FUNCTIONAL TASK TEST:

Data Review

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Neuroscience, Exercise Physiology & Cardiovascular Laboratories

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
- Torque Generation
- Jump Down
- Construction Activity

**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

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
- Ladder Climb
- Rock Translation
- Torque Generation
- Construction Activity
- Jump Down
# Functional Tests: Parameter List

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<thead>
<tr>
<th>TestName</th>
<th>TestCondition</th>
<th>Parameter</th>
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<td>Time to Complete Activity Board Test</td>
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<td>Time from Start to Portal Entry</td>
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<td>Settling Time of the Vertical Ground Reaction Force upon Landing</td>
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<td>Torque Generation: Maximum Isometric Force</td>
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<td>Head pitch: Sum of FFT Spectral Powers between 1.5-2.5 Hz</td>
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<td>Maximum Lag from the Cross-Correlation of Head Pitch and Torso Pitch</td>
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<td>Maximum Value of the Cross-Correlation of Head Pitch and Torso Pitch</td>
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<td>Maximum Lag from the Cross-Correlation of Head Pitch and Torso Vertical Position</td>
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<td>Maximum Value of the Cross-Correlation of Head Pitch and Torso Vertical Position</td>
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<td>Average Step Time while Walking for the DVA Test</td>
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<td>Torso Pitch: Sum of FFT Spectral Powers between 1.5-2.5 Hz</td>
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<tr>
<td>Locomotion</td>
<td>Dynamic</td>
<td>Torso Vertical Position: Sum of FFT Spectral Powers between 1.5-2.5 Hz</td>
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<tr>
<td>Locomotion</td>
<td>Dynamic</td>
<td>Visual Acuity Score Post Bed Rest relative to Average Pre Bed Rest</td>
</tr>
</tbody>
</table>
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

Pre                  Postflight

Pre               Post Bedrest

Shuttle

ISS

Bed Rest

Control

Exercise

Exercise+T
Seat Egress and Walk Test (Supine)

Shuttle

ISS

Bed Rest

Pre               Post Bedrest

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

ISS

Bed Rest

Pre flight

Postflight

Control

Exercise

Exercise+T
Recovery from Fall: Postural Settling Time

Shuttle

ISS

Bed Rest

Pre                     Postflight
Pre               Post Bedrest
Shuttle
ISS
Bed Rest

Control
Exercise
Exercise+T
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

- 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

Pre                     Postflight
Control                 Exercise                 Exercise+T
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

ISS

Bed Rest

Control

Exercise

Exercise+T
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

Control
Exercise
Exercise+T
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
Comparison of Functional Tests

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**

<table>
<thead>
<tr>
<th>BR-7</th>
<th>BR-3</th>
<th>BR+0</th>
<th>BR+1</th>
<th>BR+6</th>
<th>BR+11</th>
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<tbody>
<tr>
<td>Pre</td>
<td></td>
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<td></td>
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<tr>
<td>Post Bedrest</td>
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</table>

- Control
- Exercise
- Exercise+T
Tandem Walk Test: Torso Roll Velocity RMS

Shuttle

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<thead>
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<th>Time</th>
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ISS

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Bed Rest

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<th>Pre</th>
<th>Post Bedrest</th>
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<tr>
<td>BR-3</td>
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<tr>
<td>BR+11</td>
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Red = Control
Blue = Exercise
Green = 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

POSTURAL EQUILIBRIUM SCORE (MEDIAN)

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

POSTURAL EQUILIBRIUM SCORE (MEDIAN)

Shuttle

ISS
Postural Equilibrium Control: Bed Rest

![Graph showing postural equilibrium control during bed rest with different groups: Control, Exercise, and Exercise+T.](image)
Locomotion/Dynamic Visual Acuity Test

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: Dynamic Visual Acuity Test

Bed Rest

Eye Chart Lines

-0.4  -0.2  0  0.2  0.4  0.6  0.8

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<th>AVG Ctrl</th>
<th>AVG Ex</th>
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<tr>
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<td></td>
</tr>
<tr>
<td>BR+11</td>
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</table>

- AVG Ctrl
- AVG Ex
Locomotion: Gait Cycle Timing/Step Time

Shuttle

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

Pre

Postflight

ISS

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

Pre

Postflight

Bed Rest

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

Pre

Post Bedrest

Legend:
- Red: Control
- Blue: Exercise
- Green: Exercise+T
Fine Motor Control Test

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

**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, BR+1, BR+6, BR+11
- Post Bedrest: BR-7, BR-3, BR+0, BR+1, BR+6, BR+11

Completion Time (sec)
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.
Standing Heart Rate

1. Exercise attenuates the increase in standing HR.
2. No difference between Ex and Ex&T groups.
3. Recovered by BR+11?
Stand Test Heart Rate Response

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. \( \downarrow \) 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?
Plasma Volume

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

ISS

Bed Rest

Pre               Postflight
Pre                  Postflight
Pre                  Post Bedrest

Control
Exercise
Exercise+T
Lower Body Max. Power

Shuttle

ISS

Bed Rest

Ex & T Dominated by one subject

Maximum Power (W)

Pre

Postflight

Control

Exercise

Exercise+T
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

Control
Exercise
Exercise+T
Upper Body Maximum Total Work

Shuttle

ISS

Bed Rest

Total Work (J)

Pre               Postflight

Pre                  Post Bedrest

Control
Exercise
Exercise+T

2500 3000 3500 4000 4500 5000

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

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
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

Pre               Postflight
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) = SD force output / mean force output
Lower Limb Force Control: With Visual Feedback

Shuttle

ISS

Bed Rest

Pre                     Postflight
Pre                 Post Bedrest
Pre                  Postflight
Pre                  Post Bedrest

Control
Exercise
Exercise+T
Lower Limb Force Control: Without Visual Feedback

Shuttle

Pre                 Postflight

ISS

Pre                  Postflight

Bed Rest

Pre                 Post Bedrest

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

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

Control

Exercise

Exercise+T
Upper Limb Force Control: With Visual Feedback

Shuttle

ISS

Bed Rest

Pre                 Post Bedrest

Pre                  Postflight

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

**Shuttle**

- L-60, L-30, R+0, R+1, R+6, R+30
- Force Control (CV)

**ISS**

- L-60, L-30, R+0, R+1, R+6, R+30
- Force Control (CV)

**Bed Rest**

- BR-7, BR-3, BR+0, BR+1, BR+6, BR+11
- Force Control (CV)

- 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

Sensorimotor

Muscle Performance

Cardiovascular

Legend:
- Bed rest Control
- Bed rest EX
- Bed rest EX + Test.
- Spaceflight ISS
- Spaceflight Shuttle

Bars represent Change Pre/Post (rank)
Inflight Treadmill Exercise and Postflight Dynamic Walking Performance

Kendalls Tau = 0.60 (p < 0.01)

More time on treadmill associated with improved postflight postural stability control
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)

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

- Pearson $r = -0.844$ ($p=0.017$)
- $R^2 = 0.717$
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-bearings

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)

### Sensorimotor

<table>
<thead>
<tr>
<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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</thead>
<tbody>
<tr>
<td>Fall Recovery</td>
<td>Fall Recovery</td>
<td>Fall Recovery</td>
<td>Fall Recovery</td>
<td>2. Fall Recovery</td>
<td>2. Line Test</td>
<td>2. Fall Recovery</td>
<td>2. Fall Recovery</td>
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<tr>
<td>(Mean Resultant Sway Speed)</td>
<td>(Mean Resultant Sway Speed)</td>
<td>(Mean Resultant Sway Speed)</td>
<td>(Mean Resultant Sway Speed)</td>
<td>3. Line Test (Torso Resultant Acceleration)</td>
<td>3. Treadmill (Trunk Pitch)</td>
<td>3. Line Test (Trunk Pitch)</td>
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<tr>
<td>Treadmill (Trunk Pitch)</td>
<td>Treadmill (Trunk Pitch)</td>
<td>Treadmill (Step Time)</td>
<td>Treadmill (Step Time)</td>
<td>5. Line Test (Percent Correct Steps)</td>
<td>5. Jump (Setting Time)</td>
<td>5. Treadmill (Step Time)</td>
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<tr>
<td>Line Test (Percent Correct Steps)</td>
<td>Line Test (Percent Correct Steps)</td>
<td>Jump (Setting Time)</td>
<td>Jump (Setting Time)</td>
<td>7. Jump (Setting Time)</td>
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### Exercise

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<th>Leg Press MIF</th>
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<th>KnLegPress MIF</th>
<th>Leg Press Power</th>
<th>Upper Body Power</th>
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<th>Leg Press Power</th>
<th>Leg Press Work</th>
<th>Upper Body Power</th>
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### Cardio

<table>
<thead>
<tr>
<th>Plasma Volume</th>
<th>Prone Heart Rate Fall Recovery</th>
<th>Plasma Volume</th>
<th>Prone Heart Rate Fall Recovery</th>
<th>Plasma Volume</th>
<th>Prone Heart Rate Fall Recovery</th>
<th>Plasma Volume</th>
<th>Prone Heart Rate Fall Recovery</th>
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