Countermeasures: ASCR and MSK Support for Astronaut Corps

February 14th, 2025

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Musculoskeletal Medicine and Rehabilitation Lead

Disclosure

- No relevant financial relationship exists.

Learning Objectives

- Discuss MSK risks in the Astronaut Corps as it relates to Space Flight
- Detail pre-flight, in-inflight and post-flight training

Content Outline

- MSK Injury Data Discussion
- In-flight Exercise Capabilities and Programming
- Post-flight Reconditioning

Astronaut Human Health and Performance Team



Bruce Nieschwitz
Athletic Trainer/Strength Coach - ASCR
- Certified Athletic Trainer (ATC)
- Texas Licensed Athletic Trainer (LAT)
- USA Weightlifting, Sports Performance Coach (USAW)
- Certified Mobility Specialist FRc



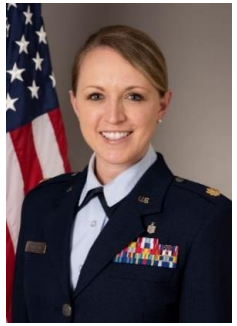
Corey Twine
Strength Coach - ASCR
- Strength and Conditioning Coach Certified- CSCCa
- Certified Strength and Conditioning Specialist (CSCS)
- Certified Mobility Specialist FRc



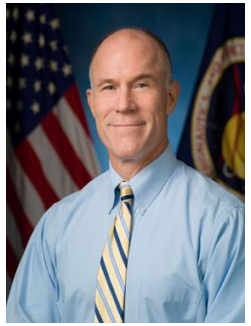
Christi Keeler
Athletic Trainer - ASCR
- Certified Athletic Trainer (ATC)
- Texas Licensed Athletic Trainer (LAT)
- Certified Mobility Specialist FRc
- Graston M-1 Technique Trained
- Dry Needling Certified



Stephanie Petery
Athletic Trainer- ASCR
- Certified Athletic Trainer (ATC)
- Texas Licensed Athletic Trainer (LAT)
- Certified Mobility Specialist FRc
- Graston M-1 Technique Trained
- Mental Health First Aid Certified (MHFA)
- Dry Needling Certified



Danielle Anderson, Lt Col, USAF
MSK Medicine and Rehabilitation Clinical Lead
- Doctor of Physical Therapy/Doctor of Science in PT Orthopedic Certified Specialist (OCS)
- Fellow, American Academy of Orthopedic Manual PT (FAAOMPT)
- Certified Strength and Conditioning Specialist (CSCS)
- Certified Dry Needling/Instructor



Richard Scheuring, COL (retired)
Artemis II Flight Surgeon, MSK Medicine and Rehab Lead Physician
- Doctor of Osteopathic Medicine (DO)
- Fellow, Aerospace Medical Association (FAsMA)
- Registered in Musculoskeletal Ultrasonography (RMSK)

MSK Medicine and Rehabilitation Program

Background

1. Reduce astronaut MSK-related injuries through early identification (pre-injury) conditions and intervention
2. Reduce off-site astronaut time for orthopedic work-up and treatment (improve efficiency of clinical care by having on-site orthopedic surgeon/MSUS availability)
   - Space Act Agreement with Methodist Hospital Dept of Orthopedic Surgery was created and signed in Jan 2012. We have rotated 20+ board-certified orthopedic surgeon sports-medicine Fellows through NASA at *no cost* to the Agency
3. Reduce the overall agency cost of out-of-house orthopedic diagnosis and treatment in the astronaut corps
4. *Facilitate* communications between the MSK Medicine team, Flight Surgeons, Flight Medicine Clinic and the NBL.
5. Provide coordination of specialty care to reduce unnecessary referrals (care provided in-house) that increase agency costs and impact astronaut work schedules.
6. Support Astronaut selection and retention standards and screening

ASCR and MSK Support

- Prepare for flight (assigned and general)
  - Muscular strength, endurance, power, flexibility, and coordination (upper extremity emphasis for EVA performance), Metabolic fitness, Work on individualized areas of concern
  - Coach/Teach proper technique –safety
  - Familiarize astronauts with in-flight exercise and hardware operation



ASCR and MSK Support

- Individualized Programming specific to history, identified complaints, impairments, etc (often translate inflight)
- Support On-Orbit Technology Demos and science
- Enhance informed decision making with hands on experience
- ***Surface EVA Readiness and Performance Optimization***





MSK Injuries- Astronaut Corps

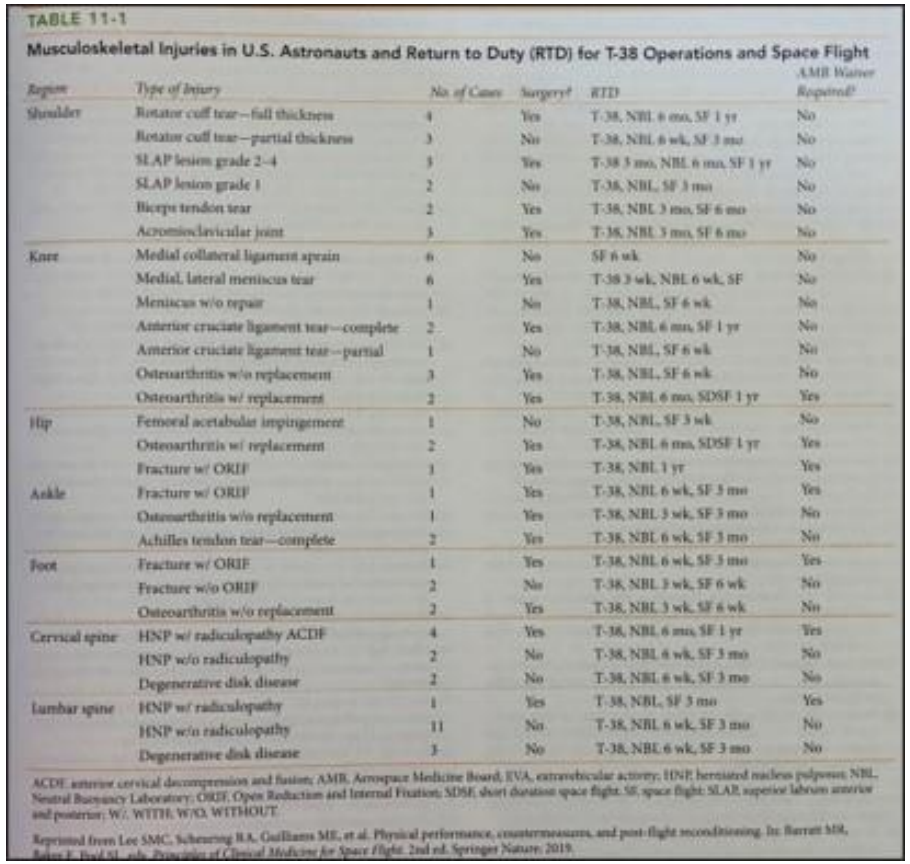


TABLE 11-1

Musculoskeletal Injuries in U.S. Astronauts and Return to Duty (RTD) for T-38 Operations and Space Flight

Region	*Type of Injury*	*No. of Cases*	*Surgery?*	*RTD*	*AMB Waiver Required?*
Shoulder	Rotator cuff tear—full thickness	4	Yes	T-38, NBL 6 mo, SF 1 yr	No
	Rotator cuff tear—partial thickness	3	No	T-38, NBL 6 wk, SF 3 mo	No
	SLAP lesion grade 2–4	3	Yes	T-38 3 mo, NBL 6 mo, SF 1 yr	No
	SLAP lesion grade 1	2	No	T-38, NBL, SF 3 mo	No
	Biceps tendon tear	2	Yes	T-38, NBL 3 mo, SF 6 mo	No
	Acromioclavicular joint	3	Yes	T-38, NBL 3 mo, SF 6 mo	No
Knee	Medial collateral ligament sprain	6	No	SF 6 wk	No
	Medial, lateral meniscus tear	6	Yes	T-38 3 wk, NBL 6 wk, SF	No
	Meniscus w/o repair	1	No	T-38, NBL, SF 6 wk	No
	Anterior cruciate ligament tear—complete	2	Yes	T-38, NBL 6 mo, SF 1 yr	No
	Anterior cruciate ligament tear—partial	1	No	T-38, NBL, SF 6 wk	No
	Osteoarthritis w/o replacement	3	Yes	T-38, NBL, SF 6 wk	No
	Osteoarthritis w/ replacement	2	Yes	T-38, NBL 6 mo, SDSF 1 yr	Yes
Hip	Femoral acetabular impingement	1	No	T-38, NBL, SF 3 wk	No
	Osteoarthritis w/ replacement	2	Yes	T-38, NBL 6 mo, SDSF 1 yr	Yes
	Fracture w/ ORIF	1	Yes	T-38, NBL 1 yr	Yes
Ankle	Fracture w/ ORIF	1	Yes	T-38, NBL 6 wk, SF 3 mo	Yes
	Osteoarthritis w/o replacement	1	Yes	T-38, NBL 3 wk, SF 3 mo	No
	Achilles tendon tear—complete	2	Yes	T-38, NBL 6 wk, SF 3 mo	No
Foot	Fracture w/ ORIF	1	Yes	T-38, NBL 6 wk, SF 3 mo	Yes
	Fracture w/o ORIF	2	No	T-38, NBL 3 wk, SF 6 wk	No
	Osteoarthritis w/o replacement	2	Yes	T-38, NBL 3 wk, SF 6 wk	No
Cervical spine	HNP w/ radiculopathy ACDF	4	Yes	T-38, NBL 6 mo, SF 1 yr	Yes
	HNP w/o radiculopathy	2	No	T-38, NBL 6 wk, SF 3 mo	No
	Degenerative disk disease	2	No	T-38, NBL 6 wk, SF 3 mo	No
Lumbar spine	HNP w/ radiculopathy	1	Yes	T-38, NBL, SF 3 mo	Yes
	HNP w/o radiculopathy	11	No	T-38, NBL 6 wk, SF 3 mo	No
	Degenerative disk disease	3	No	T-38, NBL 6 wk, SF 3 mo	No

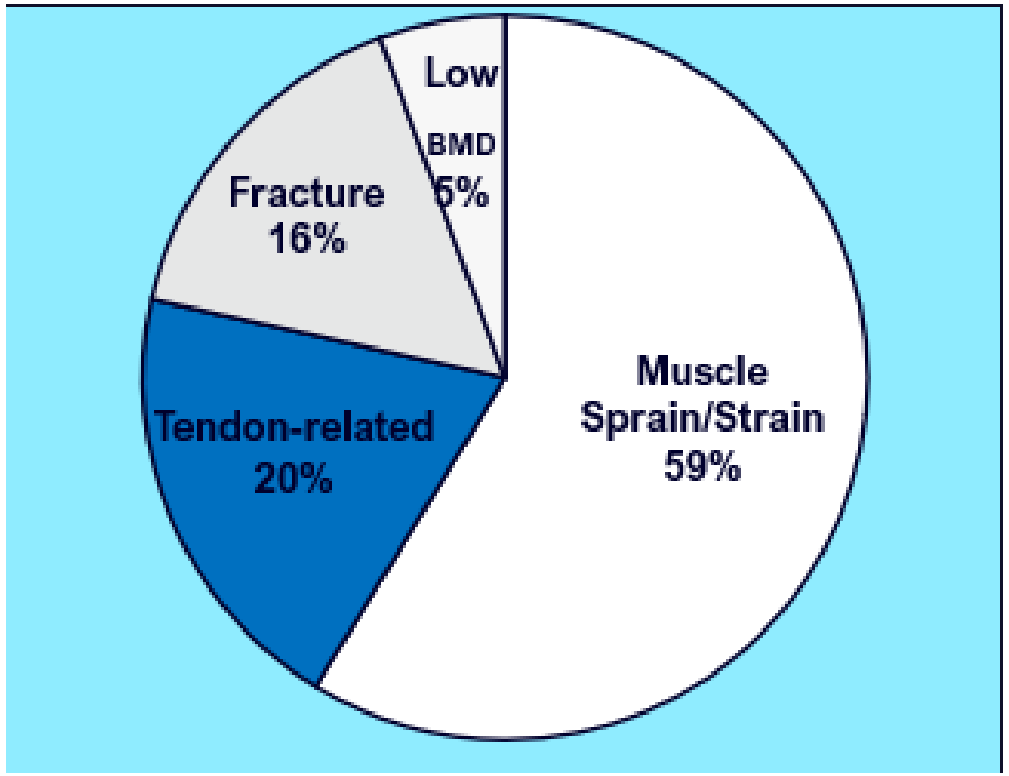
ACDF, anterior cervical decompression and fusion; AMB, Aerospace Medicine Board; EVA, extravehicular activity; HNP, herniated nucleus pulposus; NBL, Neutral Buoyancy Laboratory; ORIF, Open Reduction and Internal Fixation; SDSF, short duration space flight; SF, space flight; SLAP, superior labrum anterior and posterior; W/, WITH; W/O, WITHOUT.

Reprinted from Lee SMC, Scheuring RA, Guilliams ME, et al. Physical performance, countermeasures, and post-flight reconditioning. In: Barratt MR, Baker E, Pool SL, eds. *Principles of Clinical Medicine for Space Flight*. 2nd ed. Springer Nature; 2019.

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

Scheuring, et al 2012, Strock, et al. IEEE Aerospace, 2022

MSK Injuries- Astronaut Corps



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

Strock, et al. IEEE Aerospace, 2022

MSK Injuries- Astronaut Corps

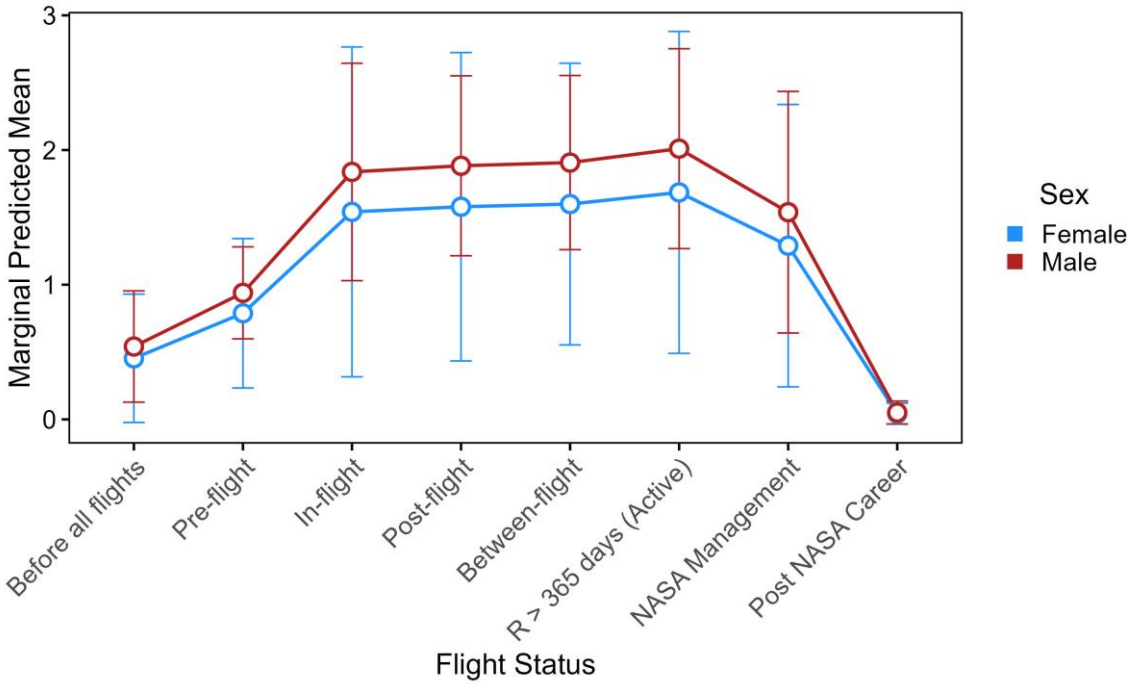


Figure 1. Predictive margins of flight status and sex with 95% Cis for all musculoskeletal injuries.

Table 4: Marginal rates of all musculoskeletal injuries by flight status and sex.*

Variable	Margin	Delta-method std. err.	[95% CI]
Female flight status			
Before all flights	0.454	0.243	[-0.023 - 0.930]
Pre-flight	0.788	0.283	**[0.233 - 1.343]**
In-flight	1.541	0.625	**[0.316 - 2.765]**
Post-flight	1.579	0.584	**[0.434 - 2.724]**
Between-flight	1.599	0.534	**[0.553 - 2.644]**
R > 365 days (Active)	1.685	0.610	**[0.490 - 2.880]**
NASA Management	1.290	0.535	**[0.242 - 2.338]**
Post NASA Career	0.043	0.040	[-0.035 - 0.120]
Male flight status			
Before all flights	0.541	0.211	**[0.128 - 0.954]**
Pre-flight	0.940	0.174	**[0.598 - 1.281]**
In-flight	1.837	0.412	**[1.031 - 2.644]**
Post-flight	1.883	0.341	**[1.215 - 2.551]**
Between-flight	1.907	0.330	**[1.260 - 2.553]**
R > 365 days (Active)	2.010	0.379	**[1.268 - 2.752]**
NASA Management	1.538	0.458	**[0.641 - 2.435]**
Post NASA Career	0.051	0.043	[-0.034 - 0.136]

*Findings in bold are statistically significant

MSK Injuries- Astronaut Corps

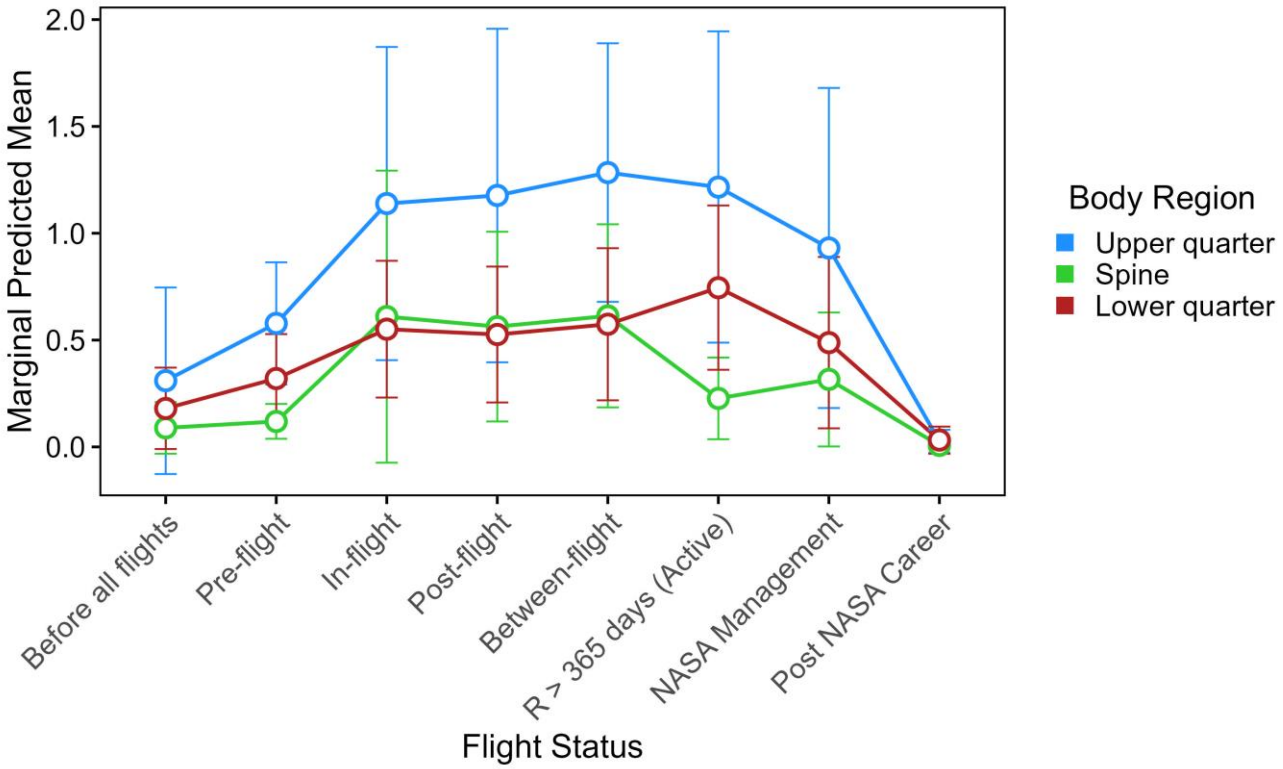


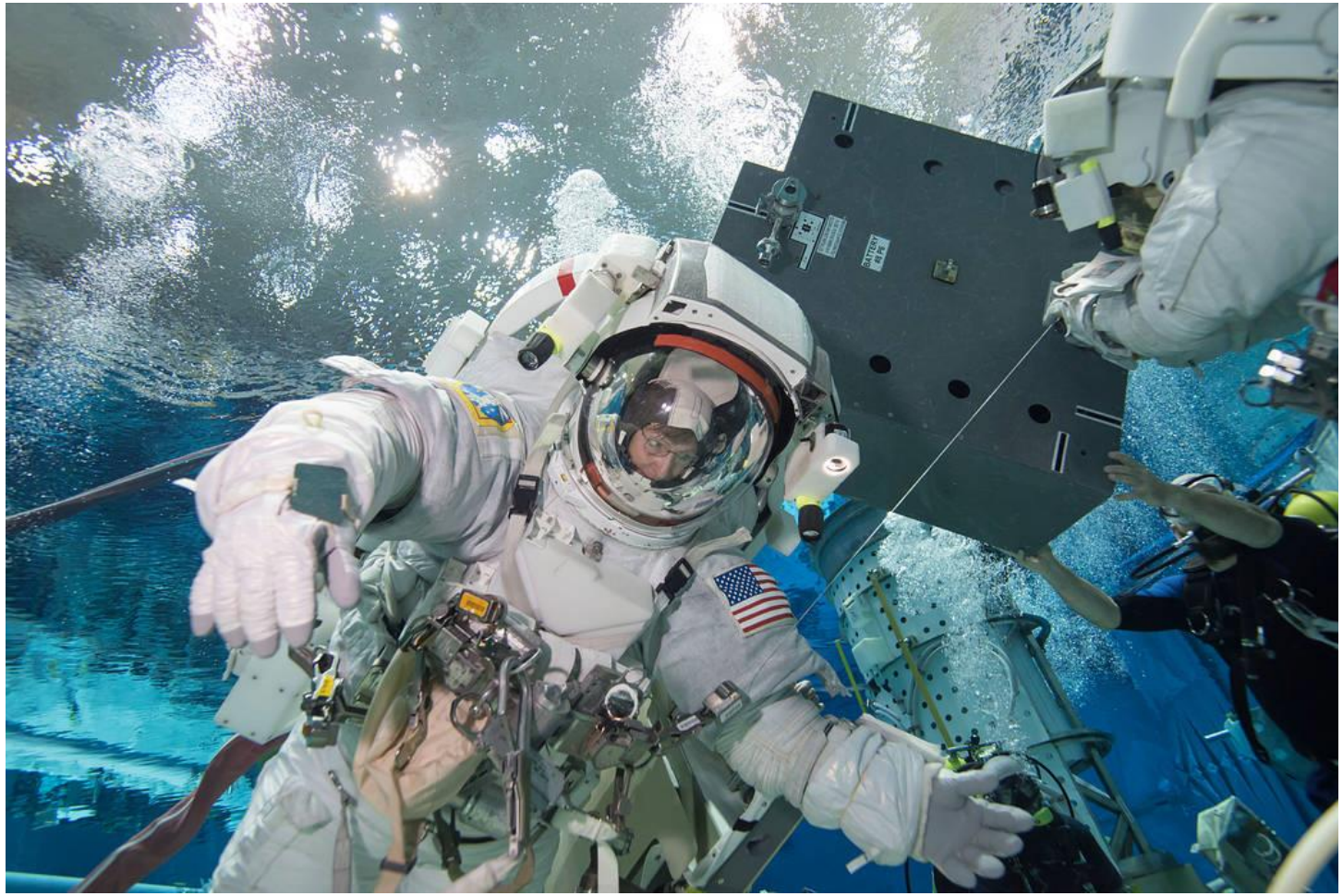
Figure 9. Predictive margins of flight status and sex with 95% CIs for all musculoskeletal injuries from the body regions upper quarter, spine, and lower quarter, by flight status in male astronauts.

Table 15: Marginal rates of all musculoskeletal injuries from the body regions, upper quarter, spine, and lower quarter, by flight status in male astronauts.*

Variable	Margin	Delta-method std. err.	[95% CI]
Upper quarter (Flight status)			
Before all flights	0.310	0.223	[-0.127 - 0.746]
Pre-flight	0.578	0.146	**[0.292 - 0.864]**
In-flight	1.139	0.374	**[0.406 - 1.872]**
Post-flight	1.177	0.398	**[0.396 - 1.957]**
Between-flight	1.284	0.309	**[0.679 - 1.889]**
R > 365 days (Active)	1.216	0.372	**[0.488 - 1.945]**
NASA Management	0.931	0.382	**[0.182 - 1.680]**
Post NASA Career	0.026	0.027	[-0.027 - 0.080]
Spine (Flight status)			
Before all flights	0.089	0.062	[-0.032 - 0.210]
Pre-flight	0.119	0.042	**[0.038 - 0.201]**
In-flight	0.610	0.349	[-0.074 - 1.293]
Post-flight	0.563	0.226	**[0.119 - 1.007]**
Between-flight	0.613	0.219	**[0.185 - 1.042]**
R > 365 days (Active)	0.227	0.098	**[0.036 - 0.418]**
NASA Management	0.316	0.160	**[0.002 - 0.629]**
Post NASA Career	0.007	0.009	[-0.011 - 0.025]
Lower quarter (Flight status)			
Before all flights	0.180	0.097	[-0.010 - 0.371]
Pre-flight	0.320	0.106	**[0.112 - 0.528]**
In-flight	0.551	0.163	**[0.231 - 0.871]**
Post-flight	0.526	0.162	**[0.208 - 0.844]**
Between-flight	0.574	0.182	**[0.218 - 0.930]**
R > 365 days (Active)	0.745	0.196	**[0.361 - 1.130]**
NASA Management	0.488	0.205	**[0.087 - 0.889]**
Post NASA Career	0.032	0.032	[-0.032 - 0.095]

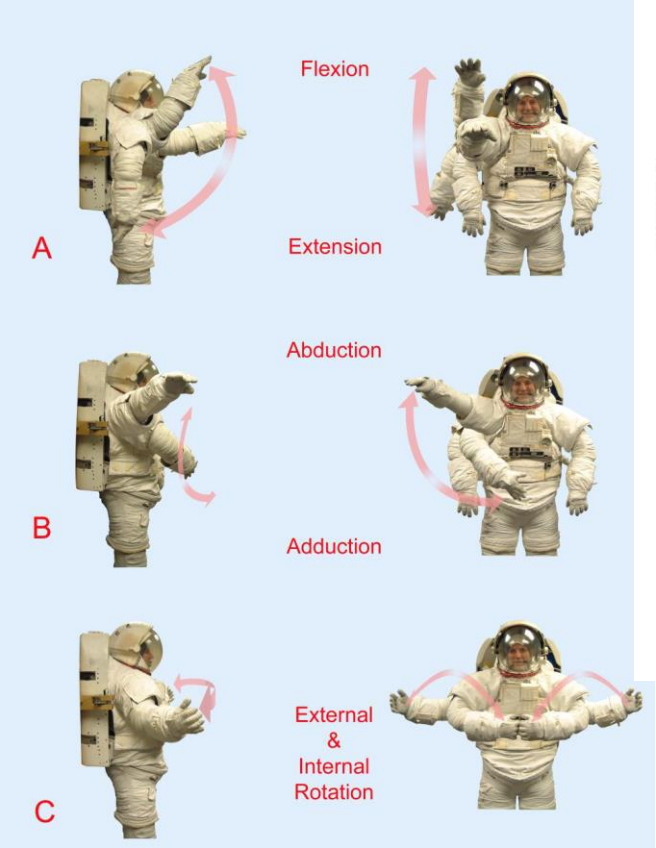
*Findings in bold are statistically significant

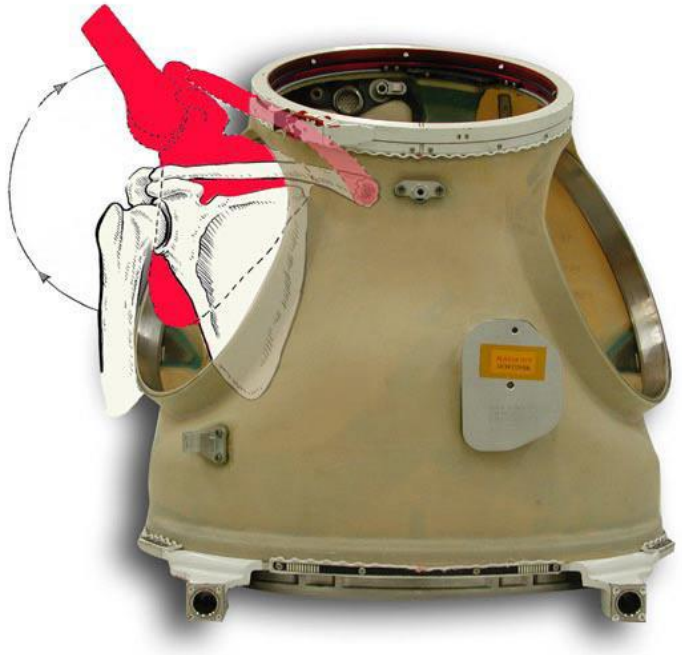
EMU Suit- NBL and EVAs



NASA astronaut Peggy Whitson in spacesuit during training underwater

EMU Suit- NBL and EVAs





- Suit general overview
  - Hard Upper Torso
  - Primary Life Support System
  - Bubble Helmet, Soft Lower Torso Assembly
  - Body Seal Closure
  - Maximum Absorbency Garment
- Injury data
  - Of 199 suited runs, 24% resulted in pain/injury
  - Hand/shoulder most common
- Recent Changes
  - Frequency of training
  - Positions of training (avoiding long inverted ops)
  - Comprehensive Physical Training

NASA astronaut Peggy Whitson in spacesuit during training underwater

MSK Injuries- Astronaut Corps- In Flight

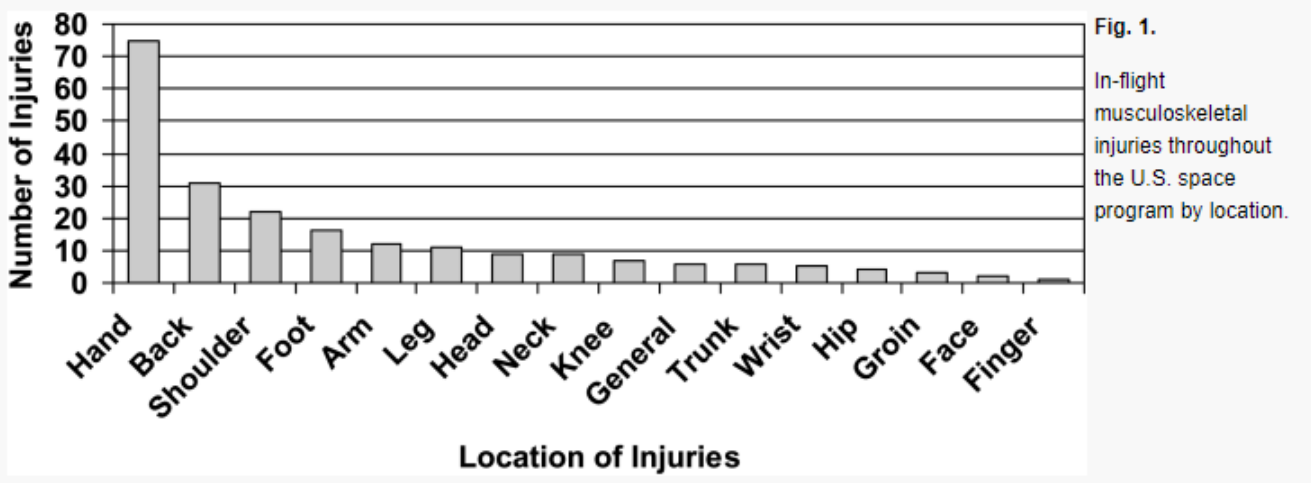
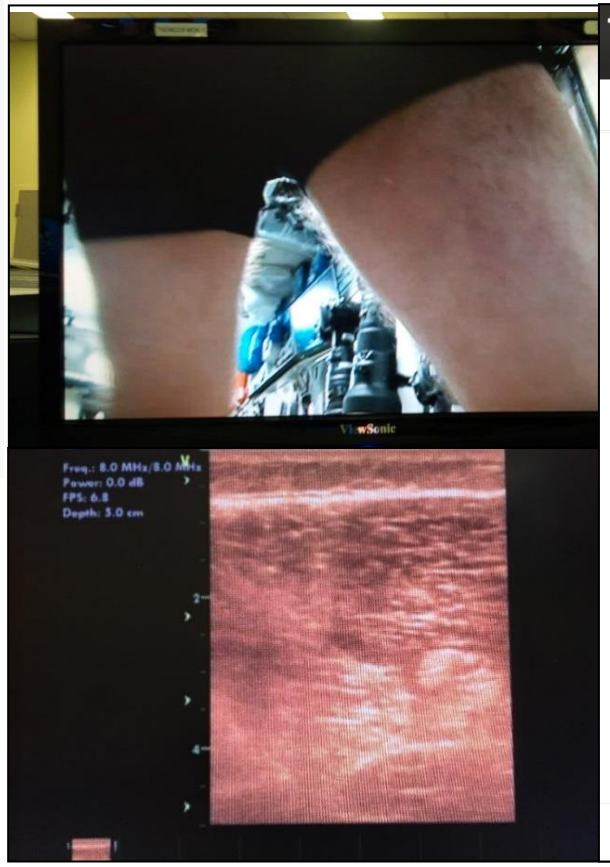


Fig. 1.

In-flight musculoskeletal injuries throughout the U.S. space program by location.





- Require skilled clinical decision making, on-orbit ultrasound and conservative management
- Full scope human performance team to maintain fitness/manage conditions

Space Adaptation Back Pain

53% of Crew Members Experience, 90% resolve by Flight Day 12

85% mild pain, non-duty limiting

Precise mechanisms unknown, currently no accepted preventative measures

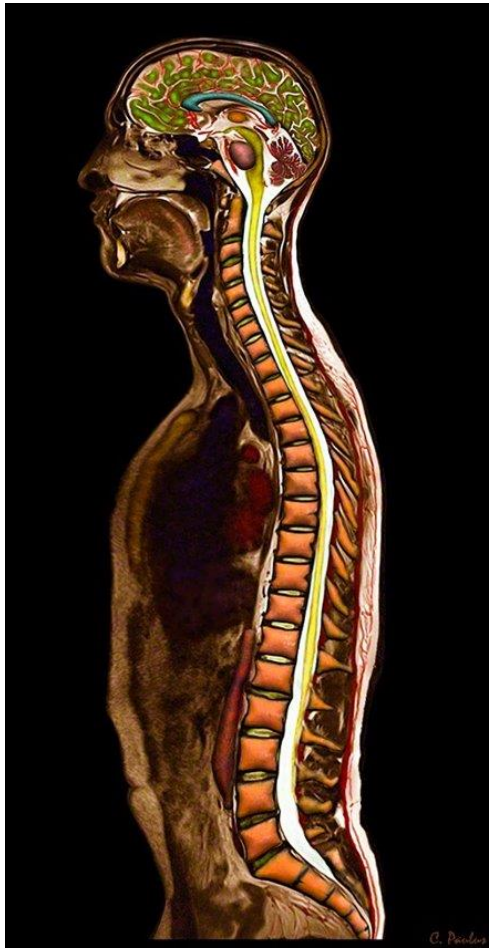
Potential mission impacted related to uncontrolled pain, sleep disturbance, or the adverse side effects of anti-inflammatory medications



MSK Considerations Astronaut Corps- In Flight

2021 NASA Human Research Program: Biomechanics of the lumbar spine following spaceflight and incidence of post-flight disc herniation

- N=12 subjects (10 males, 2 females)
- Evaluation:
  - **3T MRI** for facet arthropathy, endplate irregularities, HIZ, disc herniation, degeneration, water content and multifidus CSA, mCSA, m%
  - **Spine segment kinematics** max flexion-extension/lateral flexion/translation ROM per segment
  - Time points: pre-flight, R+2-7 (after 6 mos) and R+30-60

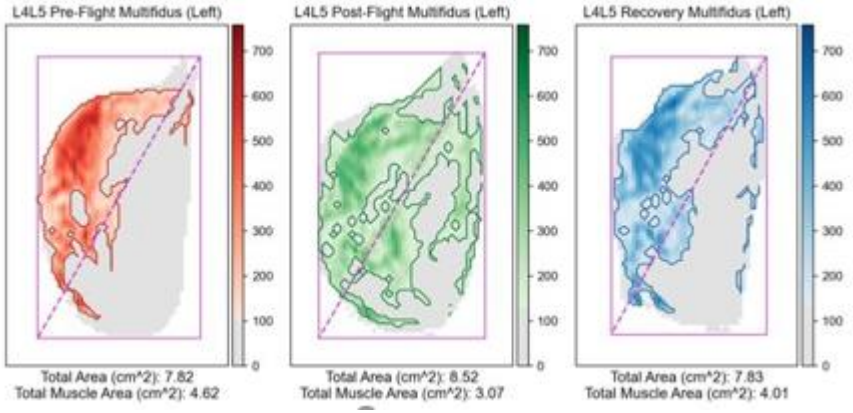


Bailey et. Al, IWS, 2021

MSK Considerations Astronaut Corps- In Flight

2021 NASA Human Research Program: Biomechanics of the lumbar spine following spaceflight and incidence of post-flight disc herniation

- **Results:**
  - 50% (6 out of 12) of crew members returned from space with a symptomatic disc protrusion/herniation
  - Decreased ROM → upper lumbar spine
    - **Associated with endplate irregularities**
  - Lower pre-flight average multifidus % and higher asymmetry
  - Decreased average multifidus % and increased asymmetry → lower lumbar spine
  - Water content, muscle CSA, other spinal pathology did not associate



Bailey et. Al, IWS, 2021

Goals for In-Flight Training

Maintain Crew Fitness and Prevent Injury

- Protect Functionality and Capability
- Minimize Losses
  - strength, power, endurance, flexibility & mobility, coordination, stamina, metabolic fitness and BMD
- Optimize performance, maximize reconditioning efforts and return to preflight status or better during postflight

Schedule

- 2.5 hr/d, 6 d/wk
- 1.5 hr Resistive, 1 hr Metabolic (includes setup and clean up)
- Many crew will exercise 7 d/wk

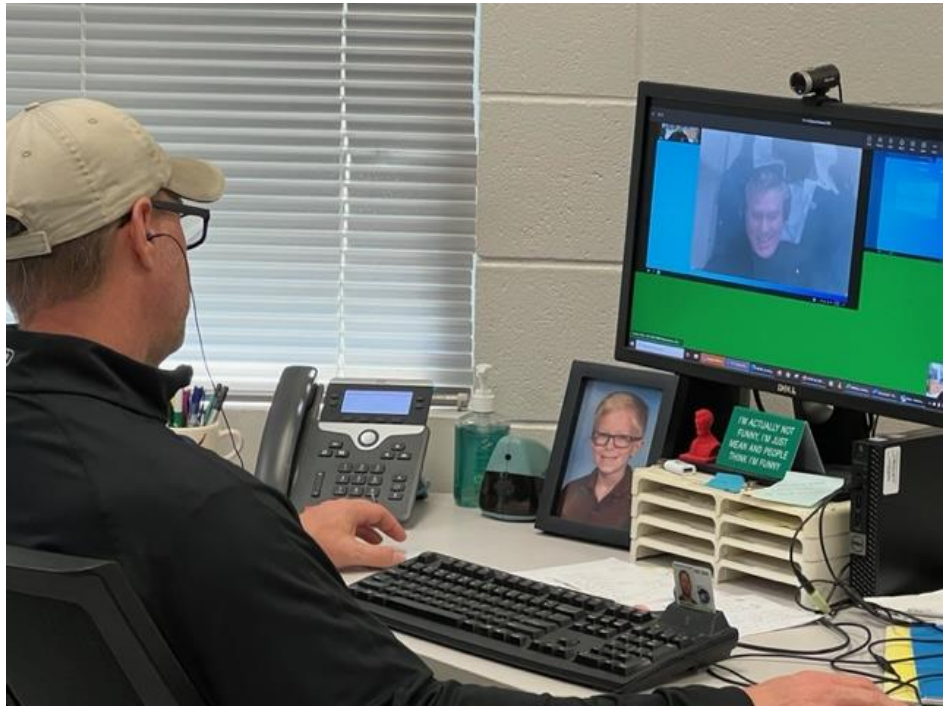


To CUP

In-Flight Monitoring

Subjective Measures

- Private Medical Conference (PMC)
- Photo/TV
  - Live or video recording FD15, then every 30 days
- Private Exercise Conference (PEC) pictured



Objective Measures

- On-Orbit Strength and Conditioning Monitoring & Weekly exercise HR analysis
- Max CEVIS (VO2 Max on ISS)
- *Isometric Mid-Thigh Pull on ARED

Risk of symptomatic IVD ~2-21X

BMD Loss ~8%

mCSA decrease in lower leg musculature/ type 1 fiber reduction



Lower extremity strength/ endurance reduce >10%

Peak Aerobic Capacity and power reduced ~8-10%

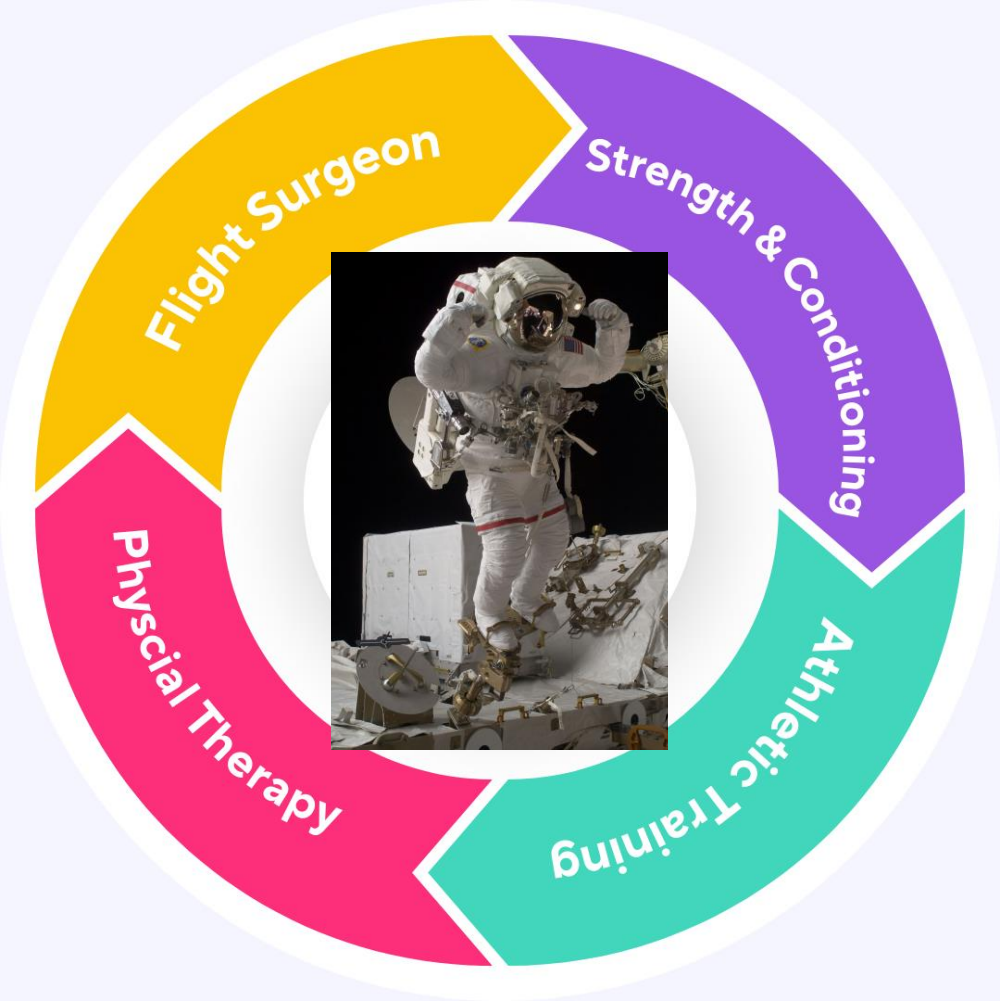
Decreased sensorimotor capability

Post-Flight Reconditioning 30,000 Foot View

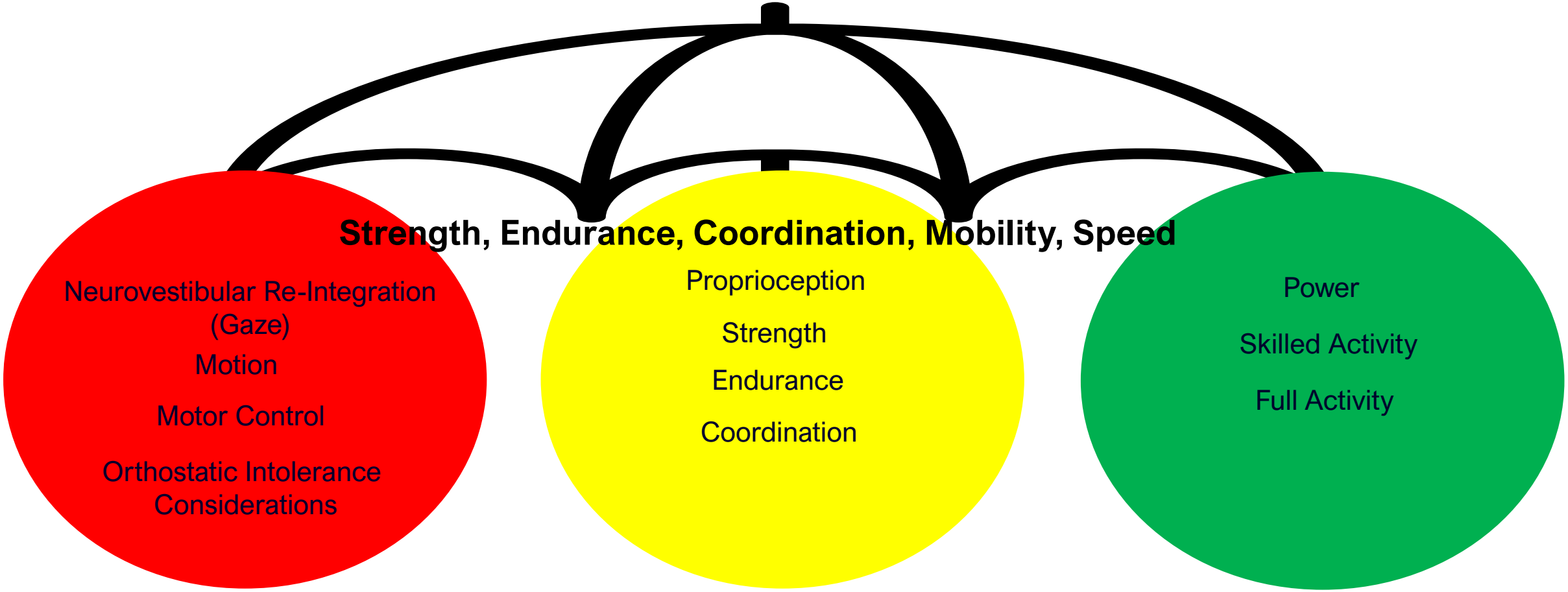
Team Approach

Progressively load impairments of the multisystem degradation to ***enhance safe and effective*** re-adaptation and return to ***prior level of function and individualized goals***

Continual ***monitoring*** and ***adjustments*** to programming based on ***individual system priorities and response to stimuli over the 45 day period***



Post-Flight Reconditioning Considerations/Progressions



1.) Physiologic Effects of Space Flight

2.) Functional Abilities

3.) Crew Members Goals and Training Desires

4.) Other demands (operational, research, etc)

Goals: Reduce adaptation pain, enhance intersegmental mobility, restore normal firing patterns of deep core stabilizers, and improve joint position sense





PHASE 1





Spinal Considerations- Phase 1

Goals: progress intersegmental and multi-joint mobility, advance neuromuscular re-education to functional movements, progressively begin loading the spine





PHASE 2





Spinal Considerations- Phase 2

Goals: progression of multi-joint mobility with load, advance strength and power, development of skilled and functional activity… build spinal resiliency!!





PHASE 3





Spinal Considerations- Phase 3

Neurovestibular Evidence

Central Nervous System adaptations to space flight → reinterpretation of vestibular and somatosensory inputs

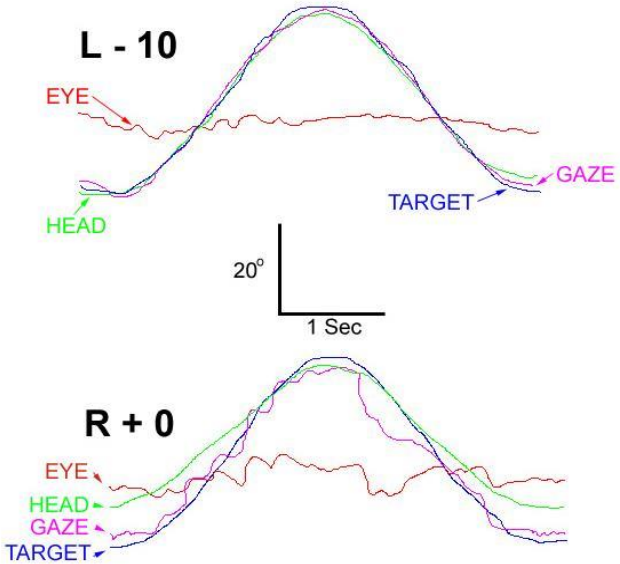
Excessive postural sway, decreased proprioception, and locomotor control

Altered gaze stability

Alterations in muscle activation

Alterations in head-trunk coordination

Impaired cognitive and somatosensory dual processing



Macaulay, et al, Front Syst Neurosci, 2021

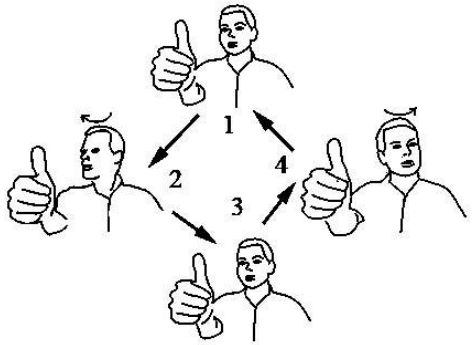
Neurovestibular Evidence





Macaulay, et al, Front Syst Neurosci, 2021

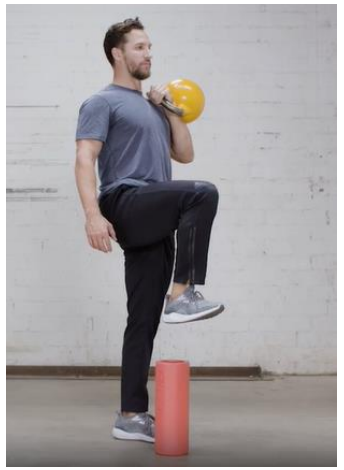
Goals: normalize gaze stabilization, integrate vestibular, somatosensory and visual systems for balance, normalize proprioception and somatosensory system





PHASE 1

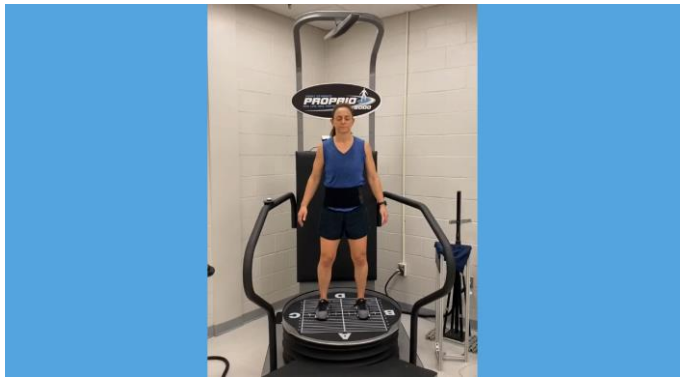




Neurovestibular Considerations- Phase 1

Goals: progress gaze stability exercises to unstable surface, reactive and varying surface training, and gradual addition of dual-tasking





PHASE 2





Goals: progression to dual-task training with varying intensity and surfaces, progression of coordination and agility





PHASE 3





Neurovestibular Considerations- Phase 3

Risk of symptomatic IVD ~2-21X

mCSA decrease in lower leg musculature/ type 1 fiber reduction

Return to preflight functional fitness



Cortical bone return to baseline 1year, trabecular bone remains decreased

Aerobic capacity near preflight at 30 days

Neurocom platform test normal by R+14

Surface EVA Readiness and Performance Optimization







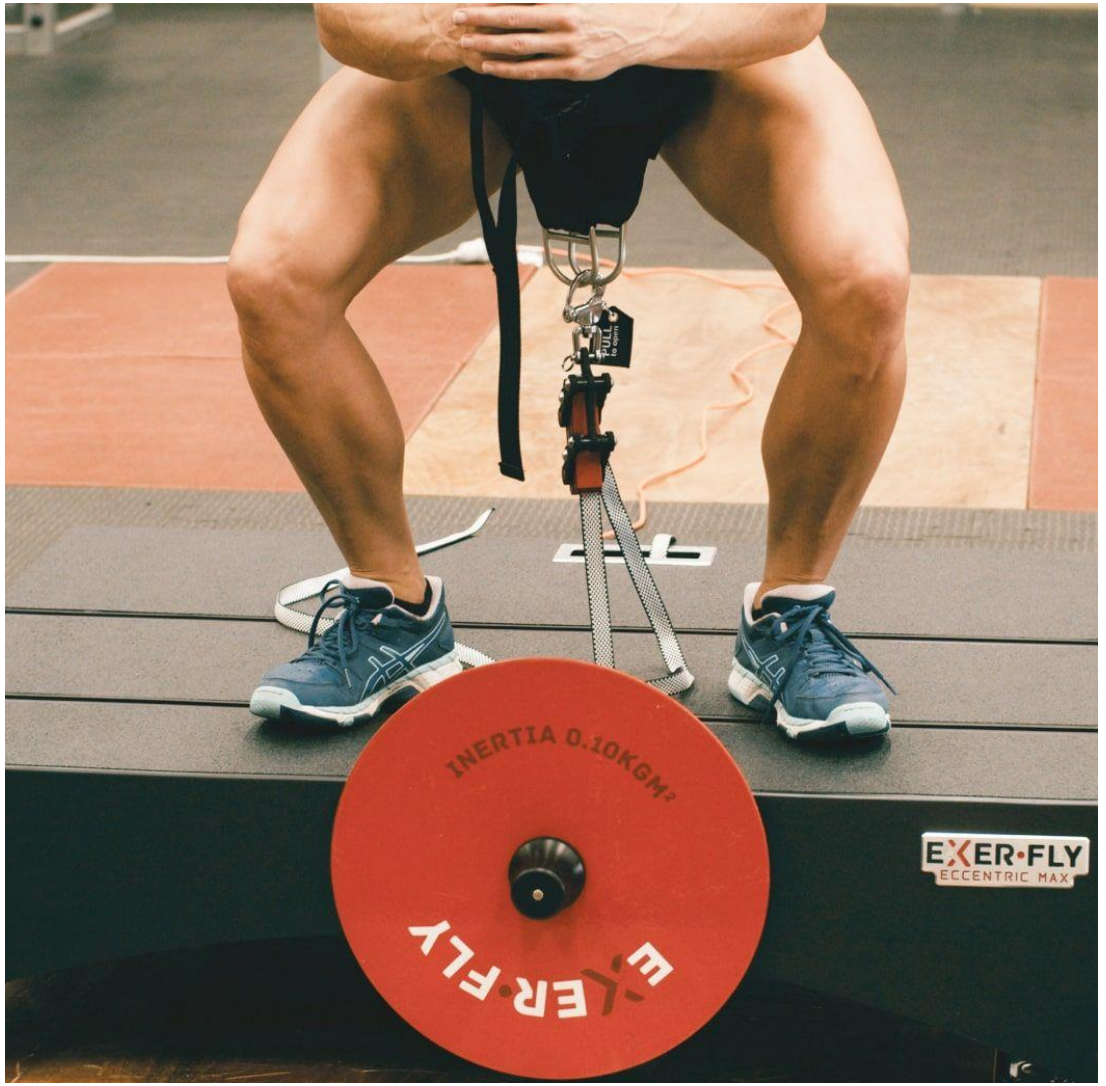

Surface EVA Readiness and Performance Optimization

Goals:

- Identifying musculoskeletal (MSK) injury mechanisms in ***anyone*** training in the xEMU or analog suits/environments
- ***Mitigating*** training related MSK injuries through early reporting AND protective barriers during training (i.e currently limit inverted time in the EMU)
- Enhance ***performance*** in the xEMU in training and on the lunar surface with a holistic approach to human performance optimization
- Improving crew ***readiness*** for training and surface EVA through integration of comprehensive human performance strategies

Exploration Inflight Challenges

- Inflight Exercise Capabilities will differ than current ISS countermeasures
- Flywheel device will be the sole exercise device for initial Artemis missions
- Serve both cardiovascular and muscular fitness
- SABP with EVA tempo earlier in mission phase
- Higher tempo EVA, maintaining fitness to optimize performance, and reduce risk of injury



Surface EVA Readiness and Performance Optimization






Questions?

Thank you Federal Section, Speakers, and the team at JSC

