FUNCTIONAL TASK TEST:
Data Review
June 30, 2014
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NASA-Johnson Space Center, Houston, TX
Background

After space flight there are changes in multiple physiological systems including:

- Cardiovascular function
- Sensorimotor function
- Muscle function

How do changes in these physiological systems impact astronaut functional performance?
Objectives

1. Determine the effects of space flight on astronaut’s ability to perform mission critical functional tasks.

2. Identify the key physiological factors that contribute to decrements in functional performance.

Inform the design of targeted countermeasures
Functional Task Test (FTT)

Functional Performance
- Seat Egress and Walk
- Ladder Climb
- Recovery from Fall/Stand
- Rock Translation
- Construction Activity
- Torque Generation
- Jump Down

Physiological Measures

Muscle
- Strength
- Power
- Control
- Neuromuscular Drive

Sensorimotor
- Balance
- Gait
- Dynamic Visual Acuity
- Fine Motor Control

Cardiovascular
- Plasma Volume
- Heart Rate
- Blood Pressure

Interdisciplinary testing regimen maps postflight functional performance to related physiological changes.
Subject Groups

**Shuttle:** 7 subjects
12-16 day flights

**ISS:** 12 subjects (total n=13)
6 month flights

**Bed Rest:**
- Controls: 11 subjects
- Exercise: 9 subjects
- Exercise + Testosterone: 8 subjects

70 days bed rest
Testing Schedules

Preflight
L-180  L-60  L-30

Postflight
R+0   R+1  R+6  R+30

Preflight
L-180  L-60  L-30

Postflight
R+1   R+6  R+30

Pre-bed rest
BR-12  BR-7  BR-1

Post-bed rest
BR+0  BR+1  BR+6  BR+12

70 days in bed rest
Using Bed Rest as a Sensorimotor Analog

Space flight modifies:

Vestibular and body load information

Bed rest modifies:

Body load information

Bed rest serves to delineate the role of body unloading in space flight performance changes
Receptors that Detect Body Load

Muscle Spindles

Mechanoreceptors
Mechanoreceptors of Hairy Skin

Golgi Tendon Organ

Body loading information controls motor output:

- Balance control
- Generation of stepping patterns
- Termination of gait
Functional Tests

- Seat Egress and Walk
- Recovery from Fall/Stand
- Rock Translation
- Ladder Climb
- Construction Activity
- Torque Generation
- Jump Down
## Functional Tests: Parameter List

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<td>Visual Acuity Score Post Bed Rest relative to Average Pre Bed Rest</td>
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Instrumentation for Functional Testing

Body motion sensors on head and trunk: kinematics

Holter monitor: ECG

Portapres: continuous blood pressure
Subject unbuckled a harness, stood up from a seat and then completed an obstacle course.

Testing occurred with:
- Seat upright (Upright Seat Egress)
- Seat positioned with its back to the floor (Supine Seat Egress)
Seat Egress and Walk Test (Upright)

Shuttle

ISS

Bed Rest

Time (sec)

Pre                  Postflight

Control
Exercise
Exercise+T
Seat Egress and Walk Test (Supine)

Shuttle

ISS

Bed Rest

Control
Exercise
Exercise+T
Recovery from Fall/Stand Test

Subjects were asked to lie face down on a foam surface for 2 minutes and then stand up as quickly as possible and step on a force plate and remain standing for 3 minutes.
Recovery from Fall: Mean Sway Speed

Shuttle

Mean Sway Speed (mm/sec)

Pre                    Postflight

L-60 L-30 R+0 R+1 R+6 R+30

ISS

Pre                    Postflight

L-60 L-30 R+1 R+6 R+30

Bed Rest

Mean Sway Speed (mm/sec)

Pre                    Post Bedrest

BR-7 BR-3 BR+0 BR+1 BR+6 BR+11

Control

Exercise

Exercise+T
Recovery from Fall: Postural Settling Time

**Shuttle**

- L-60, L-30, R+0, R+1, R+6, R+30
- Time (sec)
- Pre, Postflight

**ISS**

- L-60, L-30, R+0, R+1, R+6, R+30
- Time (sec)
- Pre, Postflight

**Bed Rest**

- BR-7, BR-3, BR+0, BR+1, BR+6, BR+11
- Time (sec)
- Pre, Post Bedrest

- Control
- Exercise
- Exercise+T
Rock Translation Test

Subjects transferred three weights with handles (2.7 kg, 4.5 kg, 9 kg), one at a time, a distance of 2.4m and placed them in a receptacle and then transferred the weights back to the initial receptacle.
Rock Translation Test

Shuttle

ISS

Bed Rest

Pre
Postflight
Pre
Control
Exercise
Exercise+T
Jump Down Test

Subjects jumped down from a platform (30 cm height) onto a force plate to measure postural stability
Jump Down Test: Postural Settling Time

Shuttle

ISS

Bed Rest

Settling Time (sec)

Pre                  Postflight

Control
Exercise
Exercise+T

1.5 2.5 3.5 4.5
L-60 L-30 R+0 R+1 R+6 R+30

1.5 2.5 3.5 4.5
BR-7 BR-3 BR+0 BR+1 BR+6 BR+11

1.5 2.5 3.5 4.5
L-60 L-30 R+1 R+6 R+30

1.5 2.5 3.5 4.5
BR-7 Pre BR-3 BR+0 BR+1 BR+6 BR+11
Subjects performed a variety of standard construction and assembly tasks:

- Connecting hoses to receptacles
- Mating a series of electrical connectors
- Using a cordless power tool to remove and tighten bolts on a handle assembly
Construction Activity Board

**Shuttle**

![Graph showing time (sec) for Shuttle with L-60, L-30, R+0, R+1, R+6, R+30 Pre and Postflight stages.

**ISS**

![Graph showing time (sec) for ISS with L-60, L-30, R+1, R+6, R+30 Pre and Postflight stages.

**Bed Rest**

![Graph showing time (sec) for Bed Rest with BR-7, BR-3, BR+0, BR+1, BR+6, BR+11 Pre and Post Bedrest stages.

Legend:
- **Control**
- **Exercise**
- **Exercise+T**
Torque Generation Test

To simulate a hatch-opening task subjects applied torque to a wheel assembly while standing in two conditions:

1) Wheel fixed: subjects applied peak torque.

2) Wheel freely moveable with constant resistance. Subject turned the wheel as many times in 20 sec. at 50% peak torque.
Torque Generation Test: Max. Isometric Force

**Shuttle**

**ISS**

**Bed Rest**

- **Control**
- **Exercise**
- **Exercise+T**
Torque Generation Test: Total Work

Shuttle

Iss

Bed Rest

Pre                  Postflight
Pre               Post Bedrest
Control
Exercise
Exercise+T
Ladder Climb Test

To simulate ladder climbing subjects climbed 40 rungs on a passive treadmill ladder at a self-generated pace.
Ladder Climb Test

Shuttle

ISS

Bed Rest

Pre                    Postflight
Pre               Post Bedrest
Control
Exercise
Exercise+T
Functional tests with requirements for postural equilibrium to complete (Seat Egress, Recovery from Fall, Rock Translation, Jump Down) showed greatest postflight decrement in performance.
Summary: Functional Tests

High Demand for Postural Stability Control

- Seat Egress and Walk
- Rock Translation
- Recovery from Fall/Stand
- Jump Down

Low Demand for Postural Stability Control

- Torque Generation
- Construction Activity
- Ladder Climb

Both space flight and bed rest subjects (control and exercisers) showed greatest deficits in functional tests with higher demand for postural stability control.
Physiological Tests

Sensorimotor
Postural stability
Fine motor control
Gait control
Dynamic visual acuity

Cardiovascular
Plasma volume
Heart Rate
Blood Pressure

Muscle Performance
Lower body:
Max. isometric force, power/endurance, force control and neuromuscular drive

Upper body:
Max. isometric force, force control, power/endurance
Tandem Walk Test

Subjects attempted to walk 10 steps with the eyes closed, arms folded across the chest, while placing the feet in a tandem heel-to-toe position for each step.
Tandem Walk Test: Percentage of Correct Steps

**Shuttle**

Incorrect Steps: sidestepped, opened eyes, or paused for more than three seconds between steps.

**ISS**

**Bed Rest**

Control

Exercise

Exercise+T
Tandem Walk Test: Torso Roll Velocity RMS

Shuttle

ISS

Bed Rest

Pre                  Postflight

Pre               Post Bedrest

Control

Exercise

Exercise+T
Postural Control Test

cEQ = (12.5 – Peak to Peak Sway)/12.5 * % trial completed
Postural Equilibrium Control: Space Flight

SHORT Duration: Computerized Dynamic Posturography
Recovery curve for SOT 5 Head Erect Shown for Comparison

LONG Duration: Computerized Dynamic Posturography
Eyes Closed on Unstable Support with Head Moving (±20° @ 0.33Hz)
Postural Equilibrium Control: Bed Rest

![Graph showing SOT 5M EQ Score over Post-BedRest (Days) for different conditions: Control, Exercise, Exercise+T.](image)
Subject walked at 6.4 km/h for 90 s on a treadmill while performing a dynamic visual acuity (DVA) test consisting of identifying gaps in the letter C presented on a computer screen.
Locomotion: Torso Pitch Stability

Shuttle

Pre
Postflight
L-60 L-30 R+0 R+1 R+6 R+30

Total Frequency Power

ISS

Pre
Postflight
L-60 L-30 R+1 R+6 R+30

Total Frequency Power

Bed Rest

Pre
Post Bedrest
BR-7 BR-3 BR+0 BR+1 BR+6 BR+11

Total Frequency Power

Legend:
- Control
- Exercise
- Exercise+T
Locomotion: Dynamic Visual Acuity Test

Bed Rest

![Graph showing eye chart lines over time during bed rest and postflight with AVG Ctrl and AVG Ex lines.]
Locomotion: Gait Cycle Timing/Step Time

Shuttle

ISS

Bed Rest

Pre | Postflight
---|---
L-60 | R+0 | R+1 | R+6 | R+30
Pre | Post Bedrest

Control
Exercise
Exercise+T

Locomotion: Gait Cycle Timing/Step Time

Avg Step Time (s)

0.42 0.44 0.46 0.48 0.5 0.52
The Grooved Pegboard Test was used to assess fine motor control. Subjects were required to rotate pegs with a key along one side to match the insertion hole.
Fine Motor Control Test

![Image of Fine Motor Control Test](image)

- **Shuttle**
  - Completion Time (sec)
  - L-60 L-30 R+0 R+1 R+6 R+30
  - Pre Postflight
- **ISS**
  - Completion Time (sec)
  - L-60 L-30 R+0 R+1 R+6 R+30
  - Pre Postflight
- **Bed Rest**
  - Completion Time (sec)
  - BR-7 BR-3 BR+0 BR+1 BR+6 BR+11
  - Pre Post Bedrest

- Control
- Exercise
- Exercise+T
Summary: Sensorimotor Tests

• Tests of balance and dynamic gait control control show greatest deficits for both space flight and bed rest.

• Bed rest control subjects show alterations in gait cycle timing and dynamic visual acuity.

• Fine motor control not reduced after Shuttle and bed rest; trend for reduction after ISS.

• Bed rest data indicate that body support unloading is a contributing factor in postflight functional performance decrement.

• Points to the importance of providing axial body loading as a central component of an integrated training system.
Functional Task Test: Cardiovascular

Goals
• Identify CV responses during multiple functional tasks.
• Determine if exercise prevents the negative CV adaptations during bed rest and maintains functional task performances.
• Use the ‘Recovery from Fall, Stand Test’ as a controlled orthostatic challenge to identify changes in the CV system that may contribute to functional task impairment.

Measurements
• Heart rate, plasma volume, blood pressure
- Following bedrest HR is elevated during multiple Functional Tasks.
- Returns towards Pre-BR values over 11 days.
Exercise reduces the elevated HR following bedrest.
Smaller difference in HR between pre- and post-BR
• Testosterone does not provide an additional benefit beyond Exercise alone in minimizing the change in HR between pre- and post-bedrest.
• Are certain functional tasks “riskier” due to greater CV stress?
Functional Task: Recovery From Fall

- Controlled maneuver
- Provides orthostatic stressor to CV system
- 3 min to minimize probability of syncope
- Continuously monitor BP and HR
- Incorporate balance/sway measures

- All subjects completed the task.
- No signs of pre-syncope.
1. Exercise protects prone HR from rising.
2. Appears to be no difference between Ex and Ex&T groups.
1. Exercise attenuates the increase in standing HR.
2. No difference between Ex and Ex&T groups.
3. Recovered by BR+11?
1. Standing HR response is increased on BR+0.
2. The increase is reduced on BR+1, but may remain elevated on BR+11.
3. Is there a difference between Ex&T and Ex on BR+0?
Potential Factors Contributing to an Elevated HR Response

1. Cardiac dysfunction
2. ↓ PV
3. Altered autonomic function

- Previous bed rest studies suggest a reduced LV mass and diastolic dysfunction, leading to reduced SV.
- Exercise training during 2-8 weeks of bed rest prevents these changes, preserves cardiac function.


1. Does the difference from BR+0 to BR+1 indicative of remaining cardiac dysfunction?
2. Does Testosterone provide protection against cardiac dysfunction?
1. PV decreases following bed rest in all groups.
2. Recovers by BR+1.
Autonomic Function

- During and/or post spaceflight sympathetic outflow is increased and exaggerated.
- Following 10 d of HDT, blood volume is reduced and greater reductions in arterial pressure during CV stress are compensated for by ↑HR (via increased SNS activity) to maintain BP.


1. Sympathetic modulation is augmented following bed rest.
2. Recovers by BR+1, suggesting an appropriate response to a fall in SV on BR+0.
1. Following bed rest, prone HR is elevated in Control, but not Exercise subjects.

2. To accomplish the Functional Task of moving from Prone to Standing:
   - Greater ↑HR on BR+0
   - Exercise may provide some protection?
   - Does Exercise + Testosterone provide more protection?
   - HR remains 3-5 bts/min greater on BR+11

3. PV is decreased on BR+0 and almost completely recovers by BR+1.

4. Syncope did not occur during 3 min of quiet standing.
Lower Limb Muscle Performance

**Maximum Isometric Force:** Subject in leg press system pushes against a fixed force plate.

**Power/Endurance:** Subject pushes a weight away as fast as possible (40% max force, 21 repetitions, ballistic, concentric only, magnetic brake catches weight).
Lower Body Maximum Isometric Force

**Shuttle**

- Pre: L-60, L-30, R+0, R+1, R+6, R+30
- Postflight: L-60, L-30, R+0, R+1, R+6, R+30

**ISS**

- Pre: L-60, L-30, R+1
- Postflight: L-60, L-30, R+1

**Bed Rest**

- Pre: BR-7, BR-3, BR+0
- Post Bedrest: BR-7, BR-3, BR+0

Colors:
- Red: Control
- Blue: Exercise
- Green: Exercise+T
Lower Body Max. Power

Shuttle

Ex & T Dominated by one subject

Bed Rest

Pre                Postflight
Pre                  Post Bedrest
Control
Exercise
Exercise+T

Maximun Power (W)
Upper Limb Muscle Performance

**Maximum Isometric Force:** Subject in leg press system pushes against a fixed force plate.

**Power/Endurance:** Subject pushes a weight away as fast as possible (40% max force, 21 repetitions, ballistic, concentric only, magnetic brake catches weight).
Upper Body Maximum Isometric Force

Shuttle

ISS

Bed Rest

Pre               Postflight

Control
Exercise
Exercise+T

L-60  L-30  R+0  R+1  R+6  R+30
Pre    Postflight

BR-7  BR-3  BR+0  BR+1  BR+6  BR+11
Pre    Post Bedrest

Force (N)
Upper Body Maximum Total Work

Shuttle

ISS

Bed Rest

Pre                               Postflight
Pre               Post Bedrest
Shuttle
ISS
Bed Rest

Control
Exercise
Exercise+T
Upper Body Maximum Max. Power

Shuttle

ISS

Bed Rest

Maximum Power (W)

- L-60
- L-30
- R+0
- R+1
- R+6
- R+30

Pre
Postflight

Pre
Post Bedrest

Control
Exercise
Exercise+T
Central Neural Activation Capacity

Loss of muscle strength due to space flight could be caused by changes in two factors:

1) Change in central neural activation, leads to changes in ability to recruit muscle fibers

2) Muscle atrophy

Twitch interpolation method used to assess neural activation capacity. Electrical muscle stimulus was provided to thigh muscle during maximal isometric leg extension.
Central Neural Activation Capacity

Shuttle

ISS

Bed Rest

Control
Exercise
Exercise+T
Assessment of Force Control

Subject matched leg or arm force with a reference force displayed on computer screen during isometric arm and leg extension (5% max force). Test done with and without visual feedback.

Coefficient of Variation (COV) = \( \frac{SD \text{ force output}}{mean \text{ force output}} \)
Lower Limb Force Control: With Visual Feedback

**Shuttle**

- Force Control (CV) ranges from 1 to 3.
- Data points for different time periods: Pre, Postflight, and PostBedrest.
- Comparison of L-60, L-30, R+0, R+1, R+6, R+30 conditions.

**ISS**

- Similar force control chart with additional data for Bed Rest conditions.

**Bed Rest**

- BR-7, BR-3, BR-0, BR+1, BR+6, BR+11 intervals.
- Control, Exercise, and Exercise+T conditions are visualized.

The charts illustrate changes in force control over time in spaceflight and bed rest scenarios, with visual feedback.
Lower Limb Force Control: Without Visual Feedback

Shuttle

ISS

Bed Rest

Force Control (CV)

Pre                      Postflight
Pre                  Post Bedrest

Control
Exercise
Exercise+T
Upper Limb Force Control: With Visual Feedback

Shuttle

ISS

Bed Rest

Pre                  Postflight
Pre                  Postflight
Control
Exercise
Exercise+T
Upper Limb Force Control: Without Visual Feedback

Shuttle

ISS

Bed Rest

Force Control (CV)

L-60 L-30 R+0 R+1 R+6 R+30
Pre Postflight

L-60 L-30 R+1 R+6 R+30
Pre Postflight

BR-7 BR-3 BR+0 BR+1 BR+6 BR+11
Pre Post Bedrest

Control
Exercise
Exercise+T
Summary: Muscle Performance

- Control bed rest subjects show decreased muscle performance of lower limbs.
- Central neural activation capacity altered for control bed rest subjects.
- No overall changes in force control were detected in all groups.
### Comparison of Physiological Tests

<table>
<thead>
<tr>
<th>Sensorimotor</th>
<th>Muscle Performance</th>
<th>Cardiovascular</th>
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<tr>
<td>Pegboard</td>
<td>Leg Press (MIF)</td>
<td>Plasma Volume</td>
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<tr>
<td>Recovery Fall (Mean</td>
<td>Leg Press (Maximum Power)</td>
<td>Prone Heart Rate (Fall</td>
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<tr>
<td>Resultant Sway Speed)</td>
<td>Leg Press (Total Work)</td>
<td>Recovery)</td>
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<tr>
<td>Line Test (Torso</td>
<td>Upper Body (MIF)</td>
<td>Standing Heart Rate</td>
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<tr>
<td>Resultant Acceleration)</td>
<td>Upper Body (Maximum Power)</td>
<td>(Fall Recovery)</td>
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<tr>
<td>Line Test (Percent</td>
<td>Upper Body (Total Work)</td>
<td>Hematocrit</td>
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<tr>
<td>Correct Steps)</td>
<td>Interpolated Twitch</td>
<td>Hemoglobin</td>
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<tr>
<td>Treadmill DVA (Torso</td>
<td>Central Activation Capacity)</td>
<td>BloodVolume</td>
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<tr>
<td>Pitch)</td>
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<td>RedCellVolume</td>
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<tr>
<td>Treadmill (Step Time)</td>
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<tr>
<td>Treadmill (DVA)</td>
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</tbody>
</table>
Inflight Treadmill Exercise and Postflight Dynamic Walking Performance

More time on treadmill associated with improved postflight postural stability control

Kendalls Tau= 0.60 (p< 0.01)
Inflight Treadmill Exercise and Postflight Posture Control

Kendalls Tau = 0.49 (p < 0.05)

Increased body loading on treadmill associated with improved postflight postural stability control
Exercising with greater loads improves postflight functional mobility (previous Mobility study)

- Greater loads during inflight squat exercises associated with enhanced postflight functional mobility
- Increased body loading on treadmill enhanced recovery of postflight functional mobility

![Graph showing the relationship between average body load and percent change in FMT. Pearson r = -0.844 (p=0.017). R^2 = 0.717.]

**Functional Mobility Test (FMT)**
Integrated Countermeasure System: Requirements

1) Aerobic Exercise
2) Resistive Exercise
3) Balance training using treadmill walking
   - Support surface motion
   - Modified visual flow
   - Axial body loading
Sensorimotor Adaptability Training System

Train on a treadmill with surrogate sensory challenges:

- Altered visual information
- Support surface motion (motion base treadmill system)
- Variation in body loading
Gravity-Bed: Method to Provide Balance Training During Bed Rest

Backpack frame freely moving on air-bearing

Oddsson et al. A rehabilitation tool for functional balance using altered gravity and virtual reality
Journal of NeuroEngineering and Rehabilitation 4:25, 2007
Sample Postural Stability Data

Tilted Room One-Leg Standing

Upright One-Leg Standing

Gravity Bed Produces Similar Instability to Upright Standing

Courtesy Lars Oddsson
Sample Postural Stability Data

Gravity Bed Produces a Balance Training Effect

Courtesy Lars Oddsson
Gravity-Bed Training Study

- Balance board in supine
- 10 training sessions over two weeks
- 5+5 healthy young subjects
- 10 trials 1-leg balancing for 35 s max

- Increase in Balance Time of 58% (17.3s to 27.3s, p < 0.05)
- No Change in Control Subjects

*Oddsson & Wall 2002*

Gravity-Bed Produces Improvement in Balance Control
Gravity Bed Training Improves Balance in Patients with Severe Balance Problems
Integrated Countermeasure System: Bed Rest Study

Training Group

1) Aerobic Exercise
2) Resistive Exercise
3) Balance training using treadmill walking
   - Support surface motion
   - Modified visual flow
   - Axial body loading

Compare with Control and Exercise subjects from CFT70
Publication Plan

1) Combined space flight and bed rest paper

2) Multiple discipline/topic specific papers
Backup Slide
### Correlations between Functional and Physiological Tests (all data combined)

**Somers D : Within Subject Significant Relationship**

<table>
<thead>
<tr>
<th>Sensorimotor</th>
<th>Upright Egress</th>
<th>Supine Egress</th>
<th>Fall Recovery</th>
<th>Rock Translation</th>
<th>Activity Board</th>
<th>Torque Generation (Maximum)</th>
<th>Torque Generation (Work)</th>
<th>Ladder Climb</th>
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<td>2. Fall Recovery (Mean Resultant Sway Speed)</td>
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<td>2. Fall Recovery (Mean Resultant Sway Speed)</td>
<td>2. Fall Recovery (Mean Resultant Acceleration)</td>
<td>2. Line Test (Percent Correct Steps)</td>
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<td>5. Treadmill (Step Time)</td>
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<td>2. Stand Heart Rate Fall Recovery</td>
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