Artificial Gravity
Research Plan

AG Research Group

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Artificial Gravity Research Plan

This document describes the forward working plan to identify what countermeasure resources are needed for a vehicle with an artificial gravity module (intermittent centrifugation) and what Countermeasure Resources are needed for a rotating transit vehicle (continuous centrifugation to minimize the effects of microgravity to Mars Exploration crewmembers.)
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Continuous AG5: We do not know if additional countermeasures will be required to supplement continuous AG during transit .................................................................
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HRP ARTIFICIAL GRAVITY RISK
The most serious risks to long duration flight involve radiation, behavioral stresses, and physiological deconditioning. Artificial gravity (AG), by substituting for the missing gravitational cues and loading in space, has the potential to fully mitigate the last of these risks by preventing the adaptive responses from occurring.

Risk Statement
The rotation of a Mars-bound spacecraft or an embarked human centrifuge offers significant promise as an effective, efficient multi-system countermeasure against the physiological deconditioning associated with prolonged weightlessness. Virtually all of the identified risks associated with bone loss, cardiovascular deconditioning, muscle weakening, sensorimotor disturbances, space anemia, and immune compromise might be alleviated by the appropriate application of AG.

Risk Context
Experience with AG in space has been quite limited and a human centrifuge is currently not available on board the ISS. A complete R&D program aimed at determining the requirements for gravity level, gravity gradient, rotation rate, frequency, and duration of AG exposure is warranted before deciding the best technique for implementing AG in space.

Criticality Metric
The current criticality rating for physiological deconditioning is…

Operational Relevance
During the Exploration program all crewmembers will need to perform at a high level of competence after landing on Mars. There is evidence that following a six-month stay in microgravity, bone and muscle mass are lost, the cardiovascular, pulmonary and immune systems are weakened, vision could be impaired, the vestibular system no longer senses tilt and as a result balance could be off.

Mitigation Strategy
Past efforts to mitigate physiological deconditioning have focused on countermeasures delivered in a piece-meal fashion, e.g., LBNP and fluid loading for the cardiovascular system, exercise for muscle and bone. Although the risk due to physiological deconditioning has been greatly reduced through these countermeasures, it is at the expense of significant crew time and equipment. Artificial gravity (AG) presents the advantage of reproducing Earth-like gravity and therefore affecting all the physiological systems. AG can be generated by rotating the entire spacecraft continuously, or by means on an on-board short-radius centrifuge that the crewmembers will ride intermittently. We need to determine the rotation rate, radius, and duration of exposure that are the most efficient for maintaining physiological conditioning in microgravity so that optimal decisions on the vehicle capabilities can be made early in the Exploration Program.
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Point of Contact
Gilles Clement

Gaps and Tasks
Artificial gravity generated by a rotating environment is an untested area in orbit. Simulations will be performed using short and long-radius centrifugation in ambulatory subjects, patients with VIIP syndrome, during bed rest, immersion, and head-up tilt. Investigations will also be conducted in animals in ground-based simulation studies and during centrifugation on board the ISS.

The first series of gaps will address the issues with intermittent centrifugation using an onboard short-radius centrifuge (IAG). The second series of gaps will address the issues with continuous rotation of the space vehicle (CAG).

Information gained during the tasks in IAG Gap 1 will primarily determine the most effective AG level and duration during short-radius centrifugation (SRC) for protecting against sensorimotor disturbances and orthostatic intolerance in microgravity, as well as preventing from adverse health consequences, including neurocognitive impairment. The tasks in IAG Gap 2 will assess the protective role of SRC on the musculoskeletal in humans and animals, and whether additional exercise, integrated on the centrifuge or not, is required for better protection. The tasks in IAG Gap 3 will assess the effects of SRC on intracranial pressure. The tasks in IAG Gap 4 will specifically investigate the effects of Martian gravity (0.38 G) on physiological deconditioning during simulation studies or immediately after six-month stays in actual microgravity. This information will be important for determining whether AG will be needed on the Martian surface.

The tasks in CAG Gap 1 will assess crew health and performance of the various physiological systems during long-duration exposure to a rotating environment compatible with those of a rotating space vehicle. The tasks in CAG Gap 2 will validate the limits for rotation rate and radius regarding exercise, ambulation, material handling, and EVA operations. The more information gained through CAG Gaps 3 and 4 will result in a more efficient closure of CAG Gap 2 by assessing the consequences of spin-up and spin-down of a rotating transit vehicle. Finally CAG Gap 5 will determine if additional countermeasures will be required to supplement continuous AG during transit.

Intermittent AG1: We do not know if a Short-Radius Centrifuge (SRC) is effective for protecting against sensorimotor disturbances (SM) and orthostatic intolerance (OI) in microgravity

Present State: SRC have been used during 5-21 day bed rest studies for generating 1-2 G at the heart along the subjects’ body axis for 30 minutes to 2 hours per day. This intermittent centrifugation has been beneficial for maintaining orthostatic tolerance, blood volume, parasympathetic activity, exercise capacity, and postural stability. However, it was not efficient
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for preventing immune system deficiency, and the effects on cognition and muscle and bone loss were inconclusive. In addition the effects of multiple (shorter) daily centrifugation sessions vs. a single bout of centrifugation have not been systematically studied so far. In all the past studies the subject’s head was immobilized so the effects of cross-coupled angular and Coriolis accelerations during head and limb movements are not known. Finally, a human factor analysis of crew acceptability and comfort is not currently available.

**Target for Closure: TBD**

**Interim Stages:**

<table>
<thead>
<tr>
<th>Task</th>
<th>Incomplete/Complete</th>
</tr>
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<tbody>
<tr>
<td>Determine the most effective AG level</td>
<td>Incomplete</td>
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<td>Incomplete</td>
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</table>

*Note: Closure metric = (number of tasks completed/number of tasks) x 100*

**Approach:** A multidisciplinary AG working group including scientists, engineers, and flight surgeons will convene to determine the range of AG level and duration to be tested in these tasks, and the standard baseline core data to be measured before, during and after centrifugation.

**Effectiveness of SRC against SM and OI**

- **Short Title:** Effectiveness of SRC against SM and OI
- **Not Completed**

**Task Narrative:**

This ground-based effort is required to validate if AG level at the heart lower than 1 Gz and if the duration of SRC less than 1 hour still prevents sensorimotor and cardiovascular deconditioning. A slower rotation rate would induce less cross-coupled angular and Coriolis acceleration (and the associated spatial disorientation) during head and body movements, thus being more acceptable by the crew. The specific effects of the gravity gradient will also be investigated by comparing the same rotation rate between short-and long-radius centrifugation. The effects of SRC on neurocognitive function and post-flight decrease in performance will also be evaluated.

**Resources:**

**Deliverables:**