Artificial Gravity & Countermeasures

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Thanks to Prof. Larry Young, Dr. Chuck Oman, Jessica Marquez, Dr. Andrew Liu, and Dr. Heiko Hecht

Space Biomedical Engineering and Life Support

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Outline

- Exercise countermeasures
- Artificial gravity (the ultimate countermeasure?)
- Visual orientation countermeasures

General Effects of Long Duration Spaceflight on Humans

- Cardiovascular
  - baroreflex down regulation, orthostatic intolerance
- Muscular
  - atrophy of anti-gravity muscles, shift of fibers
- Skeletal
  - decreased osteoblastic activity & losses as high as 1-2% / month
- Vestibular
  - adverse effects to spatial orientation and balance mechanisms
- Immunology, Radiation, Human Factors

Past/Current Exercise Countermeasures

- Lower Body Negative Pressure (Chibis)
- Saline loading (OI)
- Penguin suit, ESA
- G-Suits
- On ISS: two exercise *sessions* a day
  - workout designed by trainers on ground
  - they keep track of progress
- Machines
  - treadmill, ergometer, resistive device
- ISS tour

Exercise Machines on ISS

- Treadmill (4 workouts a week)
  - 900 lb in Service Module
- Two stationary bikes (4 workouts a week)
  - American built: Laboratory Module
  - Russian built: Service Module
- "Lift" weights: RED -- resistive exercise device (6 workouts a week)

Treadmill

- Vibrationally isolated
- Harness, bungee straps
  - Contact points on shoulders and hips -- get sore after running a while
- Walk (1 mi), run (couple sets of 1/2 mi)
- Targets:
  - aerobic exercise
  - "loading" of skeletal system: hips and legs

Videos of Treadmill

http://spaceflight1.nasa.gov/gallery/video/shuttle/sts-81/mpg/81d03c5.mpg
http://spaceflight.nasa.gov

Stationary Bicycles

- Mounted facing two 'windows', watch Earth below
  - Don't sit on seat
- Bursts of high resistance, longer workout at lower resistance
  - heart rate monitor, records pulse
- Aerobic exercise, measuring aerobic fitness per month with resistance profile routine

Video of Ergometer

http://spaceflight1.nasa.gov/gallery/video/shuttle/sts-87/mpg/87d15c3.mpg

Resistive Exercise Device

http://spaceflight.nasa.gov

- Canisters with cords that wrap around in a spiral pulley that unwinds as being pulled
  - resistance provided by stacked series of disks with rubber spokes in side.
  - choose resistance level: up to 120 pounds on EACH side (total = x2)
    - add bungees, up to 190 lbs per side

"This is the device that seems to make the most difference with respect to overall strength and reducing bone loss." Ed Lu

RED, cont.

- Workout at near maximum strength the major weight bearing muscles
  - hips, lower back, legs
- Types of exercises
  - squats (single leg also), dead lifts, heel raises, bench press, upright rows, abdominal crunches, leg extensions, holding positions (for thighs and hips)

http://spaceflight.nasa.gov

Video of RED

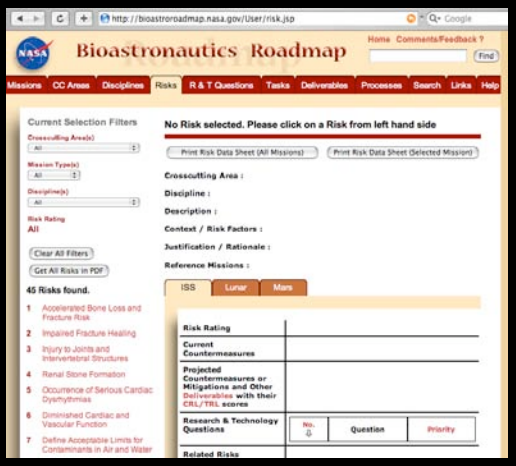
Spacelab resistive exercises

Expedition Six Commander Ken Bowersox, wearing the Lower Extremity Monitoring Suit, or LEMS, participates in the Foot/Ground Reaction Forces During Spaceflight, or FOOT, experiment.
As part of the experiment, Bowersox exercises on the Treadmill Vibration Isolation System, or TVIS (exp6tvis).

http://spaceflight.nasa.gov

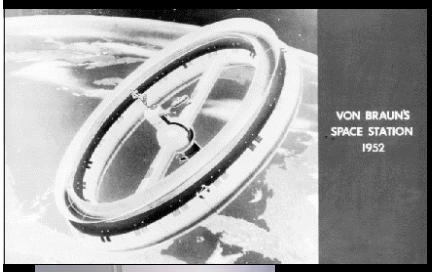
Issues

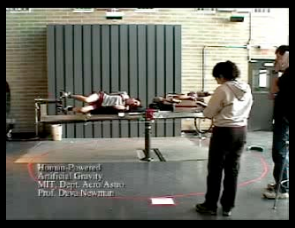
- Motivation? Enjoyment?
- How many physiological systems?
- Countermeasure for both bone density loss and muscle atrophy?
- Beyond Exercise?
- NASA Roadmaps on-line
  http://bioastroroadmap.nasa.gov



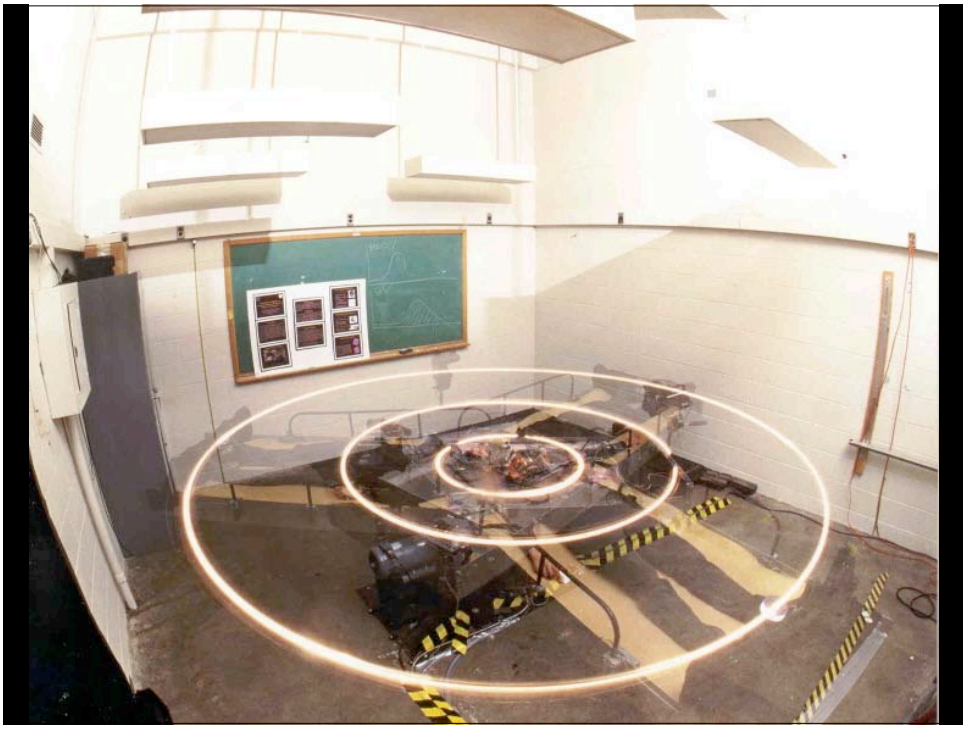
Producing AG

- Artificial gravity produced by rotation, utilizing centrifugal force as gravity





MIT Artificial Gravity Simulator



AG Tradeoffs

Cost
Vibration
Environment
Gravity Gradients
Docking Complexities
Starting & Stopping Rotation

AG Design Factors

Radius & Rate of Rotation
Artificial Gravity Level (Centripetal Accel.), $r\omega^2$
Coriolis Forces, $-2\,m\,(\omega \times v)$
Gravity Gradients, h/r
Cross-coupled Angular Accelerations, $\omega_{SRC} \times \omega_{Head}$

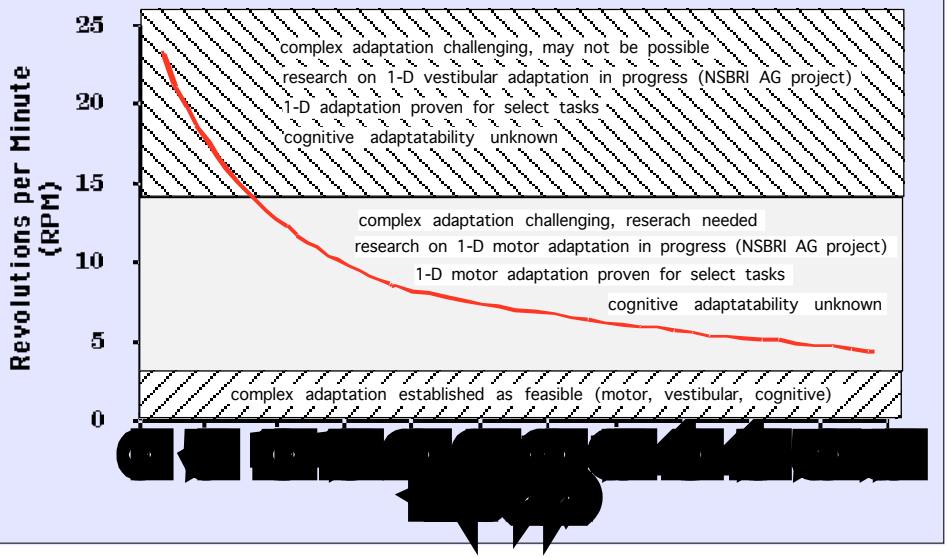
Why AG? How much? When? Physiologic limits? Design/costs?

[Diamandis, pg 162]

Types of Centrifugation

EXPOSURE \ RADIUS	short	long
intermittent	adaptation less critical 1-D adaptation may be sufficient	impractical if not impossible
continuous	adaptation most critical complex adaption to the fullest extent mandatory	complex adaptation critical but manageable due to small magnitude

Types of Centrifugation



Intermittent Short-Radius Centrifugation

- "Spin in the Gym"
- "Prescribed AG Dosage"
- "AG Sleeper"

Benefits

- ✓ Cost-effective
- ✓ Space-efficient
- ✓ Relatively easy to implement
- ✓ Fits within ISS/Spacehab

Concerns: "Things to work on"

- Out-of-plane head movements during rotation produce sensory conflict
  - *vestibular vs. visual and kinesthetic*
  - Inappropriate non-compensatory nystagmus
  - Motion sickness
  - Illusory tilt sensations
  - Postural instability
- Yet to demonstrate effectiveness against bone, muscle, and cardiovascular deterioration

AG: The Ultimate Countermeasure?

In Class Exercise

Countermeasures for Neurovestibular and Spatial Memory Problems in μ-g

Neurovestibular Risks of Spaceflight

- Impaired cognitive and/or physical performance
- Disorientation and inability to egress safely or perform other physical tasks
- Impaired neuromuscular coordination and/or strength
- Autonomic dysfunction
- Permanent impairment of orientation or balance function

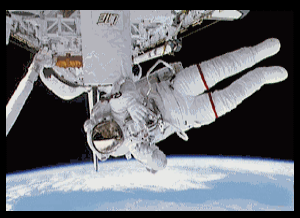
Space Illusions

• In weightlessness, “down” cues from the inner ear otolith organs are absent. Astronauts are thought to rely more heavily on vision.

• Many astronauts perceive a “subjective vertical”. When it changes direction, it can cause disorientation and motion sickness.

Inversion Illusions - Common immediately after reaching orbit

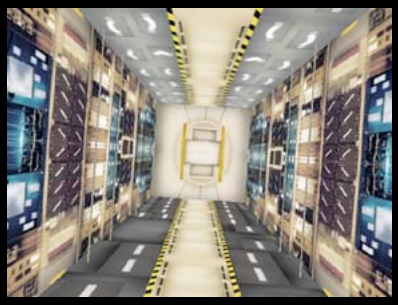
Visual Reorientation Illusions (VRIs) - surface below feet seems like floor



EVA acrophobia - sudden fear of falling towards the Earth

Visual Cues to Orientation in 0-G

What surface is the “floor” ? Which way is “down” ?

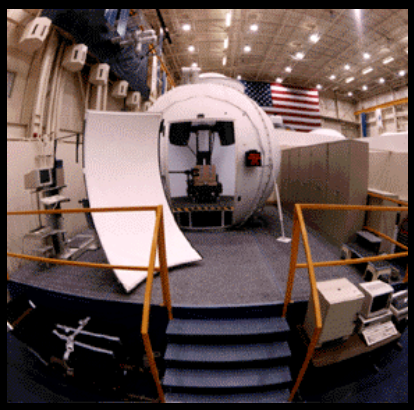


Cues include: Visual tilt, visual motion, visual polarity

Knowledge could lead to better interior design.

York facilities

Preflight Adaptation Training



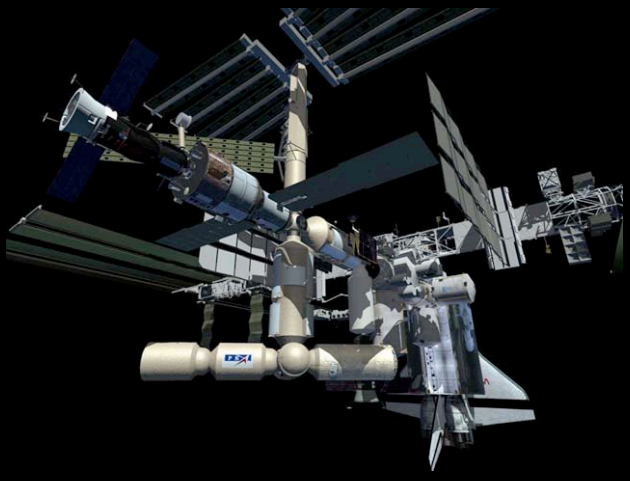
- JSC, early 1990's
- Device for Orientation and Motion Environments (DOME) apparatus
- Tilt Translation Device (TTD) device

3D Spatial Memory and Navigation

- What makes orientation and navigation in 6 dof difficult?
  - Body movements are unconstrained by gravity.
  - Inconsistencies in visual verticals of the various modules.
  - 3D configuration of modules and nodes is difficult to mentally image and rotate.

3-D Spatial Memory

Mir-22 Mission Commander Valeri G. Korzun Enters
Node That Connects Station Modules



International Space Station

Physical Mock-ups

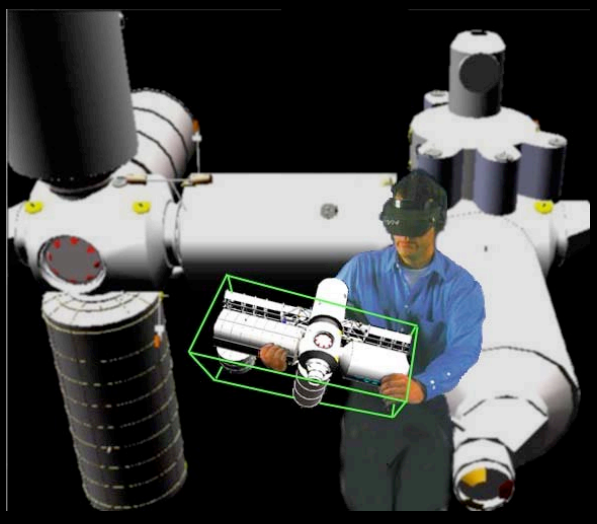
3D Spatial Memory Expts

Jason Richards (2000)

Training to reduce direction vertigo

- Astronauts who have trained in space station ground simulators with modules not connected in their actual 3D flight configuration have later reported difficulties making spatial judgments involving the two modules in flight configurations. (Benveniste, 2003)

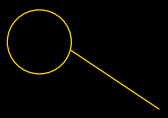
VR Navigation Training Tools



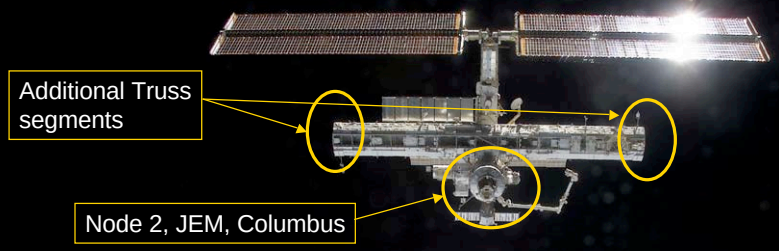
Spacecraft-in-Miniature: A 3D Navigation Tool

- Extends “World-in-miniature” (Pausch et al.,1995) to 3D space.
- Provides “survey” knowledge like a “you-are-here” type map.
- Encodes orientation and position information with respect to any location in the environment through the physical manipulation of SIM and “fly-in”.

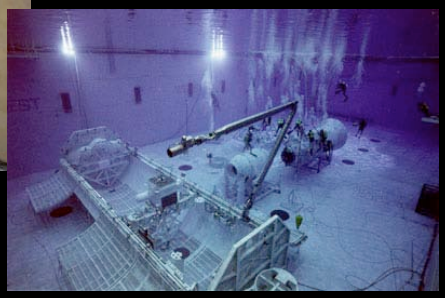
Spatial Ability in Space Ops



Future SSRMS Operations



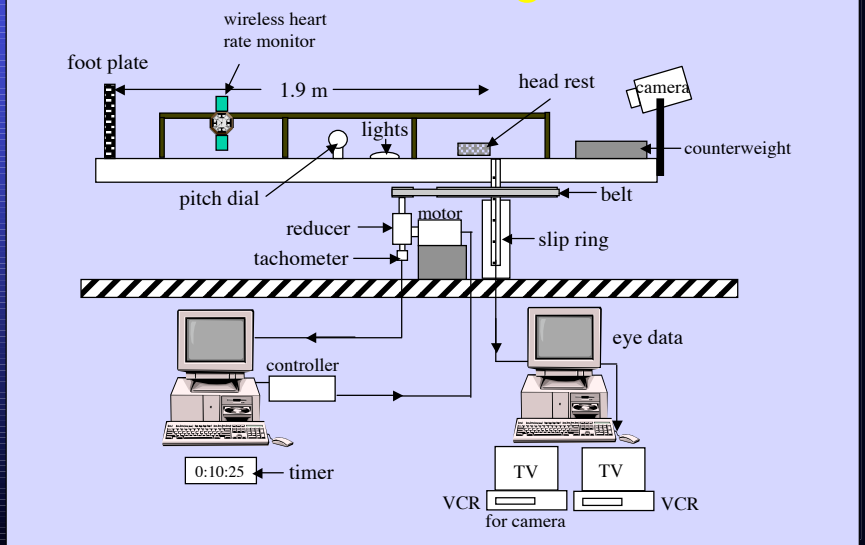
Countermeasures: Training

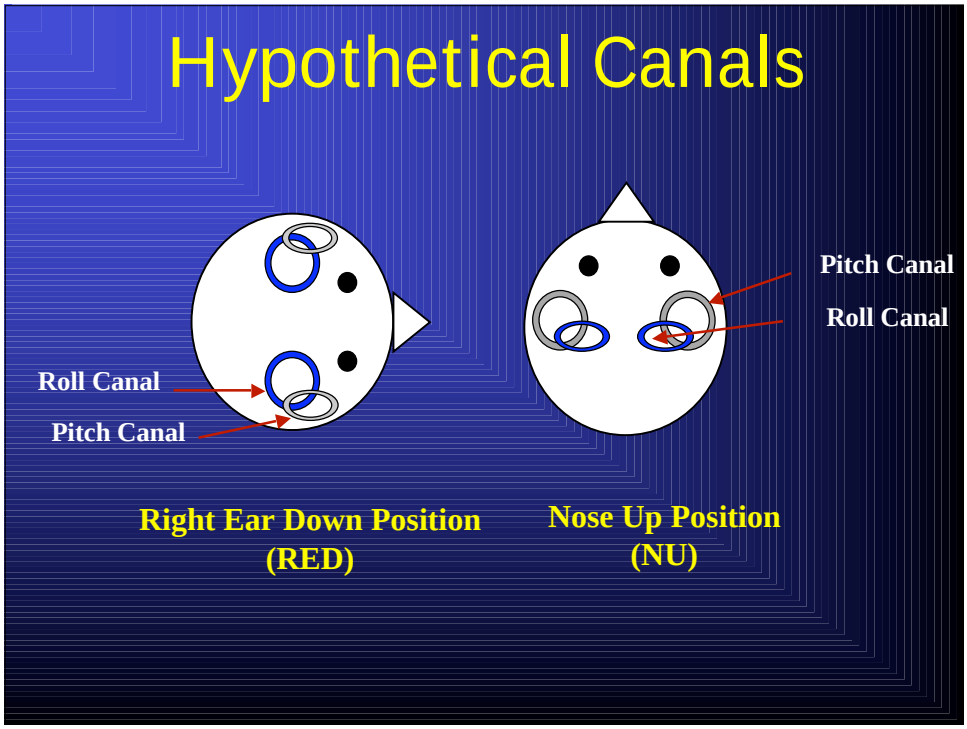


•Experience in mockups, parabolic flight, and neutral buoyancy and VR simulators is anecdotally helpful.

back ups

Schematic of MVL Short-Radius Centrifuge




Hypothetical Canals
Roll Canal
Pitch Canal
Pitch Canal
Roll Canal
Right Ear Down Position
(RED)
Nose Up Position
(NU)