Integrated Human Performance: Delivering Care and Capability in Constrained Environments

Lt Col Danielle Anderson, DPT, DSc, OCS, CSCS, FAAOMPT
Clinical Lead, Musculoskeletal Medicine and Rehabilitation
NASA

Corey Twine, CSCCa, CSCS, FRc
Strength Coach, Astronaut Strength, Conditioning and Rehabilitation
NASA

Bruce Nieschwitz, LAT, ATC, USAW, FRc
Athletic Trainer/Strength Coach, Astronaut Strength, Conditioning and Rehabilitation
NASA

Stephanie Petery, MS, LAT, ATC, FRc, Graston M1, MHFA
Dry Needling Athletic Trainer, Astronaut Strength, Conditioning and Rehabilitation
NASA

Christi Keeler, MS, LAT, ATC, Graston M1, FRc
Dry Needling Athletic Trainer, Astronaut Strength, Conditioning and Rehabilitation
NASA

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Presenters

Lt Col Danielle Anderson, DPT, DSc, OCS, CSCS, FAAOMPT
Clinical Lead, Musculoskeletal Medicine and Rehabilitation
National Aeronautics and Space Administration
Houston, TX

Corey Twine, CSCCa, CSCS, FRc
Strength Coach, Astronaut Strength, Conditioning and Rehabilitation
National Aeronautics and Space Administration
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Dry Needling Athletic Trainer, Astronaut Strength, Conditioning and Rehabilitation
National Aeronautics and Space Administration
Houston, TX

Christi Keeler, MS, LAT, ATC, Graston M1, FRc
Dry Needling Athletic Trainer, Astronaut Strength, Conditioning and Rehabilitation
National Aeronautics and Space Administration
Houston, TX

Lt Col Danielle Anderson, DPT, DSc, OCS, CSCS, FAAOMPT

Lt Col Danielle Anderson serves as the Clinical Lead for Musculoskeletal Medicine and Rehabilitation at the National Aeronautics and Space Administration (NASA) in Houston, Texas. She holds both a Doctor of Physical Therapy (DPT) and a Doctor of Science in Physical Therapy (DSc), with advanced specialization as an Orthopedic Certified Specialist (OCS). A Fellow of the American Academy of Orthopedic Manual Physical Therapy (FAAOMPT), Lt Col Anderson brings exceptional expertise in evidence-based orthopedic care and manual therapy. She is also a Certified Strength and Conditioning Specialist (CSCS) and a Certified Dry Needling Instructor, blending advanced rehabilitation with performance optimization. Through her leadership and clinical expertise, she plays a pivotal role in advancing astronaut musculoskeletal health, injury prevention, and recovery to ensure mission readiness.

Corey Twine, CSCCa, CSCS, FRc

Corey Twine is a dedicated strength coach specializing in astronaut strength, conditioning, and rehabilitation for KBR, embedded at the National Aeronautics and Space Administration (NASA) in Houston, Texas. He is a Strength and Conditioning Coach Certified (CSCCa) and a Certified Strength and Conditioning Specialist (CSCS), bringing advanced expertise in performance training and physical preparedness. In addition, Corey is a Certified Mobility Specialist (FRc), equipping him with specialized skills in movement optimization, injury prevention, and functional resilience. Through his work, he plays a vital role in preparing astronauts to meet the physical demands of spaceflight while supporting their health, strength, and recovery.

Bruce Nieschwitz, LAT, ATC, USAW, FRc

Bruce Nieschwitz, LAT, ATC, USAW, FRc, is a highly experienced athletic trainer and strength coach specializing in astronaut strength, conditioning, and rehabilitation for KBR, embedded at the National Aeronautics and Space Administration (NASA) in Houston, Texas. He is a Certified Athletic Trainer (ATC) and a Texas Licensed Athletic Trainer (LAT), bringing extensive expertise in sports medicine and human performance. In addition, he is a USA Weightlifting Sports Performance Coach (USAW) and a Certified Mobility Specialist (FRc), blending advanced knowledge in movement, injury prevention, and performance optimization. With his unique combination of clinical skill and performance coaching, Bruce plays a critical role in supporting astronaut health, resilience, and mission readiness.

Stephanie Petery, MS, LAT, ATC, FRc, Graston M1, MHFA

Stephanie Petery is a skilled athletic trainer specializing in astronaut strength, conditioning, and rehabilitation with KBR at Johnson Space Center \ National Aeronautics and Space Administration (NASA) in Houston, Texas. She is a Certified Athletic Trainer (ATC) and a Texas Licensed Athletic Trainer (LAT), bringing clinical expertise to human performance and injury prevention. Stephanie is also a Certified Mobility Specialist (FRc), trained in Graston M-1 Technique, Dry Needling Certified, and holds Mental Health First Aid certifications, reflecting her commitment to both physical and mental well-being. Through her diverse skill set and advanced training, she plays a vital role in optimizing astronaut health, mobility, and recovery to ensure readiness for the demands of spaceflight.

Christi Keeler, MS, LAT, ATC, Graston M1, FRc

Christi Keeler is an accomplished athletic trainer specializing in astronaut strength, conditioning, and rehabilitation for KBR, embedded at the National Aeronautics and Space Administration (NASA) in Houston, Texas. She is a Certified Athletic Trainer (ATC) and a Texas Licensed Athletic Trainer (LAT), with advanced expertise in mobility, recovery, and performance optimization. Christi is a Certified Mobility Specialist (FRc), trained in the Graston M-1 Technique, and Dry Needling Certified, equipping her with specialized skills in musculoskeletal treatment and functional movement care. Through her diverse clinical background and advanced certifications, she plays a vital role in promoting astronaut health, injury prevention, and rehabilitation to support mission readiness.

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Agenda

Welcome and Opening Remarks

- Introduction of speakers and session objectives

1. Domains of Deconditioning in Spaceflight - (Spaceflight is Hard)

- Multisystem deconditioning: cardiovascular, muscular, bone, tendon/ligament, cartilage, spinal, sensorimotor
- Physiological, anatomical, and performance impacts
- Evidence streams: ISS, head-down tilt, parabolic flight, animal models

2. Countermeasure Strategies During Spaceflight – (Exercise is Essential)

- Roles of the ASCR/MSK Team: fitness assessments, program design, hardware training, injury prevention, SME functions
- Concurrent training in long-duration spaceflight
- Resistance countermeasures: ARED and Sprint Study
- Cardiovascular countermeasures: CEVIS and T2 treadmill, Sprint protocols

3. Reconditioning Pathways After Spaceflight – (Recovery is Critical)

- Dual-lens perspective: Physical Medicine and Strength & Conditioning
- Neuromuscular & vestibular, musculoskeletal, and orthostatic challenges
- Phase-based framework: Reset → Rebuild → Refine
- Integration and key takeaways for sustaining astronaut health and readiness

Disclosures

- Lt Col Anderson, Mr. Twine, Ms. Petery, Mr. Nieschwitz, and Ms. Keeler have no relevant financial or non-financial relationships to disclose relating to the content of this activity.
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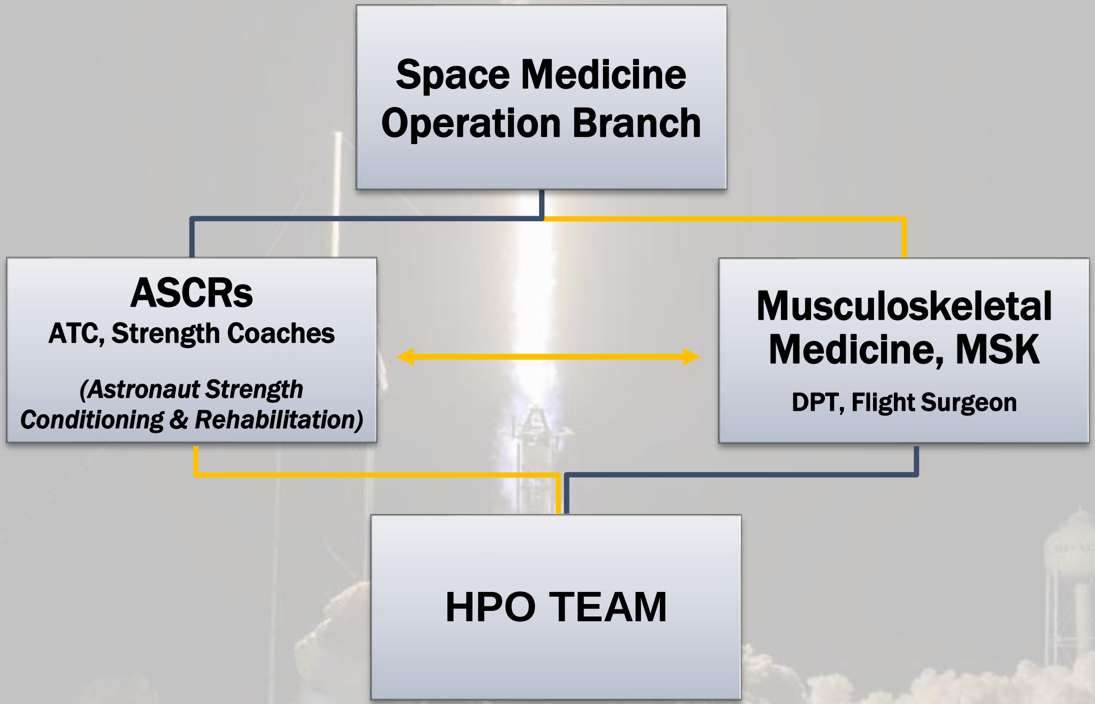
Learning Objectives

By the end of this session, participants will be able to:

1. **Discuss** the multisystem nature of astronaut deconditioning and its operational consequences.
2. **Identify** the primary exercise countermeasures used aboard the International Space Station.
3. **Explain** the role of interdisciplinary collaboration in preserving astronaut health and performance.
4. **Summarize** the importance of targeted reconditioning strategies upon return to Earth.
5. **Evaluate** how lessons learned from spaceflight can inform human performance optimization in other extreme environments.

Human Performance Organization (HPO) Chart



Improving Health and Building Readiness. Anytime, Anywhere — Always

Mission & Vision

Mission

- Optimize the performance, durability, and sustainability of the Astronaut corps by utilizing an interdisciplinary approach towards enhancing physical readiness and recovery as Astronauts train for, live in, and return from space.

Vision

- Ensure every astronaut is fully prepared to meet the demands of spaceflight and beyond—supporting mission success and long-term health through cutting-edge, data-driven strategies.

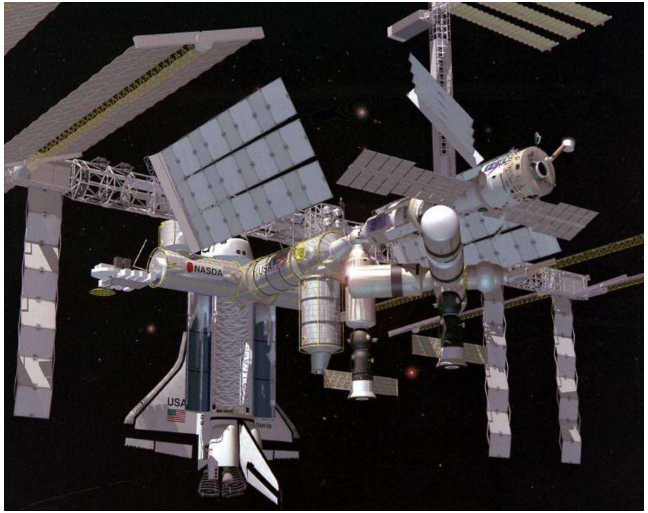
Core Values

- Evidence-based practice
- Interdisciplinary collaboration
- Precision in training and recovery
- Sustainable human performance
- Accountability and continuous improvement

ASCR
ASTRONAUT STRENGTH CONDITIONING & REHABILITATION

Spaceflight: The Ultimate Extreme Environment

International Space Station (ISS)



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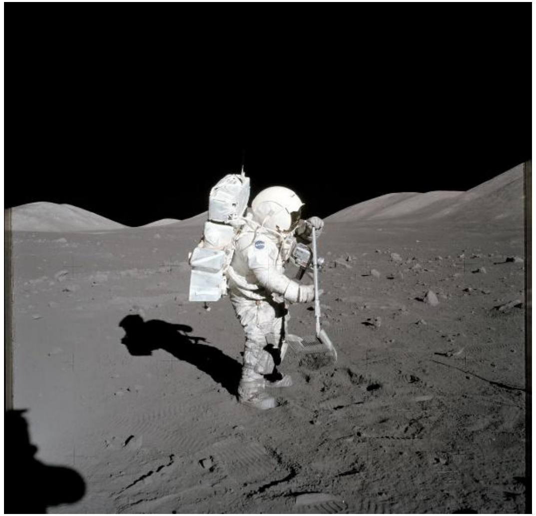
Future Lunar Extravehicular (EVA)



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Artemis and Beyond- Exploration

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Multisystem Deconditioning

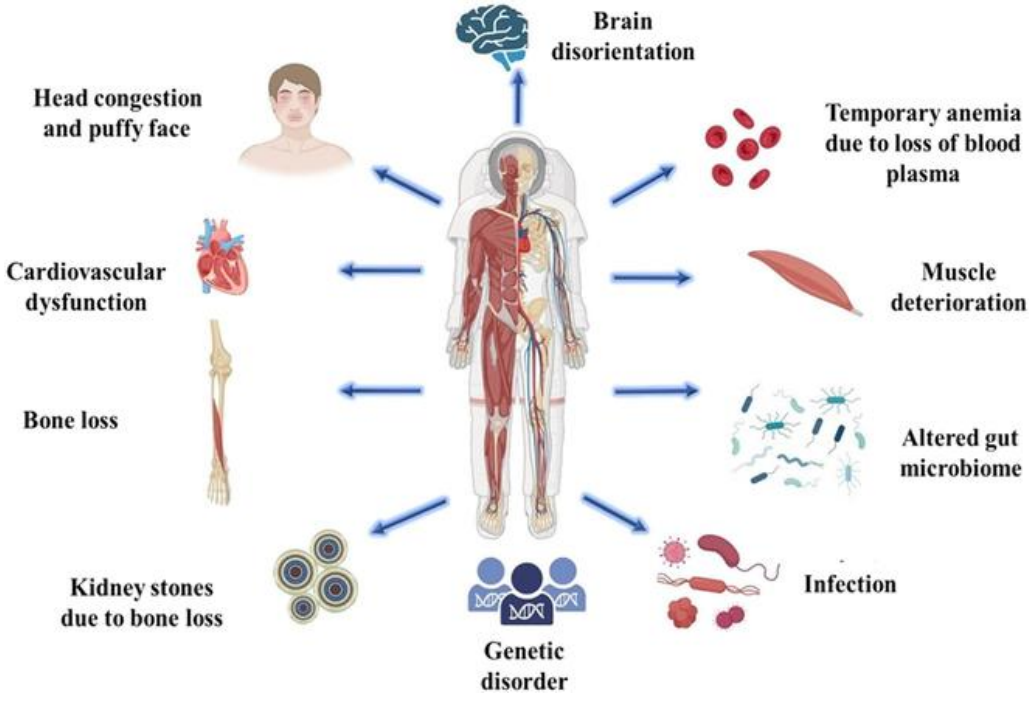

Fig. 1. Physiological changes in spaceflight environment (Wani A, et al. 2024)

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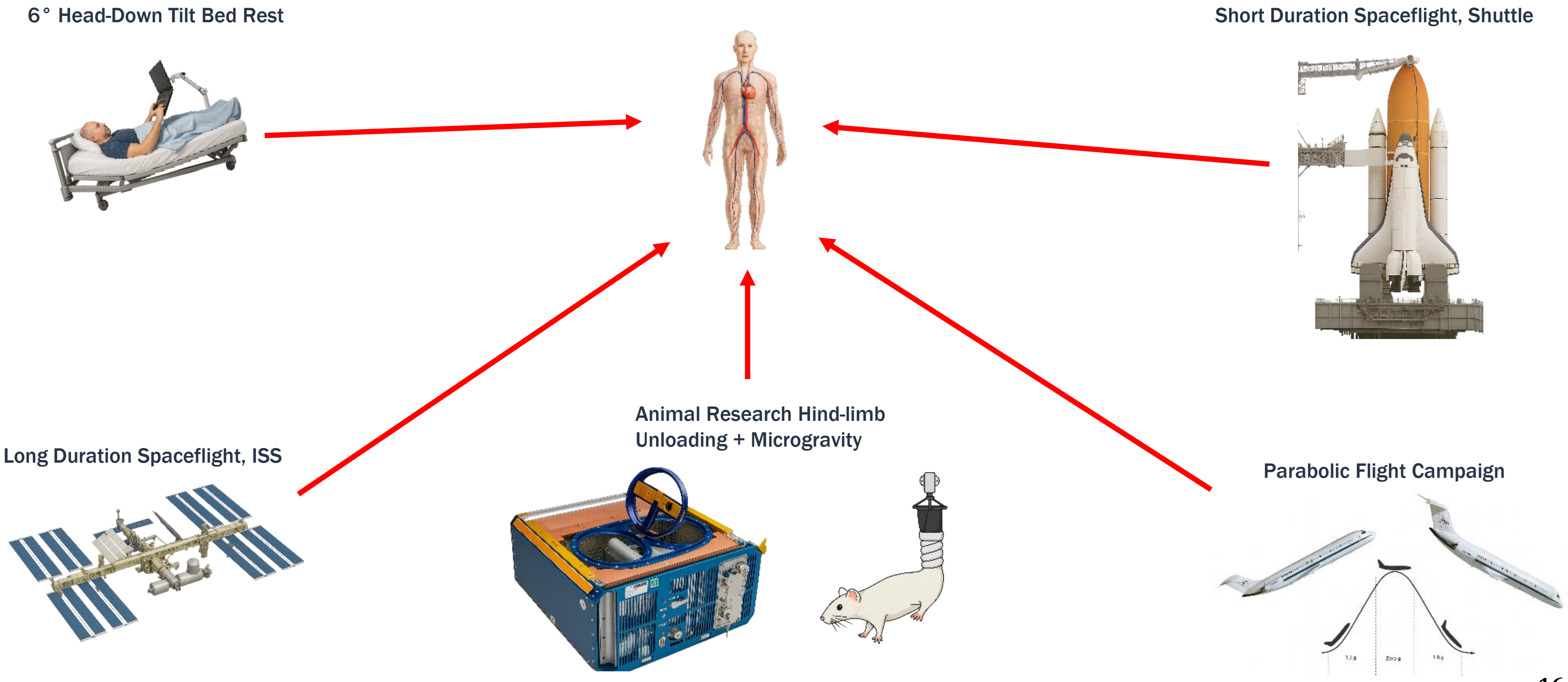
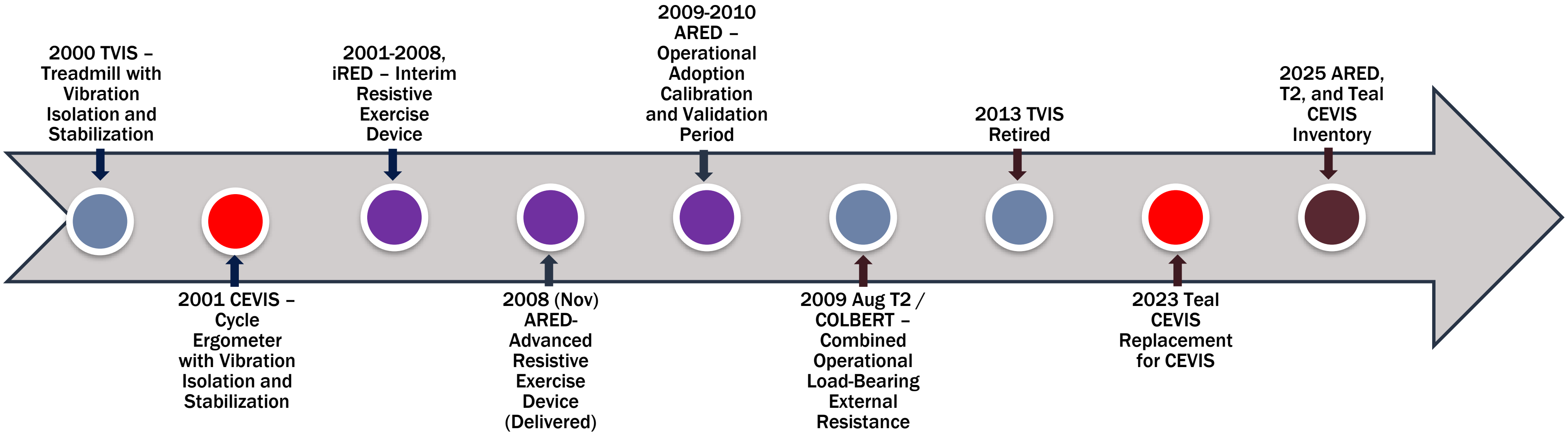
Evidence Streams for Spaceflight Deconditioning



International Space Station Exercise Hardware Timeline



Key
- Resistive iRED, ARED
- CEVIS Cycle Ergometer
- TVIS - Treadmill

Three-Domain Framework For Deconditioning

Rationale

- *Deconditioning* from long-duration spaceflight is multifaceted, involving interrelated changes in **physiology**, **anatomy**, and **performance.**
- Using these domains ensures a comprehensive description of adaptation loss and its operational consequences.

Framework Basis

- **Physiological** – Captures changes in functional capacity of systems (e.g., plasma volume loss, altered cardiovascular control).
- **Anatomical** – Reflects structural adaptations or degradation (e.g., cardiac atrophy, vascular remodeling).
- **Performance** – Links physiological and anatomical changes to mission-relevant outcomes (e.g., orthostatic intolerance, reduced VO_2 peak).

Integration with Literature

- *Cardiovascular deconditioning*: Functional and structural changes in the heart and blood vessels due to spaceflight or reduced gravity *(Stenger et al, 2019)*.
- *Detraining*: Loss of physiological, anatomical, and performance adaptations when training is reduced or stopped *(Mujika et al, 2017)*.
- Microgravity is an extreme form of involuntary detraining, driving measurable changes in each domain.

Cardiovascular Deconditioning

[Human – Long Duration Spaceflight]

Physiological

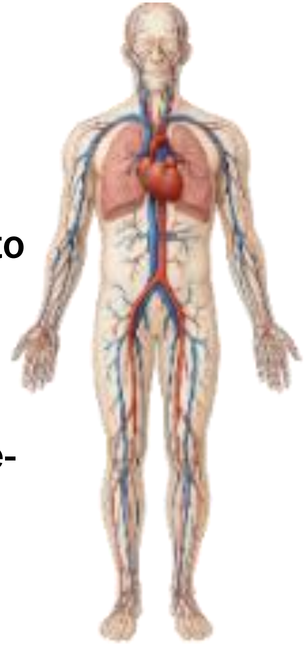
- Plasma volume loss – Long-duration spaceflight induces a rapid decline in plasma volume, contributing to reduced stroke volume and cardiac output postflight (*Lee et al., 2019*).

Anatomical

- Cardiac atrophy – Left ventricular mass decreases after prolonged exposure to microgravity despite exercise countermeasures (*Shibata et al., 2023, p. 679-681*).

Performance

- Orthostatic intolerance – Impaired ability to maintain upright posture upon re-exposure to gravity; VO_2 peak is significantly reduced after return (*Lee et al., 2019*).



Muscular Deconditioning

[Human – Long Duration Spaceflight]

Physiological

- **Fiber-type shift** – Long-duration spaceflight causes a shift from slow-twitch (Type I) to fast-twitch (Type IIa/x) fibers in the soleus and gastrocnemius, along with reduced oxidative enzyme activity and slower postflight recovery of mitochondrial capacity (*Fitts et al., 2010, p. 3575- 3578*).

Anatomical

- **Atrophy** – Soleus muscle fiber cross-sectional area declined by ~35–45% in Type I fibers and ~20–30% in Type II fibers following ~180 days in space. Gastrocnemius atrophy was also observed, though less severe (*Fitts et al., 2001, p. 3205- 3207; Fitts et al., 2010, p. 3573*).

Performance

- **Strength loss** – Astronauts experienced a 20–48% reduction in maximal voluntary contraction force in the plantar flexors post-flight, impairing functional locomotion and posture control (*Trappe et al., 2009, p. 1162-1163*; *Fitts et al., 2010, p. 3579- 3581*).

Bone Deconditioning

[Human – Long Duration Spaceflight]

Physiological

- **Calcium mobilization** – Long-duration spaceflight accelerates bone resorption while suppressing formation early in the mission. Bone resorption markers increased by ~113% within the first 11 ± 2 days of flight, while bone formation markers remained unchanged for the first 30 days and rose at only ~7% per month thereafter (*Pouille et al, 2020, p. 4-5*).

Anatomical

- **Site-specific loss** – In astronauts flying 4–6-month ISS missions, trabecular bone mineral density (vBMD) at the hip decreased by 2.2–2.7% per month, while cortical vBMD declined more slowly at 0.4–0.5% per month, primarily due to endocortical thinning. Spine losses were less severe, averaging ~0.9% per month (*Lang et al, 2004, p. 1008-1010*).

Performance

- **Fracture risk** – Weight-bearing skeletal sites such as the pelvis and lower limbs experienced losses of ~0.8% per month, leading to cumulative deficits of 4–6% after 6 months. These reductions in structural integrity elevate the risk of fracture upon reloading in gravity environments (*Pouille et al, 2020, p. 6-7*).

Tendon and Ligaments Deconditioning

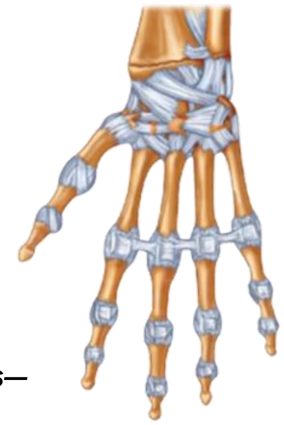
[Human & Animal Model – Ground-Based]

What Tendons & Ligaments Respond To

- These connective tissues adapt to **tensile loading**—pulling forces created by muscle contractions
- In response to repeated load:
  - ↑ **Collagen synthesis** within days (Kjær, 2009, p. 503)
  - ↑ **Cross-sectional area (CSA)** and tendon hypertrophy (Heinemeier & Kjaer, 2011, p. 116)
  - ↑ **Stiffness**, improving force transmission and joint protection
- Tendon adaptation is **strain- and region-specific** (Heinemeier & Kjaer, 2011, p. 118)

What Happens in Unloading

- Without mechanical loading (e.g., bed rest or spaceflight analogs):
  - ↓ **Collagen turnover** and synthesis (Kjær, 2009, p. 504)
  - ↓ **Tendon stiffness and CSA** over time
  - Delayed or incomplete recovery post-unloading (Heinemeier & Kjaer, 2011, p. 119)
- *These effects have been documented in both humans (via unloading analogs) and animal models—but **no validated human spaceflight tendon data** yet exists.*



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Key Point

- **Tendons and ligaments depend on regular, high-tension loading to maintain structure and function**
  ➞ Countermeasures must include **progressive, forceful mechanical load** to protect against performance loss and injury risk

Cartilage Deconditioning

[Animal Model – Spaceflight & Ground-Based]

Cartilage Requires Mechanical Loading

- Articular cartilage is avascular and relies on **cyclic mechanical loading** to maintain nutrient flow and matrix integrity
- **Hindlimb unloading (HLU) studies** and **simulated microgravity** consistently show:
  - Loss of proteoglycans and reduced matrix synthesis
  - Reduced stiffness and cartilage degeneration
  - Active exercise *prevents* degradation in HLU models
- Engineered cartilage constructs in microgravity also showed **less proteoglycan synthesis and reduced dynamic stiffness**

Unloading Consequences (Not Human Data)

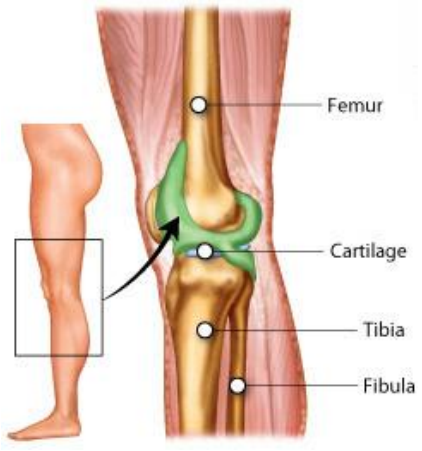
- In rodent Hindlimb Unloading (HLU) and microgravity analogs:
  - ↓ Proteoglycan content
  - Early signs of matrix breakdown
  - **Radiation** exposure worsens cartilage loss
- No current data on cartilage biomarkers in astronauts, but authors recommend **fluid sampling + imaging expansion**

Key Point

- **Cartilage depends on mechanical load to stay healthy**

  ➞ Without 1G loading, tissue rapidly deteriorates in analog and animal studies

  ➞ Countermeasures must recreate **intermittent, joint-specific loading patterns**



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Fitzgerald, J. (2017)

Spinal Loading Is Essential—But Spaceflight Alters the System

[Human – Long Duration Spaceflight] | [Human Analog – Bed Rest]

Why Spinal Loading in Spaceflight Is Complex (But Necessary!)

The Intervertebral Disc Needs Load

- Intervertebral discs (IVDs) rely on cyclic axial compression to maintain structure and function
- In microgravity, this mechanical loading is removed, contributing to changes in spinal alignment and tissue stress
- Bailey et al. (2018) found postflight spinal changes consistent with reduced lumbar curvature and altered disc morphology, but MRI did not confirm increased hydration
- *These changes likely reflect postural adaptation and muscle atrophy, not disc swelling
  → *Hydration appears preserved postflight despite elongation*

Consequences of Unloading

- Reduced lumbar lordosis and spinal flattening (Bailey et al, 2018)
- Multifidus and spinal extensor atrophy observed in both flight and bed rest analogs
- Prolonged disc morphology changes have been documented >5 months post-bed rest (Belavý et al, 2011)
- These adaptations may increase susceptibility to disc herniation or back pain during reloading
- Space Adaptation Back Pain (SABP)
    - Reported in 52% of astronauts during early spaceflight (Kerstman et al, 2012)
    - Usually mild and self-limited, but 14% report moderate to severe pain
    - Most common location: lower back
    - Most effective interventions:
        - Fetal positioning (91%)
        - Exercise and analgesics (85%)

Spinal Loading Is Essential—But Spaceflight Alters the System (1 of 2)

[Human – Long Duration Spaceflight]

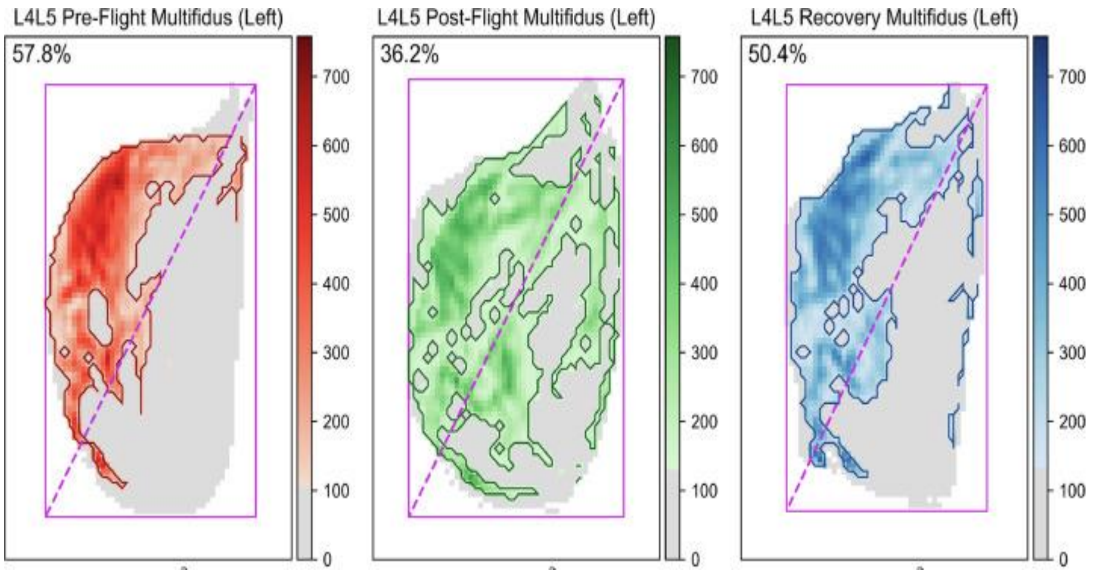


Fig. 2. Example of longitudinal changes in multifidus %m (lean muscle in grey and fat infiltration in red, green, and blue depending on timepoint) representative of study findings that m% significantly decreases in lower lumbar levels following spaceflight (L4L5: -6.2%, p=.009; L5S1: -7.0%, p=.006), then recovers to values not significantly different from preflight levels.

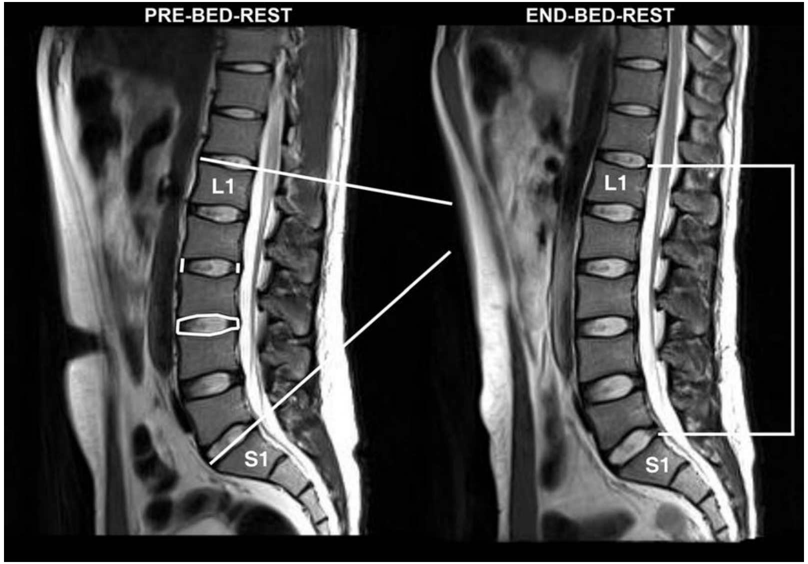
Bailey et al., 2022 *Biomechanical Changes in the lumbar spine following spaceflight and factors associated with post spaceflight disc herniation"*

Spinal Loading Is Essential—But Spaceflight Alters the System (2 of 2)

[Human – Long Duration Spaceflight] | [Human Analog – Bed Rest]

Key Point

- While disc hydration may be preserved, spinal muscle atrophy, alignment shifts, and altered biomechanics increase the risk for pain and injury post-flight
  ➞ Targeted loading strategies are necessary to preserve segmental stability and reduce reconditioning risk.



"Note the lengthening of the spine at the end of bed rest, increase in disk size, and flattening of the spinal curvature" (Belavy, et al., 2010).

Sensorimotor and Spaceflight

[Human – Long Duration Spaceflight]

Physiological

- Neurovestibular adaptation – Long-duration spaceflight alters vestibular function and sensorimotor integration, requiring central nervous system reweighting of sensory inputs (Mulavara et al, 2010, p. 138S- 140S).

Anatomical

- Structural brain changes – Spaceflight is associated with neuroplastic changes in brain regions involved in motor control and sensory integration, including shifts in gray matter volume distribution (Seidler et al, 2015, p. 1-3).

Performance

- Locomotor and postural instability – Postflight performance is degraded in gait, dynamic balance, and coordinated movement tasks, increasing fall and injury risk during early re-adaptation to gravity (Mulavara et al, 2010, p. 138S- 142S).

Macaulay, et al, Front Syst Neurosci, 2021

The Language of Tissues is Load

✅ **Tissue Adaptation to Loading: Evidence-Based Summary**

Tissue Type	Required Load Stimulus	Supporting Research (Model Type)
Bone	High-impact, axial loading (e.g., 1–2× BW, jumping/landing, resisted locomotion)	**[Human – Long Duration Spaceflight]** Lang et al. (2004) – Hip and spine BMD loss with unloading (QCT, DXA) **[Human Analog – Bed Rest]** LeBlanc et al. (2007); Sibonga et al. (2019) – ARED provides partial protection against bone loss
Cartilage	Cyclic compression and shear (e.g., ambulation, weight-bearing joint use)	**[Animal Model – Spaceflight & Ground-Based]** Neufer et al. (2022); Bailey et al. (2018) – Cartilage thinning and proteoglycan loss under unloading in rodent models
Tendon & Ligament	Progressive tensile load (e.g., strength training, plyometrics, eccentric loading)	**[Animal Model – Ground-Based]** Kjær et al. (2009); Heinemeier & Kjaer (2011) – Rodent studies show ↑ collagen turnover and CSA with tensile loading
Muscle	Mechanical tension & metabolic stress (e.g., 70–85% 1RM, hypertrophy training, BFR)	**[Human – Long Duration Spaceflight]** Fitts et al. (2010); Trappe et al. (2009) – Muscle atrophy with unloading, preserved with high-load resistance training **[Human – Long Duration Spaceflight]** Sibonga et al. (2019) – ARED effectiveness
Nervous System	Neuromuscular control under fatigue (e.g., dynamic balance, perturbation, load tracking)	**[Human Analog – Ground-Based]** Mulavara et al. (2010); Ruffieux et al. (2017) – Sensorimotor adaptability influenced by individual factors and training in analog environments

Roles of the ASCR/MSK Group (General)


NASA ID: as17-152-23392

Subject Matter Expert (SME) – Spaceflight Human Performance & Optimization

Responsibilities

- **Design, Direct, and Supervise**
  - Evidence-based physical training programs for all active astronauts
  - Annual Fitness Assessments
  - Group exercise programming and implementation

Clinical Services

- **Provide Musculoskeletal (MSK) Support**
  - Injury prevention, assessment, and rehabilitation
  - Collaboration with the MSK multidisciplinary team to ensure continuity of care

Technical Expertise

- **Contribute to Hardware Development**
  - In-flight exercise hardware: requirements generation, design input, and operational integration

Roles of the ASCR/MSK Group (Pre-Flight / In-Flight)

Comprehensive Training Plan

- Align with mission objectives & crew goals
- Modalities: Strength, Endurance, Metabolic Conditioning, Flexibility/Mobility, Mission-Specific Tasks (e.g., EVA prep)

Fitness Assessments

- Conduct Flight Fitness Assessments (annual, pre-/post-flight)
- Monitor and track performance trends

Exercise Hardware Training

- Instruct crewmembers on Crew Management System (CMS) hardware operation & safety
- Develop and Deliver 2.5 hr./day, 6 days/week: 1.5 hr. Resistive + 1 hr Metabolic
- PT/V and PEC sessions integrated into training

MSK Injury Prevention & Collaboration

- Identify and address MSK issues impacting readiness
- Prescribe **targeted** prevention & rehab protocols
- Coordinate with Flight Surgeons & MSK team to align training and medical goals

Technical SME Role

- Serve as subject matter experts on CMS hardware functionality & operational issues

Lee et al., 2019

Concurrent Training In Long-Duration Spaceflight

Definition

- Concurrent Training (CT) = simultaneous strength + endurance in the same program/session.
- First described by Hickson (1980); often shows an **"interference effect,"** now called the **Concurrent Training Effect (CTE)**.

Key Insights

- **Greatest interference:** when endurance is long, continuous, and high in weekly volume → can reduce strength and hypertrophy gains.
- **Lower interference:** when endurance is short, high-intensity intervals (HIIT/SIT), especially cycling → strength gains are better preserved while aerobic fitness still improves.
- **Order & frequency:**
    - Resistance → endurance tends to favor strength outcomes.
    - Endurance → resistance may favor aerobic outcomes.
    - Separating by 3–24 h lowers interference compared with same-session training.
    - Ratios: 2–3:1 (strength:endurance) supports hypertrophy/strength; 1:1 or 1:2 favors endurance development.

Operational Relevance (ISS)

- Astronauts often complete **ARED (strength) + CEVIS/T2 treadmill (endurance)** within the same duty day.
- Order is usually driven by mission timelines, so adaptations may vary.

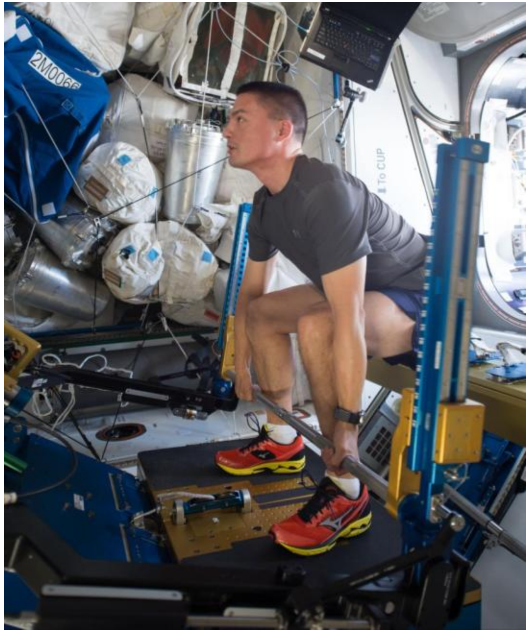
(Methenitis, 2018)

Exercise on ARED: Preserving Bone and Muscular Strength

Purpose of ARED:
- To simulate free-weight resistance training in microgravity using vacuum cylinders and flywheel mechanisms.
- Enables astronauts to perform high-load, multi-joint exercises critical for maintaining musculoskeletal health.

Why It Matters:
- Microgravity causes muscle atrophy and bone loss, especially in the lower body and spine.
- ARED provides the mechanical loading necessary to preserve strength, power, and functional movement capacity.

Key Features:
- Accommodates compound lifts (e.g., squats, deadlifts, bench press).
- Adjustable resistance: up to ~600 lbs. equivalent.
- Integrated sensors to monitor bar speed and loading consistency (when enabled).



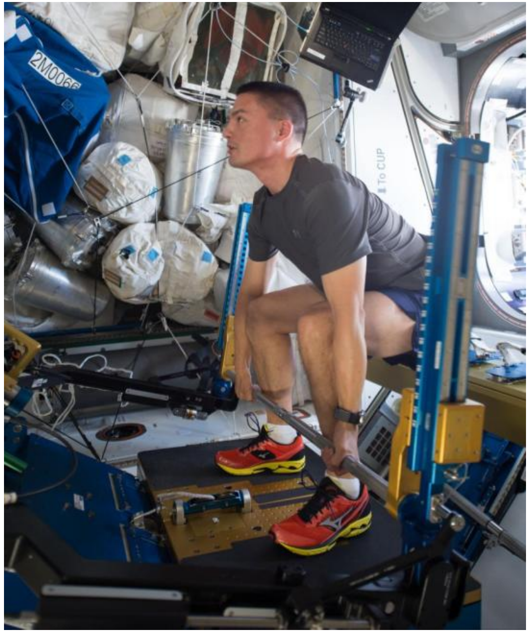
Astronaut Lindgren exercises in Node 3 module

NASA ID: iss044e024392

Resistance Training (ARED) – NASA Sprint Study

High Intensity / Lower Volume (Sprint Protocol)

- Frequency: **3 days/week**
- Model: **Undulating periodized** over a 24-week mesocycle
- Initial 2-week acclimatization, then:
  - **High volume:** 4 × 12 reps
  - **Moderate volume:** 4 × 8 reps
  - **Low volume:** 4 × 6 reps
- Fourth set performed **to muscle failure** at near-maximal load
- Rotation among three routines throughout the mission
- Typical sequence:
  - Squat variations (back, single leg, sumo)
  - Heel raise variations (bilateral, single leg)
  - Deadlift variations (conventional, Romanian, sumo)
  - Upper body lifts on the same schedule as the control group
- Time: ~3 hours/week for resistance work
- Average loads for squat, heel raise, and deadlift were **6–15% higher** than control despite **41–46% fewer reps/week**



Astronaut Lindgren exercises in Node 3 module

NASA ID: iss044e024392

English et al., 2020

Exercise on CEVIS: Cardiovascular Conditioning in Microgravity

Purpose of CEVIS:

- Designed to provide aerobic exercise in microgravity through stationary cycling.
- Helps maintain cardiovascular health, endurance capacity, and metabolic function during long-duration spaceflight.

Why It Matters:

- In microgravity, the heart and vascular system decondition rapidly without sustained aerobic stimulus.
- CEVIS supports cardiac output, oxygen uptake (VO_2), and blood volume maintenance.

Key Features:

- Adjustable resistance and cadence to prescribe training at various intensities up to 600 watts.
- Used with or without harness support depending on exercise goals.
- Integrated into daily crew countermeasure protocols.
- Vibration Isolation System prevents unwanted motion transfer to the ISS structure.

Astronaut Nick Hague exercices on CEVIS

NASA ID: iss072e031339

Exercise on T2: Load-Bearing Aerobic Training in Microgravity

Purpose of T2 Treadmill:

- Provides aerobic exercise while delivering axial loading through a harness and bungee system.
- Mimics the mechanical forces of walking and running on Earth to preserve cardiovascular and musculoskeletal health, maybe.

Why It Matters:

- Microgravity eliminates natural ground reaction forces—T2 reintroduces these forces to help maintain:
  - Bone density
  - Muscle mass (especially lower body)
  - Cardiopulmonary function

Key Features:

- Harness and bungee loading system provides up to 70–80% bodyweight simulation.
- Adjustable speed up to 12 mph with programmable intensity settings.
- Data tracking for distance, pace, heart rate, and mechanical load.
- Mounted on a vibration isolation system to prevent disturbances to the ISS structure.

Astronaut Moghbeli exercises on the T2

NASA ID: iss070e100775

Cardiovascular Training (CEVIS & T2) - NASA Sprint Study

High Intensity / Lower Volume (Sprint Protocol)

- Frequency: **6 days/week** (alternating intervals and continuous sessions)
- Interval Workouts (each completed 1×/week):
    - **8 × 30 s** ~100% VO_2peak, >90% HRmax (CEVIS or T2)
    - **6 × 2 min** ~95–100% VO_2peak, >90% HRmax
    - **4 × 4 min** ~90–95% VO_2peak, >90% HRmax
- **Continuous Aerobic: 30 min @ ~75% VO_2peak**
- Intensity monitored by HR; adjusted in-flight based on VO_2peak testing and crew feedback
- CEVIS: 25–350 W range, pedal speed 30–120 RPM, strapped in for stability
- T2 treadmill: Running speeds 2.4–19.3 km/h, harness loading began at ~60% bodyweight, progressed to ~75–80% as tolerated
- Aerobic exercise volume for Sprint was **17% lower** than that of the control, with similar intensity for matched workouts

NASA ID: iss018e042649

English et al., 2020

Sprint vs. Standard Care Protocols (ARED / CEVIS / T2)

Feature	Sprint (High Intensity / Lower Volume)	Standard Care (Lower Intensity / Higher Volume)
Resistance Training (ARED)	3 days/week; Undulating periodized model (4×6, 4×8, 4×12); 4th set to failure; Higher average loads (↑6–15%); 41–46% fewer reps/week; ~3 h/week total	6 days/week; 9-day linear periodization across 2 mesocycles; Progressive loading 70–120% RM; Squat, heel raise, deadlift variations daily; Heel raises 4×20 reps; ~6–7 hours/week total
Cardiovascular (CEVIS/T2)	6 days/week alternating: 3 × interval sessions (8×30s; 6×2min; 4×4min @ >90% HRmax) and 3 × continuous sessions (30 min @ ~75% VO_2peak); Harness load ~60%→75–80% BW; ~3 hours/week total	6 days/week; Combination of continuous and interval; CEVIS @ 70–100% VO_2peak; T2 @ 70–100% HRmax; Harness load ~60%→75–80% BW; ~3–4 hours/week total
Weekly Time	~6 hours/week total exercise	~9–10 hours/week total exercise
Key Advantage	Equal or better physiological outcomes in less time; Higher intensity, lower volume	Established protocol, higher total training volume

English et al., 2020

Cardiovascular Training (CEVIS & T2) – NASA Sprint Study

Key Findings from This Figure

Strength preservation

- The sprint group generally had smaller losses in isokinetic knee, ankle, and trunk extension strength compared to the Control.
- Leg Press 1RM: Control showed significant decreases; Sprint group losses were much smaller.

Aerobic fitness

- VO_2peak and Ventilatory Threshold declines were less severe in the Sprint group — indicating better preservation of cardiovascular capacity.

Lean mass

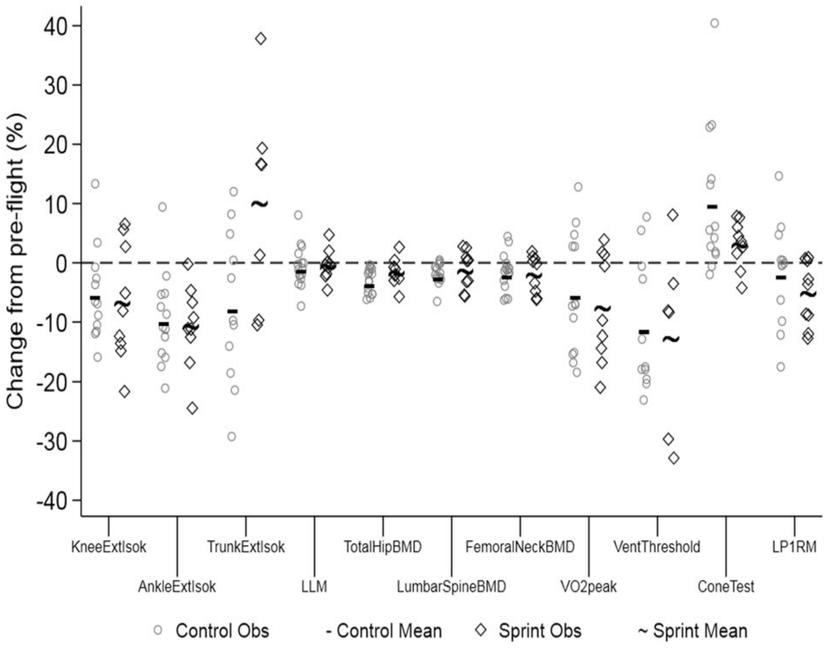
- Lean leg mass (LLM) declined in both groups, but the Sprint group losses were smaller.

Bone health

- BMD losses at hip, femoral neck, and lumbar spine occurred in both groups with no meaningful difference between them — indicating Sprint training did not mitigate spaceflight bone loss.

Functional agility (Cone Test)

- Both groups showed variability, but the Sprint group was closer to baseline performance.



English et al., 2020

Cardiovascular Training (CEVIS & T2) – Bottomline

Effects of Exercise Countermeasures on Multisystem Function in Long-Duration Spaceflight Astronauts

- **How intensity was set/tracked:** T2 treadmill prescribed by **%HR_{max}** from **preflight max testing**; in-flight intensity recorded as **%HR_{max}** during active exercise.
- **Key point: More time at ≥70% HR_{max} → smaller post-flight VO_2peak drop** (intensity/volume signals shown in the study's association analyses).

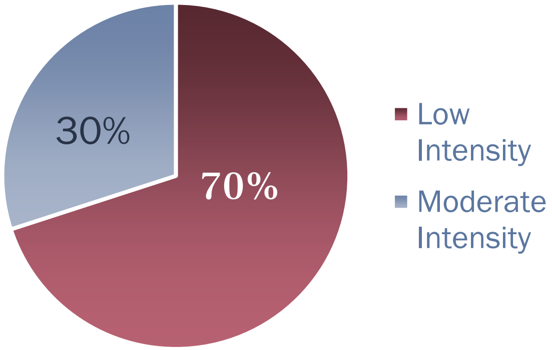
Time in zone (plain language):

- **T2:** median ~**69%** of aerobic time ≥70% HR_{max} *(most crew ~54–81%)*
- **CEVIS:** median ~**76%** of aerobic time ≥70% HR_{max} *(most crew ~65–92%)*

Outcome size: Mean VO_2peak ↓ ~7%, with individual changes ranging −30% to +5%.

Takeaway: Hold more cardio at ≥70% to help protect cardiovascular fitness as measured by VO_2peak during long duration spaceflight.

% of Time in HR Zone



Scott et al. 2023

Post-Flight Reconditioning – Long Duration Spaceflight

Framing the Problem – Dual Lens Perspective

Neuromuscular & Vestibular Challenges

- Disrupted sensorimotor integration, altered proprioception, gaze instability, reduced motor control
- Balance impairments, high fall risk in early R+ phase
- **Physical medicine (PM)**: Prioritize vestibular rehab, proprioceptive retraining
- **Strength & Conditioning (S&C)**: Reinforce posture, stability, re-learn basic locomotor patterns *(Macaulay et al, 2021)*

NASA ID: NHQ201910030033

Musculoskeletal Injuries

- ~92% of postflight injuries occur in the initial 12 months **after landing**
- Lumbar disc herniation (50% in one study), low multifidus %, and asymmetry linked to injury risk
- **PM**: Manual therapy, mobility restoration, avoid early axial load
- **S&C**: Controlled reloading → strength → agility → skilled movement *(Bailey et al, 2022)*

Orthostatic Intolerance

- ↓ Plasma volume, impaired baroreflex, venous pooling
- Avoid rapid posture changes early in rehab
- **PM**: Compression garments, upright tolerance training
- **S&C:** Progress to upright aerobic work (upright cyclic, running, walking, emphasize calf pump and normal gait.

Assessments – Needs Based Practice

ASCR — Astronaut Strength Conditioning & Rehabilitation

Crewmember Name:

	Preflight	Initial	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Mobility Assessment									
Standing									
Prisoner Squat (10 Reps)	0	0	0	0	0	0	0	0	0
Overhead Squat (10 Reps)	0	0	0	0	0	0	0	0	0
Standing Cervical Rotations (10 Reps Each Side)	0	0	0	0	0	0	0	0	0
Prone									
Prone Dowel Y	0	0	0	0	0	0	0	0	0
Prone Dowel Extensions	0	0	0	0	0	0	0	0	0
Cobra	0	0	0	0	0	0	0	0	0
Child's Pose	0	0	0	0	0	0	0	0	0
Activation Assessment									
Glute/Lge Extension									
Double Leg Bridge (30 secs); or Single Leg Raise (30 s	0	0	0	0	0	0	0	0	0
Single Leg Heel Raise (20 reps)	0	0	0	0	0	0	0	0	0
Core									
Forearm Plank (30 secs)	0	0	0	0	0	0	0	0	0
Bird Dog with Rotational Stability (5 reps)	0	0	0	0	0	0	0	0	0
Step Down	0	0	0	0	0	0	0	0	0
Progressive Vestibular Assessment									
Tandem Balance (10 sec/Eyes Closed 20 sec)	0	0	0	0	0	0	0	0	0
ASCR Triangle (Cones 8ft apart)	0	0	0	0	0	0	0	0	0
Drinking Bird (5 reps)	0	0	0	0	0	0	0	0	0
Tandem Walk with Head Turns (10 ft)	0	0	0	0	0	0	0	0	0
	Score	Score	Score	Score	Score	Score	Score	Score	Score
	0	0	0	0	0	0	0	0	0

Green	16, 17, 18, 19, 20, 21, 22, 23, 24, 25
Yellow	26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37
Red	38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48

Absense of NMSK Tandem stance >30 seconds (1/3) VOR no symptoms (1/3) >15 single leg heel raises (1/3) Double leg bridge (1/3) 30 seconds Forearm plank (1/3) >30 seconds Drinking Bird: 5/5 good control (1/3) APR Total: 15-25

Absense of NMSK Tandem stance 15-30 seconds (2/3) Dirty bird: 3/5 good control (2/3) VOR mild symptoms (2/3) 10-15 single leg heel raises (2/3) Double leg bridge (2/3) 20-30 seconds Forearm plank (2/3) 20-30 seconds APR Total: 26-37

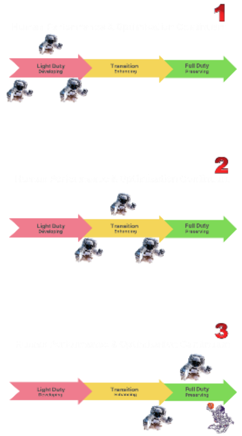
Any NMSK complaints Tandem stance <15 seconds (3/3) VOR Dizziness (3/3) Fixated Gaze <10 single leg heel raises (3/3) Double leg bridge (3/3) <10-20 seconds Forearm plank (3/3) <10-20 seconds APR Total: 38-48

Name: MAP-R Assessment Acronym Meaning:

- **M**obility
- **A**ctivation
- **P**ostural Control – (Includes vestibular function)
- **R**eadiness

Post Flight Reconditioning – Long Duration Spaceflight (1 of 2)

45-Day Framework | ~2 hrs/day | Individualized Based on System Recovery



Progressive Loading Strategy

- Must respect multisystem deconditioning: central nervous system (CNS), MSK, cardiovascular
- Phase-Based Return:
    - Phase 1: RESET - Restore proprioception, joint integrity, gaze control
    - Phase 2: REBUILD - Begin unstable surfaces, reintroduce load
    - Phase 3: REFINE - Power, agility, complex task integration

Dual Goals

- **PM/Rehab:** Mitigate pain, restore movement competency, re-establish neuromuscular firing
- **S&C:** Rebuild strength, work capacity, and functional readiness for everyday task demands

Monitor & Adapt

- Fatigue, dizziness, joint pain = red flags
- Functional tests: heel raises, tandem stance, bridge, plank
- Use **subjective markers** of recovery + movement quality

Post Flight Reconditioning – Long Duration Spaceflight (2 of 2)

Key Takeaways for Coaches and Clinicians

- Injuries peak during **early reconditioning**; functional movement must precede fitness
- Prior injury history and spine health are predictive of post-flight issues
- Early **load intolerance** requires modified strength programming

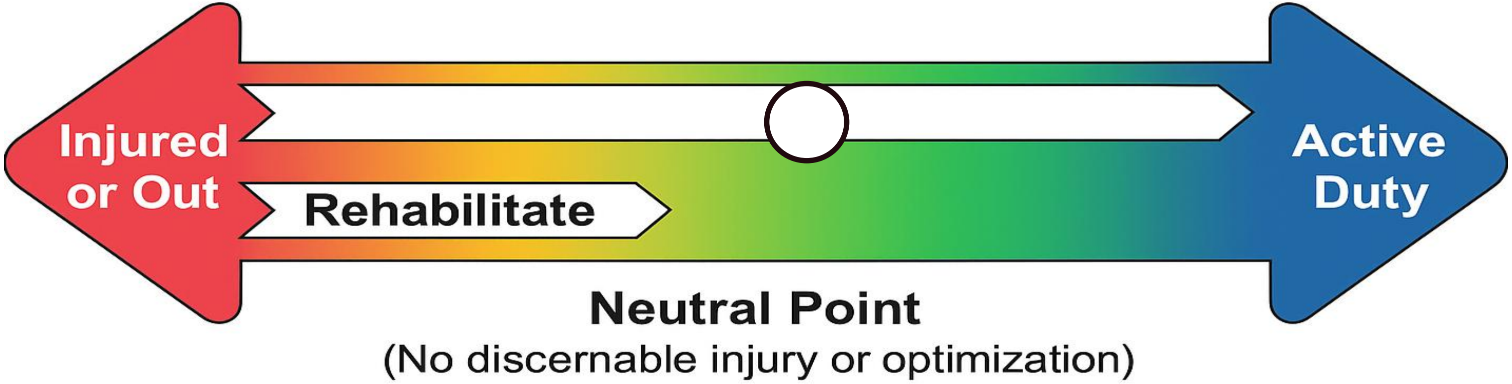
Daily Management

- Monitor total training volume and activity outside rehab hours
- Balance desire to return to preflight fitness with medical evidence and tissue readiness
- Use mixed-method delivery (in-person, web-based coaching, travel flexibility)

Integration of Systems

- Performance gains only emerge when rehab and S&C are tightly aligned
- Both disciplines must co-lead: shared decisions, shared outcomes
- 🔗 *"Reconditioning isn't about restarting training—it's about re-educating the entire neuromuscular system in a new gravity context."* (Bailey et al., 2022)

Human Performance Continuum



Key Points:

- *Image <u>adopted</u> from the Illness–Wellness Continuum developed by Dr. John W. Travis in 1972.
- Demonstrates the full spectrum of human performance from *injured/out* to *active duty*.
- Emphasizes rehabilitation and optimization as proactive processes, not just the absence of injury.
- Encourages viewing performance as a dynamic continuum, where targeted actions can move individuals toward high-functioning readiness.
- Supports an integrated approach—physical, mental, and operational capabilities are all interconnected in achieving peak performance.

ASCR / MSK TEAM

Bruce Nieschwitz
Email:
bruce.e.nieschwitz@nasa.gov

Christi Keeler
Email:
christi.l.keeler@nasa.gov

Danielle Anderson, Lt Col, USAF
Email:
danielle.n.anderson@nasa.gov

Stephanie Petery
Email:
stephanie.m.petery@nasa.gov

Corey Twine
Email:
Corey.a.twine@nasa.gov

Adrian Marrero, Lt Col, USAF
Email:
Adrian.n.marrero@nasa.gov

Key Takeaways

Spaceflight is the ultimate extreme environment — it drives multisystem deconditioning that impacts cardiovascular, musculoskeletal, and sensorimotor performance.

- **Deconditioning is multifaceted** — physiological, anatomical, and performance changes are interlinked and require targeted countermeasures.
- **Evidence-based exercise countermeasures** like ARED, CEVIS, and T2 remain essential to preserving astronaut strength, endurance, and functional readiness.
- **The NASA Sprint Study** demonstrates that high-intensity, lower-volume training can maintain performance while reducing training time.
- **Postflight reconditioning must be phase-based** — progressing from neuromuscular stability to strength and functional performance while respecting tissue recovery.
- **Collaboration is critical** — integrating strength & conditioning, physical medicine, and operational needs ensures mission success and long-term astronaut health.

THANK YOU

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Exercise Countermeasures Hardware Timeline

Year	Device / Acronym	Event & Description	Source Link
2000	TVIS – Treadmill with Vibration Isolation and Stabilization	First treadmill for aerobic exercise on ISS; vibration isolation prevented disturbance to spacecraft structure.	https://ntrs.nasa.gov/api/citations/20160012791/downloads/20160012791.pdf
2001	CEVIS – Cycle Ergometer with Vibration Isolation and Stabilization	First ISS stationary bike for aerobic capacity training; vibration-isolated frame.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/
2001–2008	iRED – Interim Resistive Exercise Device	Provided resistive training (squat, deadlift, bench press, heel raise, etc.) until ARED arrival.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/
Nov 2008	ARED – Advanced Resistive Exercise Device (delivered)	Arrived via STS-126; piston/flywheel design allows Earth-like resistance up to ~600 lbs.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/
2009–2010	ARED – Operational adoption	Became the primary resistive training device after crew calibration and validation period.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/
Aug 2009	T2 / COLBERT – Combined Operational Load-Bearing External Resistance Treadmill	Delivered via STS-128; second treadmill on ISS; located in U.S. Node 3 (Tranquility).	https://www.nasa.gov/content/t2-treadmill
Mar 2010	MARES – Muscle Atrophy Research and Exercise System	Installed in ESA's Columbus Lab; allows detailed biomechanical study of muscle function in microgravity.	https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Columbus/MARES
Jun 2013	TVIS retired	After 12+ years of service, TVIS was removed and discarded.	https://www.space.com/21516-space-station-treadmill-trash.html
2023	FERGO – Replacement for CEVIS	Modernized cycling ergometer replaces CEVIS for continued aerobic training capability.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/
2025	ARED, T2, FERGO, MARES – Active inventory	Current integrated exercise system supports cardiovascular, strength, and research needs for all crew.	https://www.nasa.gov/missions/station/iss-research/astronaut-exercise/

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Questions?