Trajectory of Research in Support of NASA’s Journey to Mars

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Introduction
Andrea Hanson, PhD

BS Chemical Engineering, 2002

MS Aerospace Engineering, 2004

PhD Aerospace Engineering, 2008

Postdoctoral Fellowship, 2009

NASA JSC, 2011

ASGSB

AsMA

AIAA

ACSM

SWE

Lake Park, MN

Grand Forks, ND

Los Angeles, CA

Boulder, CO

Huntsville, AL

Houston, TX

Kyoto, Japan!

Professional Affiliations

BioServe Space Technologies

BOEING

NASA

Doshisha University

Space Camp
Choose A trajectory

Hohmann Transfer Orbit

Cassini Orbit
Lecture Outline

• Introduction
• Physiological Adaptation to Microgravity
• Exercise Countermeasures
• Ongoing Research
• Spaceflight Analogs
• Collaboration Opportunity
• Analogs = Simulated environments  
• Bioastronautics = The study and support of life in space  
• Countermeasures = Solutions to help mitigate problems  
• Crewmembers = Astronauts  
• ISS = International Space Station  
• Microgravity = Zero-G  
• On-orbit = Orbiting the Earth  
• STS = Space Transportation System (the Space Shuttle)
Adaptations to Microgravity

- **Posture change**
- **↑ Fluid shift**
- **↑ Height**
- **↓ Sense of smell**
- **↑ Space Motion Sickness**
- **↑ Back Pain**
- **↑ Metabolism**
- **↓ Fluid volume**
- **↓ Blood volume**
- **↓ Muscle volume**
- **↓ Muscle Strength**
- **↓ Bone Mineral Density**
- **↑ Bone fragility**
Protect Human Physiology

Muscle Strength

Bone Strength & Quality

Cardiovascular Capacity
ISS astronauts benefit from a large support team to assist during landing activities. This welcome wagon will not be waiting on the surface of Mars.
Cortical bone (compact) (80%)  Trabecular bone (Spongy) (20%)
Bone - Remodeling

**Osteoclasts**
- Release enzymes
  - Dissolves bone mineral matrix
  - Dissolves collagen
- Clears away damaged bone

**Osteoblasts**
- Fill in bony cavity with bone matrix
- Releases cytokines to attract osteoclasts

Carter & Beaupré, 2001

[Diagram showing bone remodeling]

[Graph showing bone apposition and resorption rates as a function of tissue stress stimulus (MPa/day)]
Osteoporosis is a progressive bone disease that is characterized by a decrease in bone mass, density, and microarchitecture which can lead to increased risk of fracture.
Bone Loss on ISS

- 6 month flight
- 10% loss of integral femoral neck BMD (~1.5% per month)
- 18% loss of femoral neck trabecular BMD (~2.5% per month)
- 23% decline in femoral neck bending strength index
- 20% decline in FEM failure load

Lang et al. JBMR 2006
Keyak et al. Bone 2009
Bone Strength and Bone Quality

- BMD only accounts for a fraction of overall bone health.
- Overall bone quality is important to understand to best assess fracture risk
  - Geometry
  - Remodeling Rate
  - Chemical Composition
  - Microarchitecture
  - Mineralization
  - Genetic Profile

We must protect bone strength and quality in our astronauts to reduce their risk of fracture. This is particularly important for exploration missions.
Skeletal Muscle

• Complex Structure

• Muscle → Myocytes → Myofibrils → Myofilaments

• Satellite cells

• Contraction: ↑Cytosolic Ca^{+2} → Krebs Cycle
Muscle Fiber Types

Slow (Type I) → Fast (Type II) twitch morphology during spaceflight

www.londen.com/muscle-fiber-types.jpg
Radiation

- 2-Gy dose in murine model
- 29-39% decline in trabecular volume
- 46-64% decline in trabecular connectivity
- Trip to Mars 0.5-1 Gy

Investigation of Myostatin Inhibition

Myostatin-A powerful negative regulator of skeletal muscle mass and strength.

Selective breeding increases muscle mass in cattle

Knockout model increased muscle mass in mice

Natural mutation increased muscle mass in humans, increased performance in the Whippet (a racing dog)
STS-118 Commercial Biomedical Test Module-02 (CBTM-02)
Monitoring Bone Health in Reduced Gravity Environments

Wireless Activity Monitoring / Daily Load Stimulus

Combined Countermeasure Device (CCD)

Neural Networks/ Machine Learning Algorithms

LifeModeler™ Biomechanics Simulation
Exercise is the Foundation Upon Which all Other Spaceflight Countermeasures are Added

- The Human Research Program is charged with identifying the optimal exercise protocol, including intensity/load and frequency of exercise, that protects crew health during exploration missions.
Exercise Clearly Enhances Physiology

>20% difference in arm volume
Left vs. Right!
- Seminal cyclic loading study by Rubin, 1984, JBJS
- Does increasing cycles increase bone mass?
  - Isolated avian ulna
  - 0.5 Hz, 1 sec
  - 0, 4, 36, 360, or 1800 cycles

Percentage change in bone-mineral content at the mid-shaft of the ulna preparation over the six-week experimental period in bones subjected to zero (□), 4 (●), 36 (■), 360 (▲), or 1800 (●) consecutive cycles a day of an identical load regimen. The vertical lines for six-week values indicate standard deviations. The transverse scans were made using a 125I source.
Can less loading be a more effective stimulus?

• Cyclic vs rest inserted loading
  • 50 cycles/day @ 1200 μe
  • 10 sec rest between 50 cycles/day @ 1200 μe
  [Srinivasan et al., 2003, Bone]

50 cycles/day @ 1 Hz
5 days/week for 3 weeks

50 cycles/day @ 1 Hz with 10 sec rest between cycles
5 days/week for 3 weeks

• More bone on perosteal edge with rest inserted loading!
Cyclic vs Rest - # of cycles

- Rest inserted loading (1250 με) inhibits saturation with increased cycle number
- Rest inserted loading increases response to higher magnitude strain

Osteogenic stimulus is saturated

Response doubles!

Srinivasan et al., 2007, J Appl Phys.
Benefits of rest inserted exercise

- Lower magnitude
- Fewer loading cycles
- Exercise less often

- Animal studies allow rapid data turn around and exploration of cellular mechanisms
- Human studies offers clinical and operational insight

Putting these lessons to practice:
- Retrospective Approach: Design a robust exercise program targeting max weight training loads and HR, then sum accumulated loads.
- Prospective Approach: Determine the number and magnitude of accumulated loads necessary to maintain fitness.
The Daily Load Stimulus

Required Dose of Loading (Daily Loading Stimulus DLS) for Optimal Bone Health

\[ eDLS = \left( \sum_{j=1}^{k} n_j (G_j)^m + [AL]_{\text{Stnd}} \right)^{1/2m} \]

Carter et al. 1987, Genc et al. 2009, Cavanagh et al. 2010
Monitoring Bone Health by Daily Load Stimulus for Lunar Missions

• Astronauts currently lose ~1% of proximal hip BMD per month in microgravity on the International Space Station (Lang et al., 2006)
• Will normal activity in the partial gravity environments of the Moon [1/6g] and Mars [3/8g] will be osteoprotective?

Project Goals:

1) To characterize gait biomechanics in reduced gravity environments in order to assess the potential contribution to BMD maintenance

2) To provide activity recognition during lunar and Martian missions for remote monitoring
Develop accelerometer based portable activity monitoring device

• Loading profiles (Daily Load Stimulus) are calculated from GRF which is restricted to the lab or to force measuring insoles which are cumbersome (Whalen et al. 1993, Genc et al. 2009)
• Accelerometers can be body mounted to record loading histories (Jamsa et al. 2004)
• Acceleration data is also useful for activity recognition (Baek et al. 2004, Sharma et al. 2008)
• Approach: Develop a library of GRF during mission relevant activity and exercise -> use accelerometer for activity recognition in reduced gravity environments -> use a look up table to match GRF to activity -> sum accumulated loads -> test in the field
GRFs at 1G, 3/8G, and 1/6G

- Strides are longer in reduced gravity
- Step frequency decreases with decreased gravity
- Peak GRFs decrease during running

Accelerometers useful to describe gait characteristics (stride length and step counts).
- More useful as input to neural networks for activity recognition algorithms.
- Partial gravity environments are not likely to be osteoprotective on their own.

Achieved 100% recognition
Lunar Walk, Lope, Run, Hop
Exercise Countermeasures
We’ve come a long ways since Skylab...

*Skylab 1973-74 (de-orbit 1979)*

**Science meets Engineering:** Couple our knowledge of bone mechanobiology with exercise hardware and Rx design to optimize crew health.
Exercise Countermeasures on ISS

Astronauts are scheduled to exercise 2.5 hours 6 days a week!

Cycle Ergometer with Vibration Isolation System (CEVIS)
Advanced Resistive Exercise Device (ARED)
Second Generation Treadmill C.O.L.B.E.R.T. (T2)
How much time should we spend on exercise?

Hickson et al., (1981, 1982, 1985) try to preserve VO\(_2\) max

- **Duration**
  - Reduced from 40 to 26 or 13 min/day

- **Frequency**
  - Reduced from 6 to 4 or 2 days/week

- **Intensity**
  - Work rate reduced by 1/3 or 2/3

- To minimize time spent on exercise, exercise frequency and duration may be reduced but intensity must be as high as reasonably possible.

- Can we meet aerobic training needs and protect bone?
Recommendations on physical activity levels from the AHA and ACSM

The American Heart Association Recommendations for Physical Activity in Adults

- At least 30 minutes of moderate-intensity aerobic activity per week for a total of 150 minutes
- OR
- At least 25 minutes of vigorous aerobic activity per week for a total of 75 minutes
- OR
- A combination of the two

AND

- Moderate-to-high intensity muscle-strengthening activity at least 2 days per week for additional health benefits

Add years to your life one step at a time.

Physical inactivity is the leading cause of death in the United States. Just 150 minutes of exercise a week reduces your risk of death by treating and preventing heart disease, high blood pressure, diabetes, stroke and more.

How do ACSM / AHA recommendations compare to ISS exercise?

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
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<tr>
<td>ARED</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
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<tr>
<td>T2</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
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<tr>
<td>CEVIS</td>
<td></td>
<td>30 min</td>
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<td></td>
<td>30 min</td>
<td></td>
</tr>
</tbody>
</table>

- Recommended: 2 days of strength training and 150 min of moderate aerobic exercise per week
- 6 days muscle strengthening
- ~180 minutes aerobic activity
- ~10,000 steps per day are recommended
- 5-6K steps per day, 4 days a week are acquired
NASA Future Directions
HRP Risk Mitigation Maturation Plan

Now–2024 (+/-)
Develop/test mitigation approaches
- ISS
- Spaceflight analogs
- Ground-based laboratories
Inform deep-space hab designs

~2035–20nn
Fine-tune mitigation approaches
- Exploration vehicles
- Planetary surfaces

~2021–2030
Validate mitigation approaches
- Orion
- Deep-space hab
- Lunar surface (?)
Inform exploration system designs
To the Moon, Mars & Beyond!

International Space Station

Habitable Volume: 15,000 Ft³

Orion Capsule

Habitable Volume: 316 Ft³
Preparing for Exploration beyond ISS
On-Going Research
In-Flight Research

**SPRINT**

Evaluate muscle, cardiovascular fitness, and bone health following a new higher intensity, lower duration and frequency exercise prescription during spaceflight.

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
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<tbody>
<tr>
<td>Resistance</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic Interval</td>
<td>32 min</td>
<td>15 min</td>
<td>35 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic Continuous</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**VO2 Max**

Measured VO$_2$max and cardiac output using the PPFS pre-, in-, and post-flight.
- Early onset decreases in VO$_2$max
- Begin cardiovascular exercise early in mission
- Recommend revision of medical requirement for inflight assessment

**ARED Kinematics**

Exercise Hardware & Performance Monitoring

Hardware Redesign

Portable load monitoring technologies

New Exercise Hardware Evaluation

[Images of exercise hardware and performance monitoring equipment]
Partnerships with Academia, Industry, & Government Agencies

Load Monitoring Technology & Advanced Exercise Hardware

Commercial Development of Mini Earbud Based Biosensor

Wearable Biosensors & Human Exploration Research Analog
Spaceflight Analogs
Fitness for Mission Tasks Study

1. Ambulate 1.5 km and equipment deployment
2. Hill climb (1 km ascent and 1 km descent) and equipment deployment
3. Incapacitated crewmember rescue
4. Top hatch vehicle egress

Exercise Physiology and Countermeasures Team is working with the Orion Crew Survival Engineering group to conduct emergency vehicle egress exercises in the NBL and Gulf of Mexico; this field data will be correlated with the laboratory-based mission tasks testing.
The FMT Study data will yield performance curves and thresholds such as the plot shown below:

Performance threshold determined via spline regression analysis.
Background

- **NSBRI funded research grant to develop the ‘NextGen’ exercise software.**
  - Develop a software architecture to integrate instructional, motivational and socialization techniques into a common portal to enhance exercise countermeasures in remote environments.
  - Increase user efficiency and satisfaction, and institute commonality across multiple exercise systems.
  - Utilized GUI design principals focused on intuitive ease of use to minimize training time and realize early user efficiency.
  - Project requirement to test the software in an analog environment.

- **Top Level Project Aims**
  1) Improve the usability of crew interface software to exercise CMS through common app-like interfaces.
  2) Introduce virtual instructional motion training.
  3) Use virtual environment to provide remote socialization with family and friends, improve exercise technique, adherence, motivation and ultimately performance outcomes.
Logic Model for Hypothesis

- **Increased VO₂ Max**
- **Increased Sessions Completed**
- **Increased Intervals Completed**
- **Increased Time-to-Failure**

- **Aerobic and Anaerobic Conditioning**
- **Physical Readiness for Mission Task Requirements**

- **Protocol Adherence and Effort**
- **Perceived Effort and Exhaustion**

- **Treadmill Training with VR Application**
- **Environmental Experience**
- **Socialization**
- **Pacing and Competition**
- **Positive Emotion from Exercise**
- **Enjoyment**

- **Increased Positive Engagement – Exercise induced feelings inventory (EFI)**
- **Decreased RPE During Exercise**
- **Decreased Physical Exhaustion (EFI)**

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Enhance the Capabilities of In-Flight Exercise Software

One Interface
Aquarius Reef Base

Aquarius is located ~9 miles south of Key Largo, FL at ~60 feet deep.
**System Usability Assessment**

**Morae® Analysis (~20 hours of video)**
- Allows you to record and remotely observe user interactions (navigation through software screen only) and audio recording for analysis of in-session commentary.

**Key Feedback Captured**
- Connectivity issues sometimes resulted in failure to transfer exerciser protocols, pop-up of post-session survey, and transfer of data files.
- Revealed the exercise demonstration videos were in a bad location.
- It was not clear how to navigate through the Rx list.
- The Bluetooth Heart Rate Monitor was difficult to pair.
- Server issues disrupted synchronization of data files.
- Exercise threshold settings need higher tolerance to capture all repetitions performed.
- Great crew-to-crew training and shared experience.
- Get rid of need to select start/stop at each new set.

- “This is a pretty legit workout!”
- “You have to hit end/start exercise every time and I found that very annoying.”
- “That doesn’t seem to work.” (paired with screen interaction provided flag on specific issue-selecting exercise in list vs using navigation arrows)
Artificial Gravity (AG) Potential Benefits

• Better to prevent issues rather than to apply countermeasures after the fact.

• AG produces multi-system effects.

• AG is a potential countermeasure for VIIP (Visual Impairment Intracranial Pressure) syndrome.

• AG reduces countermeasure requirements after landing on planetary surface.

• Rehabilitation starts 6 months earlier than a non-AG mission, and is complete when crew returns to Earth.
NASA HRP – Human Risks of Spaceflight

Grouped by Hazards – 30 Risks & 2 Concerns

**Altered Gravity Level**
- Vision alterations
- Renal stone formation
- Sensorimotor alterations
- Bone fracture
- Impaired performance
- Reduced aerobic capacity
- Adverse host-microorganism interactions
- Urinary retention
- Orthostatic intolerance
- Back pain
- Cardiac rhythm problems
- *Effects of medication*
- *Intervertebral disk damage*

**Radiation**
- Exposure to space radiation

**Distance from Earth**
- Limited in-flight medical capabilities
- Toxic medications

**Isolation**
- Adverse cognitive or behavioral conditions
- Performance & behavioral health decrements

**Hostile/Closed Environment–Spacecraft Design**
- CO2 exposure
- Inadequate food/nutrition
- Inadequate human-system interaction design
- Injury from dynamic loads
- Injury during EVA
- Celestial dust exposure
- Altered immune response
- Hypobaric hypoxia
- Sleep loss & work overload
- Decompression sickness
- Toxic exposure
- Hearing loss
- Sunlight exposure

Risks potentially minimized by artificial gravity
Historical AG Concepts

- Tsiolkovsky (1903)
- Von Braun (1952)
- Noordung (1928)
Why Has AG Never Been Implemented?

- Lack of definitive design requirements, especially acceptable AG levels and rotation rates.
- Perception of high vehicle mass and performance penalties.
- Incompatibility of resulting vehicle configurations with space propulsion options.
- Perception of complications associated with de-spun components such as antennae and solar arrays.
- Expectation of effective crew microgravity countermeasures.
- Space research focus on microgravity, not partial gravity.

Products Necessary to Resolve Open Questions

- Subjective Assessment
  - Crew comfort
  - Crew time
  - Overall crew acceptance

- Engineering Assessment
  - Loads at interfaces with module/node
  - Vibrations, g jitters, noise
  - Heat load, air flow

- Physiological Assessment – AG Prescription
  - Optimal G level (radius & rotation rate)
  - Optimal AG duration/frequency
  - Feasibility of AG combined with exercise
Artificial Gravity Level

- G dose-physiological response
  - Partial-G parabolic flight
  - Body unloading
  - Head-up tilt
  - JAXA ISS mouse centrifuge

Body-weight unloading (Ellman et al. 2013)
AG Summary

• AG research overarching goal is to inform managers and mission designers as to the specific AG requirements and their costs and benefits for any given mission scenario.

• AG research projects, both ground- and space-based, exist worldwide.

• AG research is translational across species and physiological systems.

• AG research is multidisciplinary, combining physics, physiology, biology, human factors, and engineering issues.
Parabolic Flight
ARGOS

- ARGOS is a robotic system that simulates a reduced gravity environment
- ARGOS uses computer controlled electric motors to drive motion in all axes
  - Vertical system (Z-axis)
    - Connects and supports the test participant
    - Measures the load on the system with redundant in-line load cells that are constantly monitored by the control system
    - Control system commands the motor to raise or lower as the test participant while maintaining a constant offload force
  - Horizontal system (X, Y-axis)
    - Driven by electrical motors attached to friction drive wheels
    - Motion of test participant is measured by a cable angle sensor
    - The cable angle laser sensor provides data which commands the system to keep the lifting mechanism centered above the load
- Backup

HILT
• Examples of Payloads in ARGOS

Unsuited Human Participants

Suited Human Participants

Robotic Payloads
Collaborations
Research & Collaboration Opportunities

• OP3
• NSPIRES
• CASIS
• Space Biology
Summary

• Bone and muscle loss remain a serious risk to crew health.
• Our experience base is limited to 6 month missions.
• Quantify the exercise data we have today as a baseline from which we can continue to improve upon.
• Must apply lessons in bone mechanobiology with data being collected today to develop robust predictive algorithms.
• Identify new tools to help quantify loading profiles.
• Utilize ISS as a laboratory to conduct tech demos of new gadgets.
• Inspire the next generation of space life scientists and engineers to help find solutions to protecting human health during planetary exploration.
Focus on the Fundamentals
Be Persistent and Demonstrate Competence
Network & Seek out Strong Mentors
Communications is a key to making operations smooth: understand how it works, ask questions, and state expectations.
Don’t settle into the comfortable, Be Proactive and Create New Opportunities
Work-life balance
Follow your passion, love what you do, share it with others
Thank you! ありがとうございます!

Contact Info:
Dr. Andrea Hanson
andrea.m.hanson@nasa.gov
Applying to be an Astronaut: Requirements

• Must be US citizen.
• Qualifying degrees: Engineering, Biological Science, Physical Science, Computer Science, or Mathematics.
• Either 3 years of professional related experience, or 1,000 hours of pilot-in-command time in jet aircraft.
• Ability to pass the NASA long-duration Astronaut physical, which includes visual acuity is correctable to 20/20.
• Must meet anthropometric requirements (height and body measures) for the vehicle and EVA suit.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 14, 2015</td>
<td>Vacancy Announcement opens in USAJOBS</td>
</tr>
<tr>
<td>February 18, 2016</td>
<td>Vacancy Announcement closes</td>
</tr>
<tr>
<td>February–September 2016</td>
<td><strong>Qualified Applications reviewed to determine Highly Qualified applicants. Qualifications Inquiry form sent to Supervisors/References.</strong></td>
</tr>
<tr>
<td>October–December 2016</td>
<td>Highly Qualified applications reviewed to determine Interviewees</td>
</tr>
<tr>
<td>February–April 2017</td>
<td>Interviewees brought to JSC for initial interview, medical evaluation, and orientation. Interviewees will be selected from the Highly Qualified group and contacted on a week-by-week basis.</td>
</tr>
<tr>
<td>May 2017</td>
<td>Finalists determined</td>
</tr>
<tr>
<td>June 2017</td>
<td>Astronaut Candidate Class of 2017 announced</td>
</tr>
<tr>
<td>August 2017</td>
<td>Astronaut Candidate Class of 2017 reports to the Johnson Space Center</td>
</tr>
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</table>
Applying to be an Astronaut: The Interview

- Orientation
- Tour around JSC
- Anthropometric Measurements
- Robotic Assessment
- Written Psychological Exam
- Medical Questionnaire
- Workout with ASCRs
- The Interview: Tell us about yourself
- Meeting Other Astronauts
- Social