The Gravity Rig Trials: Cardiorespiratory Response and Performance in Gravity Environments

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Abstract

This study examines the cardiorespiratory responses of analog astronauts performing bipedal walking locomotion during extravehicular activities (EVAs) in simulated gravity environments using a dual-axis reduced gravity rig. Conducted at the SAM (Space Analog for the Moon and Mars) Habitat at the University of Arizona, the trials investigated locomotion under Martian, Lunar, and Earth gravity conditions. Physiological performance and gait adaptation were analyzed using Garmin heart rate sensors and sidereal GoPro footage. Preliminary findings suggest that individual metrics and suit constraints influence movement efficiency and fatigue. This research contributes to the optimization of EVA protocols and suit design for future planetary exploration.

Keywords: analog astronaut, EVA, bipedal locomotion, cardiorespiratory response, SAM Habitat, space exploration, human performance

Pruebas de la plataforma de gravedad: Respuesta cardiorrespiratoria y rendimiento en entornos de gravedad

Resumen

Este estudio examina las respuestas cardiorrespiratorias de astronautas análogos que realizan locomoción bípeda durante actividades extravehiculares (EVA) en entornos de gravedad simulada utilizando un equipo de gravedad reducida de doble eje. Realizados en el Hábitat SAM (Análogo Espacial para la Luna y Marte) de la Universidad de Arizona, los ensayos investigaron la locomoción en condiciones de gravedad marciana, lunar y terrestre. El rendimiento fisiológico y la adaptación a la marcha se analizaron utilizando sensores de frecuencia cardíaca Garmin e imágenes siderales de GoPro. Los hallazgos preliminares sugieren que las métricas in-

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dividuales y las limitaciones del traje influyen en la eficiencia del movimiento y la fatiga. Esta investigación contribuye a la optimización de los protocolos de EVA y el diseño de trajes para la futura exploración planetaria.

Palabras clave: astronauta analógico, EVA, locomoción bípeda, respuesta cardiorrespiratoria, hábitat SAM, exploración espacial, rendimiento humano

重力试验台试验：重力环境下的心肺反应和表现

摘要

本研究利用双轴减重力装置，在模拟重力环境下考察了模拟宇航员在舱外活动(EVA)期间进行双足行走运动的心肺反应。试验在亚利桑那大学的月球和火星模拟空间(SAM)栖息地进行，研究了火星、月球和地球重力条件下的运动情况。研究采用Garmin心率传感器和GoPro星空影像分析了生理机能和步态适应情况。初步结果表明，个体指标和宇航服的限制会影响运动效率和疲劳程度。本研究有助于优化未来行星探测的舱外活动方案和宇航服设计。

关键词：模拟宇航员，舱外活动，双足行走，心肺反应，SAM栖息地，太空探索，人体机能

Introduction

This research explores the cardiorespiratory responses of analog astronauts performing bipedal walking locomotion EVAs in simulated gravity environments. Mars presents a unique challenge: one-third Earth gravity, unfamiliar terrain, and long-duration EVAs. While robotic movement on Mars has been extensively studied, human locomotion under Martian gravity remains largely unexplored. This study aims to fill that gap by simulating EVA conditions and analyzing how astronauts respond physically and physiologically. By optimizing astronaut performance and perfecting bipedal locomotion, further explorations can be conducted more effectively on various extraterrestrial surfaces.

Methods

This research was conducted at the SAM (Space Analog for the Moon/Mars Habitat) analog facility located at the University of Arizona. EVA locomotion trials were conducted using a dual-axis reduced gravity rig system equipped with counterweights to simulate planetary gravity conditions. Five analog astronauts participated in Martian gravity trials

(0.38g), one of whom also performed trials under Earth (1g) and Lunar (0.16g) gravity. Each trial lasted 20 minutes, with a 5-minute segment selected for data analysis based on gait quality and minimal interference.

Data collection included sidereal GoPro footage for step count and qualitative gait analysis, as well as Garmin heart rate sensors worn beneath the suit for quantitative cardiorespiratory data collection. Astronauts represented a diverse range of age, gender, height, and weight, allowing for broader trend analysis.

Observations

Astronauts adapted to reduced gravity at varying rates. Fatigue increased over time, particularly due to suit constraints. Movement efficiency varied across trials, with individual metrics (age, gender, height, and weight) influencing performance. These findings may inform future suit design and EVA protocols.

In each trial, the astronaut lightly touched the treadmill handrails for stability as they adapted to the new gravity. A SAM team member provided real-time support and monitoring throughout the EVA.

Future Research

Future studies will expand participant diversity, explore alternative gaits such as jogging and skipping, and integrate terrain simulation for higher fidelity. Cardiorespiratory responses across different gravity profiles will be examined in greater detail to better understand astronaut performance and efficiency.

Personal Reflection

> "I walked out into the Mars yard, and it felt surreal. To be walking slowly, hearing the oxygen flood my helmet, the sound of my respiration echoing in my ears, my vision impaired by the dome helmet. I was living my dream. I was on Mars." ~ Keston Denhalter (Sol 2- 2/14/25)

Simulating EVAs in analog environments offers incredible insight into the human experience of space exploration. As we prepare to return to the Moon, Mars is just on the horizon, a world with unfamiliar conditions and environments. While robotic missions have mapped and sampled Martian terrain, the true test will come when humans set foot on its surface. Every analog trial conducted on Earth helps make that transition smoother, safer, and more informed.

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