions. A third problem reflected participants' insensitivity to time constraints insofar as they repeated information or requested feedback before their

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remote partner could have responded to their original message. These findings informed the design of communication protocols as they highlight which aspects of the communication process need support to ensure successful communication between remote partners under asynchronous conditions.

Protocols to support asynchronous communication

Communication protocols created for this effort were structured templates designed to facilitate remote collaboration under time-delayed conditions utilizing medium-specific affordances. Specific design goals included: to help remote team members keep track of conversational threads and the temporal sequence of contributions, and to establish common ground in an efficient manner. The content of the protocols addressed the problems associated with asynchronous communication that were identified in past research (Fischer & Mosier, 2014) as well as recommendations by Love and Reagan (2013); their structural characteristics were based on schema-based approaches to instruction design (Morrow & Rogers, 2008; Morrow et al., 1996; 1998; 2005).

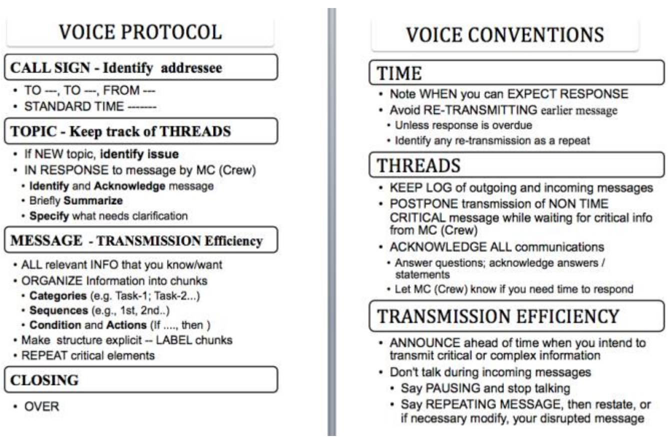

Figure 1. Protocol and conventions for voice communication

As can be seen in Figures 1 and 2, protocols consist of four segments and several communication conventions that address the major challenges of asynchronous communication—Time, Conversational Thread, and Transmission Efficiency. Media-specific instructions concern aspects of the call sign and conventions that are consistent with the affordances and constraints associated with voice or text communication. Call signs during voice communication for instance need to do more than identify who is talking to whom. They also need to catch the remote partner's attention (thus the addressee's name should be called out twice), and they need to anchor a message in time to highlight the temporal sequence of participants' contributions and thus safeguard against proximity bias. References to time need to be independent of a partner's perspective and should be linked to an objective time, such as standard time. As text messages typically include time stamps and the identity of the sender, call signs need to identify only the addressee. On the other hand, because the texting tool used in the space-mission simulations did not have an attention-getting feature such as announcing incoming messages with a chime, protocol conventions directed partners communicating via text to note the time of both their transmission and the expected response and to check for new messages accordingly. Text communication provides a written record of partners' contributions; accordingly, no record keeping is required. In contrast, when distributed team members communicate by voice, protocols required them to maintain a log of their ongoing discourse to keep track of conversational threads.

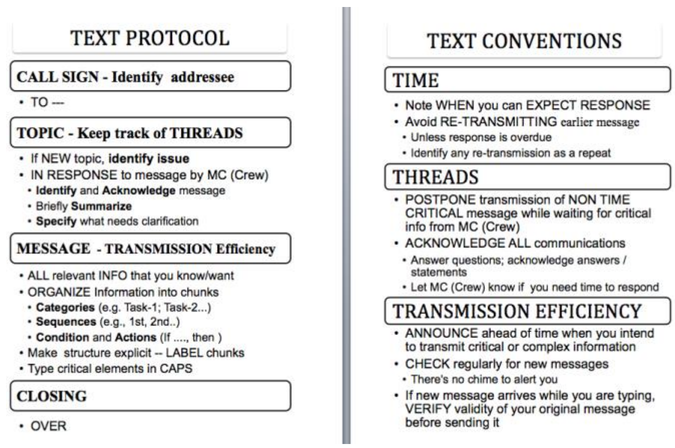

Figure 2. Protocol and conventions for text communication

Medium-independent instructions concern the topic section of a message, the message body and the final—closing—section as well as several conventions designed to support conversational coherence, message comprehension and shared task understanding, as well as communication efficiency. Team members were trained to preface their message with a topic, or to make explicit the relationship of their message to a preceding one from their partner. Doing so enables partners to keep track of conversational threads and avoid proximity bias. Team members were also instructed to transmit all relevant information in one turn, to present it in a clearly structured fashion, to repeat critical items and to postpone transmission of non time-critical information while they awaited crucial input from their partner. These elements facilitate comprehension and maintain communication efficiency as related information is kept together. Mutual understanding is further enhanced when team members explicitly acknowledge and paraphrase a partner's messages instead of providing generic feedback, such as "copy all." Moreover, by indicating their understanding of a partner's message, team members can preclude unnecessary communication. If no feedback is given, partners may repeat

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their message or ask for verification. Likewise, team members were told to note when they should receive a response to discourage unwarranted repetition that could potentially confuse their partner. Lastly, team members were instructed to announce when they plan to transmit important information to give their remote partner time to attend to it, and to mark the end of a transmission to let partners know that their message is complete.

METHOD

The communication protocols were included in several space-analog simulations conducted by NASA Johnson Space Center to assess their usability for space operations. One set of studies was conducted at the NASA Extreme Environment Operations (NEEMO) facility, an undersea research station 62 feet below sea level off Key Largo. Other studies took place in NASA's Human Exploration Research Analog (HERA), a space-analog habitat located at Johnson Space Center.

Participants

Crewmembers participating in two NEEMO missions, NEEMO-18 and NEEMO-19, agreed to use the communication protocols during space-ground interactions on days with a communication delay. Each mission involved four crewmembers from the astronaut corps of NASA and its international partners (CSA; ESA; JAXA). A second set of studies involved participants in four space-mission simulations conducted in HERA. Participants were astronaut-like research volunteers; that is, they were comparable to astronauts in terms of education, personality and age. Each HERA mission included four crewmembers.

Procedure

Pre-mission training. NEEMO crewmembers and two of the four HERA crews received 30 minutes of communication training prior to their missions. Communication training identified the challenges of asynchronous communication and explained the elements of the communication protocols and conventions. There was one joint training session for participants in the NEEMO missions, five weeks prior to NEEMO-18 and 13 weeks prior to NEEMO-19. The NEEMO-19 crew received a refresher training three weeks before their mission started. HERA crewmembers of missions 3 and 4 received training during the week preceding their mission; crewmembers of missions 1 and 2 served as control and thus did not participate in any communication training,

Mission schedule. NEEMO-18 was a 9-day mission with four days of communication delay. Two days involved a delay of 5-min one way, the other days presented a 10-min delay. Communication medium (voice vs. text) was crossed with communication delay. NEEMO-19 lasted for 7 days. On four days communication between the crew and mission control was delayed by 5 minutes one way, and remote partners could choose which medium (voice or text) to use during a given interaction.

HERA missions were 7 days long and included two days on which communication was delayed by 10 minutes one way. On the first of these days communication between the crew and mission control was voice-only; on the second day participants were given a choice of communication medium.

In all NEEMO and HERA missions communication delay occurred on consecutive mission days. Copies of the communication protocols were given to trained participants at the start of a mission to serve as a reference aid on comm delay days.

*Communication survey***.** A daily survey administered to NEEMO-18 crewmembers included one question that asked participants to rate the effectiveness of their communications with mission control. In addition, a separate communication survey was given on the days on which communication with mission control was delayed. In this survey crewmembers were asked to evaluate the extent to which the communication protocol and conventions were effective in supporting communication with mission control during two important events of the day: Extravehicular Activity (EVA), and re-planning and prioritization. In addition, respondents were asked to explain any rating lower than 4 (with 5 as the highest rating). On the mission day immediately following the days with communication delay, crewmembers received a survey in which they were asked to rate how critical elements of the protocol and individual conventions were in facilitating asynchronous communication. NEEMO-19 crewmembers received only the communication-specific as well as the final survey since their mission schedule did not provide for surveys on non time-delay days.

HERA crewmembers were given daily communication surveys assessing the effectiveness of their interactions with mission control during assigned tasks. Respondents were asked to provide an explanation for any rating lower than four. HERA crewmembers who received communication training also completed a final survey at the end of their mission evaluating protocol elements and communication conventions.

Communication surveys were administered electronically, either as a Word document (HERA missions 1 -3) or via Qualtrics software (HERA mission 4, NEEMO-18 and -19), and took 5 to 10 minutes to complete.

RESULTS AND DISCUSSION

Given the small sample size, we report only descriptive statistics. As can be seen in Table 1, trained participants considered the protocols to be effective in supporting crew-Mission Control communication when there was a transmission delay. Astronauts in the NEEMO missions as well as trained volunteers in the HERA simulations gave an effectiveness rating greater than 4 (out of 5).

Table 1. Crewmembers' Mean Effectiveness Ratings of Their Communications with Mission Control (MC)

	Effectiveness of Crew-MC Communication		Effectiveness of Protocols
	No Comm Delay	Comm Delay	
NEEMO-18	4.46 (0.69)	4.31 (0.48)	4.69 (0.52)
NEEMO-19	N/A	N/A	4.14 (0.35)
HERA (trained crews)	3.93 (0.89)	3.87 (1.14)	4.25 (0.46)
HERA (untrained crews)	4.07 (1.09)	2.95 (1.68)	N/A

Notes. Numbers reflect mean ratings across days (days with communication delay vs. no delay); standard deviations are in parentheses. Maximum rating was 5.

Moreover, participants' ratings suggest that the protocols did facilitate crewmembers' communications with mission control on days with communication delay. As shown in Table 1, trained crewmembers thought that the effectiveness of their interactions with mission control did not suffer when communication was delayed. In contrast, untrained HERA crewmembers gave considerably lower effectiveness ratings on time-delayed days compared to days with synchronous communication.

Untrained HERA participants also commented that they were less willing to contact mission control for guidance on tasks when their communication was delayed. As a result, as Mission Control noted, they performed the tasks improperly and required time-consuming additional assistance from ground.

Table 2. Crewmembers' Mean Criticality Ratings of Individual Protocol Elements and Conventions

	NEEMO-18	NEEMO-19	HERA
Repeat addressee (voice)	3.75 (1.26)	N/A	2.75 (1.28)
Include time (voice)	3.50 (1.73)	N/A	4.25 (1.04)
Provide topic	4.75 (0.50)	4.88 (0.35)	4.63 (0.52)
Acknowledge communications	4.00 (0.82)	4.25 (0.89)	3.75 (1.04)
Push information	3.25 (0.50)	3.33 (1.53)	4.63 (0.74)
Chunk information	3.50 (0.56)	3.33 (0.58)	4.25 (0.71)
Repeat critical Info (voice)	4.25 (0.50)	N/A	4.50 (0.76)
Type critical info in caps (text)	2.50 (0.56)	3.50 (1.29)	3.00 (1.07)
Note earliest time to expect response	3.00 (1.41)	3.75 (1.23)	4.25 (0.71)
Use log to track related messages	4.75 (0.50)	4.75 (0.50)	4.00 (1.60)
Announce complex or critical messages	4.50 (1.00)	4.25 (0.96)	4.75 (0.46)
Postpone non time-critical message to wait for critical info	4.00 (0.82)	3.50 (0.58)	3.63 (1.19)

Notes. Standard deviations are in parentheses. Maximum rating was 5. NEEMO-19 crew used text communication only.

As shown in Table 2, crewmembers generally rated protocol elements and conventions as fairly critical to ensuring effective communication during asynchronous conditions. The majority of the items received a criticality rating of at least 3.5. Very high ratings across crews for providing topic, using a log to track related messages, and announcing complex or critical messages reflect the value of protocols for keeping track of message threads. However, ratings for some items—most notably, pushing and chunking information and tracking time—were surprisingly low and may point to specific training needs and technological improvements. Interestingly, the NEEMO 19 crew opted to use exclusively text as their communication medium on time-delayed days. This finding may reflect the implementation in this mission of a new text tool (VOXER) whose features seem better suited to meet the demands of asynchronous communication than the text tool available to the NEEMO-18 crew and the HERA crews. For instance, the time a message was sent was prominently displayed and messages included a time stamp that indicated the earliest time a response could be received.

CONCLUSION

The present research suggests that asynchronous communication may be facilitated by protocols that aid conversational partners in keeping track of conversational threads and the temporal sequence of messages. Obviously, given the descriptive nature of this study this conclusion requires more rigorous testing. A complementary lab study with a larger N has been conducted and is expected to provide more insight into the effectiveness of the communication protocols.

The communication protocols not only target how to speak or write during asynchronous conditions but also point to technological solutions. One example is the text tool that was adopted in NEEMO-19 and assisted the crew with the temporal aspects of communication. Further improvements might be a less chat- and more email-like text tool that includes a subject header and links between related messages to make it easier for conversational partners to follow a conversational thread. A text tool could also provide a template that gives structure to a message and highlights its components. Likewise, voice communication could be facilitated if recordings of messages were available to both sender and receiver. Moreover, the recording could indicate when a message was transmitted, and it is conceivable that the recording tool would include prompts for specific message components (e.g., This message is in regard to ….)

It should also be noted that the application of communication protocols is not limited to space exploration missions but could generally support communication between remote partners, either under asynchronous conditions or when time and thus precise communication is critical.

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