Response of Ambulatory Human Subjects to Artificial Gravity (Short Radius Centrifugation)

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Background

Prolonged exposure to microgravity results in significant adaptive changes, including cardiovascular deconditioning, muscle atrophy, bone loss, and sensory-motor reorganization, that place individuals at risk for performing physical activities after return to a gravitational environment. Planned missions to Mars include unprecedented hypogravity exposures that would likely result in unacceptable risks to crews. Artificial gravity (AG) paradigms may offer multi-system protection from the untoward effects of adaptation to the microgravity of space or the hypogravity of planetary surfaces. While the most effective AG designs would employ a rotating spacecraft, perceived issues may preclude their use. The questions of whether and how intermittent AG produced by a short-radius centrifuge (SRC) could be employed have therefore sprung to the forefront of operational research. In preparing for a series of intermittent AG trials in subjects deconditioned by bed rest, we have examined the responses of several healthy, ambulatory subjects to SRC exposures.

Methods

Eleven ambulatory subjects (6M, 5F; age=24–52 yrs, height=155–183 cm, weight=48–84 kg) were tested. Prior to testing, each passed a medical examination and a cardiovascular stress test, and each provided written informed consent. AG was produced by spinning subjects on a 3.0 m radius SRC. Subjects were oriented radially in the supine position (6° head down) so that the centrifugal force was (nearly) aligned with the long body axis. Subjects were secured to a subject station that allowed free translation over approximately 10 cm along the long body axis to ensure full loading of the lower extremities and to allow for anti-orthostatic muscle contractions. The head was not restrained, but no head movements were required of the subjects. While spinning, the subject "stood" on a force plate. The radius of the plate (2.0–2.4 m) and the angular velocity of the SRC (30.6–33.4 rpm) were adjusted for each subject to achieve the desired centripetal acceleration at the feet (2.5 g) and loading gradient along the body (1.0 g at the heart level). Once the subject was secured, the centrifuge was accelerated at 5–10°/sec^2, maintained at the desired constant velocity for 60–75 min, and then decelerated at 5–10°/sec^2. Ramp-up and ramp-down times were fixed at 60 sec.

During rotation, the subject's cardiovascular responses were monitored via electrocardiogram (ECG), blood pressure, and pulse oximetry. Foot reaction forces in the body z-, y-, and x-directions were collected using a force plate. Motor activity (EMG) data were collected from the quadriceps, the bicep femoris, the tibialis anterior, and the medial gastrocnemius of the right leg. Otolith stimulation was estimated using triaxial accelerometers mounted to the subject station at the level of the subject's ears. Subjective assessments of motion sickness (scale= 1(excellent) to 20 (vomiting), with 10=half way to vomiting) were collected periodically during the spins.

Results

Six of the 11 centrifuge runs (1F, 5M) were completed as planned; five runs (4F, 1M) were terminated early due to subject health concerns (4=pre-syncope, 1=motion sickness). Mean heart rate and blood pressure increased at the onset of rotation from 70.2 ± 3.7 bpm and 85.9 ± 4.1 mmHg to 85.3 ± 3.7 bpm and 101 ± 16 mmHg, respectively. Lower extremity mechanical loading during the spins was greater than that for standing (mean z-axis reaction force was 130 ± 6 % of the subject's body weight), while z-acceleration stimulation of the otolith organs was less than that for standing (6.8 ± 0.08 m/sec^2). Active contractions of the antigravity muscles of the upper legs were infrequent, with the quadriceps and bicep femoris groups active only 1.3% and 4.1% of the total time. Active contractions of the antigravity muscles of the lower legs were more frequent, with the tibialis anterior and medial gastrocnemius groups active for 7.8%, and 26.9% of the total time. Motion sickness symptoms were reported during three of the spins, and one spin had to be terminated due to increased nausea, but, apart from the terminated run, the maximum motion sickness score was generally low (1.5 ± 2.2).

Discussion

The results obtained from this ambulatory subject group were consistent with our expectations for the physiological and perceptual responses to prolonged inertial loading along the long body axis. The relatively low incidence of motion sickness symptom development was encouraging for the next phase of testing with bed rest deconditioned subjects, but the high incidence of presyncope among the female subjects suggests that more work needs to be done understanding the cardiovascular responses within this subgroup before subjecting them to inertial loading during deconditioning. We conclude that it is safe to begin testing this set of artificial gravity parameters in male subjects deconditioned by bed rest.