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Impact of communication delays to and from the International Space Station on self-reported individual and team behavior and performance: A mixed-methods study

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ABSTRACT

Deep space explorations will involve significant delays in communication to and from Earth that will likely impact individual and team outcomes. However, the extent of these impacts and the appropriate countermeasures for their mitigation remain largely unknown. This study utilized the International Space Station (ISS), a high-fidelity analog for deep space, as a research platform to assess the impact of communication delays on individual and team performance, mood, and behavior. Three astronauts on the ISS and 18 mission support personnel performed tasks with and without communication delays (50-s one-way) during a mission lasting 166 days. Self-reported assessments of individual and team performance and mood were obtained after each task. Secondary outcomes included communication quality and task autonomy. Qualitative data from post-mission interviews with astronauts were used to validate and expand on quantitative data, and to elicit recommendations for countermeasures. Crew well-being and communication quality were significantly reduced in communication delay tasks compared to control. Communication delays were also significantly associated with increased individual stress/frustration. Qualitative data suggest communication delays impacted operational outcomes (i.e. task efficiency), teamwork processes (i.e. team/task coordination) and mood (i.e. stress/frustration), particularly when tasks involved high task-related communication demands, either because of poor communication strategies or low crew autonomy. Training, teamwork, and technology-focused countermeasures were identified to mitigate or prevent adverse impacts.

1. Introduction

Long-duration space explorations will involve significant delays in communication between astronaut crews in space and mission support personnel on Earth. On a crewed mission to Mars, for example, a one-way transmission could take up to 22 min to receive. Such delays will likely impact individual and team performance, behavior, and mood unless teams are provided with the tools and training to overcome or prevent these challenges [1,2]. Concerns about the adverse impacts of communication delays across distributed teams are not new, and are not unique to spaceflight operations [3–5]. Research suggests interrupted communication between distributed team members may lead to perceptions of an uncertain work environment, which in turn can yield negative individual and organizational outcomes such as increased stress and decreased job involvement [6,7]. Furthermore, communication delays may lead to conflict, misunderstandings and reduced trust among dispersed team members [8,9]. However, the extent of these impacts on distributed space teams and the appropriate countermeasures for their mitigation remain largely unknown.

To date, research on the behavioral and performance-related impacts of communication delays across distributed space teams has relied extensively on ground-based analog environments. For example, some studies have explored issues related to delayed voice communication as part of the larger topic of crew autonomy. These studies suggest space crews will need to be more autonomous from mission control during long-duration space missions [10,11]. In addition, research from analog environments on Earth indicate communication delays are associated with decreased task efficiency, reduced situational awareness, and weakened rapport between crewmembers and mission support personnel [12,13]. Although these studies provide important

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Table 1
Study tasks by experimental condition and complexity level.

Task #	Experimental Condition	Complexity		Description
		Critical	Novel	
1	Control	High	High	Crew replaced broken equipment used to support ISS habitability
2	Control	Low	Low	Crew performed weekly cleaning activities
3	Control	Low	High	Crew conducted scientific experiment
4	Delay	Low	Low	Crew performed weekly cleaning activities
5	Delay	High	High	Crew performed extravehicular mobility unit maintenance
6	Delay	High	Low	Crew began loading disposal items into the Cygnus spacecraft
7	Control	High	Low	Crew transferred cargo from the automated transfer vehicle to ISS
8	Control	High	Low	Crew conducted scientific experiment
9	Control	High	Low	Crew conducted scientific experiment
10	Delay	Low	High	Crew replaced broken equipment used in human physiology research

insights, they are limited in number and fidelity to actual spaceflight operations. Importantly, the reported impacts of communication delays in low fidelity environments may be underestimated, particularly for tasks involving highly complex, dangerous, and/or off-nominal situations [11]. Given these limitations, there remains an urgent need to further explore the behavior and performance-related impacts of communication delays on distributed space teams, preferably in high fidelity environments.

The current study, conducted by the Behavioral Health and Performance Element (BHP) of the NASA Human Research Program, expands on these findings by utilizing the International Space Station (ISS), a high-fidelity analog for deep space, as a research platform to examine how interdependent teams (astronauts in space and mission control personnel on Earth) interact and perform tasks with and without communication delays between the team elements [14]. After each task, participants were asked to complete post-task questionnaires that included questions about their perceptions of individual and team performance and well-being. Secondary outcomes included communication quality and task autonomy. Qualitative data from post-mission interviews conducted with astronaut participants were used to validate and expand on the quantitative findings and to elicit recommendations for countermeasures.

2. Methods

2.1. Subjects

The study included three astronauts on the ISS and 18 participating mission support personnel such as the CAPCOM (capsule communicator; the individual who communicates with the crew from mission control) and Mission Director. All subjects were fluent English speakers. Additional details on mission increment and demographic characteristics were withheld to preserve subject confidentiality and anonymity. All procedures for data collection were reviewed and approved by the Institutional Review Boards of NASA's Johnson Space Center and the University of Southern California. Prior to the start of the study, all subjects signed written informed consent.

2.2. Procedure

Participating astronauts and mission support personnel were asked to perform tasks with and without communication delays to-and-from the ISS. A 50-s one-way interval in the delay in communications between sender and receiver was used. This delay was suggested by NASA's Mission Operations Directorate (MOD) as adequate for conducting the study without jeopardizing operations on the ISS. The communication delay filter was only employed during completion of designated study tasks, all communications returned to normal upon completion of the task.

Three NASA employees with mission control experience and familiarity with task scheduling and procedures served as subject matter experts (SMEs) and identified a set of tasks representing variation on two dimensions of task complexity, criticality (low or high), and novelty (low or high), and meeting the following requirements: 1) task duration was at least 60 min (to ensure sufficient time to capture behavioral assessments and complete ratings); 2) tasks involved communication between crew and ground (> 4 transmitted messages); 3) at least two astronauts on the ISS were involved in the task (team-level task); 4) delays in communication involved all communication mediums (i.e. voice/text/video) but did not include telemetry or other hardware and/or system communications; 5) a different task was completed each day over a 4-day period early in the mission and late in the mission, and two additional tasks were completed at the mid-point of the mission (to control for team effects over time); and 6) tasks for this particular study targeted a specific ISS increment consisting of three astronauts aboard the ISS, as well as participating mission support personnel.

The original study protocol called for evaluation of 16 tasks (8 under control conditions and 8 under conditions of a 50-s one-way delay) that varied by task complexity. However due to task requirements and concerns expressed by the MOD, only 10 tasks were identified by SMEs as sufficient and acceptable (results related to the feasibility and acceptability of conducting the study on the ISS with regard to study design challenges and limitations are reported elsewhere [15]). The tasks were completed over a three-month window during the 166-day mission. Six of these tasks were completed under control conditions (no delay in communications) and four were completed under a 50-s one-way delay in communications. The imbalance (6 control vs 4 communication delay) in tasks was due to the inability to identify a fifth task that met study criteria and was acceptable to the MOD that could be conducted under the 50-s one-way delay during the three-month interval, and the unanticipated opportunity to collect data during performance of an additional task under control conditions [15]. A description of study tasks by task order and experimental condition is provided in Table 1 below.

2.3. Post-task assessments

After each task, participating astronauts and mission support personnel were asked to complete post-task questionnaires that included questions about individual and team behavior, performance and mood. The post-task questionnaire took approximately 10 min to complete and included the following items grouped by topic:

2.3.1. Performance (individual, crew and team)

All subjects were asked to rate their performance (Individual), the performance of the astronauts (Crew), and the performance of the entire team including both the astronauts and mission support personnel (Team). Each item was rated on a 9-point scale ranging