Mars-Walking: Enabling Capabilities for Crew Health and Performance during Exploration Extravehicular Activity

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The benefits, the opportunities, the challenges, and the risks of space exploration increase by orders of magnitude when sending humans out into the solar system. Keeping an otherwise healthy human alive in the most extreme of environments requires spacecraft with life support systems that provide a bubble of Earth-like atmosphere far out in the void of space. Even if that delicate bubble is successfully preserved and transported all the way from the launchpad to the surface of Mars and back again, the astronauts living inside of it are confronted with an array of challenges and stressors, some of which are immediately apparent while others may take weeks, months, or even years to manifest.

The transition from the strong pull of Earth's gravitational field to the sudden apparent weightlessness of Earth orbit can cause an array of symptoms including disorientation, headaches, nausea, vomiting, and gastro-intestinal discomfort. While these symptoms typically subside within 1-3 days as the central nervous system adapts, other long-term adaptations continue to occur in response to weightlessness, altered sleep cycles, isolation, radiation, fluctuating carbon dioxide levels and other environmental stressors. The body's muscles and bones lose strength in response to the unloading, while the ability to perform maximal or prolonged submaximal aerobic-based exercise decreases. Cephalad fluid shifts can cause congestion, affect taste and smell, and may contribute to structural changes in the eyes causing loss of visual acuity. Radiation exposure in low Earth orbit is ten times greater than that experienced on Earth, causing cellular damage that contributes to lowered immune function during spaceflight and increased lifetime cancer risk. When astronauts leave the protection of Earth's magnetosphere to explore beyond Earth orbit, the radiation exposure and associated risks become greater still. The myriad physiological stressors compound the psychological challenges associated with living in an isolated, confined and extreme environment. Astronauts typically work as members of international crews of up to seven people, with current missions lasting as long as a year; Mars missions lasting 2-3 years or more will far exceed previous human experience.

Long duration human missions to the moon and Mars will require new advanced technological capabilities, some of which do not yet exist. Where a capability is required for a future mission but it does not yet exist, NASA refers to these as Capability Gaps. This presentation describes challenges, progress, and opportunities associated with three Capability Gaps relating to maintaining human health and performance during extravehicular activity, or EVA. Sometimes referred to as spacewalking, EVA will be among the most frequent, highest workload, and highest risk activities during human missions to the moon and Mars. It is also perhaps the most important element, both functionally and symbolically, that distinguishes human space exploration from robotic missions.

Space Suit Fit and Injury. *Injury prediction, monitoring, and mitigation technologies to enable planning, training, operations, and system design for all suited mission phases and for all anticipated crewmember anthropometries.*

Multiple injuries to astronauts have occurred while working in past and present spacesuits, even with a relatively low frequency of EVAs. Reported injuries range in severity from blisters to fingernail delamination to shoulder injuries requiring surgery. In some cases, poor suit fit is believed to have been a contributing factor, and data has also shown that reduced recovery between successive EVAs also increases injury risk. Future exploration spacesuits must ensure that male and female astronauts of all potential shapes and sizes are not only accommodated by the suit, but that they can perform all necessary mission tasks without discomfort or increased injury risk. Changes in anthropometry that occur during spaceflight must also be identified and accommodated. Suits must also protect astronauts that are expected to perform far more EVAs, with far less recovery time than ever before. Apollo surface stays were up to three days in duration with astronauts wearing custom-fit spacesuits for up to three EVAs; current mission designs being considered by NASA call for as much as 24 hours of EVA per person per week throughout surface stays that may be months in duration. EVA injury incidence during Apollo as well as in the current spacesuit used on ISS suggests that musculoskeletal injuries affecting mission objectives, and potentially long term health, are not only possible but likely during these types of long duration surface missions unless improved fit and injury capabilities are developed and implemented.

EVA Crew Capabilities and Constraints. *Crewmember physical and cognitive state monitoring and prediction technologies to enable EVA planning, operations, system design, and decision support systems based on crewmember capabilities and constraints.*

When returning to Earth after long duration stays in microgravity, crewmembers are nauseated and have sometimes extremely reduced ability to perform even simple tasks such as walking until their vestibular system has readapted to the gravity environment. Unlike landing on Earth where a support team can lift astronauts out of their capsule, Mars astronauts must adapt to the transition from the microgravity of Mars transit to the partial gravity of Mars, get in their EVA suits and perform any necessary post-landing tasks themselves. Uncertainty and variability in what functions each astronaut will be capable of performing at any given point in a mission presents many challenges and this is compounded by uncertainty in the exact physical and cognitive demands and cost associated with many of those functions when performed in the lunar or Mars environment. As another example, the full-body physical workload associated with planetary EVA, especially in Mars gravity, is expected to be higher than for EVAs in microgravity where instances of fatigue-related performance decrements are already apparent. In addition to potential performance implications, this may also impact consumables usage, caloric expenditure, heat storage, CO_2 exposure, decompression sickness risk, and hydration. Capabilities to predict and monitor physical and cognitive state before and during EVA are currently very limited but will be essential to the safe planning and execution of EVA during Mars missions.

EVA Bioinformatics & Decision Support: *Ground-based and in-flight EVA decision support technologies to enable EVA crew health and performance monitoring and decision making during increasingly Earth-independent operations.*

The unavoidable communications latency between Earth and Mars will require that many of the support, monitoring, commanding, and control functions currently provided by a large team of flight controllers in Mission Control must in the future be performed by astronauts and their spacesuits or spacecraft – a paradigm shift that will require significant evolution of technology, training, and operations and is also likely to further increase the cognitive workload for EVA crewmembers. The physical and cognitive state prediction capability described above will be required to integrate with life support system models and purpose-built operational EVA planning and execution tools that protect and provide for health and performance during the planning, execution, and real-time replanning of EVAs. These capabilities are enabling for inflight crewmembers on Mars to fulfill the many critical EVA support functions currently performed by humans and systems in MCC, but they are also enhancing and possibly even enabling for high frequency EVA during lunar surface missions. Hundreds and sometimes thousands of person-hours go into planning and preparing for a single EVA on the International Space Station; significantly improved planning capabilities are required to enable high frequency exploration EVA.

Abercromby, A.F.J., et al, "Crew Health and Performance Extravehicular Activity Roadmap: 2020", NASA/TP-20205007604, https://www.nasa.gov/sites/default/files/atoms/files/tp-20205007604.pdf