TEMPORAL CHANGES IN ASTRONAUTS' MUSCLE AND CARDIORESPIRATORY PHYSIOLOGY PRE-, IN-, AND POST-SPACEFLIGHT

M.E. Downs[1], C. Ade[2], T.J. Barstow[2], J. Ryder[3], D. Martin[3], A.F. Abercromby[1], S.M. Smith[1], J. Norcross[3], E. Goetchius[4], A. Feiveson[1]

[1]NASA Johnson Space Center, Houston, TX; [2] Department of Kinesiology, Kansas State University [3]KBR, Houston, TX [4]University of Houston, Houston, TX

Abstract

Background. NASA's vision for future exploration missions depends on the ability to protect astronauts' health and safety for performance of Extravehicular Activity (EVA), and to allow astronauts to safely egress from vehicles in a variety of landing scenarios (e.g. water landing upon return to Earth and undefined planetary/lunar landings). Prolonged exposure to spaceflight results in diminished tolerance to prolonged physical activity, decreased cardiac and sensorimotor function, and loss of bone mineral density, muscle mass, and muscle strength. For over 50 years exercise has been the primary countermeasure against these physiologic decrements during spaceflight, and while the resulting protection is adequate for ISS missions (i.e., Soyuz landing, microgravity EVAs), there is little information regarding time-course changes in muscle and aerobic performance. As spaceflight progresses towards longer exploration missions and vehicles with less robust exercise capabilities compared to ISS, countermeasures will need to be combined and optimized to protect crew health and performance across all organ systems over the course of exploration missions up to 3 years in duration. This will require a more detailed understanding of the dynamic effects of spaceflight on human performance. Thus, the focus of this study is quantifying decrements in physical performance over different mission durations, and to provide detailed information on the physiological rational for "why" and "when" observed changes in performance occur.

Methods: The research proposed will temporally profile changes in astronauts' cardiorespiratory fitness, muscle mass, strength, and endurance over spaceflight missions of 2 months, 6 months, and up to 1 year in duration. Additionally, an extrapolation model will provide predictions for changes associated with exploration missions 2-3 years in duration. To accomplish these objectives astronauts will be asked to participate in pre, in, post-flight measurement of muscle performance, muscle size, cardiorespiratory fitness and submaximal performance capabilities, as well as non-invasive assessment of cerebral and muscle oxygenation and perfusion (Table 1). Additionally, ambulatory and in-flight exercise, nutrition, and sleep will be monitored using a variety of commercial technologies and in-flight assessment tools.

Significance: Our detailed testing protocol will provide valuable information for describing how and when spaceflight-induced muscle and aerobic based adaptations occur over the course of spaceflight missions up to and beyond 1 year. This information will be vital in the assessment as to whether humans can be physically ready for deep space exploration such as Mars missions with current technology, or if additional mitigation strategies are necessary.

Background

The physiological adaptations associated with unloading and the effectiveness of exercise countermeasures have been characterized during spaceflight and bed rest [1-5]. Specifically related to our aims herein, daily aerobic and resistance exercise are performed during International Space Station (ISS) missions to maintain physical fitness; however, to date these exercise countermeasures are not fully protective. Briefly, average maximal aerobic capacity (VO_2pk), lower body muscle cross-sectional area (CSA) and strength are decreased by approximately 10% to 15% after short-duration (~14 days) and long-duration (~6 months) ISS spaceflight and simulated microgravity exposure (i.e., bed rest) [1, 6-11].

Furthermore, there is considerable variability among crewmembers with respect to spaceflight induced losses in physical performance parameters ranging from no loss to 30% decline [2, 12]. Understanding individual differences in physiological adaptation and performance capabilities across different time exposures to spaceflight, and how much can be attributed to microgravity alone vs changes in other factors such as nutrition and exercise, is critical in optimizing astronauts' health and performance during exploration class missions.

This study will provide data necessary to improve or even individualize exercise prescriptions and countermeasures for exploration class mission tasks and astronaut health and performance.

Specific Aims

1. Quantify time course of changes in physical performance including cardiorespiratory fitness and muscle mass, strength, and endurance pre-, in-, and post-spaceflight missions that are 2 months, 6 months, and 1 year in duration using standardized research and medical tests previously validated in 1-G and 0-G.
2. Quantify the individual variability in astronauts' changes in the physical performance parameters (cardiorespiratory fitness, and muscle mass, strength, and endurance) pre-, in-, and post-flight in relation to exposure time to 0-G

Methods

Astronauts will be asked to participate in a battery of pre-, in-, and post-flight measurements listed (Table 1) and depicted (Figures 2-8) below. Each test has either been previously conducted with ISS astronauts and/or has been shown to be correlated with exploration mission task performance and vehicle egress. Additionally, physical activity, sleep, nutrition, and stress will be collected pre and in-flight using commercial biometric sensor tools or existing flight certified hardware.

Statistical Approach

A mixed-model regression will be used to model the time course changes of cardiorespiratory fitness and muscle size and performance over missions of varying length, up to one year. Models will include overall (mean or median) in-flight and recovery trends as well as intra- and inter-subject random effects that account for variation around those trends. With the incorporation of new data from longer missions, we expect to be able to develop a good non-linear trend model that can be extrapolated to make predictions for even longer missions, up to three years. Other than time in flight and mission duration, the model will also allow for the inclusion of possible explanatory covariates such as nutrition, exercise history, etc.

Table 1. Complete list of testing to be completed by participants with associated pre-, in- and post- flight time points.

Test	Pre-flight	In-flight	Post-flight
Muscle Strength and Size			
Muscle performance battery (Figure 1 A&B)	L-180, L-50	NA	R+1, R+5, R+30
Isokinetic muscle strength (Figure 1 C)	L-270, L-50	NA	R+5, R+14, R+30
Isometric Mid-thigh Pull (Figure 1 D)	L-180, L-50	FD7, FD14, FD30, FD45, FD60, monthly, R-7	R+1, R+5, R+30
MRI (Figure 1 E)	L-30	NA	R+1
Muscle Ultrasound (Figure 1 F&G)	L-30	FD30, FD60, FD90, FD180, FD270, R-7	R+0/1
Aerobic Fitness			
VO_2pk test paired with measures of cardiac function, arterial blood pressure, and tissue oxygen saturation (Figure 2)	L-365, L-90/30	FD14, FD45, FD75, continue monthly, R-14	R+1, R+10, R+30
Critical power test	L-365, L-90/30	FD7, FD14, FD30, FD45, FD60, continue monthly, R-14	R+5, R+30
Biometric Monitoring			
Physical activity, Nutrition, sleep, stress monitoring (Figure 3)	2 continuous week at L-180 & L-50	Continuous or as indicated by MedB and Standard Measures	No study requirement

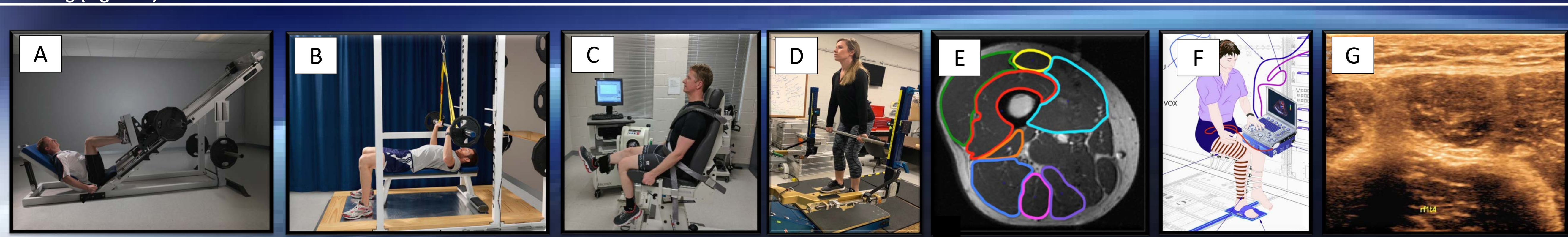

Figure 1. Battery of muscle strength and size tests. From left to right: A, B, C, & D) Battery of strength tests used to assess upper and lower body muscle performance measures of maximal isometric force, peak power, total work , and fatigue index; E) MRI image used to calculate muscle cross sectional area; F & G) Ultrasound image acquisition used to measure muscle thickness.

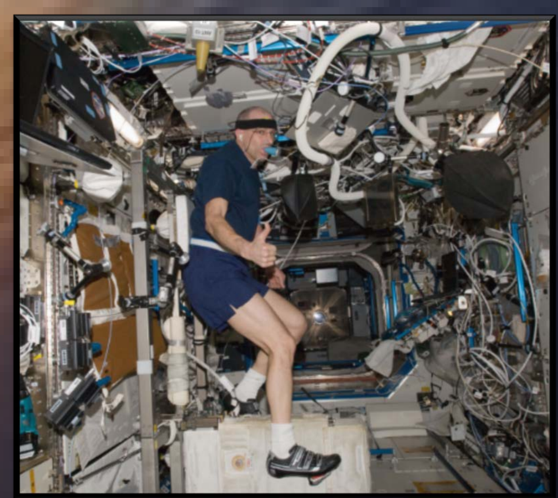

Figure 2. In-flight VO_2pk test using the Portable Pulmonary Function System (PPFS) and CEVIS.

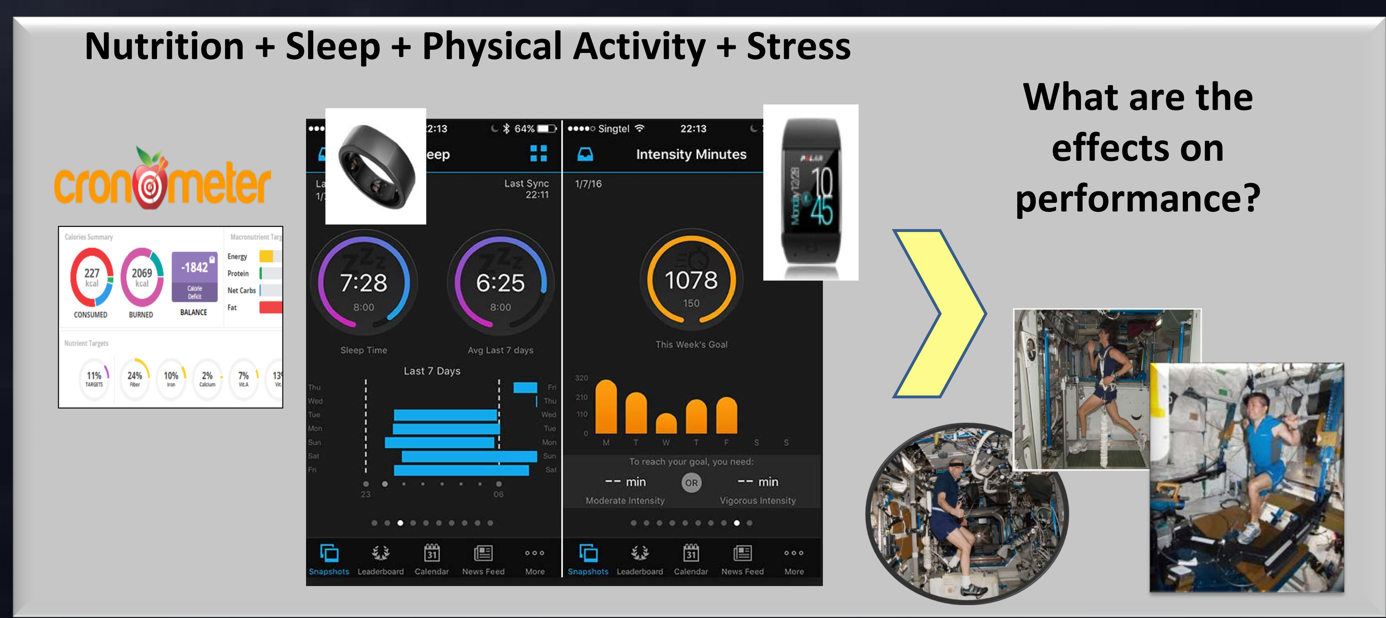

Figure 3. Example biometric monitoring used to inform physiological responses and individual variability in response.

HRP Gaps Addressed

- Risk of Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance (Gaps: M2, M4, M6, M23, M24, SM7.1)
- Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Gaps: CV2, A4, A6)
- Risk of Inadequate Nutrition (Gaps: N3.1, N3.3, N7.1, N7.2)
- Risk of Cardiac Rhythm Problems (Gaps: CV1)
- Risk of Spaceflight-associated Neuro-Ocular Syndrome (Gaps: SANS1)

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