TEMPORAL CHANGES IN ASTRONAUTS' MUSCLE AND CARDIORESPIRATORY PHYSIOLOGY BEFORE, DURING, AND AFTER SPACEFLIGHT

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Abstract

Background: NASA's planned space exploration missions will require astronauts to safely perform extravehicular activity (EVA) and to safely egress vehicles in a variety of landing scenarios. Prolonged exposure to spaceflight can diminish tolerance for physical activity, decrease cardiovascular and sensorimotor function, cause loss of bone mineral density, as well as reduced muscle mass and strength. Although exercise can mitigate these spaceflight-induced physiological decrements, little is known regarding the time-course of changes in muscle and aerobic performance during spaceflight. Furthermore, these exercise countermeasures are not fully protective. For example, maximal aerobic capacity (VO_2pk), lower body muscle cross-sectional area, and strength decrease by about 10% to 15% after short- (≈14 days) and long-duration (≈6 months) missions on the International Space Station (ISS). Future space missions longer in duration and further from Earth will employ exploration vehicles that will have exercise hardware with less robust and more constrained exercise capabilities than of those available on the ISS. Thus, countermeasures will need to be optimized to protect crew health and performance on exploration-class missions lasting up to 3 years. This requires a more detailed understanding of the dynamic effects of spaceflight on human health and performance, the ability of exercise to protect against this deconditioning, and the interaction of exercise with interrelated factors like nutrition, sleep, and environmental conditions.

Methods: We will use standardized research and medical testing protocols previously validated in 1g and microgravity to quantify the time course and the inter-individual variability of changes in physical performance, including cardiorespiratory fitness and muscle strength and endurance, before, during, and after spaceflight missions lasting 2 months, 6 months, and 1 year. Additionally, we will use an extrapolation model to predict changes associated with multi-year exploration missions. Additionally, we will monitor in-flight exercise, nutrition, and sleep using in-flight assessment tools.

Significance: Our testing protocols will provide valuable information for determining time course of change and the interindividual variability of spaceflight-induced deconditioning of aerobic capacity and muscle strength and endurance over the course of spaceflight missions up to and beyond 1 year. This information will be vital to assess whether humans can be physically ready for deep space exploration, such as on a mission to Mars, using current technology, or if additional mitigation strategies are necessary.

Objective and Aims

The objectives of this study are to quantify decrements in physical performance over various spaceflight mission durations and to provide detailed information on the physiological rational for "why" and "when" observed changes in performance occur. 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 individualized exercise prescriptions and countermeasures for exploration class mission tasks and astronaut health and performance. The specific aims for this study include:

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 1g and microgravity.
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 microgravity.

Methods

Astronauts will be asked to participate in a battery of pre-, in-, and post-flight measurements listed in Tables 1 and 2 and depicted in Figure 1. Each test has either been previously conducted with ISS astronauts and/or has been shown to be correlated with exploration mission task performance and/or vehicle egress. Additionally, data from other experiments and Medical Operations (MEDB) on physical activity, sleep, nutrition, stress, and bone health will be collected pre-, in-, and post-flight, as indicated.

This study is part of the Complement of Integrated Protocols for Human Exploration Research (CIPHER) and will collect data from 30 astronauts (n=10 for each mission duration of 2 months, 6 months, and 1 year). Data collection is projected to start early 2023.

Methods (continued)

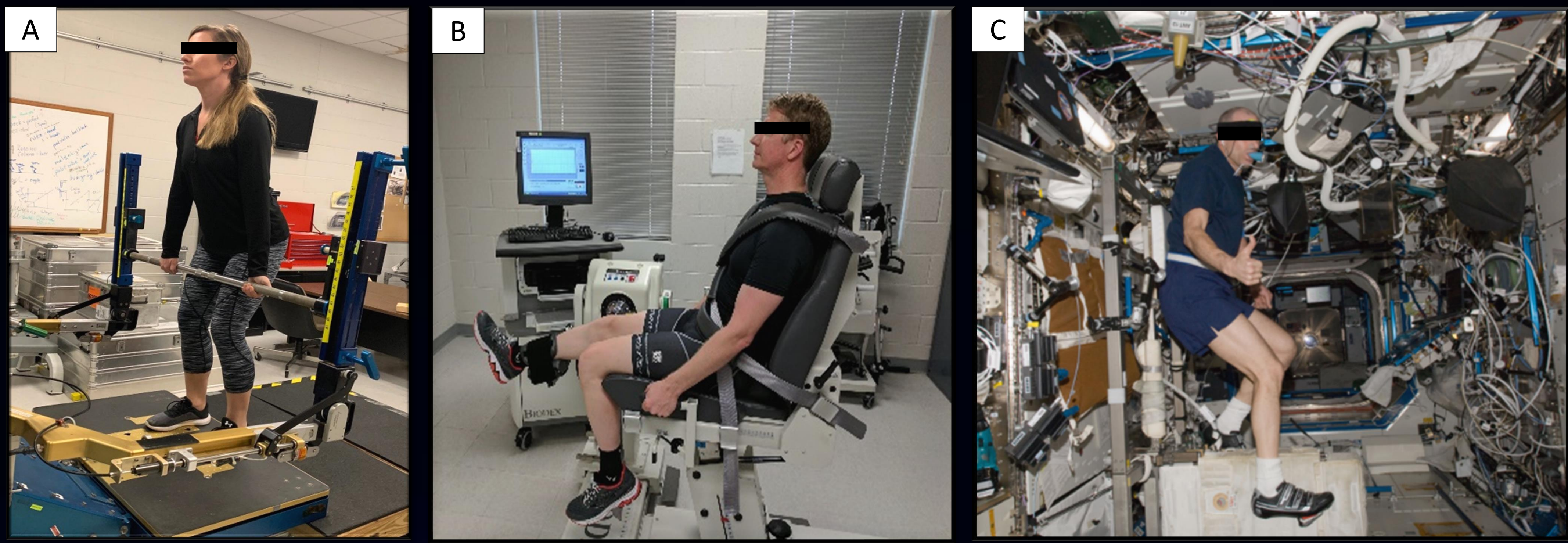

Figure 1. Primary study tests for muscle and aerobic capacity.
A) Isometric mid-thigh pull for performance measure of maximal isometric force
B) Isokinetic strength testing for isokinetic peak torque (strength) and total work (endurance)
C) Peak aerobic capacity (VO_2pk) test using the Portable Pulmonary Function System (PPFS) and CEVIS.

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

Test	Data Share	Pre-flight	In-flight	Post-flight
Muscle Strength				
Isometric Mid-thigh Pull (Figure 1A)	-	L-90/30	FD14 (±7), R-14 (±7)	R+5 to R+7, R+30 (±3)
Isokinetic muscle strength (Figure 1B)	MEDB	L-270/180, L-90/30	-	R+5 (±1), R+14 (±1), R+30 (±2)
Aerobic Fitness				
VO_2pk test (Figure 1C)	MEDB	L-180, L-60	FD14, FD75, R-14	R+5 (±2), R+30 (±4)

VO_2pk, aerobic capacity; MEDB, Medical Operations; L-XX, Launch-days; R±XX, Return±days; FD, Flight Day

Table 2. Secondary outcomes of testing to be completed by participants with associated pre-, in-, and post-flight time points.

Test.	Data Share	Pre-flight	In-flight	Post-flight
Bone				
HR-PQCT	TBone2 Study	Pre- and Post-flight measures as indicated by TBone2 Study		
DXA BMD & Body Composition	MEDB	L-180/30	-	R+5/30
Diet & Physical Activity				
Dietary and supplement intake	MEDB	L-90/30	Weekly or as clinically indicated by MEDB	R+0, R+20/30
Exercise/physical activity logs	MEDB		As indicated by MEDB	
Actigraphy	Standard Measures	-	Continuous or as indicated by Standard Measures	-
Other				
Fitness & Performance Outcomes	Egress Fitness/MEDB	L-270/180, L-90/30	-	R+5/7, R+30
Sleep, Sensorimotor, Cognition	MEDB/ Standard Measures	L-90, L-30	Continuous or as indicated by MEDB and Standard Measures	R+0, R+1, R+2, R+30

HR-PQCT, high resolution peripheral quantitative computed tomography; DXA, dual-energy X-ray absorptiometry; BMD, bone mineral density; MEDB, Medical Operations; L-XX, Launch-days; R±XX, Return±days; FD, Flight Day

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 non-linear trend model that can be extrapolated to make predictions for even longer missions, up to three years. In addition to time in-flight and mission duration, the model will also allow for the inclusion of possible explanatory covariates such as nutrition, exercise history, etc.

HRP Risks 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)

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