IEEE AEROSPACE CONFERENCE 2023
MARCH 5-12, 2023 AT THE YELLOWSTONE CONFERENCE CENTER IN BIG SKY, MONTANA

THE EFFECTS OF SPACE FLIGHT AND MICROGRAVITY EXPOSURE ON FEMALE ASTRONAUT HEALTH AND PERFORMANCE

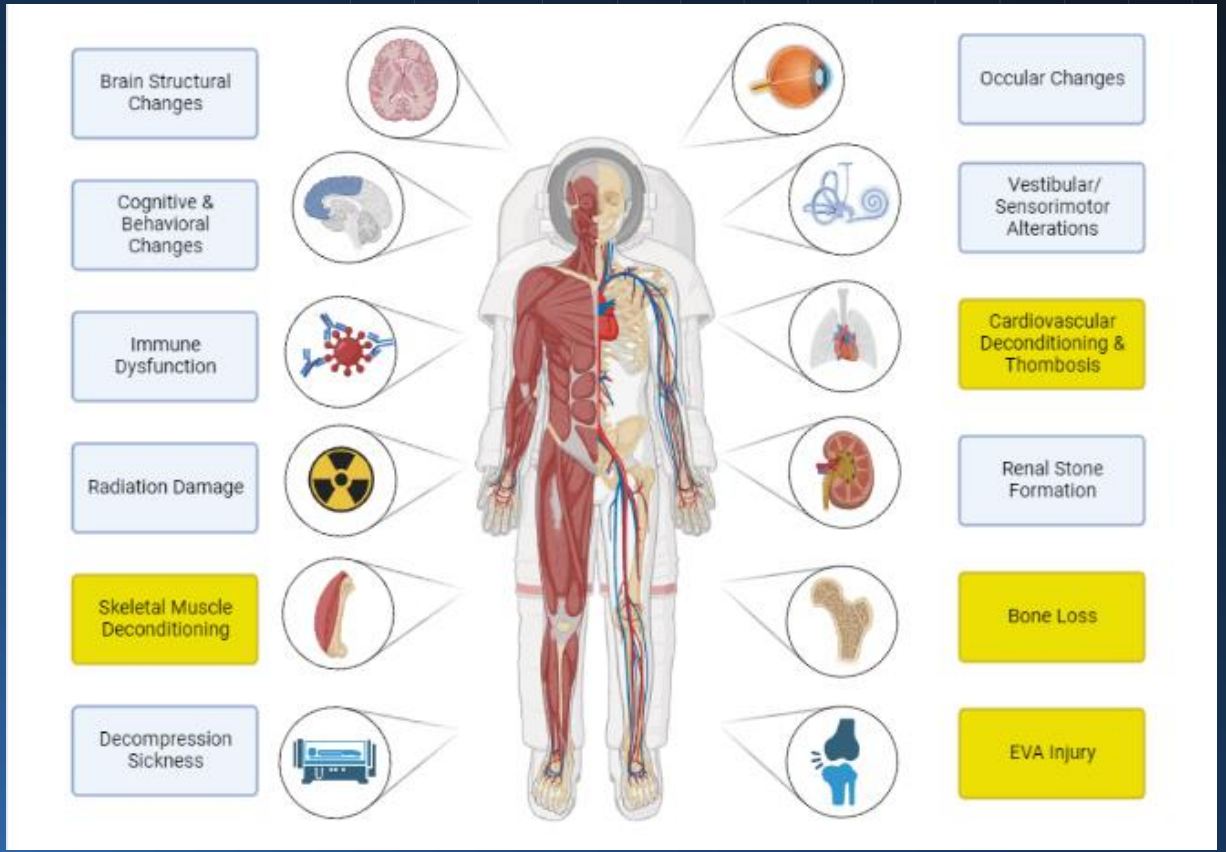
Nicole Strock, Ph.D., *KBR, Houston, TX*
Eric Rivas, Ph.D., *KBR, Houston, TX*
Karina Marshall-Goebel, Ph.D., *NASA Johnson Space Center, Houston, TX*

Funding Provided by NASA Human Research Program

Space Flight as a Multifactorial Physiological Stressor

- Current understanding of space flight-induced impacts to physiology & performance
  - Based on research in predominantly **MALE** populations

- Hormonal influence on numerous body systems can lead to sex-specific differences
  - Cardiovascular Function
  - Bone Health
  - Energy Balance & Adiposity
  - Muscle Mass & Strength
  - Response to Physiological Stress & Energetic Status



Delayed Inclusion of Females to NASA Astronaut Corps

- "Mercury 13"
  - Trained to be part America's first human spaceflight program in the early 1960s
  - Completed same intensive test battery used for male astronauts in the Mercury Program
  - Funding limitations, concerns for safety
- 1963: First female in Space
  - Valentina Tereshkova (Cosmonaut)
- 1977: First NASA astronaut class to include females
- 1983: First U.S. female in space
  - Dr. Sally Ride, Challenger STS-7

Image Credit: NASA

Image Credit: NASA

Sex differences in space flight-related research requires more research

- **Sex differences exist in numerous physiological systems**
  - Ignored/ understudied for decades
  - Males considered appropriate proxy for all humans

- **NASA has sponsored workshops to address sex differences in space flight**
  - Sex, Space and Environmental Adaptation: University of Missouri, 2002
  - NASA & NSBRI Virtual Workshop: The Impact of Sex & Gender on Adaptation to Space- 2013
    - 2014 J Women Health Vol 23 (11): The Impact of Sex and Gender on Adaptation to Space: A NASA Decadal Review

- **Artemis Lunar Exploration program increases diversity**
  - First female astronaut to Lunar surface by 2030
  - 50% female astronauts in Artemis-specific astronaut corps

➢ Greater understanding of sex differences in space flight adaptations is critical to develop/improve countermeasures to minimize risk and maintain health in **ALL** astronauts

Primary Objectives

- **Review of literature from space flight and bed rest to address gaps related to female astronaut health**
  - Hormones & menstrual characteristics
  - Bone health
  - Tendon & ligament health
  - Body mass & Energy Requirements
  - Menstrual Cycle Impacts on Performance
  - Sex Differences in Aerobic Capacity
  - Sex Differences in Muscle Strength & Endurance

- **Characterization of Female and Male Astronauts**
  - Demographic health characteristics
  - Musculoskeletal injury prevalence
  - Aerobic capacity
  - Muscle strength

Methods

- Demographic & Musculoskeletal (MSK) Injury/Diagnosis Data
  - Queried from Lifetime Surveillance of Astronaut Health (LSAH)- Aug. 2022
  - Available data from Mercury through ISS Expedition 66
    - Total 360 astronauts

- MSK included muscle sprains/strains, tendonitis, ACL injury, fractures, diagnosis of osteopenia/osteoporosis
    - Fracture data through May 2022
    - Osteopenia/Osteoporosis through March 2019
    - All other injuries through March 2020

- Reported as In-Flight or Postflight (R+0 to 2 years postflight)

Methods

- Aerobic Capacity (VO_2pk) Characteristics
  - Data from standardized medical assessments (MEDB)
    - Preflight: L-3/1 month
    - Postflight: R+3 days
  - VO_2pk testing on upright cycle ergometer, ramped protocol
    - Variables of interest: VO2pk, peak watt
  - Sample Size (n=47)
    - 11 Female
    - 36 Male

Methods

- Leg Muscle Strength & Endurance Characteristics
  - Data from MEDB
    - Preflight: L-3/1 month
    - Postflight: R+5 days
  - Isokinetic testing on dynamometer
    - Strength: Knee extension @ 60°/sec
    - Endurance: Knee extension @ 180°/sec
  - Sample Size (n=87)
    - 17 Female
    - 70 Male

Results: Demographic Data

- **As of 2022**
  - 360 NASA astronauts
    - Early programs (Mercury, Gemini, Apollo) – male only crews

- Fewer Females (17% of total)
  - Fewer spaceflight missions
  - Comparable age at selection & first mission
  - Greater cumulative duration in space

Demographics	Male	Female
Astronauts (n, %)	299 (83.1%)	61 (16.9%)
Astronauts with ≥ 1 space flight (n, %)	270 (84.4%)	50 (15.6%)
Space Flight Missions (n, %)	955 (87.3%)	139 (12.7%)
	Mean±SD	Mean±SD
Age at selection (yr)	34.4±3.7	32.5±3.5
Age at first mission (yr)	40.7±4.6	37.8±4.2
Flight Duration (days)	25.7±49.7	40.6±68.7
Cumulative Duration in Space (days)	67.6±94.8	102.4±127.2

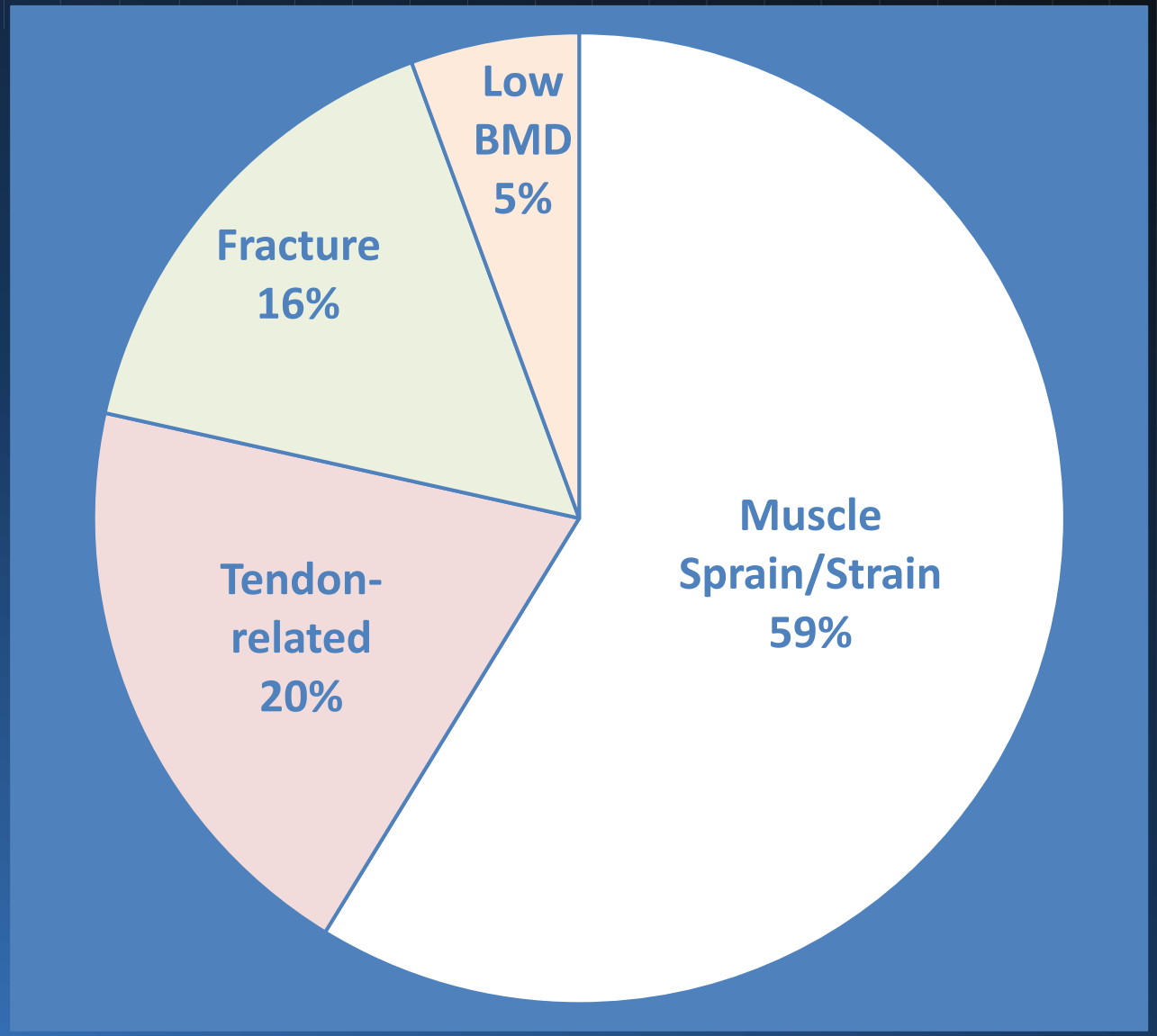
Results: Musculoskeletal injuries & Diagnoses

Total MSK injuries/diagnoses reported

- 283 in 151 astronauts
- 49.7% had multiple injuries
- 1.8 injuries per astronaut (range 1-8)

Most common injury

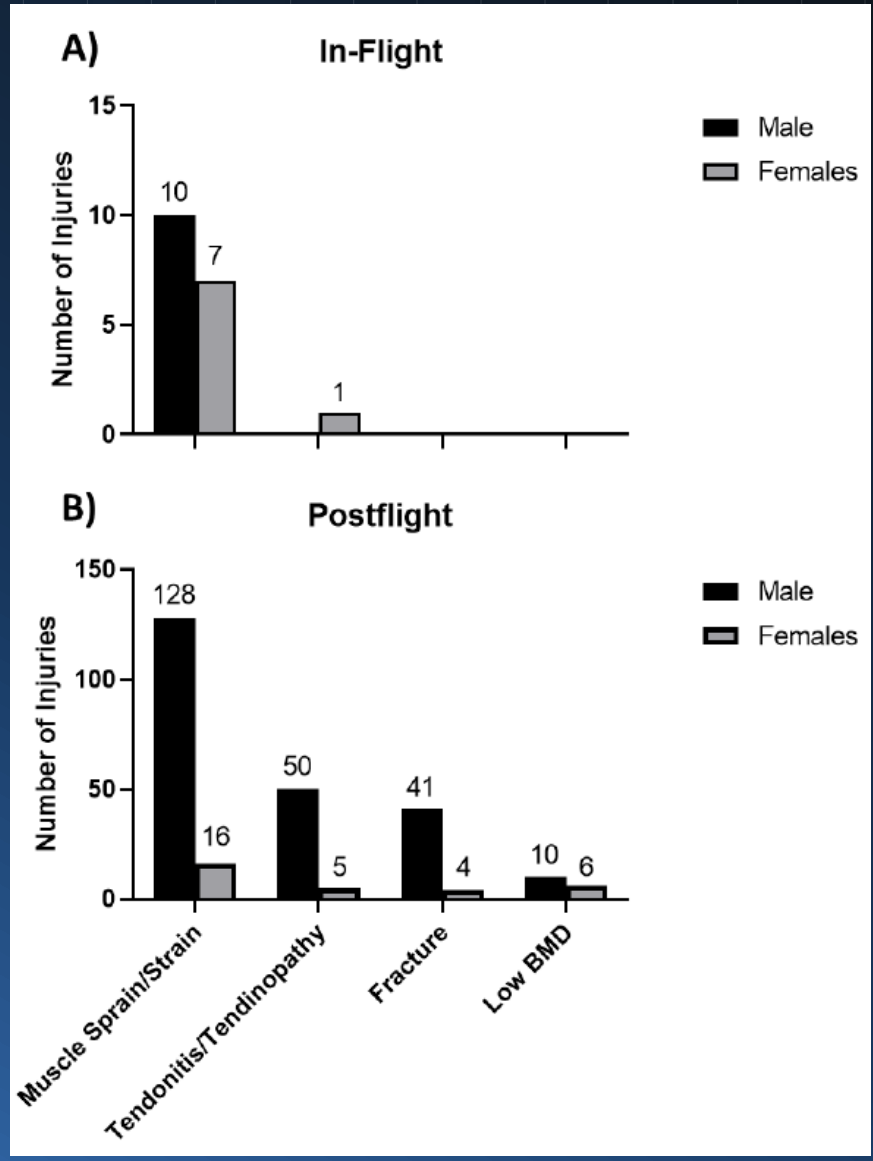
- Muscle sprain/strain (59%)



Results: Musculoskeletal injuries & Diagnoses

- Postflight injuries most common (92%)
- Large proportion of injuries (49.6%) occurred within 1 year of landing
  - 7.3% within 1 month
  - 8.1% between 1-3 months
  - 9.2% between 3-6 months
  - 25% between 6-12 months

- Fewer injuries reported in females, but higher prevalence
  - F: 39 injuries in 20 astronauts
    - 1.95 injuries per female
    - 20% of female injuries occurred in flight
    - Low BMD diagnoses in 15% of females
  - M: 244 injuries in 131 astronauts
    - 1.86 injuries per male
    - 4% of injuries occurred in-flight
    - Low BMD diagnosed in 4% male astronauts



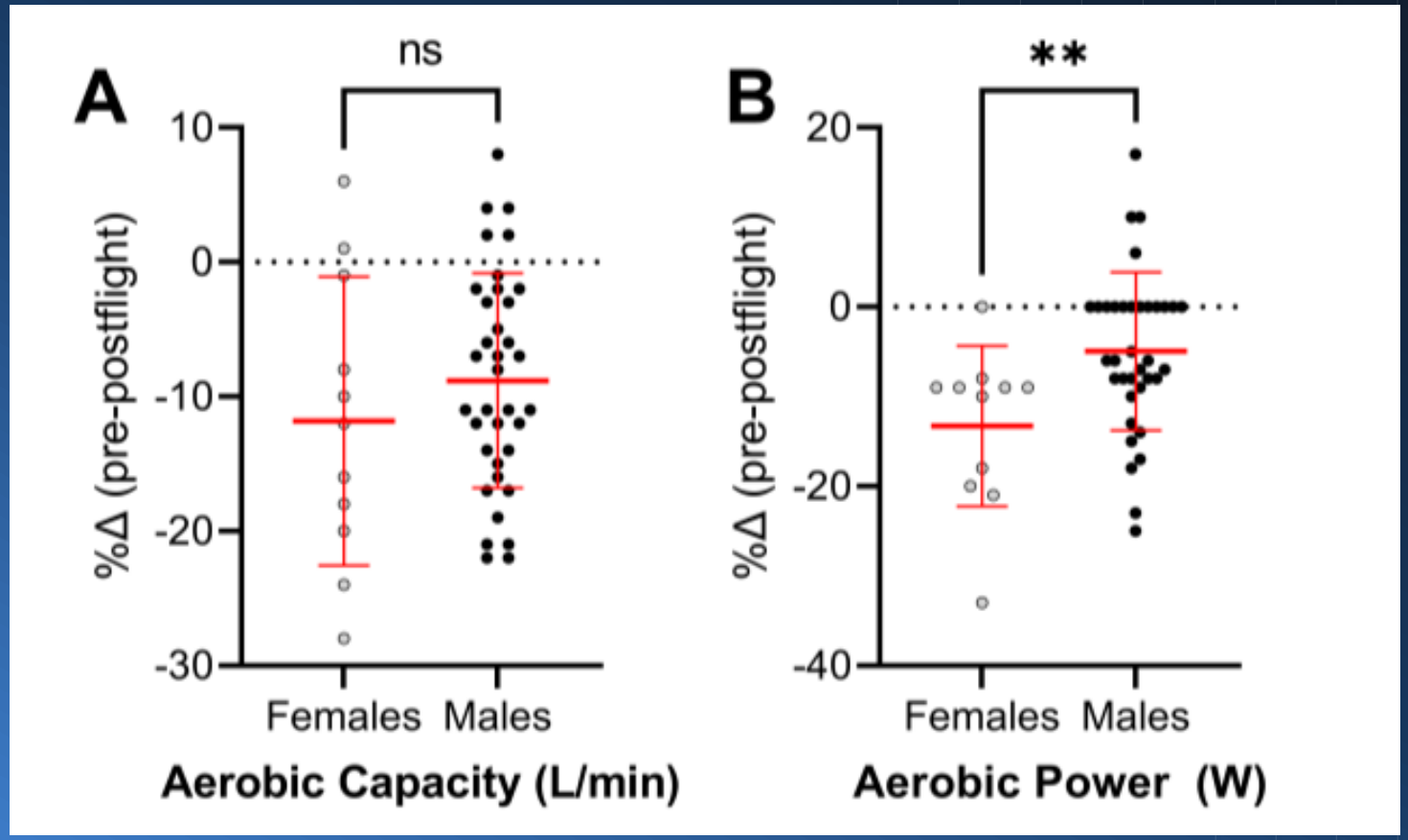
Results: Preflight Crew Demographics (*Aerobic Capacity*)

Females:

- Younger (*-4.2±2.0 yrs*)
- Weighed less (*-12.2±3.1 kg*)
- Lower VO_2pk (*-4.9±2.1 ml/kg/min*)
- Lower Peak Power (*-70.0±17.3 W*)

	Female (n=11)	Male (n=36)	P-value
Age (yr)	44.5±6.6	48.6±5.6	0.041
Body Mass (kg)	68.8±10.0	81.0±8.8	< 0.001
Flight Duration (days)	205.0±58.3	176.0±40.5	0.061
VO_2peak (ml/kg/min)	32.8±5.9	37.8±6.0	0.021
Peak Watt (W)	229.0±41.5	299.0±52.4	< 0.001
Peak Heart Rate (beats/min)	176.0±7.3	173.0±10.8	0.406

Sex Difference in Aerobic Peak Power Decrements



Results: Preflight Crew Demographics (Strength Cohort)

Females were:

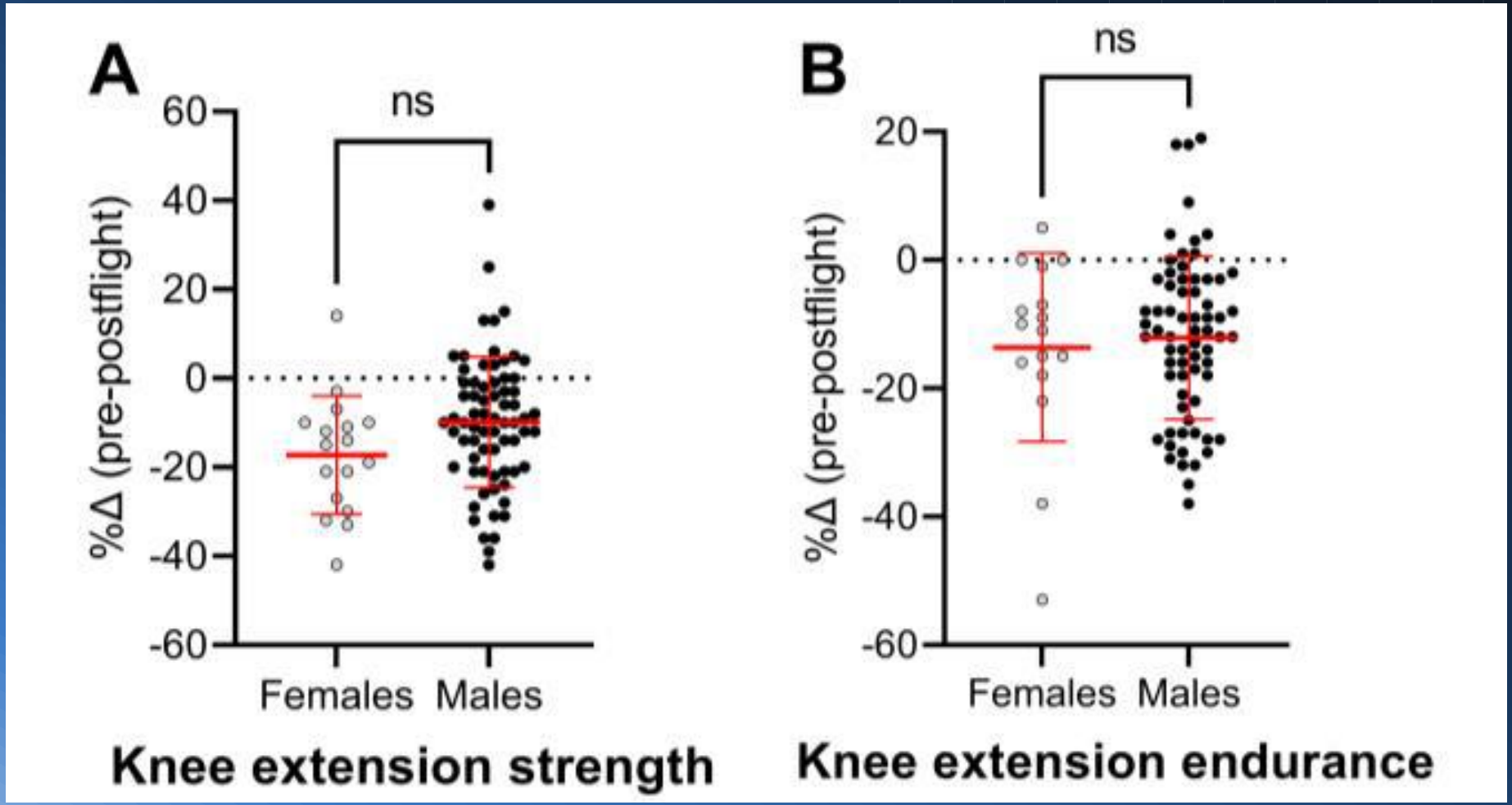
- Younger (*-5.6±1.3 yrs*)
- Weighed less (*-17.2±2.4 kg*)
- Lower Absolute Knee Strength

  (*-56.1±10.6 Nm)*
  - Normalized knee strength comparable to males
- Lower Absolute Endurance

  (*-828±158 Nm)*

	Female (n=17)	Male (n=70)	P-value
Age (yr)	42.8±3.7	48.4±5.1	< 0.001
Body Mass (kg)	65.7±6.3	82.9±8.4	< 0.001
Flight Duration (days)	179.0±50.3	173.0±33.3	0.478
Knee Extension Strength (Nm; 60/sec)	150.0±24.6	206.0±42.0	< 0.001
Normalized Knee *Extension* Strength (Nm/kg; 60/sec)	2.3±0.3	2.5±0.5	0.199
Knee Extension Endurance (Nm; 180/sec)	1546±507	2374±585	< 0.001
Normalized Knee Extension Endurance (Nm/kg; 180/sec)	23.7±6.4	28.7±7.0	0.019

Comparable Decrement in Strength Among All Astronauts



Summary

- Regardless of sex, space flight deconditioning could impact health and ability to complete EVA-associated tasks

- Data indicates majority of injuries occur postflight*
  - Implications for long term health
  - ↑ in-flight injury prevalence in Artemis missions?

- Data indicates majority of injuries occur in males
  - Likely artifact of fewer female astronauts
    - ***Females have higher proportion of in-flight injuries****
    - ***Females have higher proportion of postflight low BMD diagnoses (3x)****

- Comparable decrements VO2pk, knee extension muscle strength & endurance for all astronauts
  - Females: greater reduction in maximal external work (peak watts)

*caveat- increased time frame postflight

Implications for Exploration Missions

- Commercially developed space suit
  - Sex differences in injury risk?
- Exploration Exercise Capabilities
  - Flywheel-based device- similar efficacy in males and females?
  - Sex differences in injury risk? Deconditioning?
- In-flight unknowns
  - Trajectory of muscle strength changes?
  - Sex differences in time course of changes to functional capacity?
- Recovery of muscle strength postflight
  - New data demonstrates females take longer to recover
    - Strategic postflight rehabilitation?

THANK YOU

nicole.c.strock@nasa.gov