

Integrated Human Performance

Corey Twine

Astronaut Strength Conditioning and Rehabilitation
Human Health and Performance Contract
JSC B26, Rm 115| Houston, TX | 77058
Office: (281) 792-7866 Mobile: (757) 573-5717

Multisystem Deconditioning

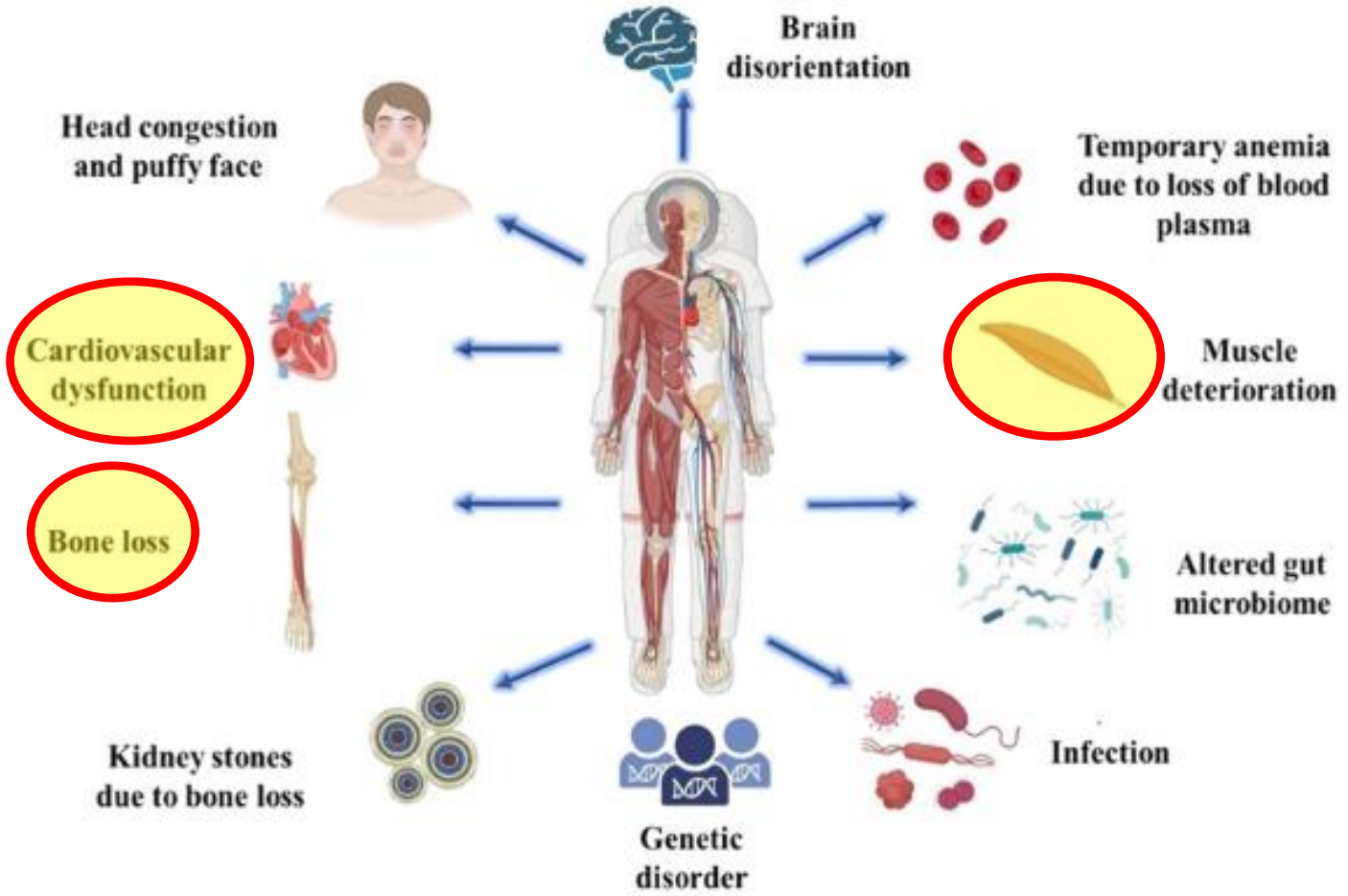


Fig. 1. Physiological changes in spaceflight environment.

(Wani A, et al. 2024)

Itemized: Multisystem Deconditioning

Cardiovascular



Physiological

Plasma volume loss – 10–15% reduction in blood volume within days of flight. Shuttle (*Convertino, 1996)*

Anatomical

Cardiac atrophy – Decreased left ventricular mass after prolonged unloading. (*Perhonen et al., 2001)*

Performance

Orthostatic intolerance – Impaired ability to stand upright post-landing., VO2Peak ↓ (*Blaber et al., 2011)*

Muscle



Physiological

Fiber-type shift – Slow-to-fast twitch transition and reduced oxidative capacity. (*Trappe et al., 2009; Fitts et al., 2010)*

Anatomical

Atrophy – ~20% decrease in **calf muscle** volume (soleus, gastrocnemius). (*LeBlanc et al., 2000)*

Performance

Strength loss – Reduced force production and impaired locomotion post-flight. (*Edgerton et al., 2001; Mulavara et al., 2018)*

Bone



Physiological

Reduced bone formation – Suppression of osteoblast activity and altered remodeling balance in microgravity. (*Smith et al., 2012)*

Anatomical

Trabecular bone loss – 1–2% per month decline in weight-bearing sites (hip, spine, femur) during long-duration spaceflight. (*LeBlanc et al., 2000); (Sibonga et al., 2019)*

Performance

Fracture risk elevation – Decline in bone strength increases risk during surface operations or post-flight reloading. (*Vico et al., 2000) (Rodent data)*

Load Is The Language of Body

Tissue Adaptation: The Body Responds to Signals, Not Intent

Our tissues don't adapt because we *intend* to get stronger—they adapt to **specific mechanical stimuli**. Each system has its own "language." Understanding this is crucial for optimizing **human performance, rehabilitation, and injury prevention**.



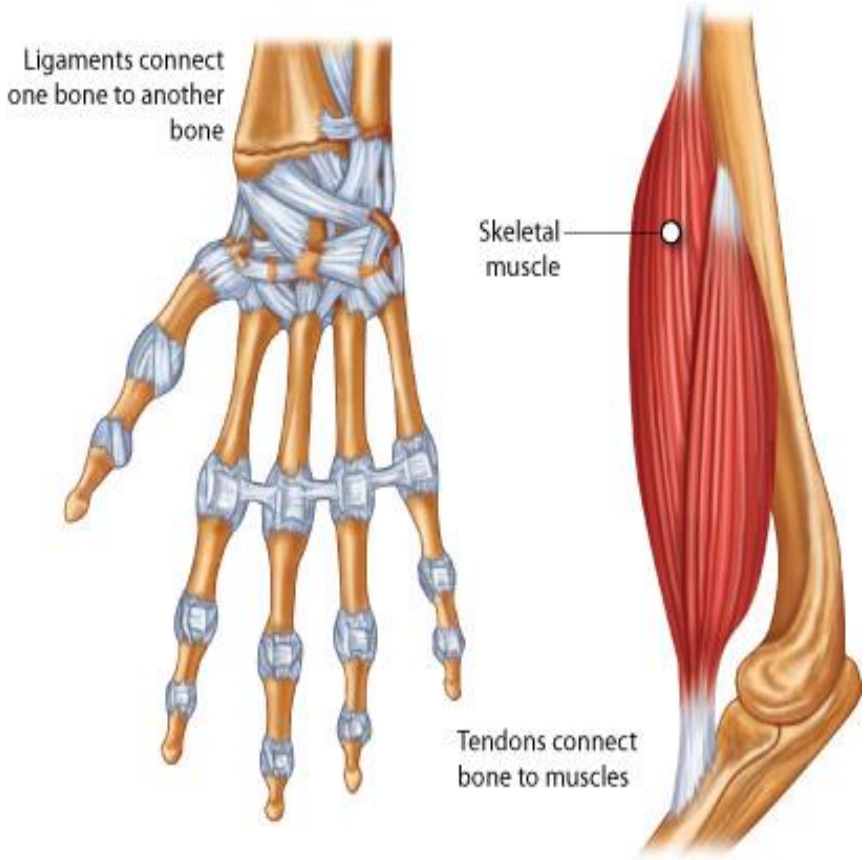
- **Muscle**
  - **Language**: Tension, time under tension, mechanical load, metabolic stress
  - **Adaptation**: **Hypertrophy**, **strength gains**, mitochondrial biogenesis, fiber type shift (characteristics / not change)
  - **Strength vs. Hypertrophy**:
    - **Strength** adaptations are driven primarily by **high-load, low-rep** training and involve **neural efficiency** and improved motor unit recruitment—not just muscle size.
    - **Hypertrophy** involves increased muscle cross-sectional area, primarily from moderate loads and higher volume. *(Schoenfeld, 2010); (Suchomel, et al., 2016): (*Wackerhage, H. et al., 2019)
- **Bone**
  - **Language**: Mechanical loading
  - **Adaptation**: ↑ Bone mineral density (BMD), trabecular remodeling
  - Bone responds to **dynamic mechanical loading** that exceeds a strain threshold (~1,000 με) (Microstrain). **Higher strain magnitude** and **faster strain rate** produce the most robust adaptation. (*Turner, 1998)*

The Language of Load – How the Body Understands Stress

Ligaments & Tendons – *"Tension is the Teacher"*

- **What They Respond To:**
  - **Tensile load.** That means pulling force.
  - Adapt by aligning collagen fibers, getting thicker (↑ CSA), and stiffer—this helps them handle more tension and protect joints during high-force movements.

- **What Happens in Space (Unloading):**
  - No gravity = no consistent tension
  - ↓ Collagen turnover and remodeling
  - ↓ Tendon cross-sectional area
  - ↓ Stiffness → tendons can't absorb or transmit force as well
  - Tendon tissue responds to mechanical loading in both humans and rodents (*Kjaer et al., 2009, 2023; Heinemeier & Kjaer, 2011 [rodent model]).*



The Language of Load – How the Body Understands Stress

Cartilage – *"Likes Pressure, Hates Neglect" ??*



- **What It Responds To: Cyclic compression** – think walking, lifting, jumping. Cartilage is nourished through intermittent loading. It's avascular—no blood supply—so load is how it gets fed.

- **What Happens When You Take That Away (e.g., microgravity, bed rest):**
  - ↓ Proteoglycans (cartilage's 'shock absorbers)
  - Thinning of cartilage layers (up to 14–27% loss depending on the model)
  - ↑ Risk for degeneration and osteoarthritis-like changes
  - *Rodent models (Nomura et al., 2017; Fitzgerald et al., 2023) show cartilage starts breaking down fast when you remove load. Combine that with radiation (like in space), and the effects worsen.*

- **1G forces are essential for cartilage health and should guide protective or rehab strategies.**
  - These include:
    - **Axial compression** (e.g., weight-bearing activities)
    - **Joint motion under load** (e.g., squats, step-downs)
    - **Hydrostatic pressure fluctuations** (from synovial fluid dynamics during movement)
    - **Intermittent loading with recovery** (as opposed to continuous static compression)
    - **Cycling Loading** (e.g., walking, running, jumping)

Spinal Loading Is Essential—But Spaceflight Alters the System

- **Why Spinal Loading in Spaceflight Is Complex (But necessary!)**
  - Intervertebral discs (IVDs) rely on **cyclical axial compression** to maintain hydration and structure (Bailey et al., 2018).
  - Microgravity eliminates this load → leads to:
    - ❑ **Disc swelling** (Belavý et al., 2011)
    - ❑ **Reduced lumbar lordosis** (~11% decrease post-flight; Bailey et al., (2018) (MRI Position ??)
    - ❑ **Impaired segmental mobility** (17–30% decrease in flexion-extension)
    - ❑ **20–30% loss in spinal extensor lean muscle mass** (multifidus, erector spinae)

Note: Despite the observed increase in seated height and spinal elongation in microgravity, there is no consistent evidence of disc swelling or increased water content post-flight based on MRI assessments (Chang et al., 2016; Bailey et al., 2018). These changes appear to reflect postural realignment and muscle atrophy rather than actual disc hydration shifts.



- **Disc hydration seems preserved in space**, but:
  - **Muscle atrophy (multifidus)** drives spinal flattening and stiffness (Jaap Swanenburg)
  - Alters biomechanics and raises **herniation risk** during reloading

- **Why It Matters**
  - These changes may increase risk for **disc herniation or chronic back pain**, especially during reloading phases.
  - **Astronauts with pre-existing endplate irregularities** are at higher risk for post-flight complications (Bailey et al., 2017).
  - Some disc morphology abnormalities **persist >5 months** post-flight or bed rest (Belavý et al., 2011).

Load is the Language We Need To Speak

In Summary,

- **Muscle (e.g., Multifidus, Erector Spinae)**
  - Responds to **tension and neuromuscular demand**
  - Requires **progressive overload**, varied movement, and motor control
  - Atrophies quickly in unloading; recovery takes time and targeted work
- **Tendon and Ligament**
  - Adapt to **tensile stress**
  - Need **consistent, progressive loading** to maintain stiffness and force transmission
  - Chronic unloading reduces collagen turnover and mechanical integrity
- **Bone (e.g., Vertebrae)**
  - Responds to **compressive and shear forces**
  - Needs **impact, axial loading, and high-strain resistance** to maintain density
  - Rapidly loses mass when unloaded
- **Intervertebral Discs (IVDs)**
  - Require **cyclical axial compression and decompression** for nutrient flow and structural balance
  - Static unloading leads to elongation, impaired mechanics, and increased herniation risk
  - Biochemical shifts (water, GAGs) vary by baseline disc health
- **Articular Cartilage (e.g., Facet Joints, Endplates) ??**
  - Maintained by **low-load, intermittent compression** across full joint range
  - Degrades under constant pressure or prolonged unloading
  - Degeneration reduces joint resilience and shock absorption
- **Key Coaching Principle:**

  Every tissue needs load. But it's not just about more—it's about the right kind of stress, applied at the right dose, over time.

The Language of Tissues is Load

Tissue Type	Required Load Stimulus	Supporting Research
Bone	High-impact, axial loading (e.g., 1–2× bodyweight, jump landings)	*Belinda R. Beck et al. (2015): Tuner (1998)*
Cartilage	Cyclic compression & shear (e.g., walking, resistance training)	*Nomura et al. (2017); Fitzgerald et al. (2023)*
Tendon & Ligament	Progressive tensile load (e.g., strength training, plyometrics)	*Kjaer et al. (2009, 2023)*
Muscle	Mechanical tension & metabolic stress (e.g., 70–85% 1RM, BFR, hypertrophy ranges)	*Wackerhage, H. et al. (2019)*
Nervous System	Neuromuscular control under fatigue (e.g., balance under load, autoregulation strategies)	*Gabbett (2016); Mann et al. (2010); Helms et al. (2018)*

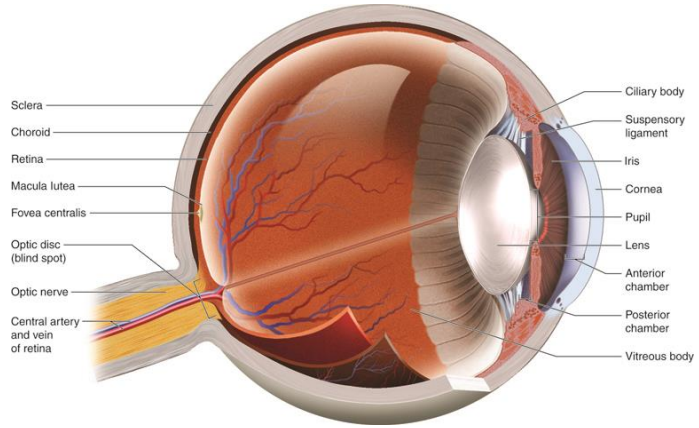
SANS: Exercise Strategies to Minimize Intracranial Pressure (ICP)

Scientific Support — ICP, Exercise, and Body Position

- **Marshall-Goebel et al., 2023**
  - Supine resistance training and Valsalva are both known to increase ICP, which could further exacerbate existing increases in ICP due to spaceflight fluid shifts.

- **Lawley et al., 2017**
  - Fluid shifts and cerebrovascular responses during exercise impact ICP regulation.
  - **Body position and breathing strategy** significantly affect intracranial pressure.
  - The absence of upright posture in microgravity may eliminate natural daily ICP fluctuations, contributing to pathology.

SANS



Inflight Spinal Loading: Risks & Recommendations

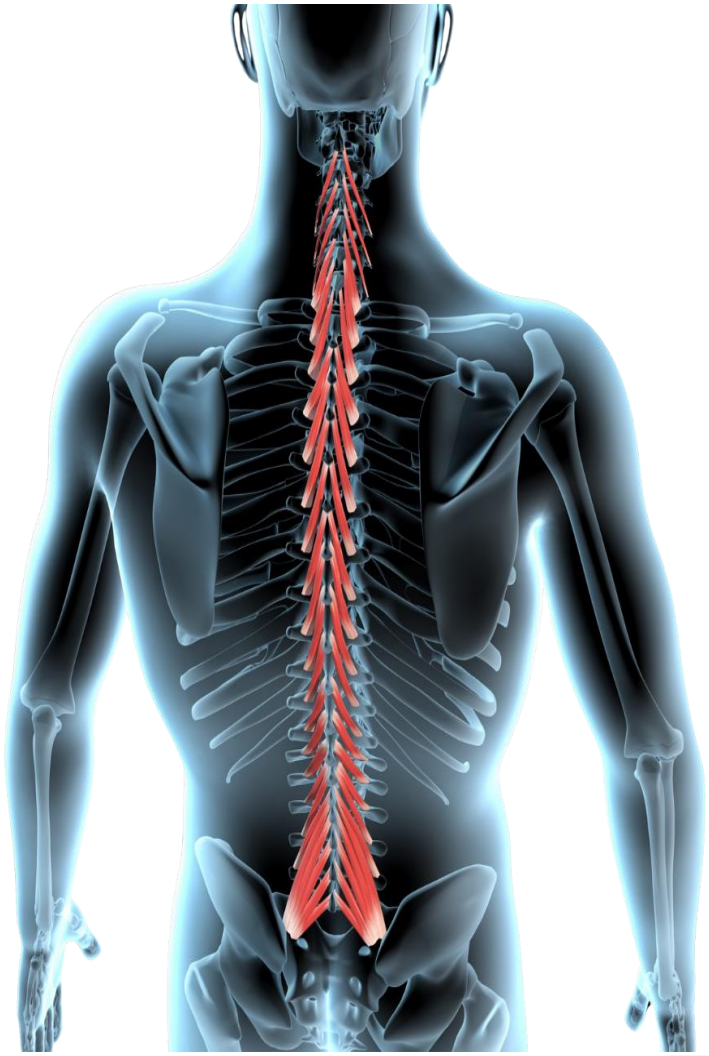
- **Risk Identification:**
  Use MRI to screen for disc degeneration or endplate irregularities. Tailor loading plans to individual spinal structure and function. *(on the way to being a MEDB)*

- **Targeted Activation:**
  Prioritize segmental stabilizers (e.g., multifidus) using low-load, high-control movements. Limit early use of global core exercises.

- **Progressive Loading:**
  Start with low axial resistance (bands, isometrics). Progress only with confirmed alignment, control, and support. Delay heavy axial lifts until foundational stability is established.

- **Monitoring & Feedback:**
  Use motion analysis or sensors to track alignment and trunk control. Adapt programming based on real-time movement data and strength changes.

- **Key Insight:**
  Disc health depends on intelligent, progressive loading—segmental control is essential for spinal integrity during spaceflight and beyond.



Common Causes of Exercise Training Injuries

1. Excessive Intensity

1. Training loads that exceed tissue tolerance (especially with poor preparation) are the most direct cause of injury.
2. *High load = high stress = high risk.*
3. *(Zatsiorsky & Kraemer, 2006); (Baechle & Earle, 2008 _NSCA)*

2. Poor Technique: Force Production vs. Force Absorption

1. Injuries often occur when individuals are not in biomechanically safe positions to produce or absorb force (e.g., spinal flexion under load, valgus knee collapse).
2. Technique breakdown is a *multiplier of risk*, especially under fatigue.
3. *(Hewett et al., 2005); (McGill, 2010)*

3. Fatigue and Volume Mismanagement

1. Excessive training volume without appropriate recovery leads to movement compensations, motor control deficits, and cumulative tissue overload.
2. Fatigue exposes weaknesses and deteriorates technique.
3. *(Gabbett, 2016); (Soligard et al., 2016)*

4. Inadequate Progression and Poor Autoregulation

1. Programs that do not adapt based on day-to-day readiness ignore key biological variability.
2. Lack of autoregulation fails to protect athletes on suboptimal days and can lead to overload on already fatigued systems.
3. *(Helms et al., 2018); (Mann et al., 2010)*



Prescribing Intensity: Objective + Subjective Precision

Intelligent Loading Begins with Good Understanding of Intensity

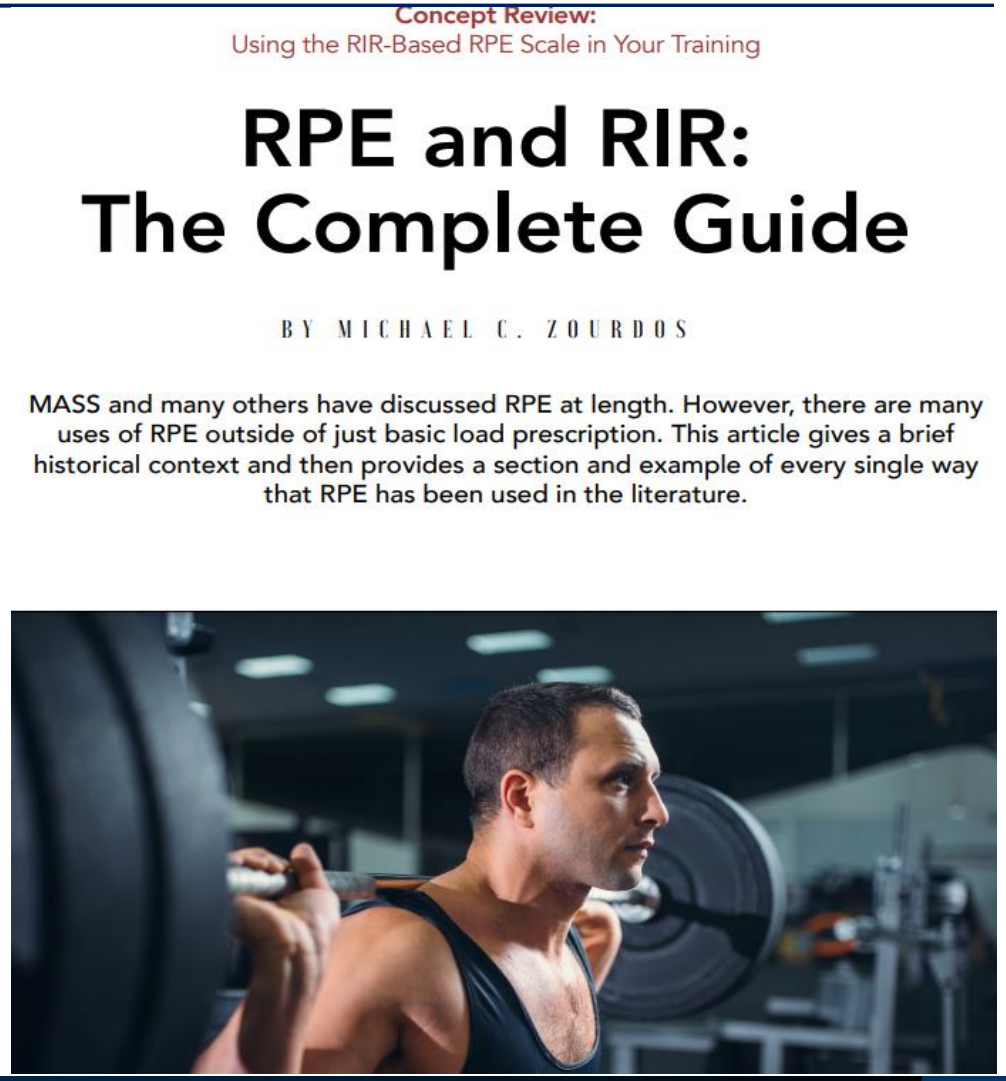
- **Objective Metrics**
  Prescribe intensity using %1-RM, velocity zones, %VO_2max, or %HRmax—based on testing or validated estimates.

- **Subjective Tools**
  When tech isn't available, use RPE and RIR to align effort with true physiological intensity—especially effective for trained individuals.

- **Neuro Integration**
  The brain rapidly synthesizes multisystem feedback into a single composite: RPE.

- **Zourdos Model**
  Zourdos et al (2015). developed a multi-tiered RPE + RIR framework to enhance precision in resistance training.

- **Three RPE Levels**
  - **Rep RPE** – intensity per rep
  - **Set RPE** – perceived effort at end of set
  - **Session RPE** – global load for the full workout



Prescribing Exercise Intensity Inflight: Objective + Subjective Tools

- **Objective Prescription (When Available)**
  - **Resistance Training**:
    - Load based on estimated **%1-Rep Max (1RM)**
    - Inflight estimates from Earth-based pre-flight testing
  - **Cardiovascular Training**:
    - Prescribed by **%VO_2max** or **%HR_{max}**
    - Derived from tests like the **302-cycle test** or field estimates

- **Subjective Prescription (Used Inflight)**
  - **Rate of Perceived Exertion (RPE)**:
    - Borg or CR-10 scales
    - Correlates well with **HR**, **lactate**, and **EMG** Eston et al., (2018)
  - **Repetitions in Reserve (RIR)**:
    - Predicts proximity to failure with high accuracy (<2 rep error)
    - Enables **fatigue management**:
      - 0–1 RIR → high fatigue
      - 2–3 RIR → better recovery *Zourdos et al.,(2015)*

- **Practical Inflight Application**
  - Use **pre-flight testing** to anchor %1RM and %HR_{max}
  - Inflight: rely on **RIR + RPE** to adjust intensity when devices aren't available
  - Combining both supports **individualized load**, **recovery**, and **injury prevention**

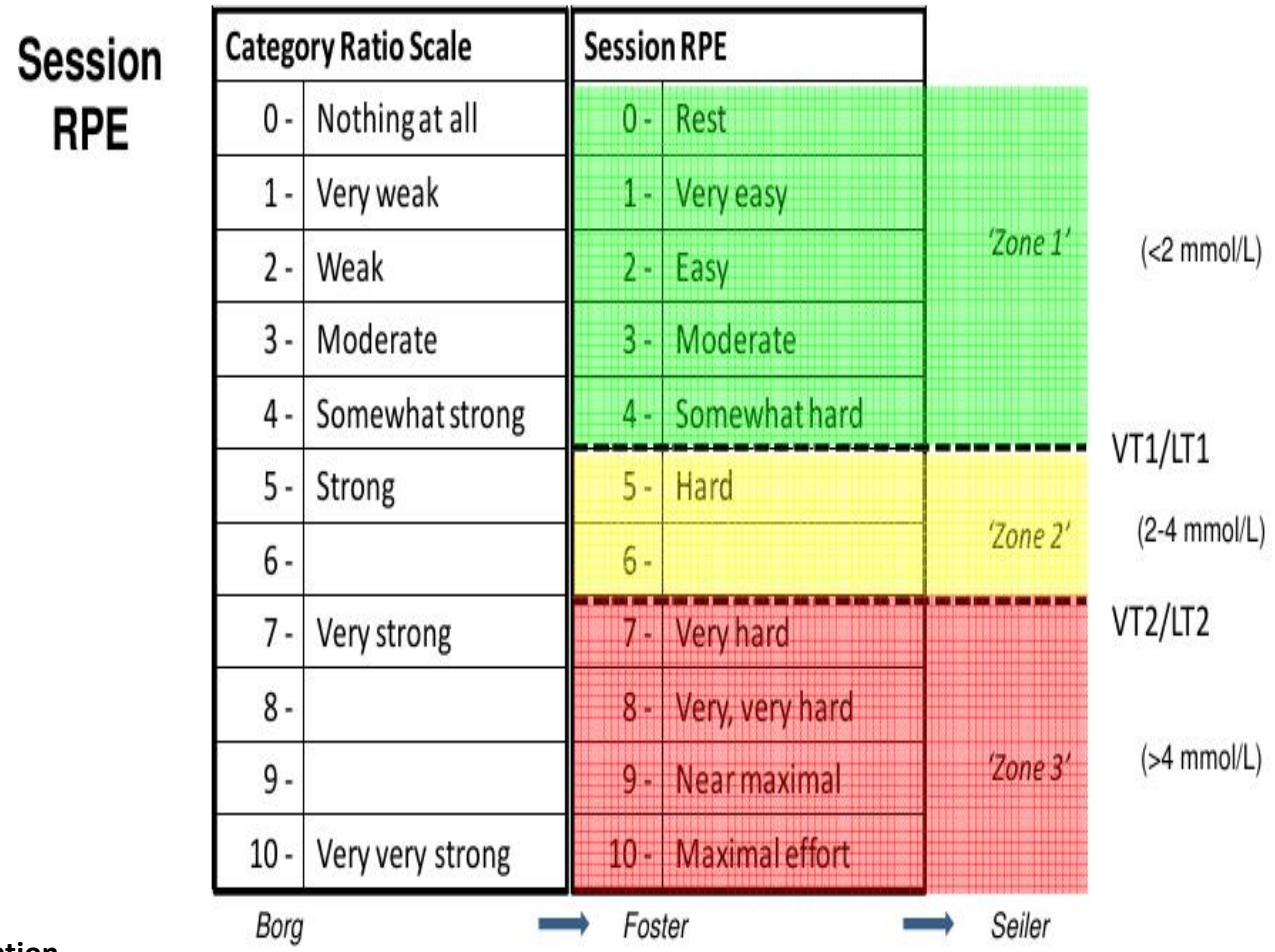


Image from: Frankie TAN, PhD Senior Sports Physiologist Singapore Sports Institute

Understanding Intensity in Resistance Training: Load vs. Effort

- **Intensity of Load (External Load)**
  - **Definition:** The **absolute weight used**, typically expressed as a **percentage of 1-repetition maximum (%1RM)**.
  - **Example:** 85% 1RM = high load; 30% 1RM = low load.
  - **Objective Measure**
  - **Primary Influence:** Neuromuscular demand and mechanical tension.
  - *Refalo et al., 2023 – Clarified that load represents the mechanical demand placed on the system, independent of subjective strain.*

- **Intensity of Effort (Proximity to Failure)**
  - **Definition:** The **degree of exertion**, or **how close a set is taken to momentary muscular failure**.
  - Measured using:
    - **RIR (Reps in Reserve)**
    - **RPE (Rate of Perceived Exertion)**
  - **Subjective but Quantifiable**
  - **High effort can occur at any load**, such as both 3RM and 20RM taken to failure.
  - *Helms et al., 2016 – Supported RPE as a reliable measure for internal effort and a key tool for autoregulating training.*

- **Key Distinction**
  - **Intensity of Load** = *"How heavy is the weight relative to your maximum?"*
  - **Intensity of Effort** = *"How close are you to failure at that load?"*

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).



Deload: Tracking Volume Load is Key

Deload Example: Reducing Fatigue Without Losing Progress

Goal: Drop volume load & intensity to promote recovery

Target: ~20–30% reduction in total volume load

- **Normal Week: 5×5 @ 80% 1RM**
  - 1RM = 100 kg
  - Load = 80 kg (80%)
  - Sets × Reps = 5 × 5
  - Volume Load = 5 × 5 × 80 = **2,000 kg**

- **Deload Week: 3×8 @ 60% 1RM**
  - Load = 60 kg (60%)
  - Sets × Reps = 3 × 8
  - Volume Load = 3 × 8 × 60 = **1,440 kg**
  - ▼ Volume Load Reduction = **28%**
  - ◆ Reduced volume and effort for recovery

	Normal Week	Deload Week (3×8)
Load % (1RM)	80% (80 kg)	60% (60 kg)
Sets × Reps	5 × 5	3 × 8
Volume Load (kg)	2,000 kg	1,440 kg
Effort (RIR)	0–1 (high)	3–4 (moderate)
Outcome	Strength gains	Fatigue reduction

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 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.
  - 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.



Sprint HIIT Intervals

Sprint Aerobic Intervals

Short Sprint

- *Warm-up:* 10 min @ 50% Hrmax
- *Main set:* 7–8 sets of 30s near-max effort + 15s rest
- *Progression:* Increase load after 9 sets
- *Adaptations:* ↑ mitochondrial function, muscle enzymes, capillary density
- *(Burgomaster et al., 2008); (Gibala & McGee, 2008); (Tabata et al., 1996)*

2-Minute Intervals

- *Warm-up:* 5 min @ 50% VO_2max
- *Main set:* 6 x 2 min at 70–100% VO_2max, ending at 80%
- *Recovery:* 2 min @ 50% VO_2max (between intervals), final 5 min @ 40% VO_2max
- *Adaptations:* Maintains aerobic capacity
- *Note:* Well tolerated on ISS
- *(Greenleaf et al., 1989)* I cannot find this paper

4-Minute Intervals

- *Warm-up:* 5 min @ ~50% Hrmax
- *Main set:* 4 x 4 min @ 90% Hrmax
- *Recovery:* 3 min active rest between intervals
- *Adaptations:* ↑ stroke volume, cardiac output
- *(Helgerud et al., 2007)*

MLSS

- *Warm-up:* 5 min @ ~50% Hrmax
- *Main set:* 20min @ 70% Hrmax
- *Recovery:* 3 min active rest between intervals

Lori Ploutz-Snyder, Ph.D.

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 and incline to tailor intensity.
  - Data tracking for **distance, pace, heart rate**, and mechanical load.
  - Mounted on a **vibration isolation system** to prevent disturbances to ISS structure.



ARED Theory: Microdosing Bone Load May Be More Effective

Bone responds to the *magnitude*, *rate*, and *novelty* of mechanical strain. Once the threshold for stimulus is reached, more repetitions beyond that point have **diminishing returns**.
Key concept: **Bone is most responsive to short bouts of high-magnitude loading, separated by recovery time.**

Turner (1998, 2006)
•Reinforced that **brief, high-intensity loading sessions spaced throughout the day** are **more effective** for bone than one prolonged session.
•Emphasized the **"refractory period"** — bone becomes less sensitive to continuous loading unless rest is provided between sessions.

Extra Slides



References

•Belavý et al., 2011 | Muscle Atrophy & Disc Morphology – **PubMed**: https://pubmed.ncbi.nlm.nih.gov/20595922/

•Belavý et al., 2011 | Persistent Disc Changes – **J Appl Physiol**: https://journals.physiology.org/doi/full/10.1152/japplphysiol.00695.2011

•Bailey et al., 2018 | ISS Astronaut Spine MRI – **Frontiers in Physiology**: https://www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2019.00837/full

•Scheuring et al., 2018 | NASA Spine Workshop – **NASA NTRS**: https://ntrs.nasa.gov/api/citations/20190001394/downloads/20190001394.pdf