FUNCTIONAL TASK TEST:

Data Review

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Neuroscience, Exercise Physiology & Cardiovascular Laboratories

NASA-Johnson Space Center, Houston, TX
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

Preflight
BR-12  BR-7  BR-1

Post-flight
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**

- Afferent nerves
- Efferent nerves
- Muscle fiber
- Muscle spindle
- Afferent nerve endings

**Mechanoreceptors of Hairy Skin**

- Pacinian corpuscles
- Ruffini organs
- Merkel disks
- Free nerve endings

**Golgi Tendon Organ**

- Sensory fiber
- Connective tissue capsule
- Tendonous area
- Muscle
- Bone

Body loading information controls motor output:

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

1) Tension
Functional Tests

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

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<td>Plasma Volume Index</td>
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<td>Locomotion</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>Locomotion</td>
<td>Dynamic</td>
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<tr>
<td>Locomotion</td>
<td>Dynamic</td>
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<td>Locomotion</td>
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<td>Dynamic</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>
</tr>
<tr>
<td>Locomotion</td>
<td>Dynamic</td>
<td>Visual Acuity Score Post Bed Rest relative to Average Pre Bed Rest</td>
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</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

Time (sec)

Pre                  Postflight

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

ISS

Time (sec)

Pre                  Postflight

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

Bed Rest

Time (sec)

Pre                  Post Bedrest

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

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

**Shuttle**

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>L-60 Pre</th>
<th>L-30 Pre</th>
<th>R+0 Postflight</th>
<th>R+1 Postflight</th>
<th>R+6 Postflight</th>
<th>R+30 Postflight</th>
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</table>

**ISS**

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>L-60 Pre</th>
<th>L-30 Pre</th>
<th>R+1 Postflight</th>
</tr>
</thead>
</table>

**Bed Rest**

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>BR-7 Pre</th>
<th>BR-3 Pre</th>
<th>BR+0 Post Bedrest</th>
<th>BR+1 Post Bedrest</th>
<th>BR+6 Post Bedrest</th>
<th>BR+11 Post Bedrest</th>
</tr>
</thead>
</table>

- **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 vs. Postflight

Pre vs. Post Bedrest

Min 1
Min 2
Min 3

10 mm
10 mm

Control
Exercise
Exercise+T
Recovery from Fall: Postural Settling Time

Shuttle

ISS

Bed Rest

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Pre</th>
<th>Postflight</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-60</td>
<td></td>
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<tr>
<td>L-30</td>
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<tr>
<td>R+0</td>
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<tr>
<td>R+1</td>
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<td>R+6</td>
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<tr>
<td>R+30</td>
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</table>

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

- 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

- Red: Control
- Blue: Exercise
- Green: 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**
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.
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

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

Pre         Postflight
Shuttle

Pre                  Postflight
ISS

Pre                  Post Bedrest
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)
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**

**ISS**

**Bed Rest**

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

Bed Rest

Postflight

Eye Chart Lines

-0.4
-0.2
0
0.2
0.4
0.6
0.8

PRE BR+0 BR+1 BR+6 BR+11

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

Shuttle

ISS

Bed Rest

Pre                     Postflight

Pre               Post Bedrest

Control

Exercise

Exercise+T
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

ISS

Bed Rest

Completion Time (sec)

Pre                  Postflight
Pre               Post Bedrest

Pre                  Postflight

Control
Exercise
Exercise+T
Summary: Sensorimotor Tests

- Tests of balance and dynamic gait control showed greatest deficits for both space flight and bed rest.
- Bed rest control subjects showed alterations in gait cycle timing and dynamic visual acuity.
- Fine motor control was not reduced after Shuttle and bed rest; a 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

- 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?
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.

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Following bed rest, prone HR is elevated in Control, but not Exercise subjects.

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

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

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

Force (N)

Pre               Postflight

Pre                  Postflight

Control

Exercise

Exercise+T
Lower Body Total Work

Shuttle

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

Pre               Post Bedrest
Shuttle

ISS

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

Pre                  Postflight
Control  Exercise  Exercise+T

Bed Rest

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

BR-7  BR-3  BR+0  BR+1  BR+6  BR+11
Control  Exercise  Exercise+T
Lower Body Max. Power

Shuttle

Ex & T Dominated by one subject

Pre                       Postflight

Pre                  Post Bedrest

Shuttle

ISS

Bed Rest

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**

- Force (N): 600, 700, 800, 900, 1000, 1100, 1200
- L-60, L-30, R+0, R+1, R+6, R+30

**ISS**

- Force (N): 600, 700, 800, 900, 1000, 1100, 1200
- L-60, L-30, R+1, R+6, R+30

**Bed Rest**

- Force (N): 600, 700, 800, 900, 1000, 1100, 1200
- BR-7, BR-3, BR+0, BR+1, BR+6, BR+11

- Pre: Control, Exercise, Exercise+T
- Post: Control, Exercise, Exercise+T

- Preflight
- Post Bedrest
Upper Body Maximum Total Work

Shuttle

ISS

Bed Rest

Control
Exercise
Exercise+T
Upper Body Maximum Max. Power

Shuttle

ISS

Bed Rest

Maximum Power (W)

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

Pre
Postflight
Pre
Post Bedrest
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**

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

**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

Legend:
- Red: Control
- Blue: Exercise
- Green: Exercise+T
Lower Limb Force Control: Without Visual Feedback

Shuttle

ISS

Bed Rest

Pre                 Postflight
Pre                  Post Bedrest
Control
Exercise
Exercise+T
Upper Limb Force Control: With Visual Feedback

Shuttle

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

Pre
Post Bedrest

ISS

- L-60
- L-30
- 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

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

Shuttle

ISS

Bed Rest

Force Control (CV)

Pre

Postflight

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

Sensorimotor

Muscle Performance

Cardiovascular

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

Tests:
- Pegboard Recovery Fall (Mean Resultant Sway Speed)
- Line Test (Torso Resultant Acceleration)
- Line Test (Percent Correct Steps)
- Treadmill DVA (Torso Pitch)
- Treadmill (Step Time)
- Treadmill (DVA)
- Leg Press (MIF)
- Leg Press (Maximum Power)
- Leg Press (Total Work)
- Upper Body (MIF)
- Upper Body (Maximum Power)
- Upper Body (Total Work)
- Interpolated Twitch (Central Activation Capacity)
- Plasma Volume
- Prone Heart Rate (Fall Recovery)
- Standing Heart Rate (Fall Recovery)
- Hematocrit
- Hemoglobin
- Blood Volume
- Red Cell Volume

Comparison of Physiological Tests: 
- Sensorimotor
- Muscle Performance
- Cardiovascular
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

Increased body loading on treadmill associated with improved postflight postural stability control

Kendalls Tau = 0.49 (p < 0.05)
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 body load and percent change in FMT](image)

- 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
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

Gravity Bed Produces Similar Instability to Upright Standing
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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.</strong> Pegboard</td>
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**Exercise**

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**Cardio**

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<tr>
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*Note: The table lists various functional and physiological tests and their corresponding correlations.*