Human Performance in Simulated Reduced Gravity Environments

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Introduction: NASA is currently designing a new space suit capable of working in deep space and on Mars. Designing a suit is very difficult and often requires trade-offs between performance, cost, mass, and system complexity.

Our current understanding of human performance in reduced gravity in a planetary environment (the moon or Mars) is limited to lunar observations, studies from the Apollo program, and recent suit tests conducted at JSC using reduced gravity simulators. This study will look at our most recent reduced gravity simulations performed on the new Active Response Gravity Offload System (ARGOS) compared to the C-9 reduced gravity plane.

Methods: Subjects ambulated in reduced gravity analogs to obtain a baseline for human performance. Subjects were tested in lunar gravity (1.6 m/s^2) and Earth gravity (9.8 m/s^2) in shirt-sleeves. Subjects ambulated over ground at prescribed speeds on the ARGOS, but ambulated at a self-selected speed on the C-9 due to time limitations. Subjects on the ARGOS were given over 3 minutes to acclimate to the different conditions before data was collected. Nine healthy subjects were tested in the ARGOS (6 males, 3 females, 79.5 ± 15.7 kg), while six subjects were tested on the C-9 (6 males, 78.8 ± 11.2 kg).

Data was collected with an optical motion capture system (Vicon, Oxford, UK) and was analyzed using customized analysis scripts in BodyBuilder (Vicon, Oxford, UK) and MATLAB (MathWorks, Natick, MA, USA).

Results: In all offloaded conditions, variation between subjects increased compared to 1-g. Kinematics in the ARGOS at lunar gravity resembled earth gravity ambulation more closely than the C-9 ambulation. Toe-off occurred 10% earlier in both reduced gravity environments compared to earth gravity, shortening the stance phase. Likewise, ankle, knee, and hip angles remained consistently flexed and had reduced peaks compared to earth gravity. Ground reaction forces in lunar gravity (normalized to Earth body weight) were 0.4 ± 0.2 on the ARGOS, but only 0.2 ± 0.1 on the C-9.

Discussion: Gait analysis showed differences in joint kinematics and temporal-spatial parameters between the reduced gravity simulators and with respect to earth gravity. Although most of the subjects chose a somewhat unique ambulation style as a result of learning to ambulate in a new environment, all but two were consistent with keeping an Earth-like gait. Learning how reduced gravity affects ambulation will help NASA to determine optimal suit designs, influence mission planning, help train crew, and may shed light on the underlying methods the body uses to optimize gait for energetic efficiency.

Conclusion: Kinematic and kinetic analysis demonstrated noteworthy differences between an offloaded environment and 1-g, as would be expected. The analysis showed a trend to change the ambulation style in an offloaded environment to a rolling-loping walk (resembling crosscountry skiing) with increased swing time. This ambulation modification, particularly in the ARGOS, indicated that the relative kinetic energy of the subject was increased, on average, per the static body weight compared to the 1-g condition. How much of this was influenced by the active offloading of the ARGOS system is unknown.