Braided Communications

Title: Topical campaign for the interactional effects of human long-duration spaceflight hazards under conditions of time-delayed communication.

In response to the call for white papers for the Decadal Survey on Biological and Physical Sciences (BPS) Research in Space 2023-2032 (BPS2023) conducted by The National Academies of Sciences, Engineering and Medicine.

Braided Communications Limited is a company based in Scotland, UK, currently collaborating with NASA, ESA and UKSA on time-delayed communication for human space exploration.

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Executive summary

In long-duration spaceflight, crew physiology will be impacted by the time-delay (signal latency) in communication caused by large distances and the finite speed of light. In order to understand the impact of latency on communication, health and performance and identify opportunities for mitigation, three interlinked changes are required over the coming decade: (1) More analog research into long duration spaceflight (2) expanded to include interactive effects between spaceflight hazards and (3) with consistent and comparable high latency fidelity (large time delays in communication that match what can be expected in deep space missions).

Time-delayed communication is a problem for human deep space exploration

As a spacecraft travels away from Earth, the distance causes a communications delay (latency). At the Moon, the signal latency is about 1.3 seconds, one-way. For a mission to Mars, the delay would increase during the transit. On the surface, delay would be just over three minutes, one-way, when Earth and Mars are at their closest and over 20 minutes when the planets are furthest apart.

With time delays of a size characteristic of a mission to Mars, space crews and ground partners in analogue research have been observed to misconstrue and misinterpret the content of messages, and misread interpersonal signals, causing frustration and confusion [1]. Even a signal latency as small as 50 seconds, one-way, imposed experimentally on the ISS during operational tasks, is sufficient to produce significant degradations in communication quality, crew morale and individual wellbeing, including significantly higher levels of stress and frustration [2]. The physical and cognitive demands of equipment operation, such as communication equipment, contributes to astronaut fatigue [3]. Fatigue plays a major role in degrading the performance of the crew [4], particularly when they are dependent on safety-critical systems.

Research into large signal latencies in operational communication has examined operational performance and found severe decrements in communication quality across several long duration spaceflight analog environments [6] Communication delays therefore pose a formidable challenge to the collaboration between space crewmembers and ground support because they impede team members' communication efficiency and may ultimately hinder their joint task success [7][8].

Space-ground interdependency

Undoubtedly, future space crews will have to be more autonomous than crews in near-term operations. The inescapable necessity for space-ground collaboration will remain, however. Crewmembers and ground support personnel will need to communicate mission-critical information to ensure that they have shared task and situation models as the mission progresses. Additionally, unforeseen problems for which crews will need assistance from ground, such as system failures or medical issues may arise as examples from Apollo missions to the present day illustrate.

While NASA recognises the health hazard presented by isolation and time delay (Human Research Roadmap, BMed106) in combination with other spaceflight hazards (BMed109), the work to investigate the possibility of mitigating the impact of latency on communication, health and performance in spaceflight largely remains to be done.

In particular, the hazards inherent in communication delays make it difficult to derive social stimulation from crew interactions with friends and family. This in turn can have a cumulative impact on astronauts' *health* and can heighten the impact of other negative stressors on cognition and performance [9]. However, most studies of communication delay in NASA analogs do not extend the delay to personal communications with friends and family. In fact, Palinkas reported that astronauts' most frequent suggestion for future research was to incorporate and examine delays in personal communications [ibid.]. Evidently, it is important for crew members to discover ways to support contact with friends and family on the ground during exploration missions, which in turn will help to maintain their health and performance on the job [10][11].

This is because close relationships are such powerful regulators of psychological and physiological states. Physiological rhythms between crew and their friends and family can be calibrated and coordinated using computer-mediated communication. However, the psychobiological linkage research does not sufficiently take account of close friends and family separated by very large distances [12], certainly not on the scale of exploration class spaceflight. This research gap is important because it is long-distance relationships that typically experience higher levels of stress [13] and never more so than when prolonged separation is accompanied by a poverty of intimate communication [14].

Broadly, the few available studies tend to have very small populations, adopt a variety of approaches to time-delayed communication with varying fidelity to deep space exploration (e.g. only involving a limited range of operational tasks and not including personal communication between crew and their friends and family), making them hard to compare and combine into a larger, meaningful, data set.

Making progress

For the USA to achieve its objectives under the Artemis programme over the coming decade and beyond, the research field will need to accelerate to a higher cadence of long duration spaceflight analog studies with increasingly comparable data sets (they simulate time-delay in comparable and consistent approaches).

The research field will also need to expand its scope to routinely include the interactional effects of isolation (incorporating time-delayed communication), radiation and microgravity upon the biological functioning of the crew (particularly autonomous nervous system activity).

In practical terms such an acceleration and expansion of the field will require that time-delayed communication is integrated by default into an increasing number of missions across a variety of analog research platforms

In particular, data is needed to explain the role of isolation and interpersonal connection in how human physiology responds to changes in microgravity and radiation. Such experiments lend themselves ideally to analog research platforms with a robust time-delay condition and would describe a diverse range of objectives in terms of understanding how the autonomic nervous system navigates the array of spaceflight hazards.

The vast majority of this experimentation can and should be done in ground-based analogs and then, as cislunar operations get underway through the next decade, findings can be advanced through replication and innovation in deep space, such as with crew on Gateway, the planned lunar space station. While many spaceflight hazards are present in that environment, the underlying signal latency is small (1.3 secs one-way to the Moon) and would provide a test-bed for researching a range of latencies for deep space exploration in a very high-fidelity context.

Research teams and analog facility providers alike will need to be provided with accessible guidance for implementing time-delayed communication across their research activities to enable a robust metadata set to evolve.   The progress of the field can also be supported by deepening the network of innovators and investigators from industry and academia, partly through an annual conference hosted by an institution with credibility in human spaceflight research.

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