Investigating parameters of autonomy and communication in (cis)lunar missions to mitigate the hazards of human spaceflight in exploration class missions

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Introduction: The Artemis Science plan lays out the scientific objective, among a number, to deliver risk reduction for sustainable human space exploration. Crewed missions to the Gateway and activities on the lunar surface will serve as analogs for exploration class missions to Mars. With specific reference to health and performance, advances are required in the mitigation of all five hazards of human spaceflight: hostile closed environments, changes in gravity, radiation, distance from Earth, and isolation/confinement. This white paper is primarily concerned with the investigation of two of these hazards; distance from Earth and isolation/confinement. It focuses on the research required to understand how the modulation of space-ground communication, caused by distance, consequently impacts operational cooperation, crew health and performance due to resulting isolation. Consideration is also given to the interconnection of the five hazards through the health risks of chronic isolation.

Motivation: There will always be a need for space-ground communication; including operational collaboration with ground personnel (Crew-MCC), private medical conferences with flight surgeons (PMCs) and private conferences with family and friends (PFCs). Regular and consistent contact with family and friends will become increasingly important as missions extend in duration and distance because humans, neurophysiologically, require consistent access to love, affection and affiliation for adequate health and functioning over time (Porges, 2011). An inescapable consequence of distance from Earth is signal latency (time delay) in communication. Even small signal latencies cause severe disruption to the communication process and mutual understanding as participants struggle to keep track of the timing and relationship of messages sent and received. Frustration and confusion result as crew and ground support personnel misconstrue or misinterpret the content of messages or misread interpersonal signals (Fischer & Mosier, 2014). A signal latency of 50-seconds, imposed experimentally on communication between ground support personnel and crew on the International Space Station, was sufficient to significantly degrade communication quality, crew morale and individual wellbeing, generating significantly higher levels of stress and frustration compared to control conditions (Palinkas et al, 2017). Signal latency poses a formidable challenge to the collaboration between crew and ground support personnel because they impede communication efficiency and may ultimately hinder their joint task success (Kraut, Fussell, Brennan, & Siegel, 2002). Task success will be particularly important should unforeseen problems occur for which crews will need assistance from the ground, such as system failures or medical issues. Research on operational communication between ground support personnel and crew under conditions of time delay identified errors in three critical features of communication: 'timing' in terms of when to expect a response; 'thread' in terms of tracking and maintaining conversational threads, and 'transmission efficiency' in terms of chunking, clustering, together relevant information into a single message (Fischer & Mosier, 2014). The same researchers who identified these problems later concluded that communication protocols can go some way to mitigating the problem through crew effort, but what is needed, ultimately, is a technical tool that can relieve crew of the burden of trying to hold utterances together by theme and sequence against the corrosive impact of time delay (Fischer & Mosier, 2016),

Challenge: Disruption to communication caused by time delay (signal latency) is a primary factor in the isolation inherent to exploration class missions. Chronic isolation is extremely toxic to psychological and physical health because it is causally related to depression, anxiety, aggression, impulsivity, sleep disturbance and cognitive impairment (Cacioppo, Capitanio & Cacioppo 2014) as well as an increased risk of cardiovascular and inflammatory disease (Hawkley & Cacioppo, 2010). The

resulting health issues can have a cumulative effect that further exacerbates the impact of negative stressors from other categories of risk for human exploration such as the impact of social and sensory deprivation due to prolonged confinement within a hostile closed environment, the neurophysiological impact of changes in gravity and the impact of radiation on inflammatory processes. Research that advances effective communication between crew, ground personnel, and friends and family in exploration class missions is therefore crucial as it directly addresses the risks anchored in distance from Earth and isolation and also, due to the fundamental psychological and physiological systems involved, interconnects with the risks inherent to confinement in hostile closed environments, changes in gravity and radiation. For this reason, research in ground-based analogs and the ISS has, and continues to, provide foundational knowledge while Artemis III presents a unique opportunity for hypotheses about the connection between attachment, isolation and connection and the heath and performance of crew in exploration class missions, to be tested in the uniquely rigorous conditions of living and working farther from Earth and fully exposed to the hazards of spaceflight, on and around the moon.

Research: NASA's (2015) *The Journey to Mars: Pioneering the Next Steps* summarises that human activity on the lunar surface and cislunar space represents a crucial *proving ground* for 'science missions and capability demonstrations to close the remaining [strategic knowledge] gaps and ensure we have the ability to get to Mars, land safely, live and work productively, and return'. This white paper suggests that a section of the Artemis science plan concerned with the challenges of sustainable human space exploration focused on the hazards of human spaceflight, particularly those connected to signal latency, should seek to investigate the following lines of scientific enquiry by experimentally simulating exploration class mission signal latencies in communication during selected (cis)lunar missions:

- What is the precise form and severity of the impact of isolation and confinement (driven by time-delayed communication within a hostile closed environment) upon health and performance during (cis)lunar space operations and how does it intersect with autonomy?
- What are the main moderating factors in terms of the (cis)lunar context (e.g. changes in gravity, tasks, environmental stressors), and intrapersonal functioning (e.g. neurophysiology of emotion regulation), interpersonal relating (e.g. interactions between crew, ground personnel and communities of family and friends) and modality of connection (e.g. text, audio, video and their timing, duration and frequency)?
- What can be derived from these (cis)lunar investigations to define the specific innovation required to mitigate the impact of chronic isolation, and shifting balance and cadence of connection and autonomy, shaped by the demands of exploration class missions?

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