Artificial Gravity

Past, Present, and Future

NASA Johnson Space Center

July 5, 2000

What is Artificial Gravity [AG]?

- AG may be generated in the spaceflight environment by
  - Linear acceleration and deceleration of the transit vehicle
  - Continuous or intermittent rotation of a spacecraft element or the entire spacecraft
- AG may serve as a countermeasure to some of the deleterious effects of space flight, whether conducted in low Earth orbit or beyond
- The concept of AG has long been visualized and expanded upon by engineers, scientists, fictional writers, and screen writers

Contents

The Stuff of Science Fiction

1869-70

Edward Everett Hale publishes "The Brick Moon" in *The Atlantic Monthly*. It is the first suggestion, fictional or otherwise, of an artificial satellite that orbits the Earth with human crew.

1896-1920

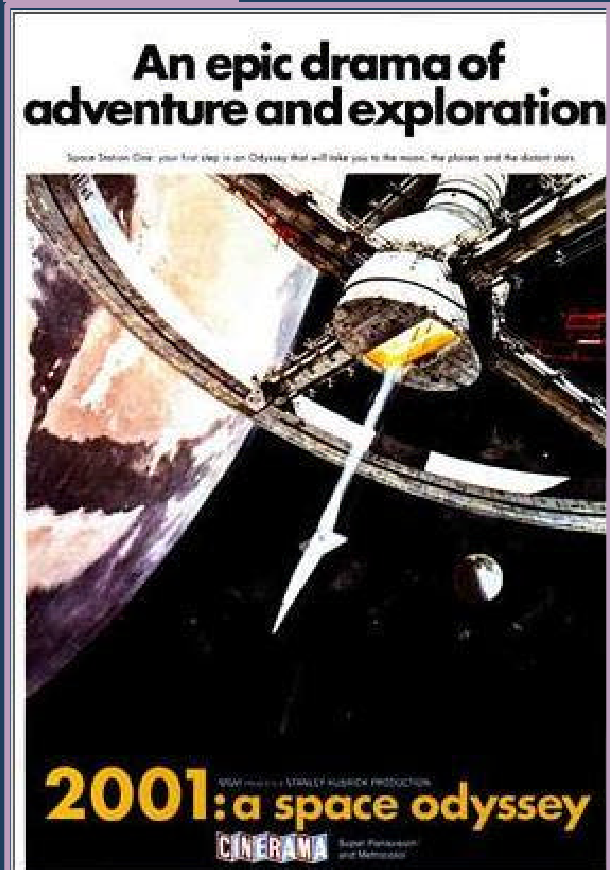
Konstantin Tsiolkovsky's *Beyond Planet Earth* is published, in which he describes how artificial gravity could be produced by rotating the cylindrical station. He later expanded his concepts to include mathematical calculations.

1929

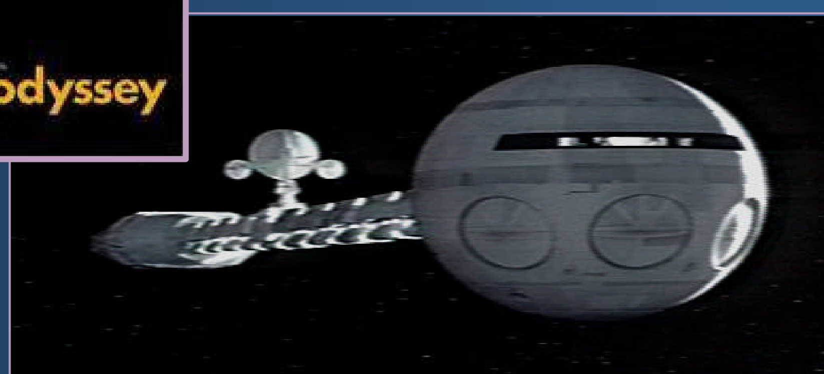
Hermann Noordung (Potocnik) publishes *Das Problem der Befahrung des Weltraums* in which the habitation module is rotated every 8 seconds to produce AG.

The Stuff of Science Fiction

1968



- Arguably, the most famous example of AG is found in Stanley Kubrick's 1968 film, *2001: A Space Odyssey*. Arthur C. Clarke wrote the screenplay and later published a book by the same name.
- The film shows a complex and large-scale space station, one component of which is a spinning doughnut, or torus. This component is spun to create artificial gravity.



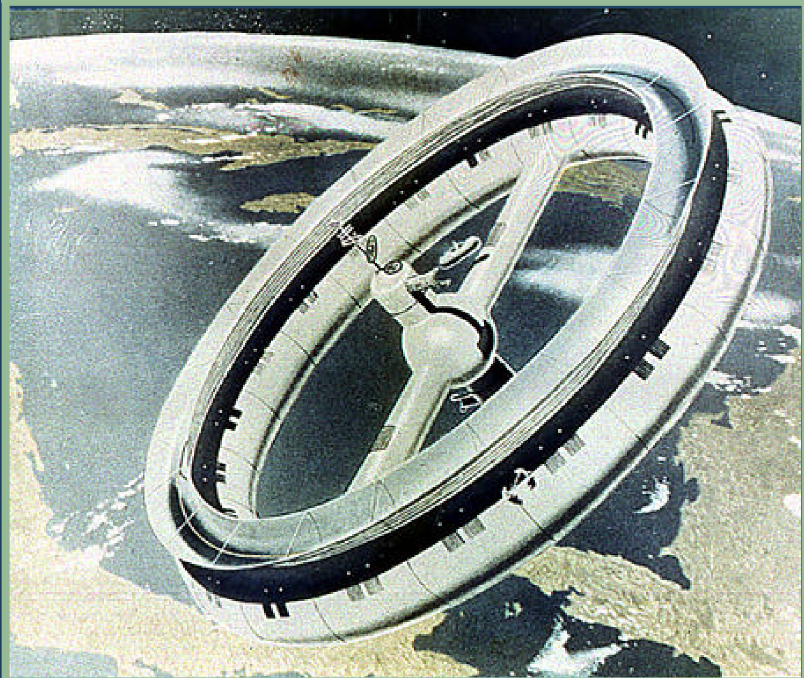
The Stuff of Science Fiction

1998

- In *Armageddon*, the fictional Russian space station is spun in order to create artificial gravity.

Historical Considerations

1952



- Dr. Wernher von Braun published his concept of an early space station in *Collier's* magazine.
- A spinning torus with a diameter of 250 feet, the station would maintain a 1075-mile-high orbit, and would be the launch point for lunar expeditions.

Historical Considerations:

Slow Rotating Room

1960's

US Naval School of Aviation Medicine in Pensacola, FL

- Experiments to test the effects of habitation in a rotating environment, similar to that necessary to produce artificial gravity
- Test subjects lived in a room rotating at 6 rpm and virtually every subject developed motion sickness
- At 2 rpm and lower, only slight symptoms were experienced.
- Subjects showed an improvement in their tolerance to the faster rates but still required a period of readaptation.
- Theorized that astronauts on a mission to Mars could readapt during the atmospheric entry and rendezvous.

Historical Considerations:

Slow Rotating Room

1960's

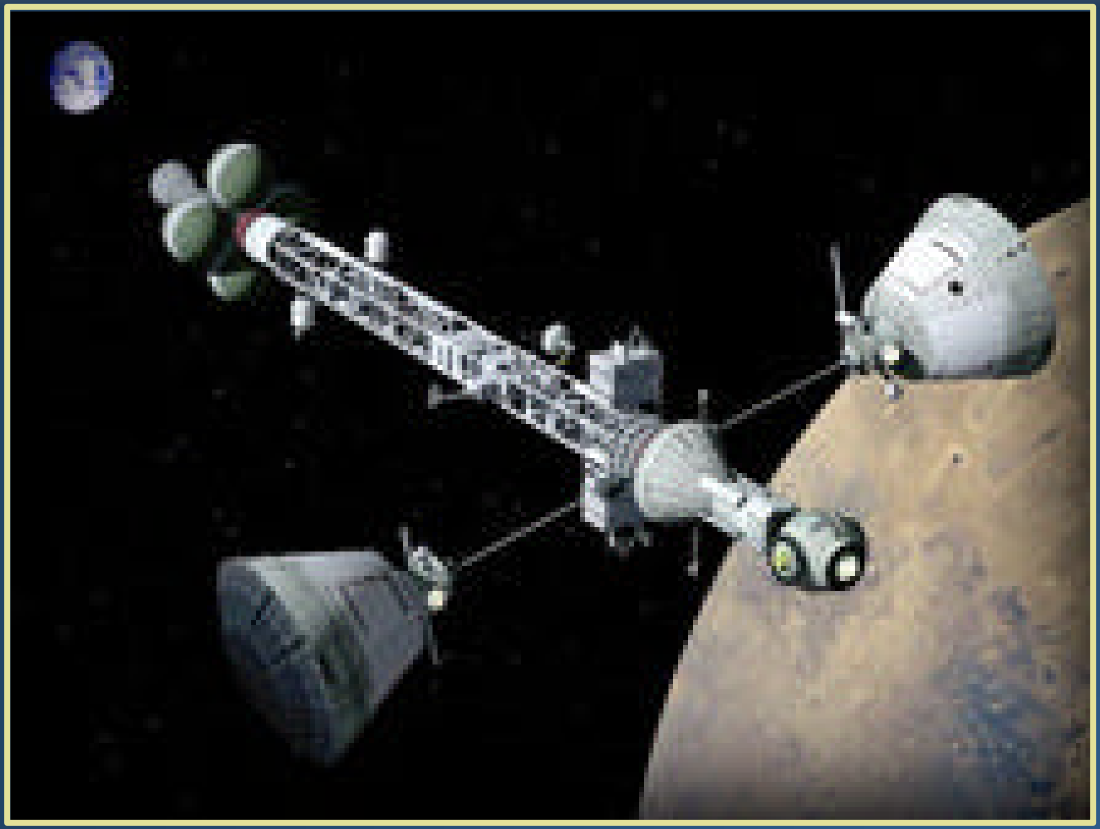
Series of Workshops Held

NASA Research

- A tethering exercise to test stationkeeping and to generate artificial gravity was conceived
- *Gemini XI* was tethered to an Agena rocket by a 36-meter lien and the two spacecraft were spun at a rate of 38-55º per minute.

On the Shoulders of Titans: A History of Project Gemini, Barton C. Hacker and Charles C. Alexander, NASA SP-4203, 1977.

NASA Concepts



- NASA has assessed the possibility of providing AG for astronauts on long-duration missions by tethering two spacecraft and rotating them about a common center of mass.

NASA Research

1965-8

The Manned Orbiting Research Laboratory[1] was used to conduct a series of experiments on short-duration exposure to hypergravity after bedrest.

- As few as four 7.5-min exposures to +1.7 G largely prevented orthostatic intolerance[2]
- Some adverse effects of bedrest, including heart rate and blood pressure, were not improved by centrifugation

1977

During the Cosmos 936 flight, rats were exposed to centrifugation during 18.5 days of spaceflight.

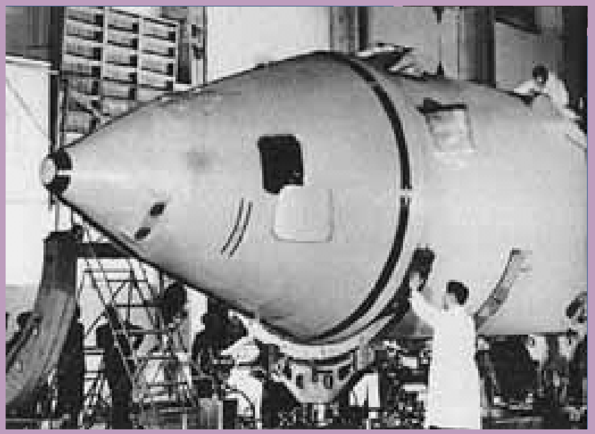
- The lifespan of centrifuged animals was significantly greater than that of non-centrifuged control animals[3].
- Hemolysis was significantly decreased in animals exposed to centrifugation, as compared to non-centrifuged controls.

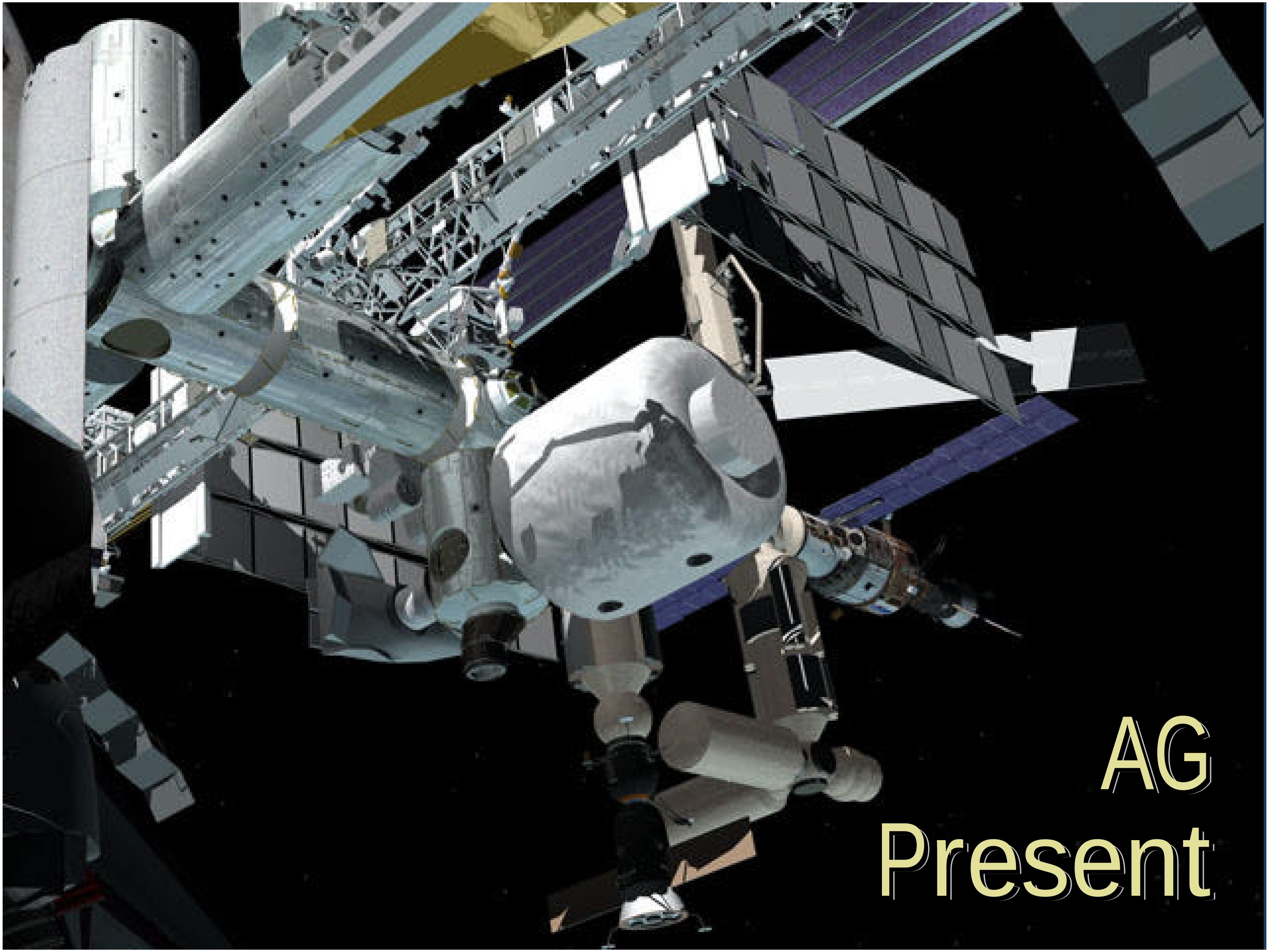
[1] Singer, 1968; Stapp, 1969
[2] W. White, 1965b; W. White, Nyberg, White, Grimes, and Finney, 1965; P. White, Nyberg, Finney, and White, 1966
[3] Leon, Serova, and Landaw, 1978

Soviet/Russian AG Research

1966

- Korolev and Tikhonarov committed the Soviet space program to constructing and orbiting a space station
  - To explore the long term effects of spaceflight and artificial gravity on the development of animals, plants, and humans.
- Korolev had planned to test AG during the *Voskhod* project, but his goals were never realized.




AG
Present

Option 1: Linear AG

Constant **acceleration** during the first half of a trip to Mars
Constant **deceleration** during the last half of a trip to Mars

$$\mathbf{F} = m\frac{d^2\mathbf{R}}{dt^2} = m\mathbf{a}$$

Fuel requirements

New propulsion systems

Surface activities and operations

Option 2: Rotational AG

$F_{centrifugal} = -mw2r$

Achieved by:

1) rotating entire vehicle during transit

or

2) providing human centrifuge within vehicle

Approximate g	Radius (m)	Angular Velocity (rpm)
1	300	0.55
1	15	2.46
1	0.75	11.02

Rotational AG

Example calculations from 2001 and clip(s)

Factors Affecting the Space Flight Crew

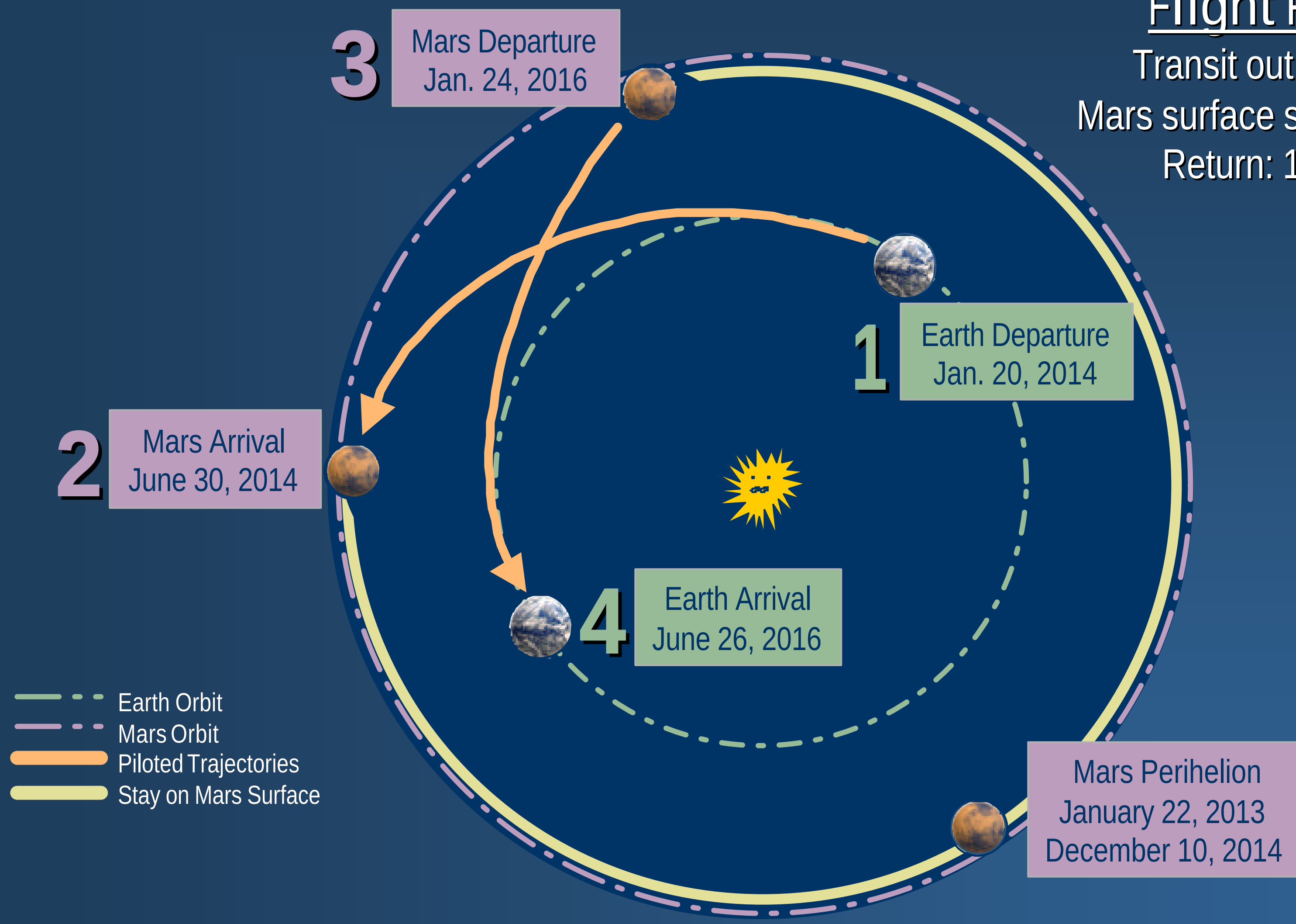
Isolation and confinement
- Psychosocial
- Nutrition
- Immunology
- Toxicology
- Microbiology

Decreased gravity
- Musculoskeletal
- Cardiovascular
- Neurosensory

Altered dark/light cycles
- Behavior
- Performance

Increased radiation

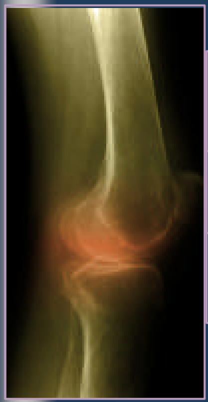
2014 Human Mars Mission Trajectory



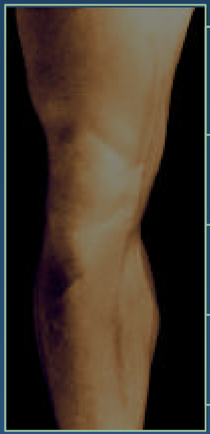
Flight Profile

Transit out: 161 days
Mars surface stay: 573 days
Return: 154 days

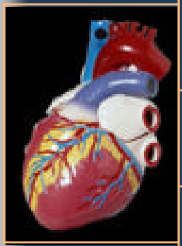
Current Countermeasure Concepts



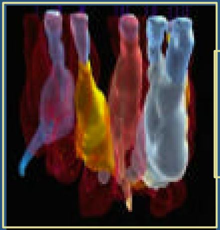
Bone
- Resistive exercise
- *Bis*-phosphonates
- **Artificial gravity**



Muscle
- Resistive exercise
- Aerobic exercise
- Growth hormone
- **Artificial Gravity**



Cardiovascular
- Lower body negative pressure
- Aerobic exercise
- **Artificial gravity**



Neurosensory
- **Artificial Gravity**

Some Biomedical Questions

- What is the minimum effective AG magnitude?
- Is there a maximum acceptable (optimum?) angular velocity?
- Is there a minimum acceptable radius?
- What countermeasures would be required to supplement AG?
- Under what conditions would AG be inappropriate?
- Is continuous AG exposure preferable to intermittent exposure?
- How will crewmembers adapt and transition to/from the AG environment?

Countermeasure Concerns

Mars Mission

Research → **Development** → **Evaluation** → **Validation**

Consider time, cost, and flight resource requirements

Operational Effectiveness

- Consider interactions and side effects
- Limit complexity to minimize crew time and maximize crew compliance

Physiological Requirements

To validate AG as an effective countermeasure for the bone, muscle, cardiovascular, neurovestibular, and other target physiological systems*:

How much AG is needed to maintain physiological function/ performance?

- What are the physiological thresholds for effective gravitational force?
- What minimum and/or optimum g-force should be used during transit?
- Would AG be required for on the Lunar or Martian surface?

What are the acceptable and/or optimal ranges for radius and angular velocity of a rotating space vehicle?

- What are the untoward physiological consequences of rotational AG?
- What are the physiological limits for angular velocity, g-gradient, etc.?

What additional countermeasures would be required to supplement AG?

* requirements for long-arm/continuous may be different from short-arm/intermittent

Research Requirements

CONCEPT: Evaluating AG as a countermeasure

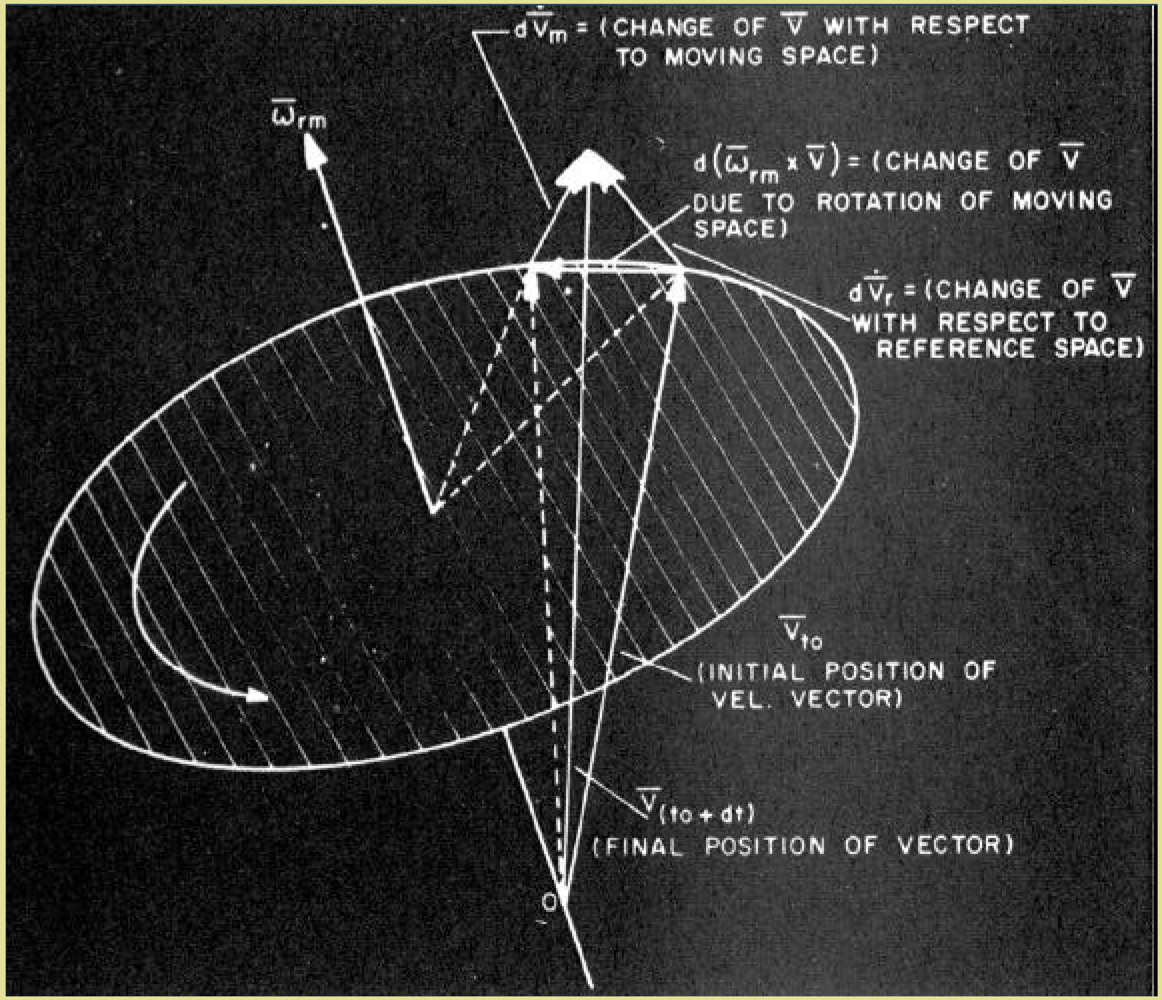
- What biomedical problems would be mitigated by an AG countermeasure?
- What other countermeasure research would be obviated by a vigorous AG research program?

APPLICATION: Pursuing an AG countermeasure

- What do we still need to learn about the physiological constraints and/or implementation requirements for AG?
  - What can be learned from animal studies?/What must be studied in humans?
  - What can be learned from ground-based studies?/What must be studied in space?
- What existing/planned facilities should be used for this research? What new facilities are required/desired?
- How should AG research activities be implemented?/prioritized?

Physics and Physiology

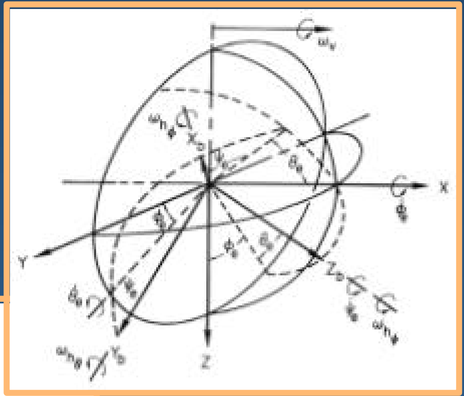
The Rotating Spacecraft or Spacecraft Element

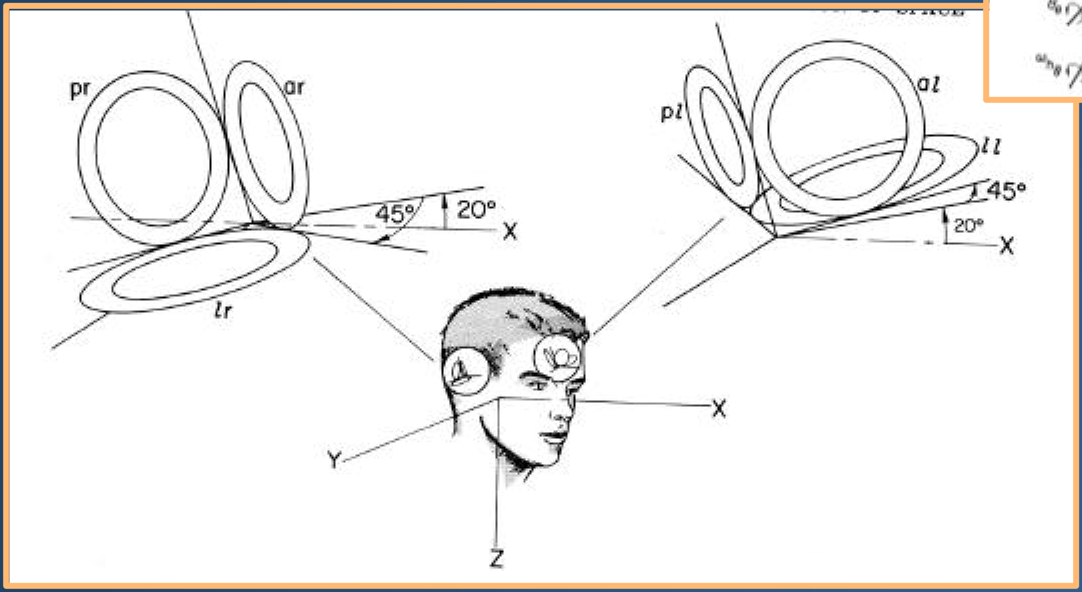


Physics and Physiology

Physiology

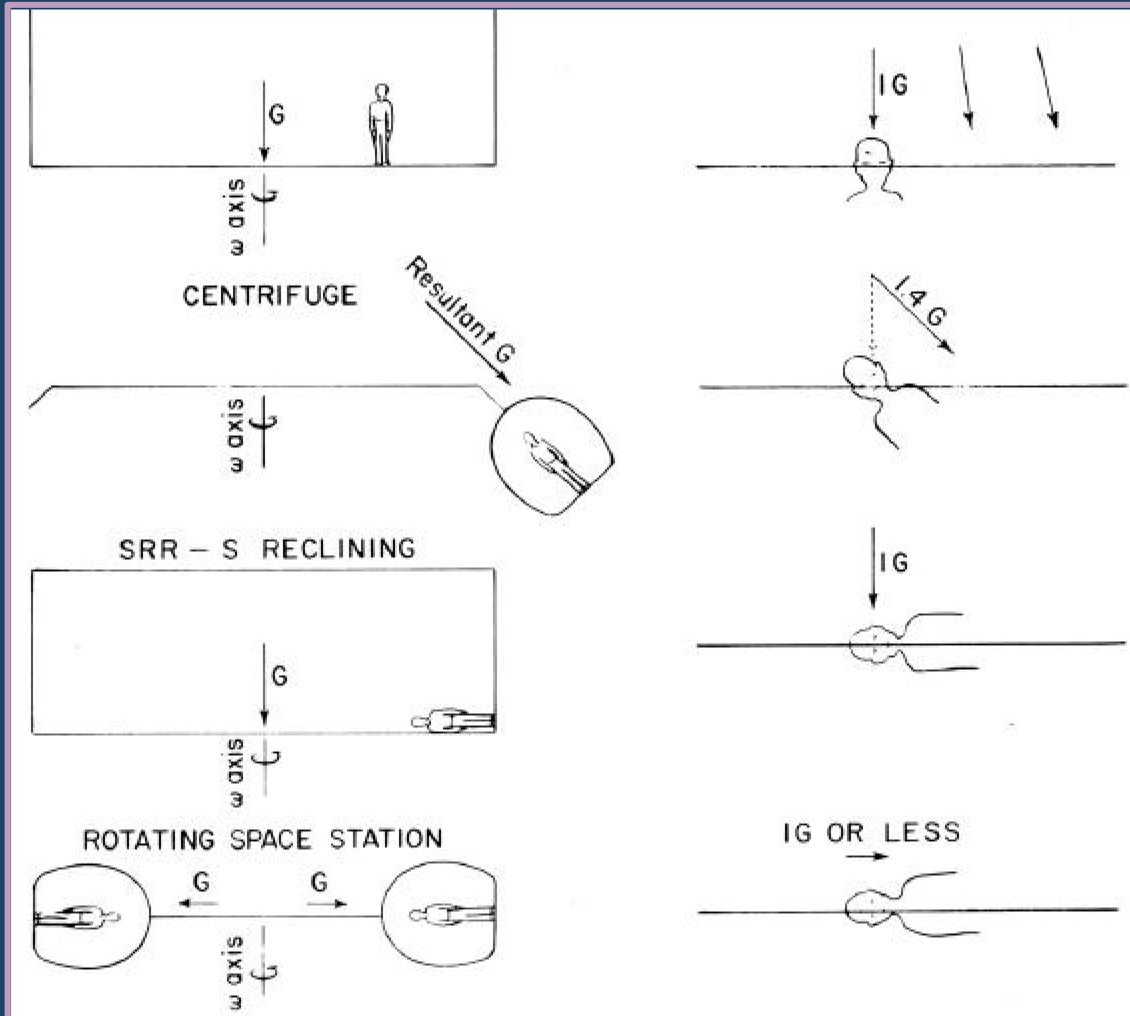
- A rotating spacecraft or onboard centrifuge could produce a 1 g environment, but would be complicated by novel, and often counter-intuitive, forces
  - Coriolis forces
  - Cross-coupling
  - Transient adaptation to/from AG
- These forces would have both biomechanical (human factors) and vestibular (e.g., spatial orientation) effects





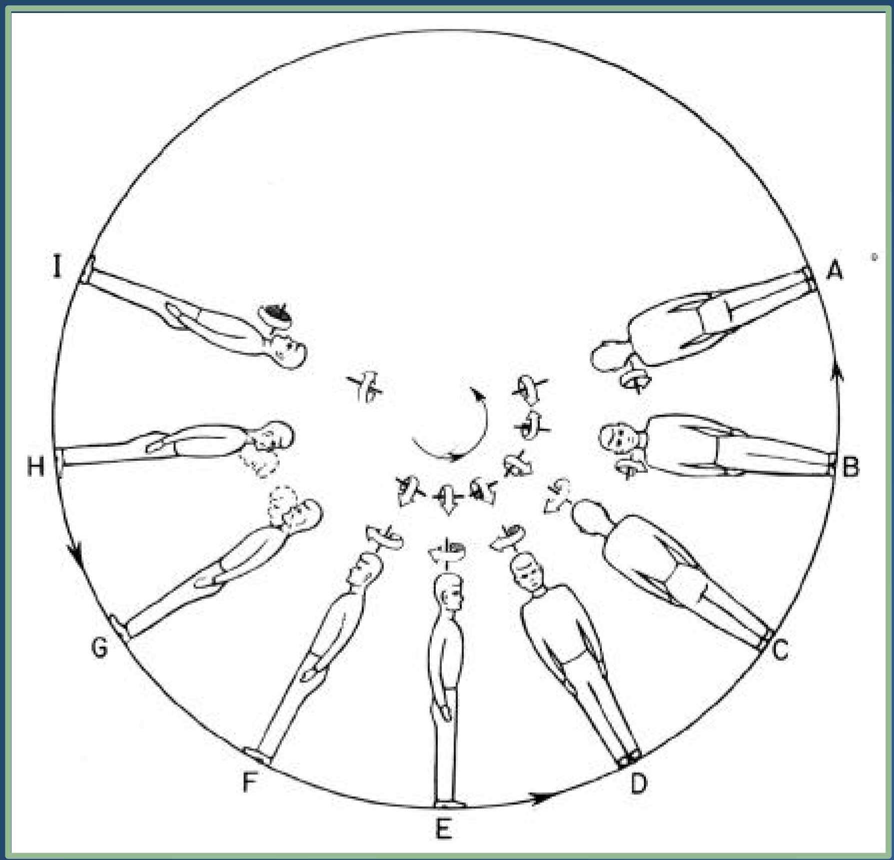
Physics and Physiology

The AG environment, on the ground or in-flight, is complex.



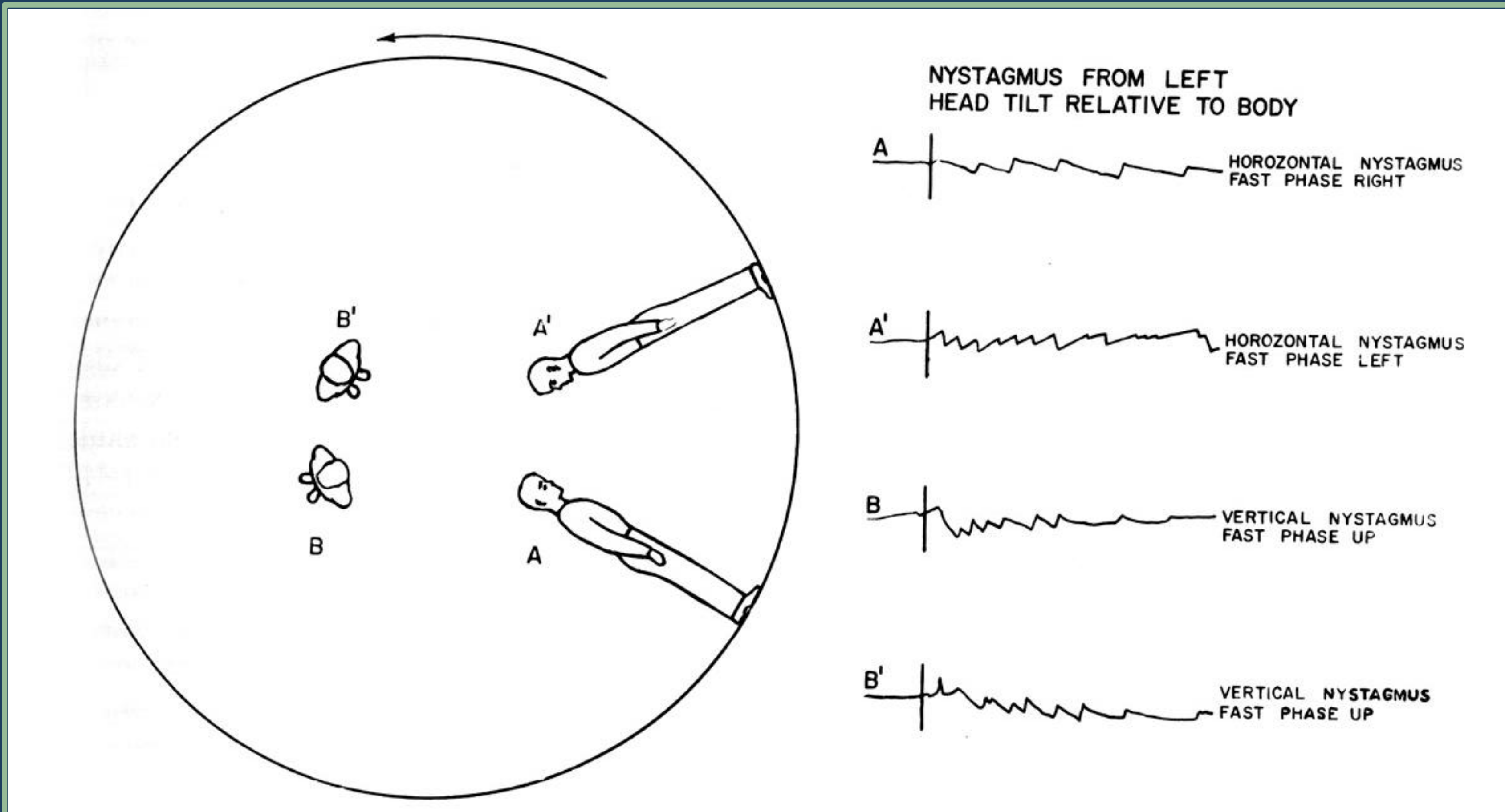
Physics and Physiology

The same head movement produces different sensory stimulation depending on orientation within the vehicle or centrifuge.

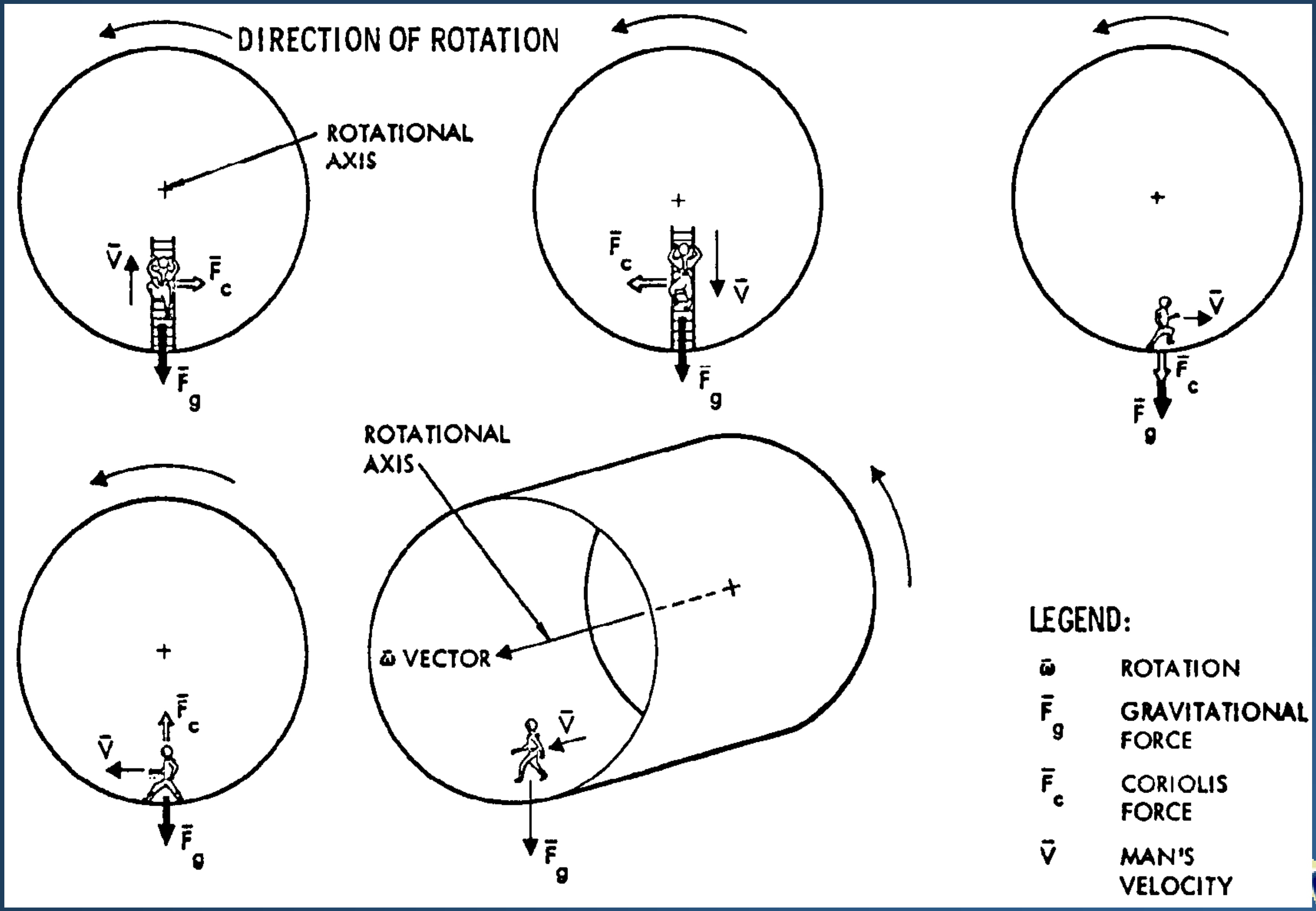


Ground-based Analog

Slow Rotating Room



Parameters for Design



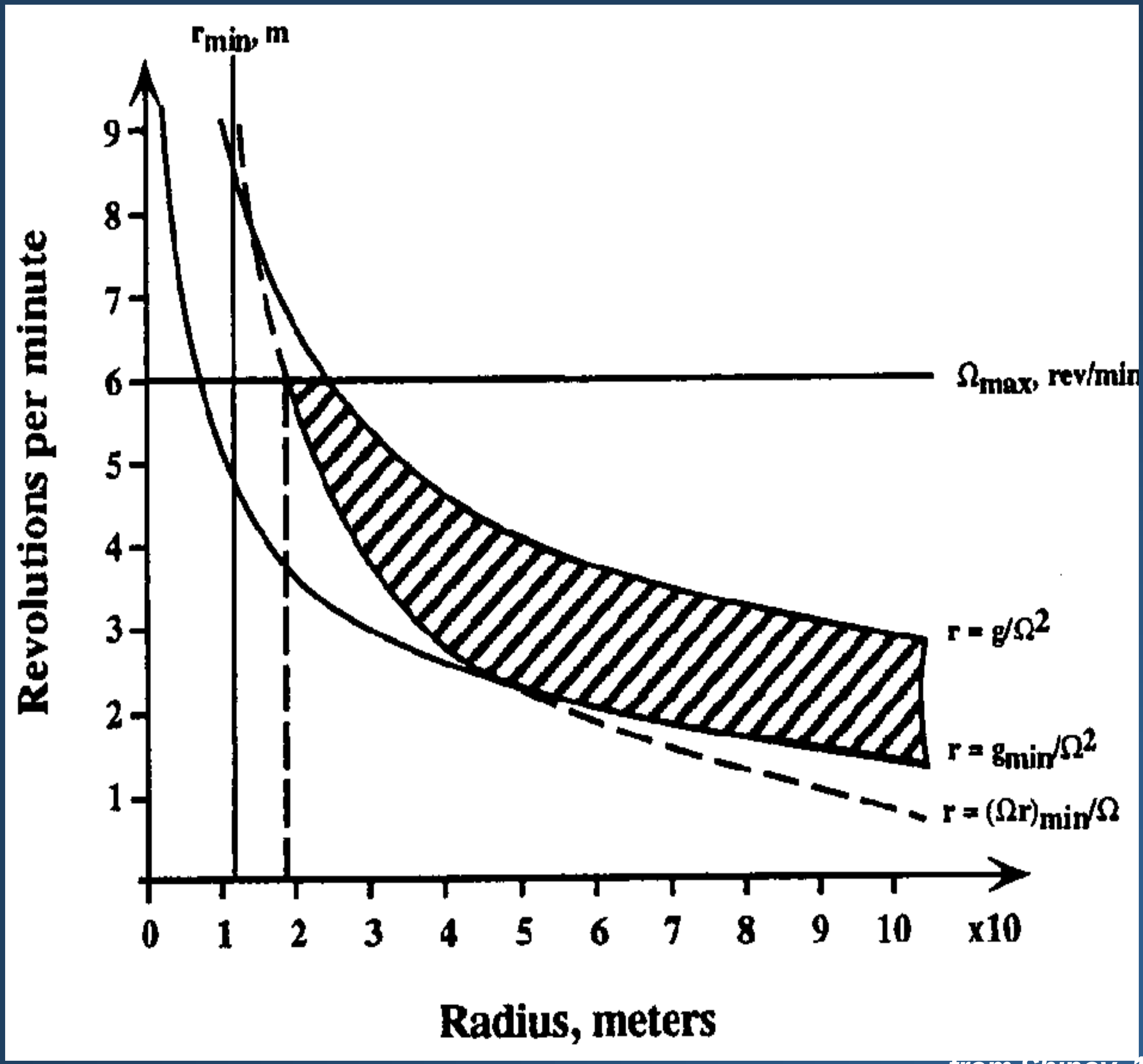
from Stone, 1970

Human Factors Concerns

Characteristics	Earth Gravity	Artificial Gravity	Physiological Limits
Static			
1 Magnitude of gravity	$F = m(R/R+h)^2 g \approx mg$	$F' = m\Omega^2 r$	$\underline{C} \le \Omega^2 r \le \bar{C}$
2 Weight of material point at height h	$F_h = m(1-2h/R)g \approx mg$	$F_h = m\Omega^2(r-h)$	$\Delta F'_h/F'_{h=0} = h/r \le C_{r1}$
3 Weight of body at height h	$Q = (1-h/R)g \approx mg$	$Q' = (1-h/2r)Q'_0 = M\Omega^2 r$	$\Delta Q'/Q'_0 = h/2r \le C_{r2}$
4 Center of gravity	$X = (1-4h/3R) / (1-h/R) \bullet h/2 \approx h/2$	$X' = (1-2h) / (1-h/2r) \bullet h/2$	$\Delta X'/X' = h/br \le C_{r3}$ $r \to \infty$
5 Hydrostatic pressure in blood vessels of extremities	$P = (1-h/R)P_0 \approx \rho gh$	$P' = (1-h/2r)P'_0 \approx \rho\Omega^2 rh$	$\Delta P'/P'_0 = h/2r \le C_{r4}$
6 Displacement of falling object from its anticipated location	$d = 2/3h\Omega_0(h/g)^{0.5} \approx 0$	$d' = [(a^2-1)^{0.5} - tg^{-1}(a^2-1)^{0.5}]r$ $a^{-1} = 1-h/r$	$\Delta d = d' \le C_{r5}$
Dynamic			
7 Coriolis moment of force	$\tilde{M}_r \approx Mh\Omega_0 V$	$\tilde{M}_{r'} \approx Mh\Omega V$	$\Delta\tilde{M}'_{r'}/\tilde{M}'_{Q'} \approx V/\Omega r \le C_{\Omega r1}$
at radial movement	$M_Q = hQ_0$	$\tilde{M}_{Q'} \approx hQ'$	
8 Dynamic weight at tangential movement	$Q_\tau \approx Q_0 + M(\Omega_0 + V/R)^2 R \approx Mg$	$Q'_\tau \approx (1+V/\Omega r)^2 Q'$	$\Delta Q'_\tau/Q' = (1+V/\Omega r)^2 \le C_{\Omega r2}$
9 Additional moment	$\tilde{M}g \approx I\omega\Omega_0 \approx 0$	$M'g \approx I\omega\Omega$	$\Delta\tilde{M}' = \tilde{M}' \le C_{\Omega 1}$
10 Angular deflection of sensory hair cells (ampullar receptors)	$\theta_i \approx \tau_i\Omega_0 \le \theta^*_i$	$\theta'_i \approx \tau_i\Omega$	$\Delta\theta'_i = \theta'_i \le C_{\Omega 2}$

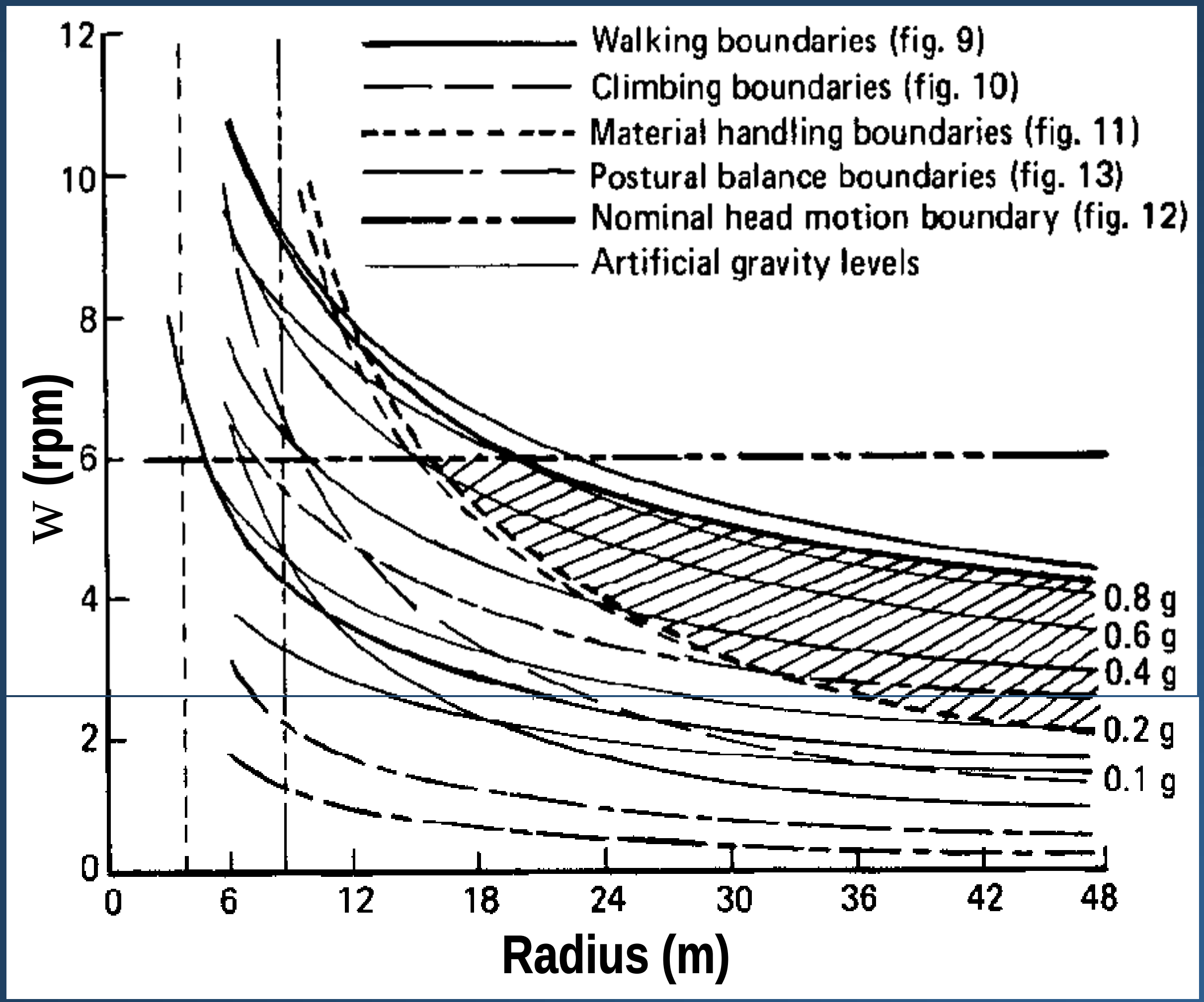
from Shipov, 1996

Parameters for Design



from Shipov, 1996

Parameters for Design

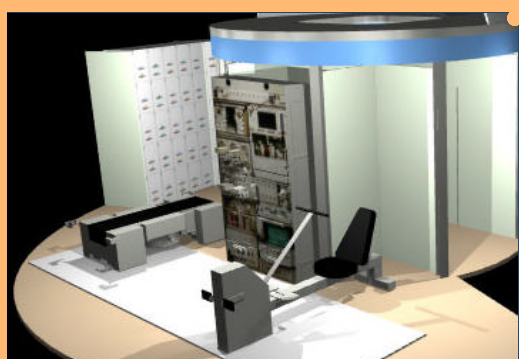


from Stone, 1970

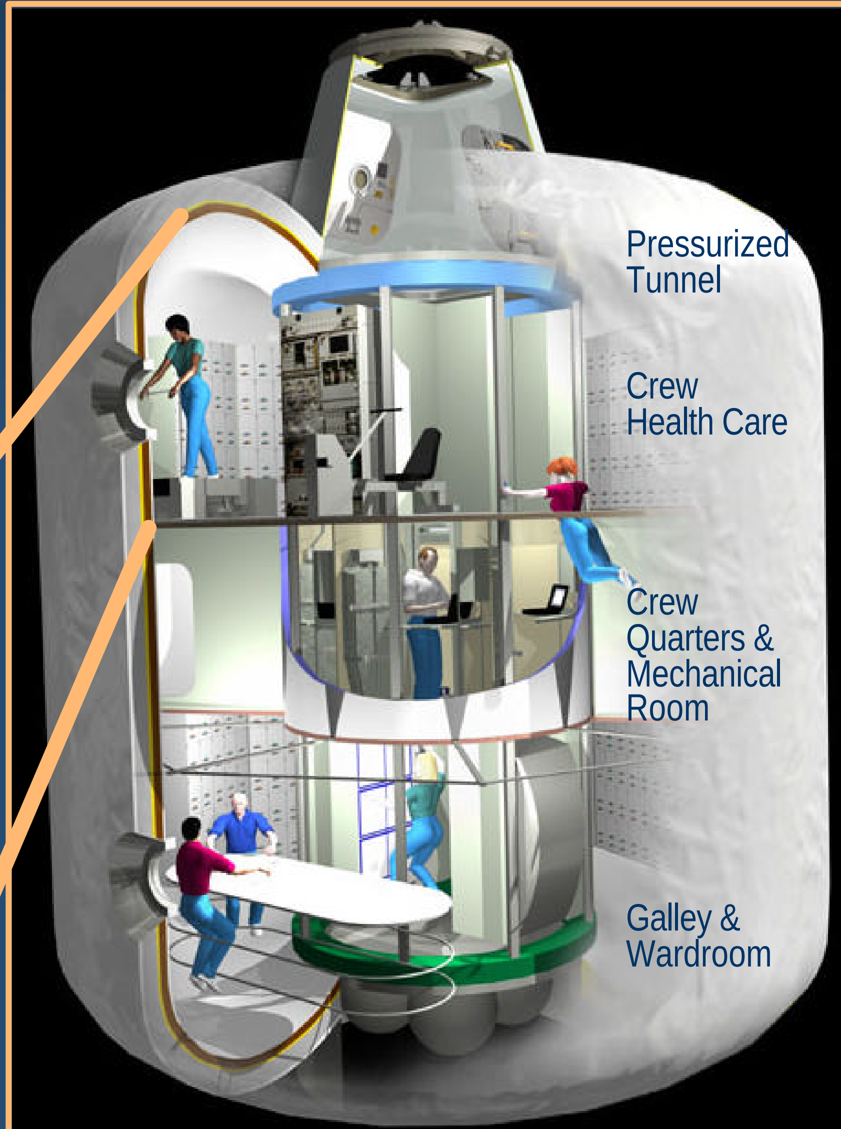
Current Concepts

TransHab

Vehicle rotation (ω ~4-6 rpm) could provide AG from 0.38 to approximately 1 g



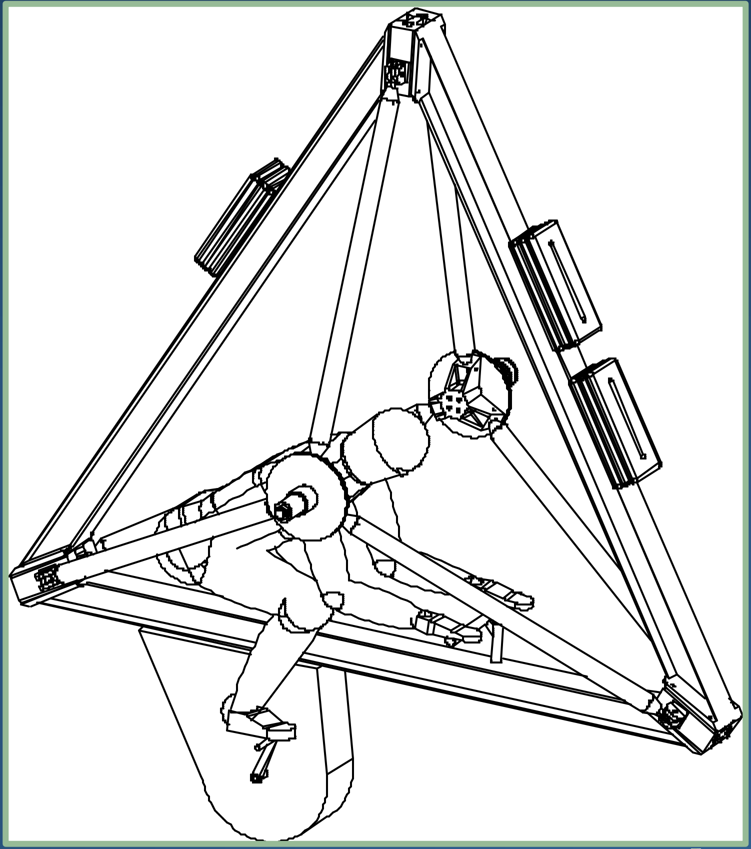
Conceptualization of crew healthcare & exercise facilities



Current Concepts

Artificial Gravity Research Aboard the R2 Mission

The Human Short-Arm Centrifuge for ISS



Flight Experiment Goals

- Develop and flight test a versatile human short-arm centrifuge facility.
- Demonstrate the feasibility of using centripetal acceleration as gravity replacement therapy during space flight.
- Test the hypothesis that AG plus moderate aerobic exercise will maintain aerobic capacity in crewmembers aboard a 16 day space flight mission.

Current Concepts

HEDS Technology Demo Mission

Mission Design Goals

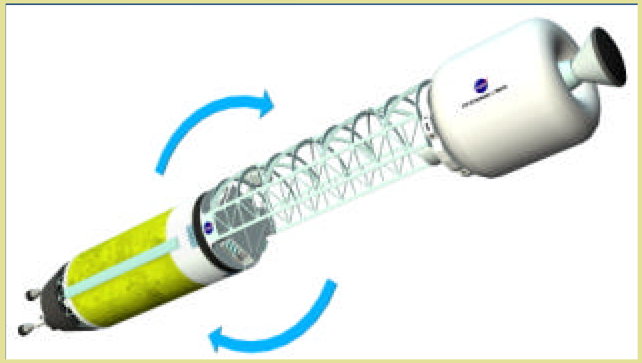
- Impose minimal modifications to the Space Shuttle and ET.
- Launch the facility on a single Shuttle mission, which takes an expended ET into orbit, deploys, inflates, and assembles the habit, attaches it to the ET, and returns to Earth.
- The research crew goes up in a second shuttle, which also carries a crew return vehicle in the payload bay.
- This return vehicle, once attached, allows extended stays at the facility after the shuttle departs. Spin-up then occurs.

As proposed by Tom Sullivan, NASA JSC

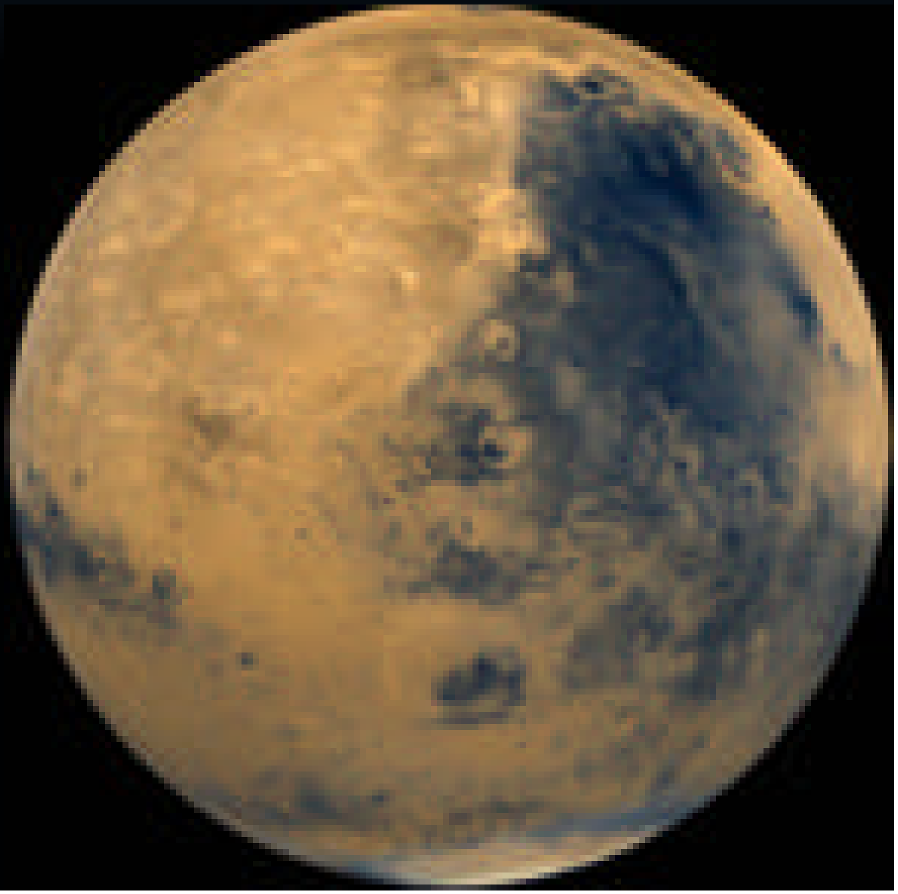
Current Concepts

Nuclear Thermal Propulsion

- Dr. Stanley K. Borowski of the Glenn Research Center has researched the possibility of a “Bimodal” NTR Crew Transfer Vehicle with artificial gravity capabilities for a 2014 piloted mission to Mars.
- CTV rotation (approx. 4-6 rpm) would provide a “variable-g_E” environment.
- Crew members would become adapted to Mars gravity outbound and readapt to near-Earth gravity inbound.



AG Future



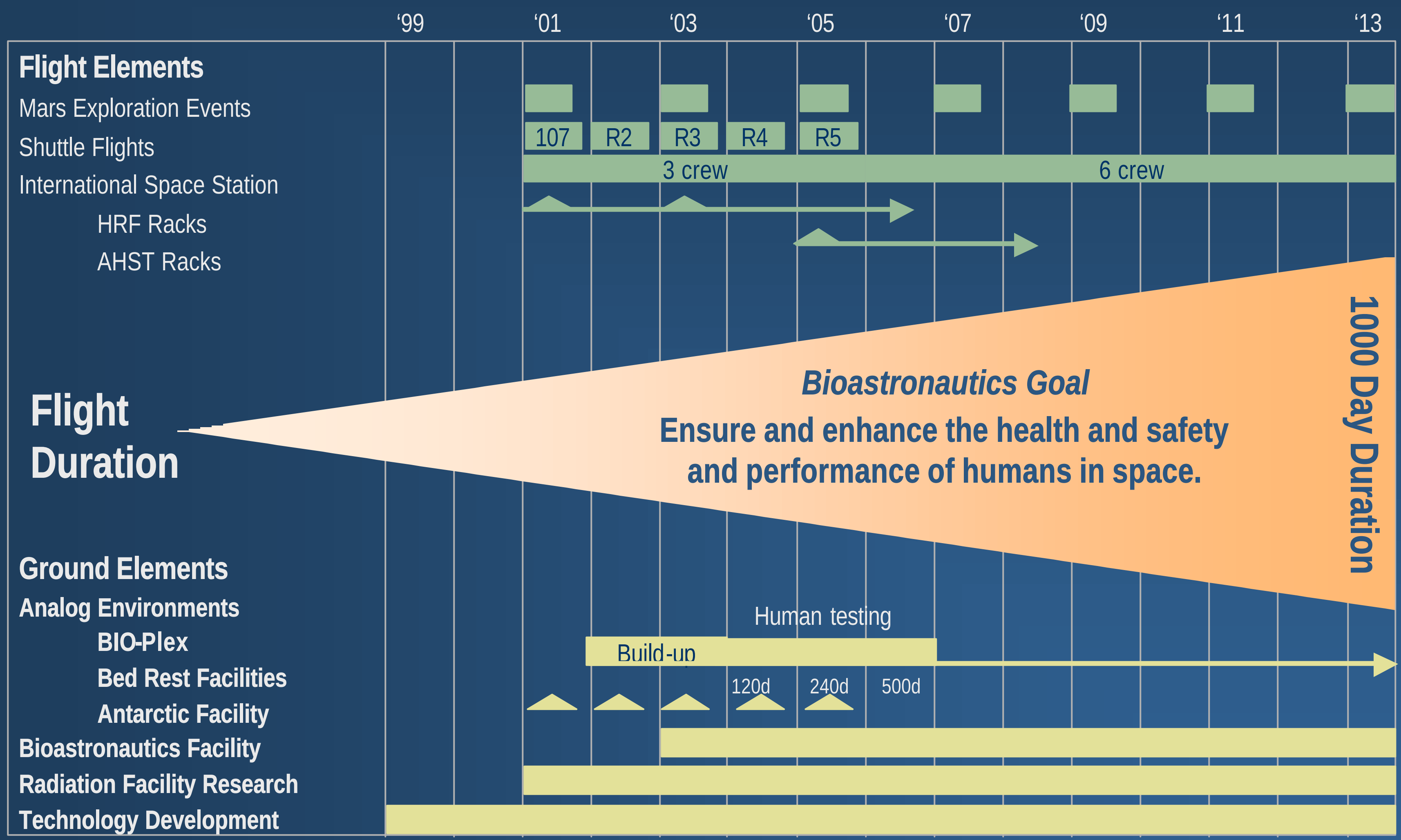
One Caveat:

A human mission to Mars is most often used to exemplify the challenges and parameters of an exploration-class mission; there are alternative and equally viable destinations for exploration.

For the purposes of AG, a human mission to Mars is the representative goal.

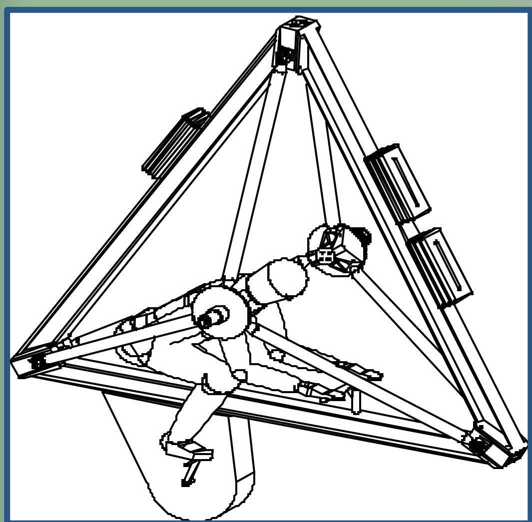
Bioastronautics Initiative

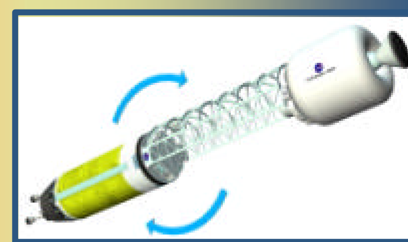
Program Elements Strategic Roadmap



Flight Test Progression

Shuttle/SpaceHab	Station	Station/TransHab	Exploration





1m radius

~4m radius

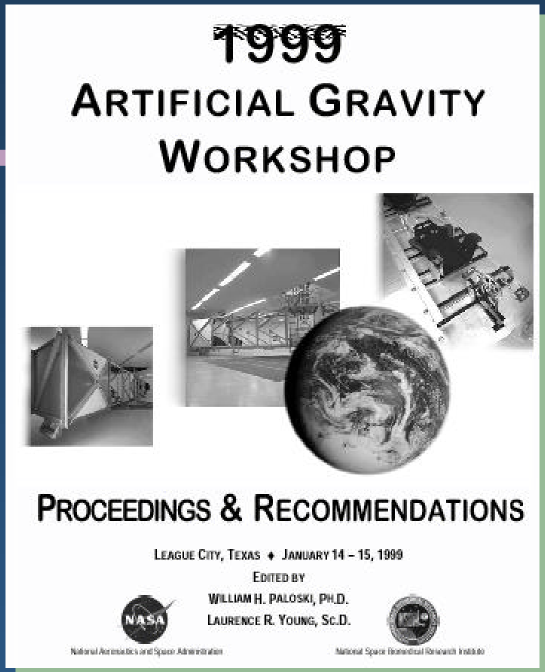
24.5m radius?

'02 '03 '04 '05 '06 '07 '08 '15 '16

1999 Workshop

Workshop Goals

- Debate the merits of pursuing AG as a countermeasure during long-duration spaceflight.
- Develop an AG research and development plan that:
  - articulates a set of long-term, fundamental goals
  - defines near-term objectives, focusing on biomedical research, technology development, and spaceflight mission activities
  - identifies critical roles of current programs and/or facilities in accomplishing these tasks
  - proposes a strategy for implementing research and technology development to enable a go/no-go decision for Mars expeditions by 2005.



1999 Workshop

Fundamental Goals for AG Activities

- Implement a rigorous, coordinated, and peer-reviewed research and development project to investigate rotational AG.
- Determine the optimal design characteristics for an AG countermeasure facility.
- Support the upgrade of existing ground and flight research sites and facilities as needed to perform fundamental research and development activities.
- Promote the participation of and communication among all concerned, including experts from various medical fields, human factors, international space agencies, mission and vehicle design, crew representation and training, and rehabilitation.

1999 Workshop

Critical Questions

- What relationships exist between operational performance and ***continuously*** applied AG (between 0 g and 1 g)?
- What relationships exist between operational performance and ***intermittently*** applied AG?
- What are the acceptable ranges of radius and angular velocity required to maintain operational performance in a rotating spacecraft? What are the optimal ranges for these same parameters?
- What is the human capacity for dual adaptation, and how can the transition process be investigated systematically?
- What are quantifiable standards for operational performance during a mission? What are the limits for degradation of the specific systems during various phases of a mission to Mars?

1999 Workshop

Immediate Objectives

- Establish an AG advisory group.
- Support and guide existing in-flight centrifuge projects.
- Incorporate the following specifications into the design of a long-arm orbital testbed for use on the ISS:
  - the largest possible diameter to yield a minimal rotation rate
  - an adjustable angular velocity that yields between 0 and 3 g
  - the space for two or more crewmembers to maneuver easily
- Identify potential opportunities for deploying a short-arm human centrifuge aboard the Space Shuttle.
- Implement a peer-review process and/or guidelines for "parametric" research and development activities.

[1] Note that concerns were raised regarding our ability to extrapolate from animal models to humans. While animal experiments should be considered, caution must be exercised in this regard.

1999 Workshop

Near-Term Objectives

- Begin funding of ground-based research activities solicited in the initial call for proposals.
- Establish a joint NASA/NIH research initiative to investigate the use of centrifuge devices in treating clinical populations (e.g., osteoporotic patients). Solicit research proposals against these objectives.
- Evaluate the degree to which critical AG questions can be addressed using the ISS animal centrifuge.
- Modify and/or expand the planned program to include specific objectives and then solicit research proposals.
- Begin AG studies on the Space Shuttle using the human-powered centrifuge.
- Provide recommendations/requirements to Mars vehicle designers.

1999 Workshop

Far-Term Objectives

- Solicit, develop, and perform centrifuge studies with animal and human subjects, both on the ground and in flight.
- Discontinue Shuttle short-arm centrifuge experiments as ISS venues become available.
- Answer critical questions to make a go/no-go decision for a 2014 Mars mission.
- Focus funding on AG countermeasure development activities, as warranted by research findings.

Sustaining Objectives

- Provide funding for the upgrade and support of key ground-based AG facilities.
- Strive for a peer-reviewed research program that balances basic and applied research.

1999 Workshop

Conclusions

- Rotational AG as a multi-system countermeasure and may be most effective if combined with existing countermeasures.
- NASA Headquarters should commit now to a rigorous, peer-reviewed research program.
- The capacity to transition between different g environments will be a critical factor in developing an AG countermeasure.
- AG research should not preclude research or development of other countermeasure concepts.
- Theoretical and animal models cannot substitute for systematic studies of the human response to AG.
- Standards for operational performance during spaceflight should be established.

1999 Workshop

Recommendations

The participants of the 1999 AG Workshop conclude that NASA Headquarters should commit now to a rigorous, peer-reviewed research program that will systematically investigate rotational AG as a multidisciplinary countermeasure during long-duration, exploration-class missions.

Resources

Humans in Space

1999 AG Workshop: Proceedings and Recommendations

1999 Minutes: Ad Hoc AG Discussion Group

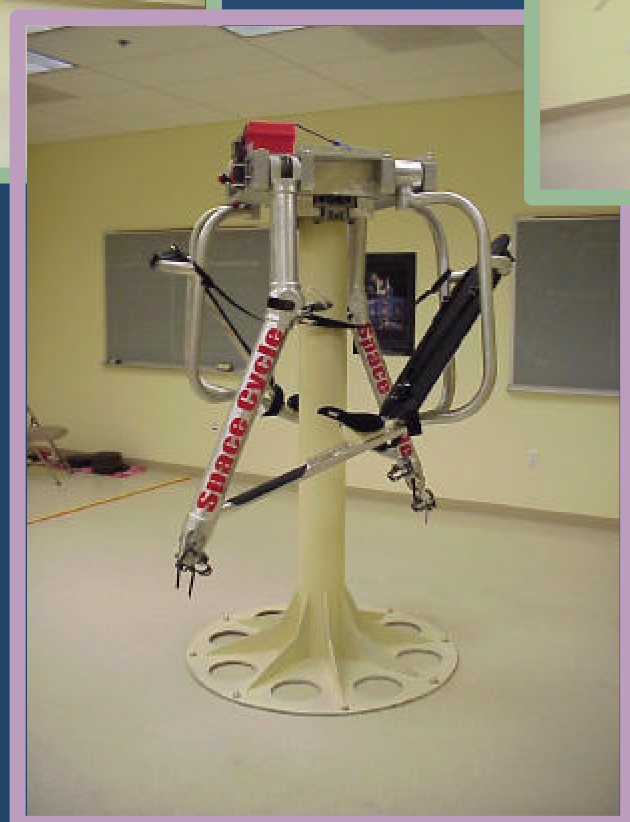
2000 Meeting Report: R2 Mission

AG and HEDS Technology Demo Mission

“Bimodal” Nuclear Thermal Rocket Architecture

Backup

SpaceCycle



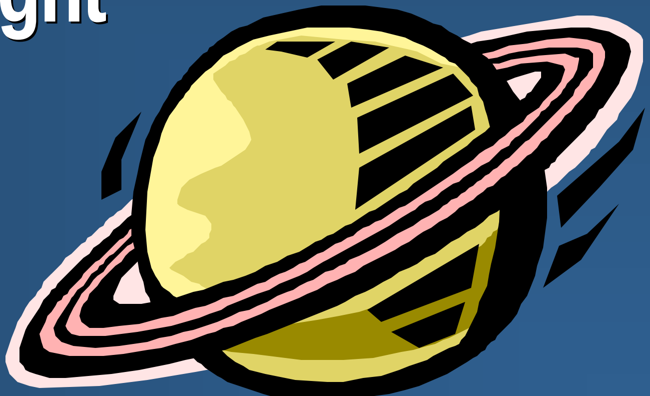
ARTIFICIAL GRAVITY

Recent Findings Using the MIT Short-Radius Centrifuge

Principal Investigator:	Laurence R. Young, ScD
Post-doc:	Heiko Hecht, PhD
Graduate Assistants:	Kathleen Sienko Lisette Lyne Carol Cheung
Visiting Student:	Jessica Kavelaars

Motivation: Why Artificial Gravity?

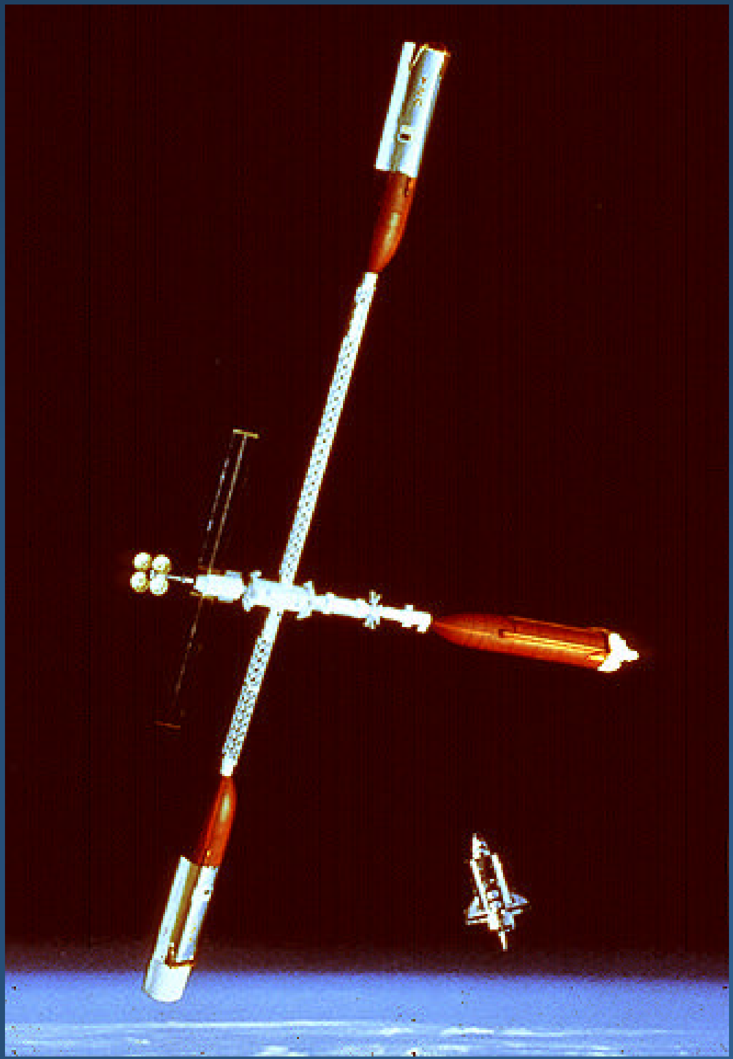
Current countermeasures are not sufficient to prevent the detrimental physiological effects of long-duration space flight



Types of Artificial Gravity

Continuous
vs.
Intermittent

Large-Radius
vs.
Short-Radius



http://permanent.com/sp-etsta.html

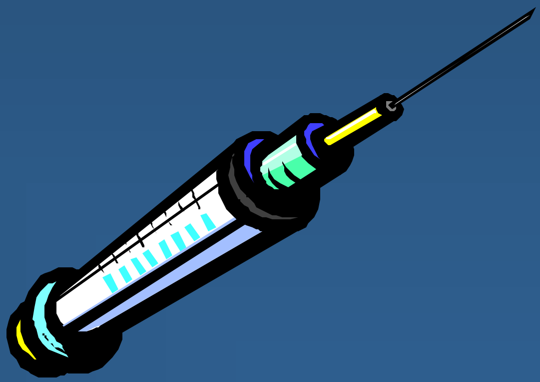
The Potential New R_x

Intermittent Short-Radius Centrifugation

“Spin in the Gym”

“Prescribed AG Dosage”

“AG Sleeper”



Intermittent Short-Radius Centrifugation

Benefits

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

Intermittent Short-Radius Centrifugation

Concerns

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**

Major Features of Rotating Environment

Artificial Gravity Level (Centripetal Accel.)

$\underline{r}\omega^2$

Coriolis Forces

$-2\mathbf{m}(\underline{\omega} \times \underline{v})$

Gravity Gradients

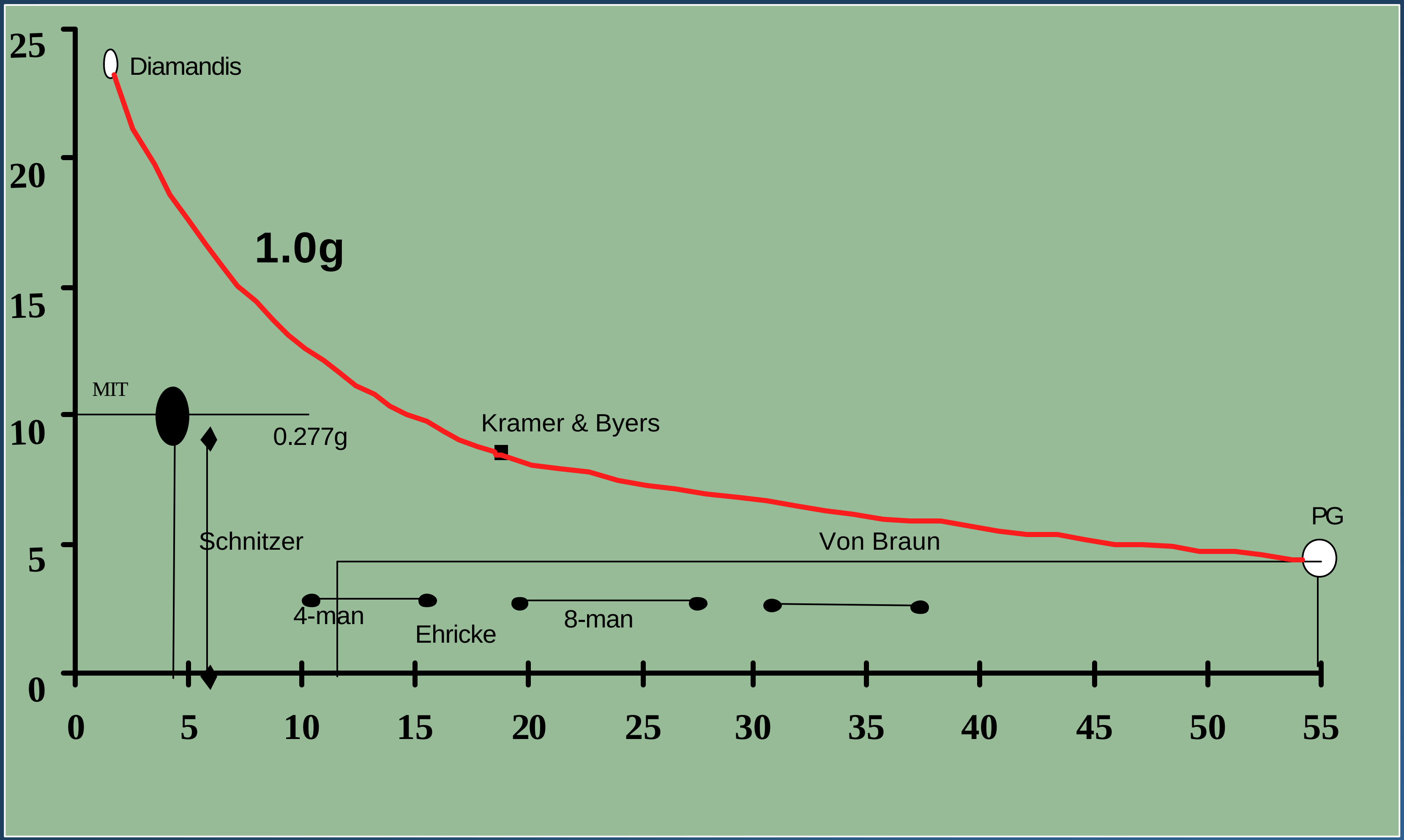
$h/\underline{r}$

Cross-coupled Angular Accelerations

$\omega_{SRC} \times \omega_{Head}$

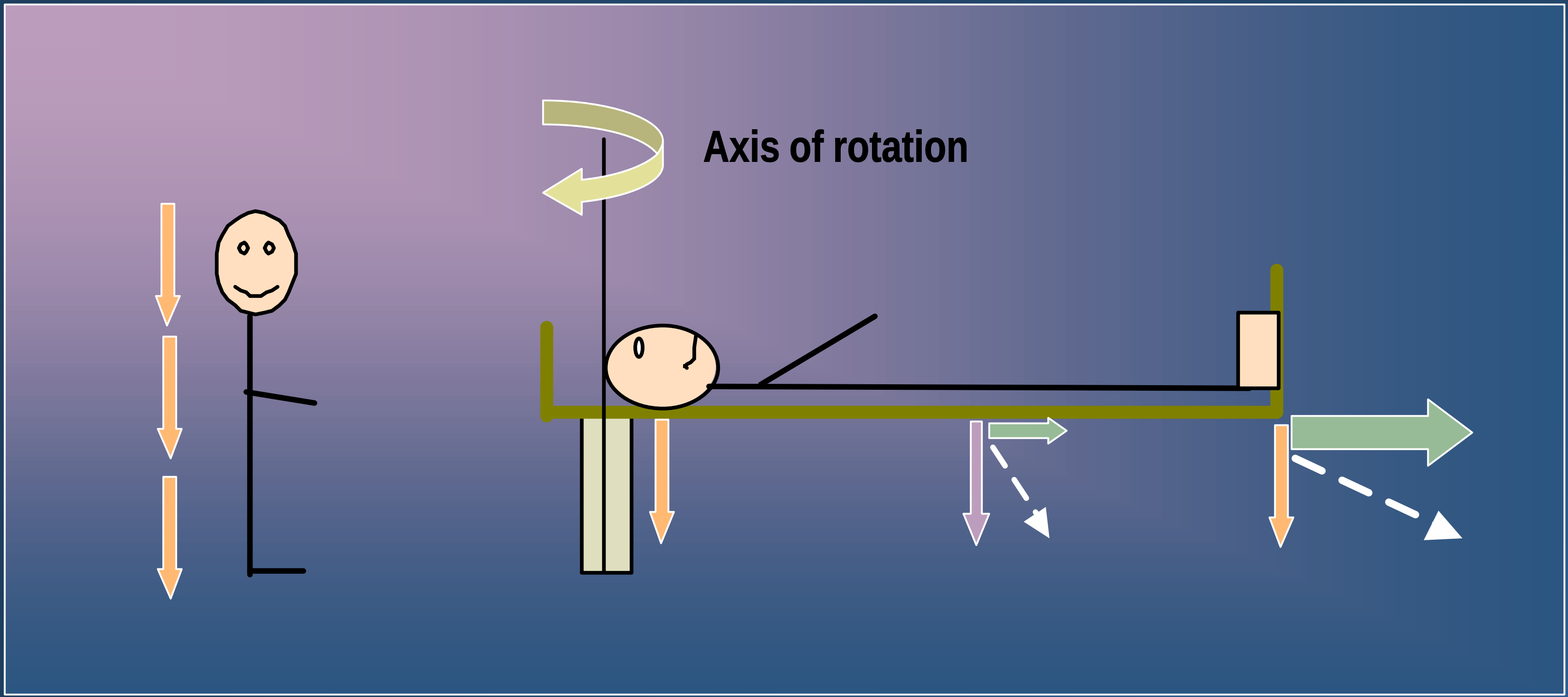
Artificial Gravity Level Tradeoff

30

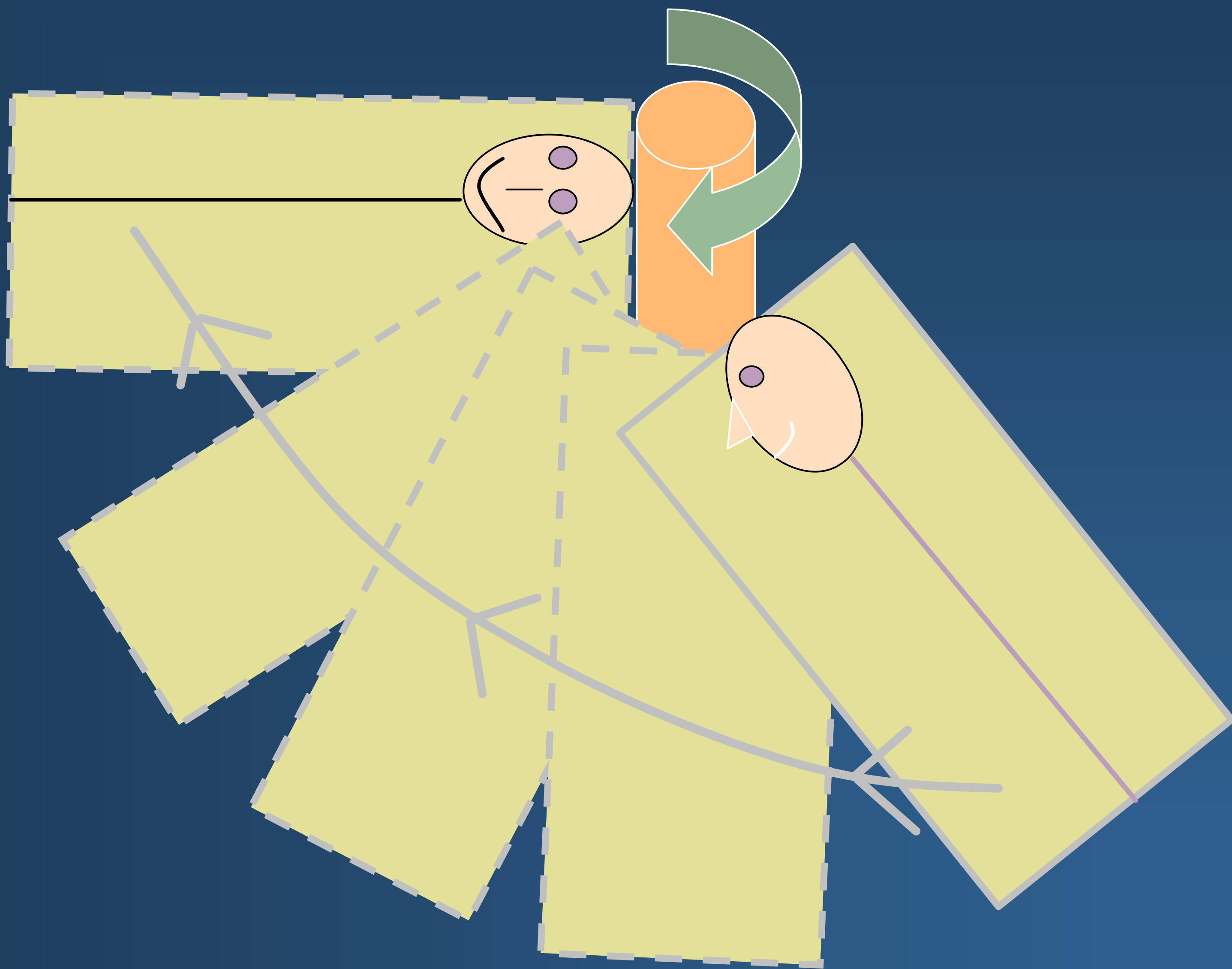


Forces Experienced During Centrifugation

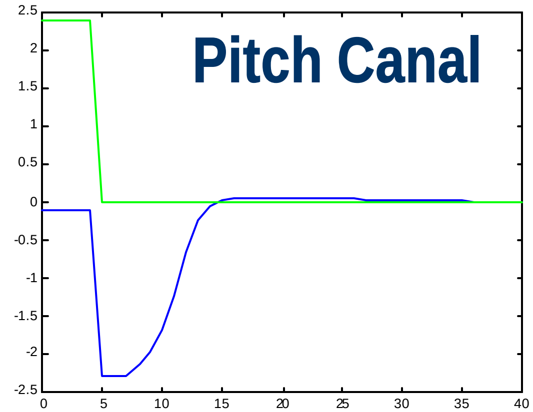
Gravito-inertial force upright and on a centrifuge

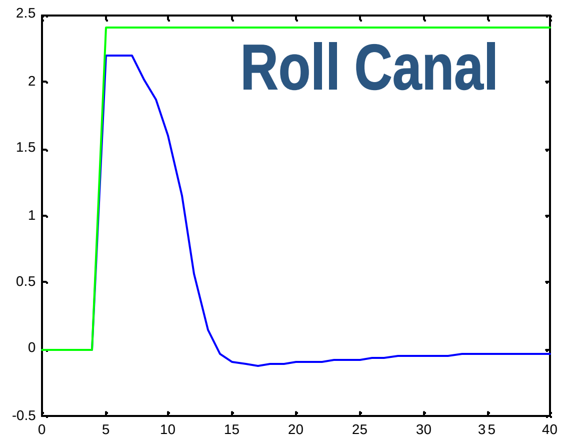


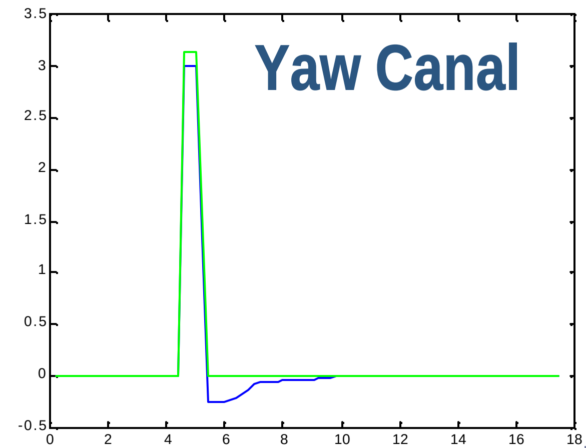
Stimulus



Semicircular Canal: *Cupula Dynamics*



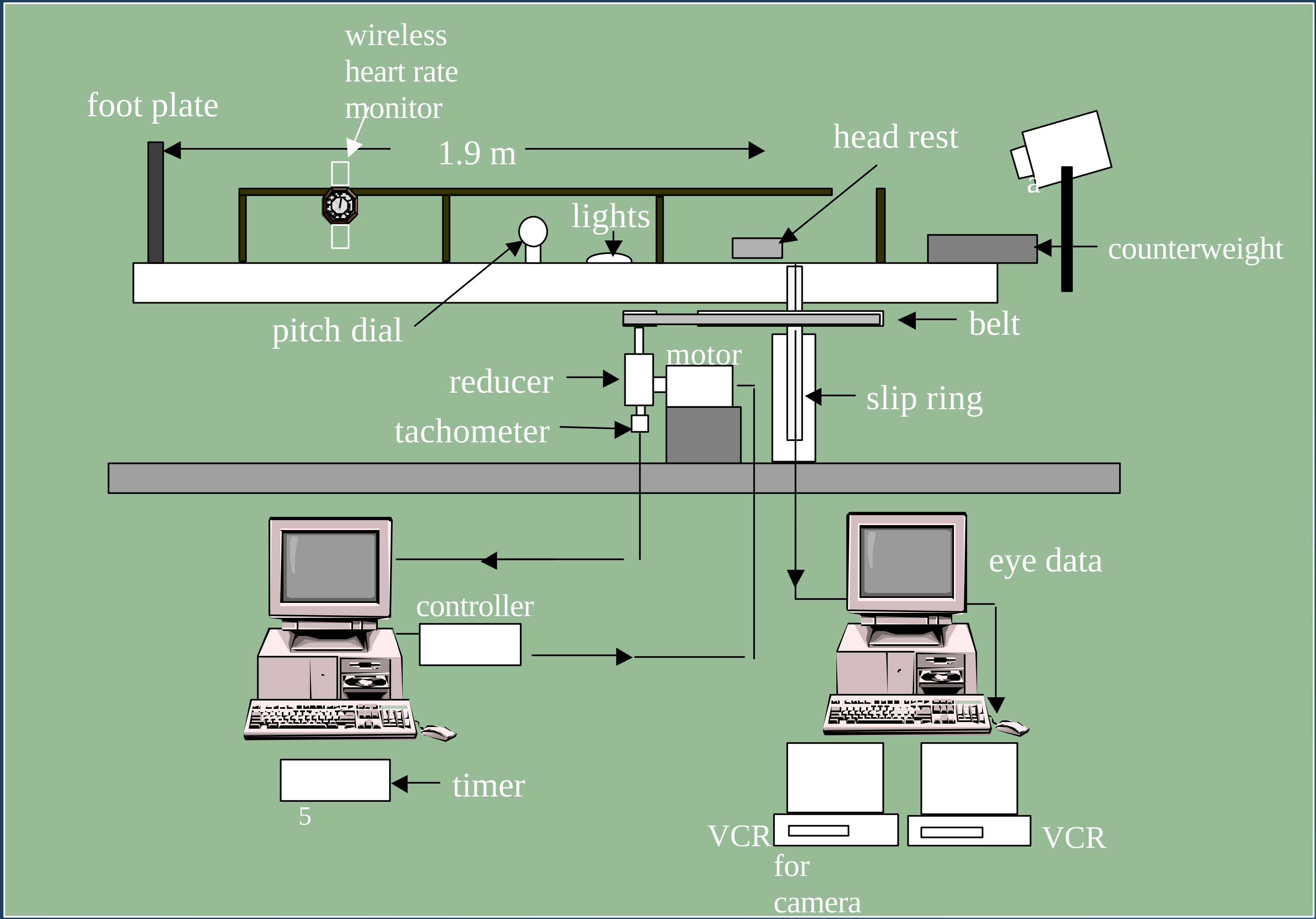




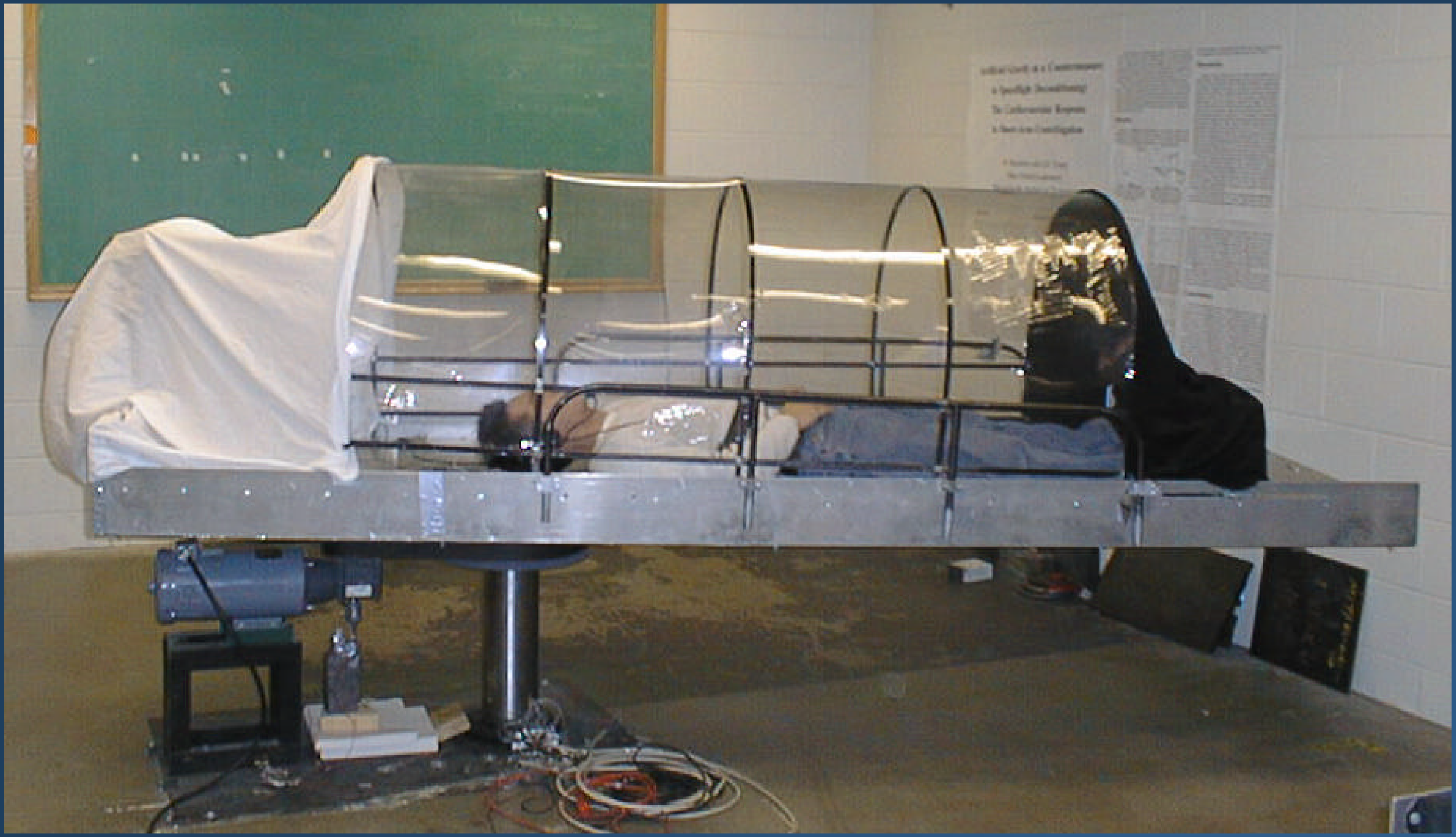
Response of the **cupula** 90 degree yaw **head turn** on a 23 rpm centrifuge from the “right ear down” to “nose up” position

Based on Young-Oman Laplace transfer function model

Schematic of MVL Short-Radius Centrifuge



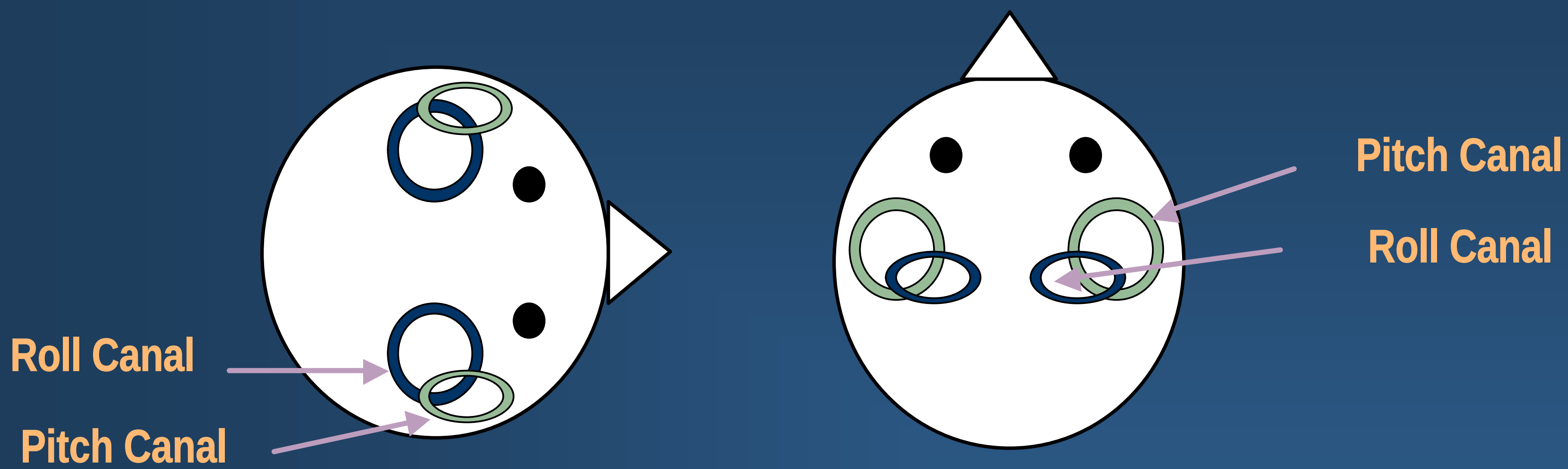
MIT Short-Radius Centrifuge



- 2 meter radius platform
- Variable rotation rate
- 100 % gravity gradient along longitudinal body axis

MIT Movie Clip

Equivalent Canals



Right Ear Down Position (RED)

Nose Up Position (NU)

Problems Before Adaptation

What are the side-effects of head movements during rotation?

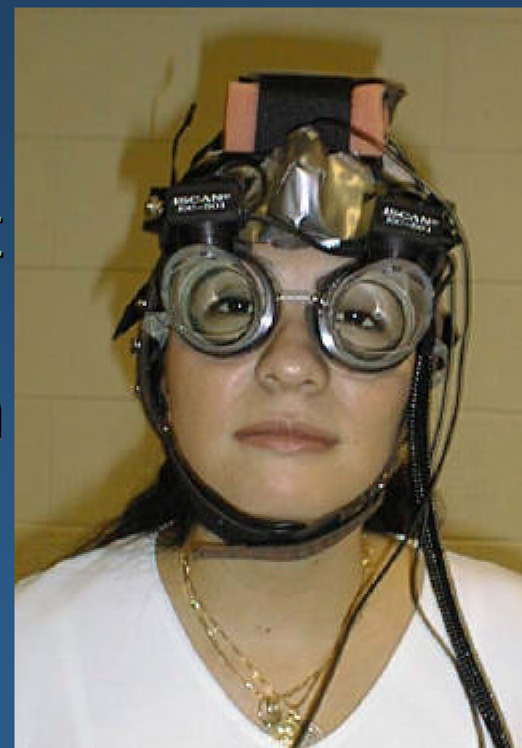
–Inappropriate eye responses
–Motion sickness
–Illusory tilt

To What Extent Does Adaptation Occur?

- Which measures adapt?
- Are subjective measures correlated with physiological measures?
- Is adaptation retained over several days?

Equipment

- MVL short-radius centrifuge
- ISCAN infrared eye position monitor
- WATSON Angular rate sensors to detect head movements
- Verbal Reports/Survey to monitor motion sickness
- Pitch Dial to indicate degree of subjective tilt
- Acumen wireless heart rate monitor



Experiment 1

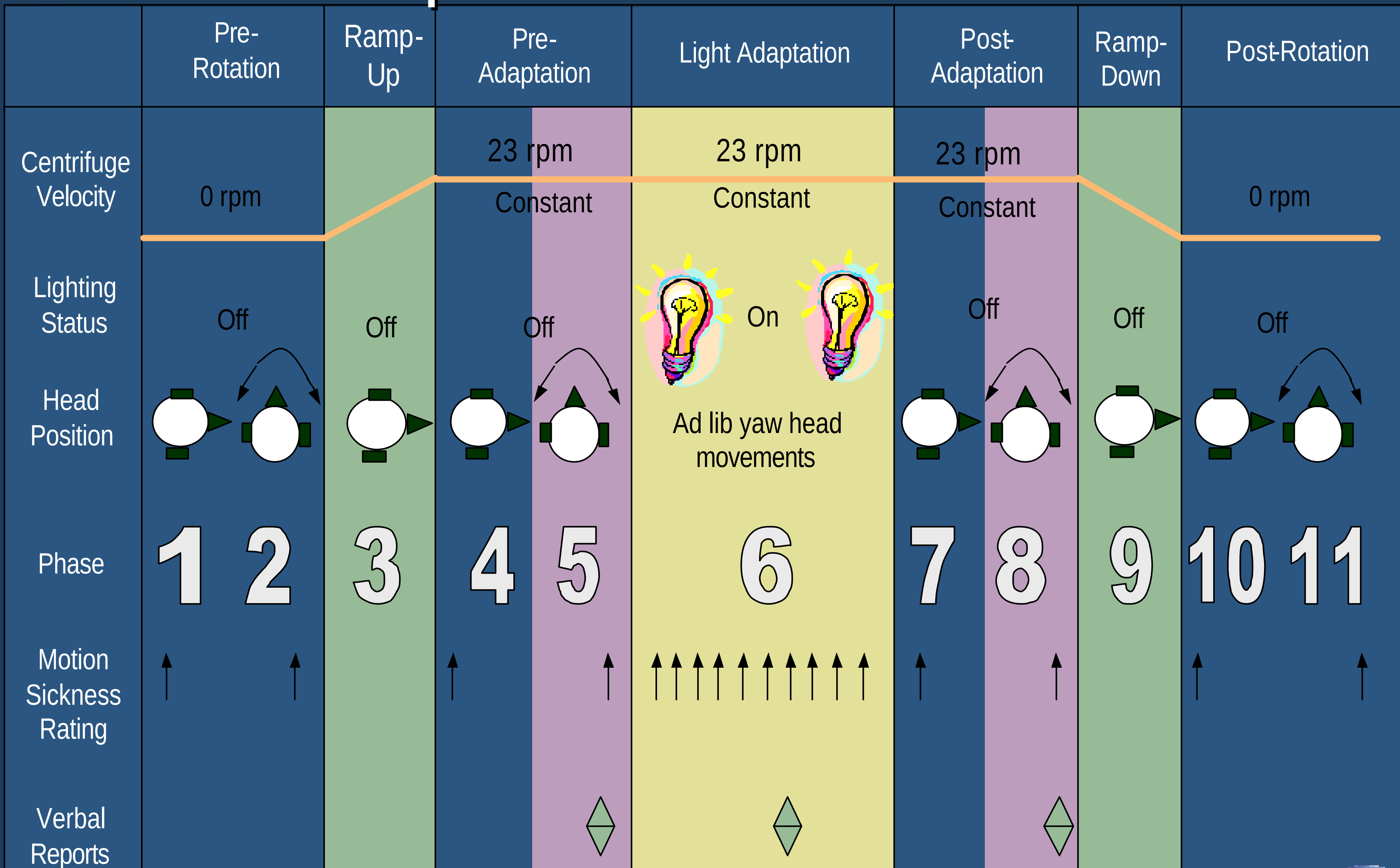
Adaptation of the **Vestibulo-Ocular Reflex** and **Subjective Sensations** to Yaw Head Movements During Centrifugation at 23 rpm

Hypothesis

Inappropriate vertical nystagmus will be reduced following adapting head movements.

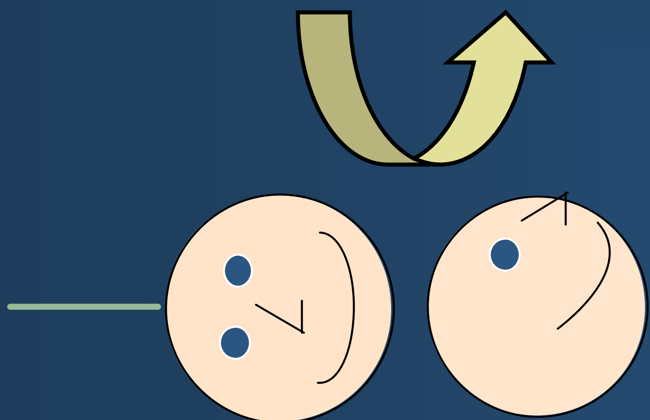
Pitch illusions, heart rate, and motion sickness will also be adapted.

Experimental Protocol

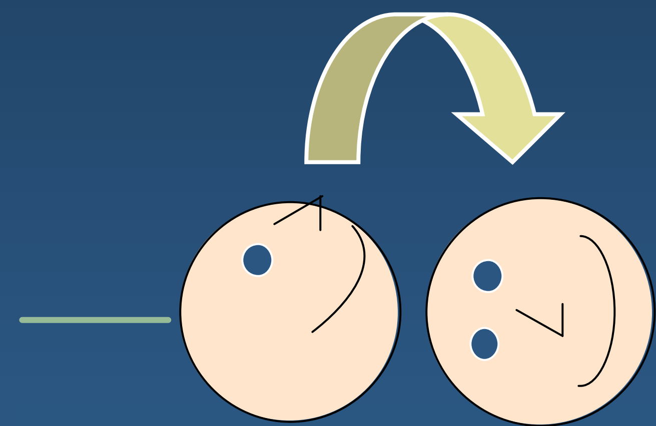


Eight subjects were tested on Days 1, 2, and 8

Yaw Head Movement



20 second hold in "nose-up" position



"right ear down" → "nose-up"

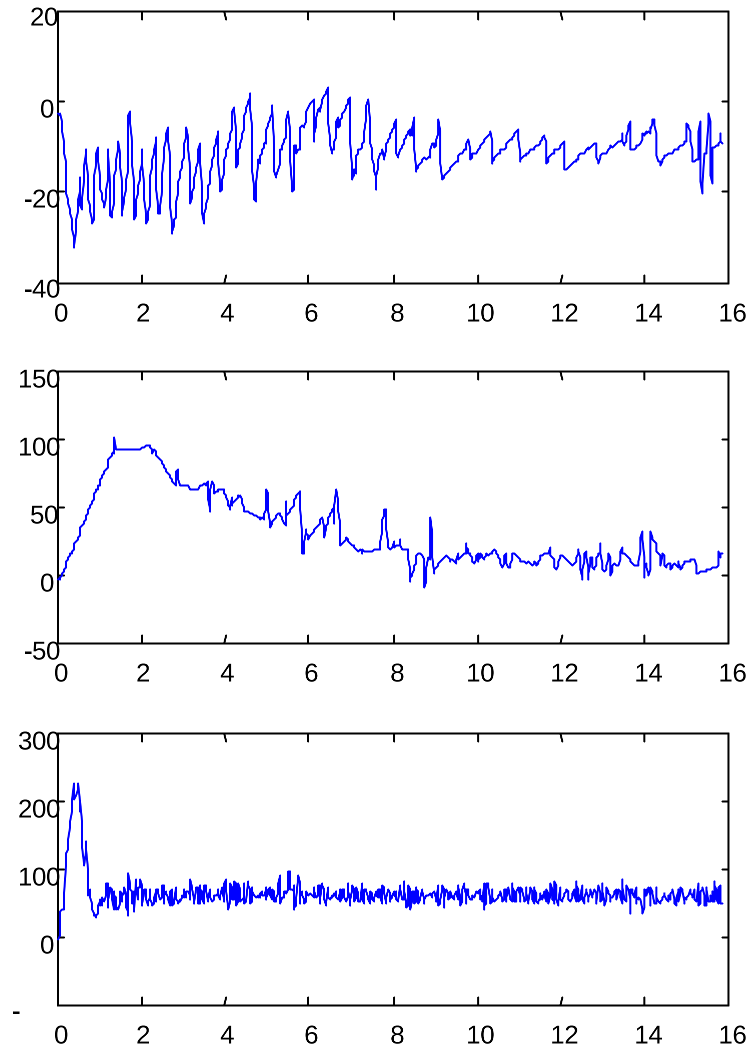
"nose-up" → "right ear down"

Exemplar Recording of Vertical Eye Response to Yaw Head Movement

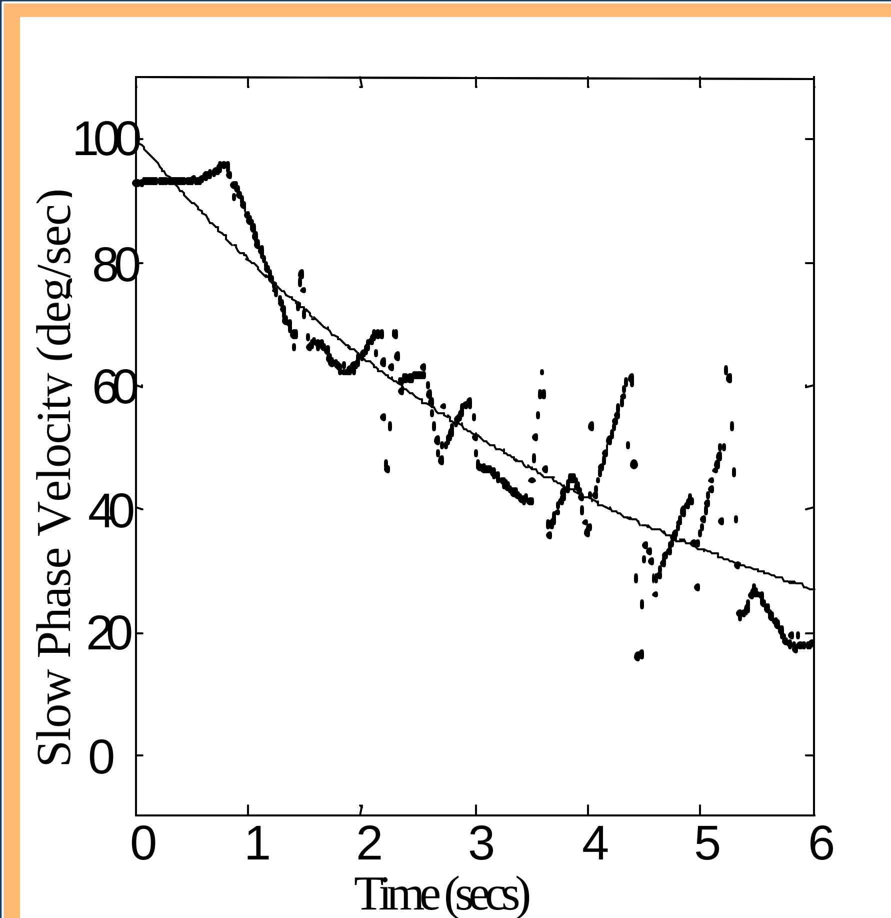
Raw Vertical Eye Position (degrees)

Slow Phase Velocity (degrees/sec)

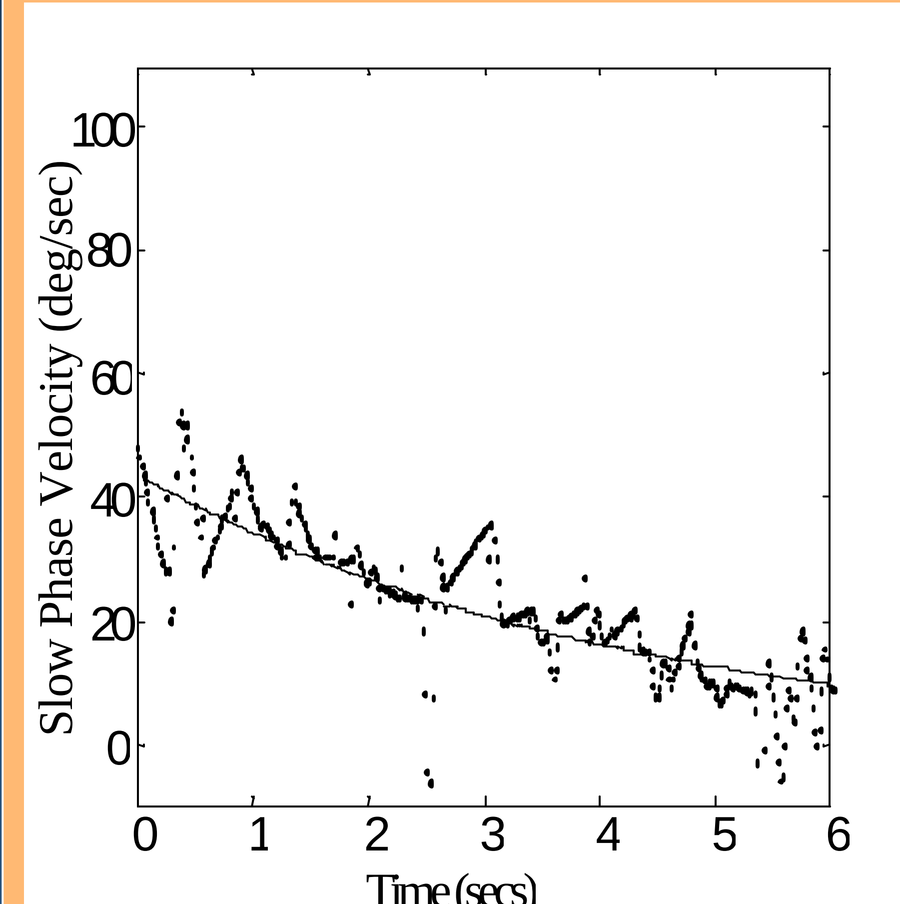
Head Movement (degrees/sec)



Slow Phase Velocities (n=1)



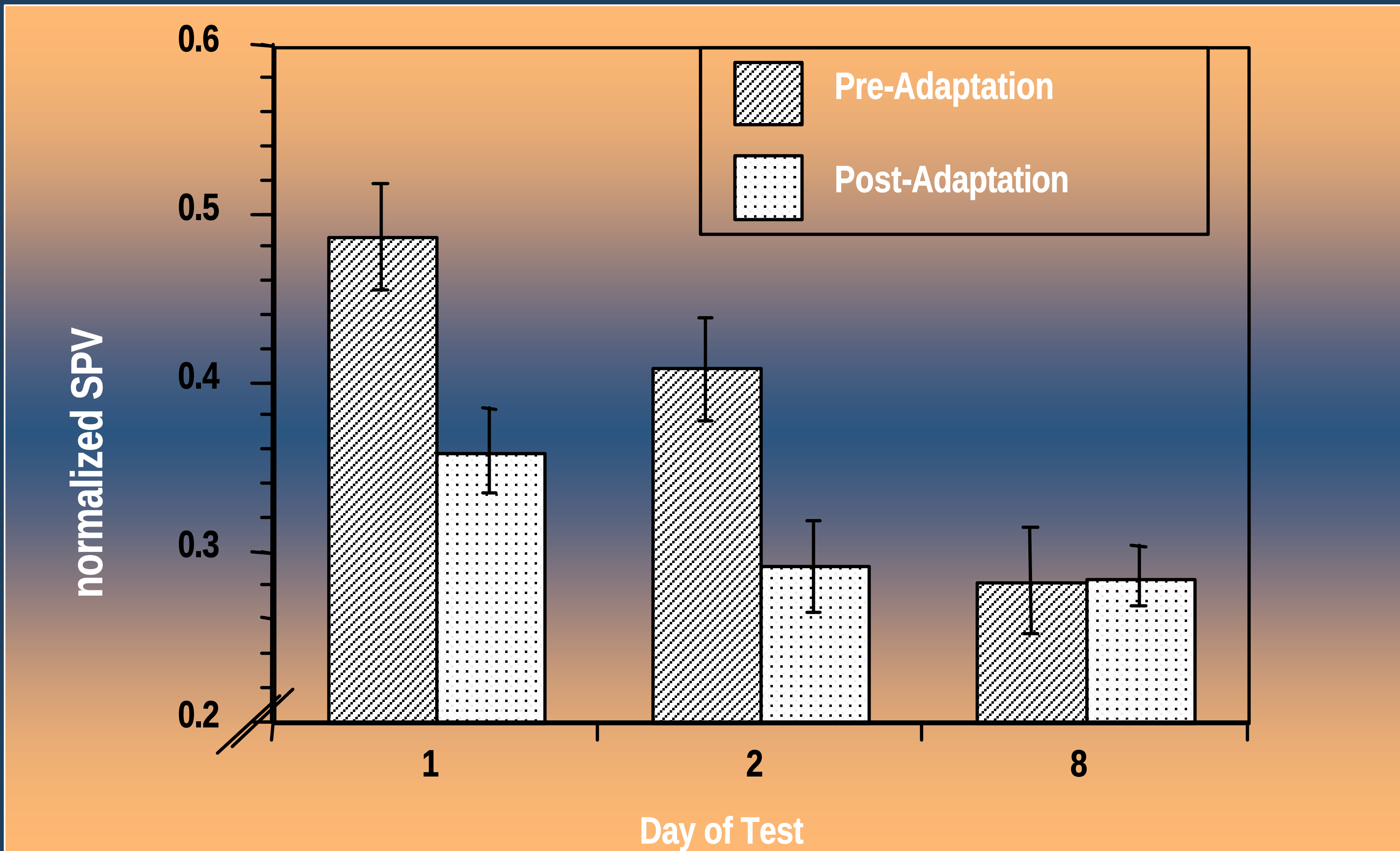
Day 1 Rotating Pre-Adaptation



Day 8 Rotating Post-Adaptation

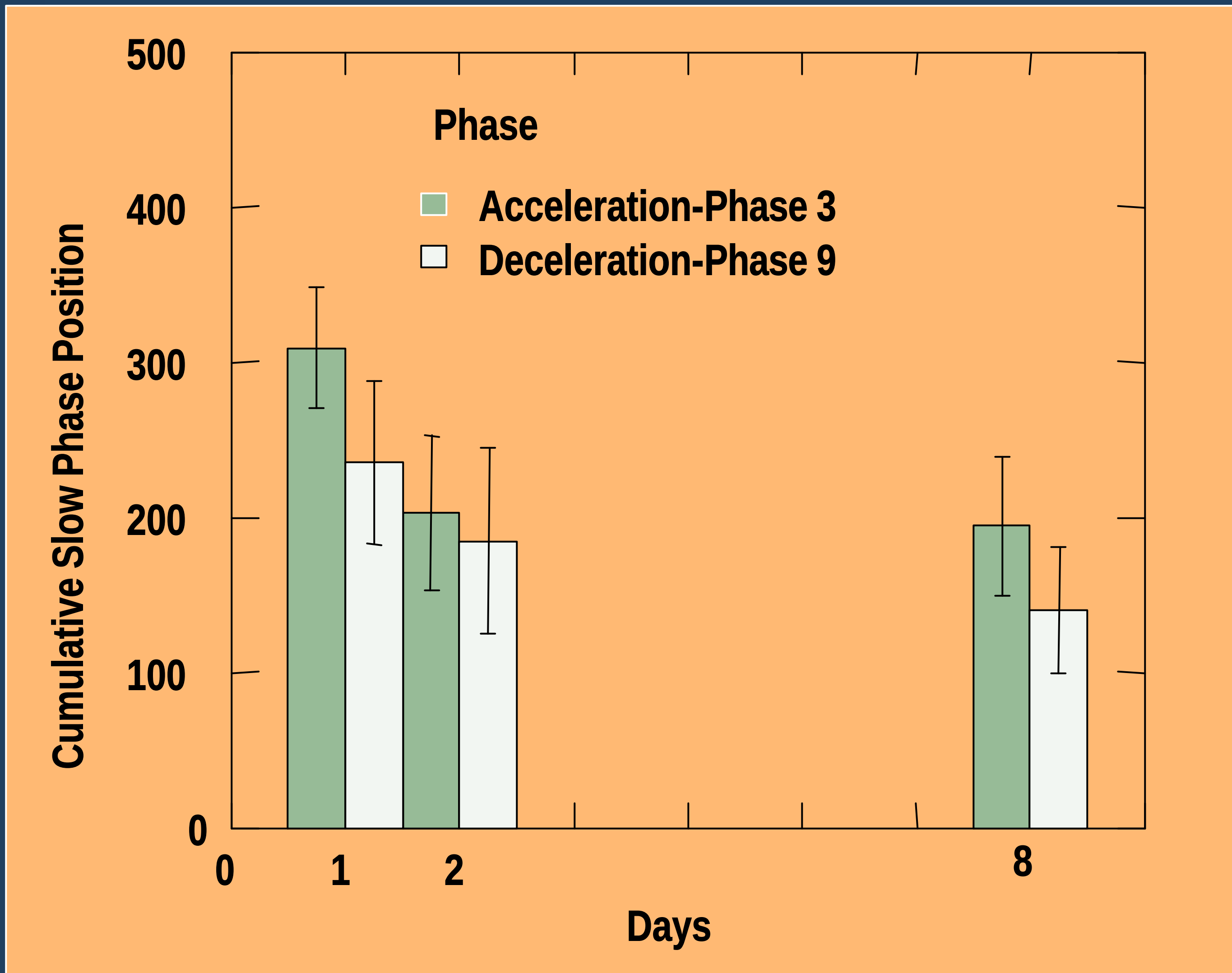
Vertical eye response to yaw head movement from "right ear down" to "nose-up," 2nd repetition

Normalized Slow Phase Velocity (n=8)

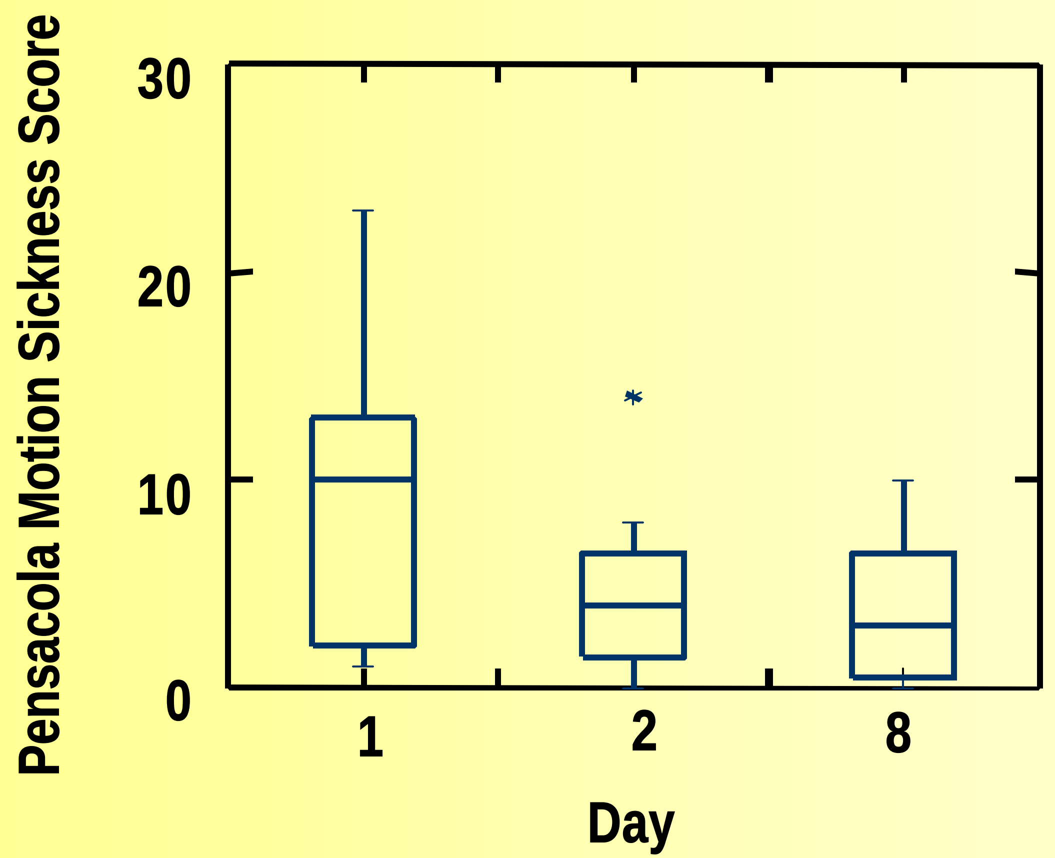


Normalized slow-phase velocities measured before and after 10-min adaptation period in the light. The values reflect averages of the second and third set of head movements

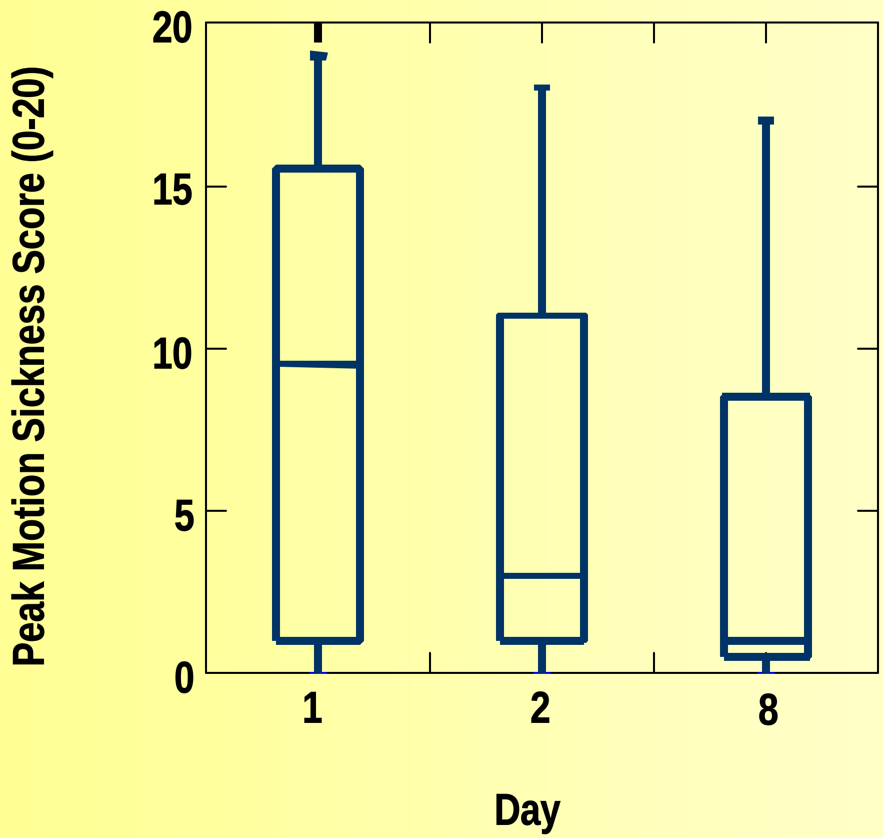
Cumulative Slow Phase Position During Acceleration/Deceleration



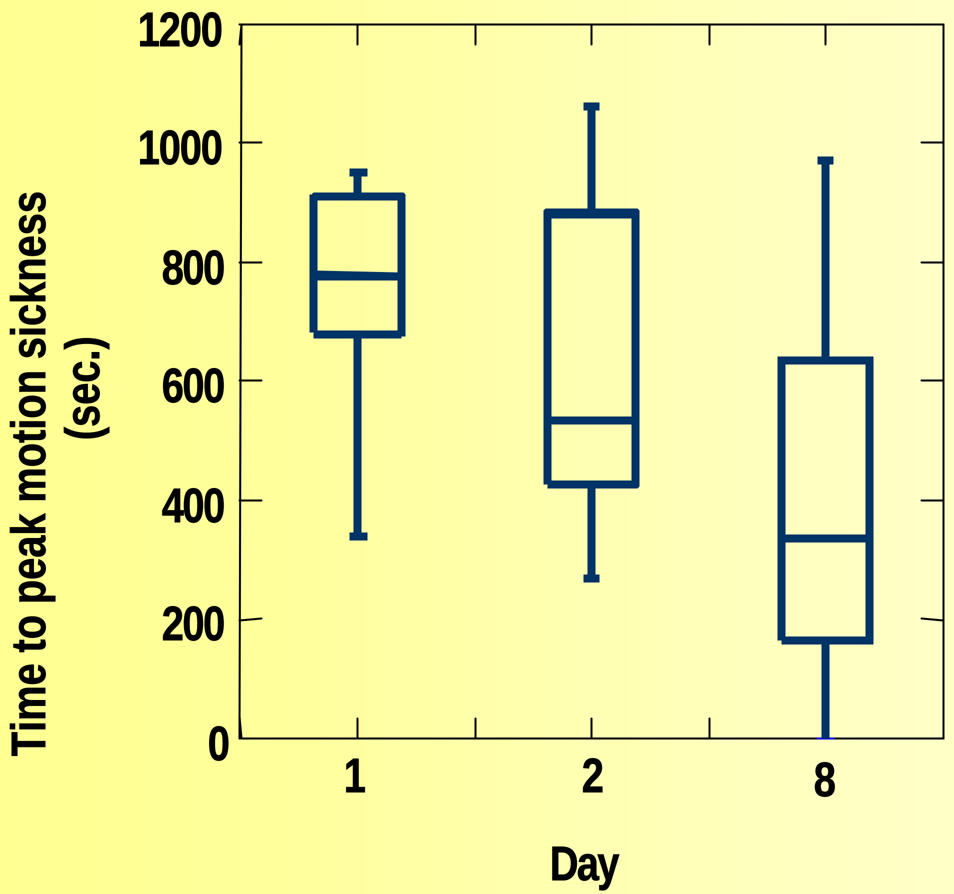
Pensacola Motion Sickness Scores (n=8)



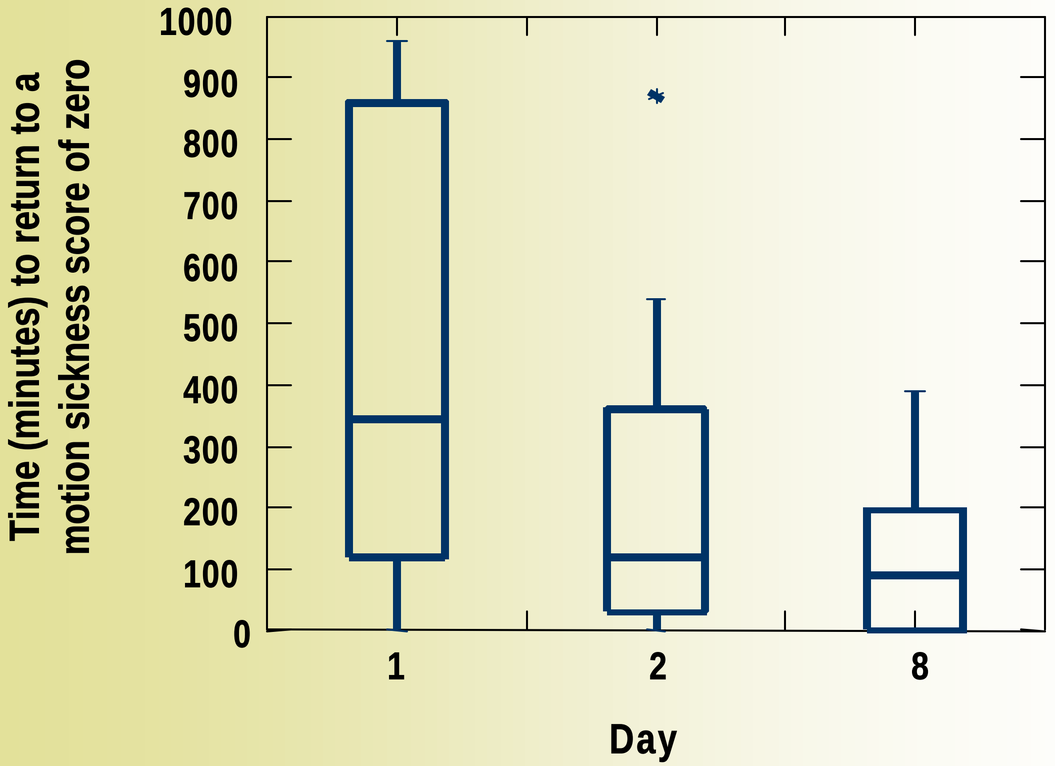
Peak Motion Sickness Score (n=6)



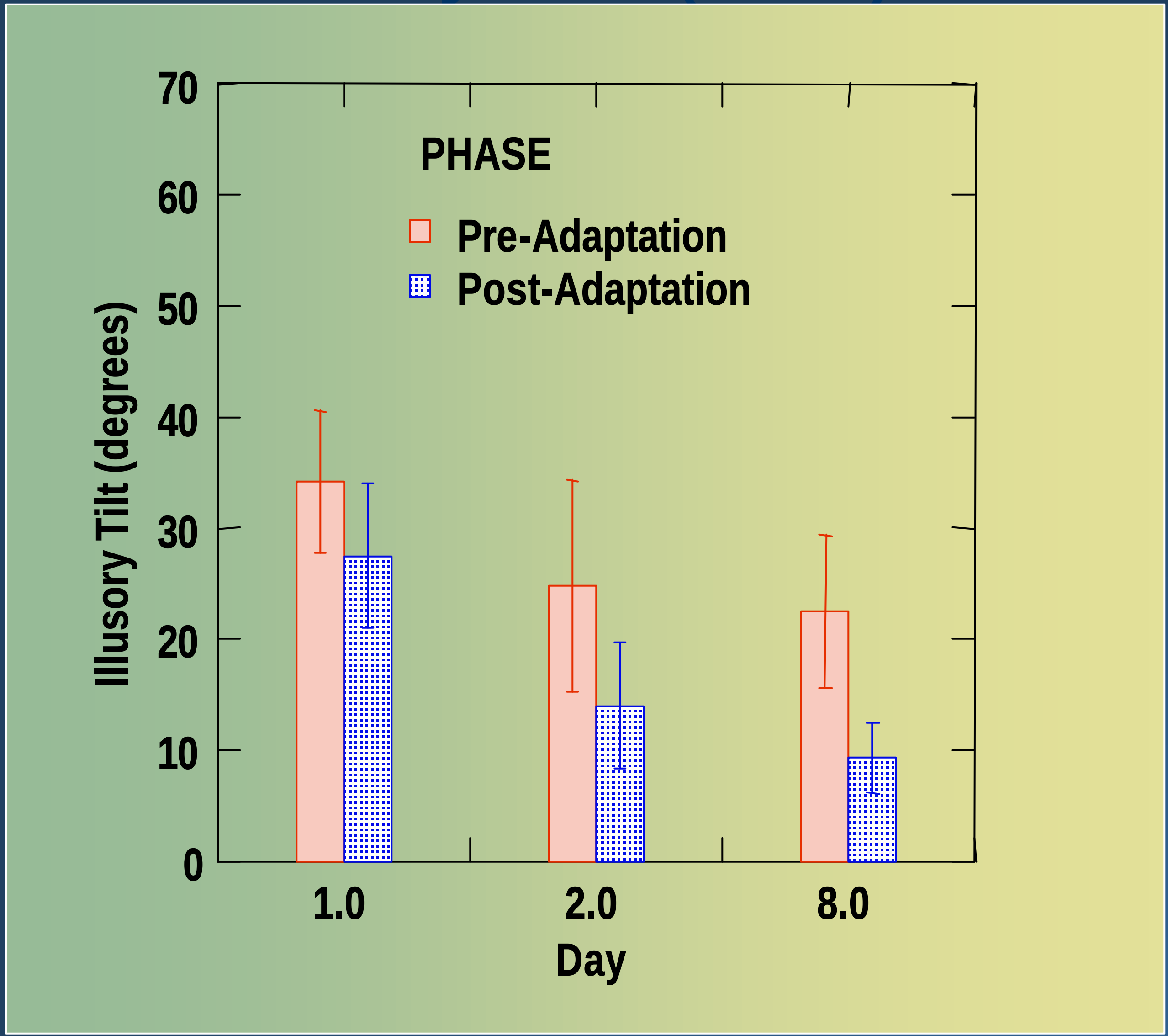
Time to Reach Peak Motion Sickness (n=6)



Motion Sickness Recovery Times (n=8)



Illusory Tilt (n=6)



Results

Decrease in **inappropriate nystagmus**

Decrease in **motion sickness**

Decrease in **subjective body tilt**

Decrease in **heart rate variability**

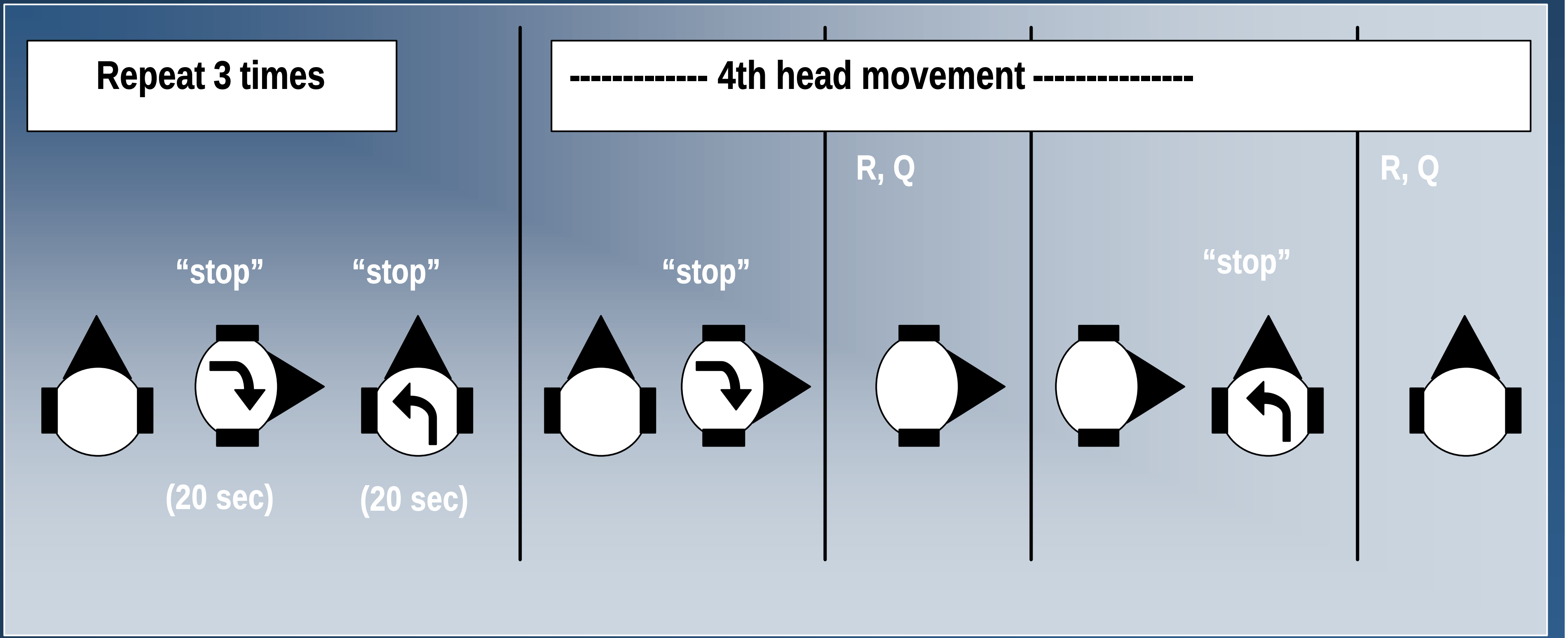
- **Adaptation occurred**
- **Adaptation was maintained**

But after three sessions of centrifugation, it was by no means complete

Experiment 2

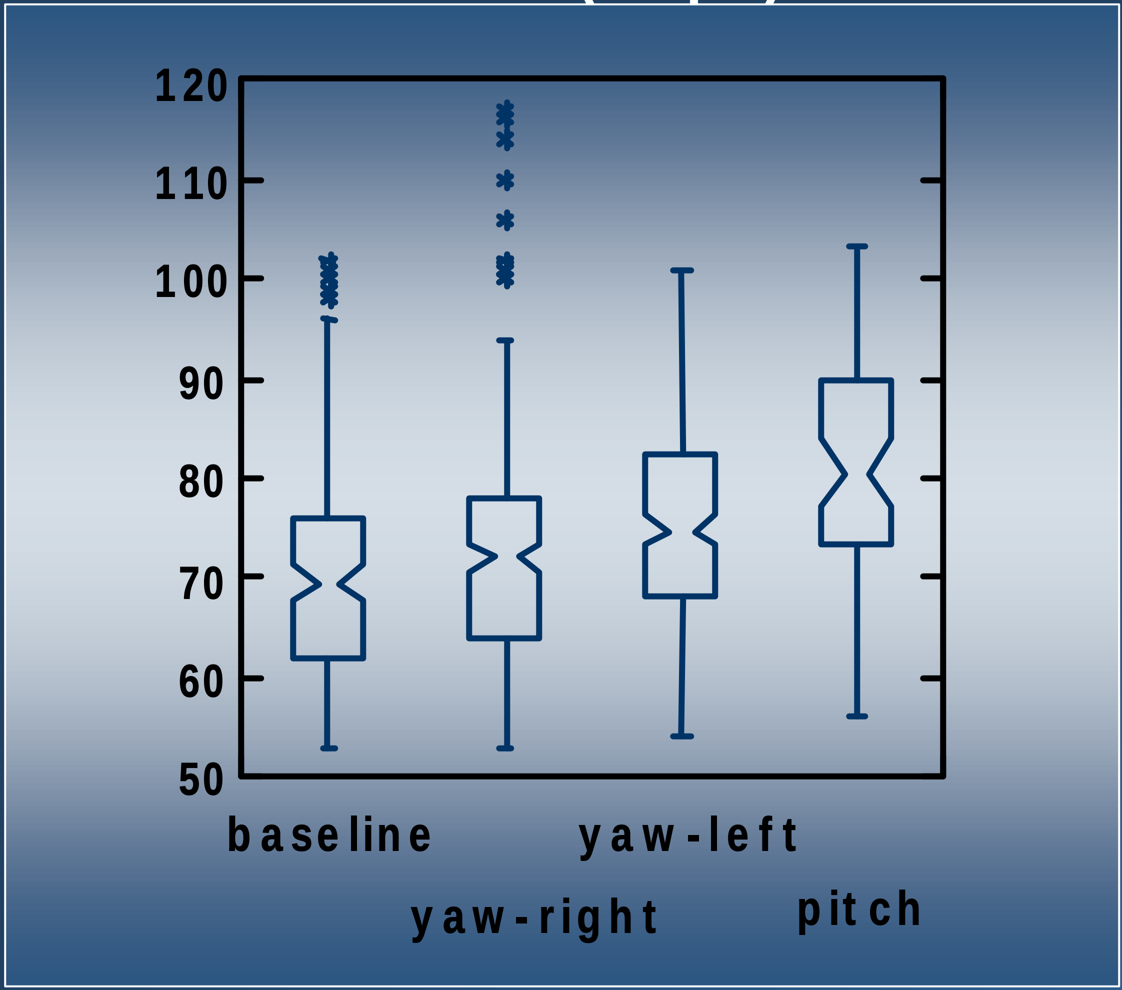
Further examination of illusory tilt, its direction and persistence, and heart rate

Experimental Protocol



Heart Rate during Head Turns

Heart Rate (in bpm)



Type of Head Movement

Predicted and experienced motions (Yaw head-turns)

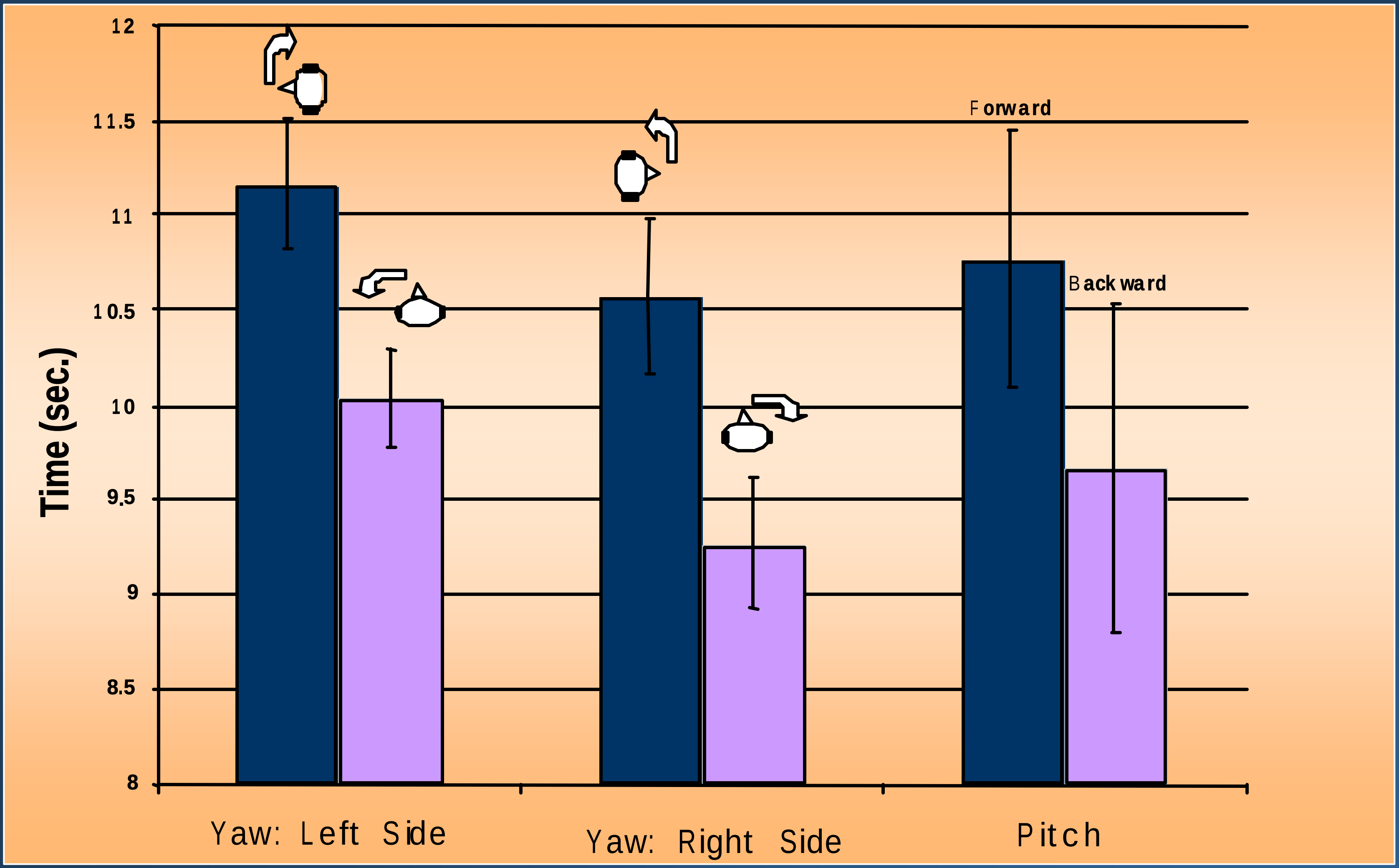
Motion	Predicted	Opposite	Not Predicted
Pitch	76 %	13%	11%
Roll	60%	13%	27%
Yaw	0%	0%	11%

Predicted and experienced motions (Pitch head-turns)

Motion	Predicted	Opposite	Not Predicted
Pitch	0%	0%	40% *
Roll	53%	0%	47%
Yaw	43%	7%	50%

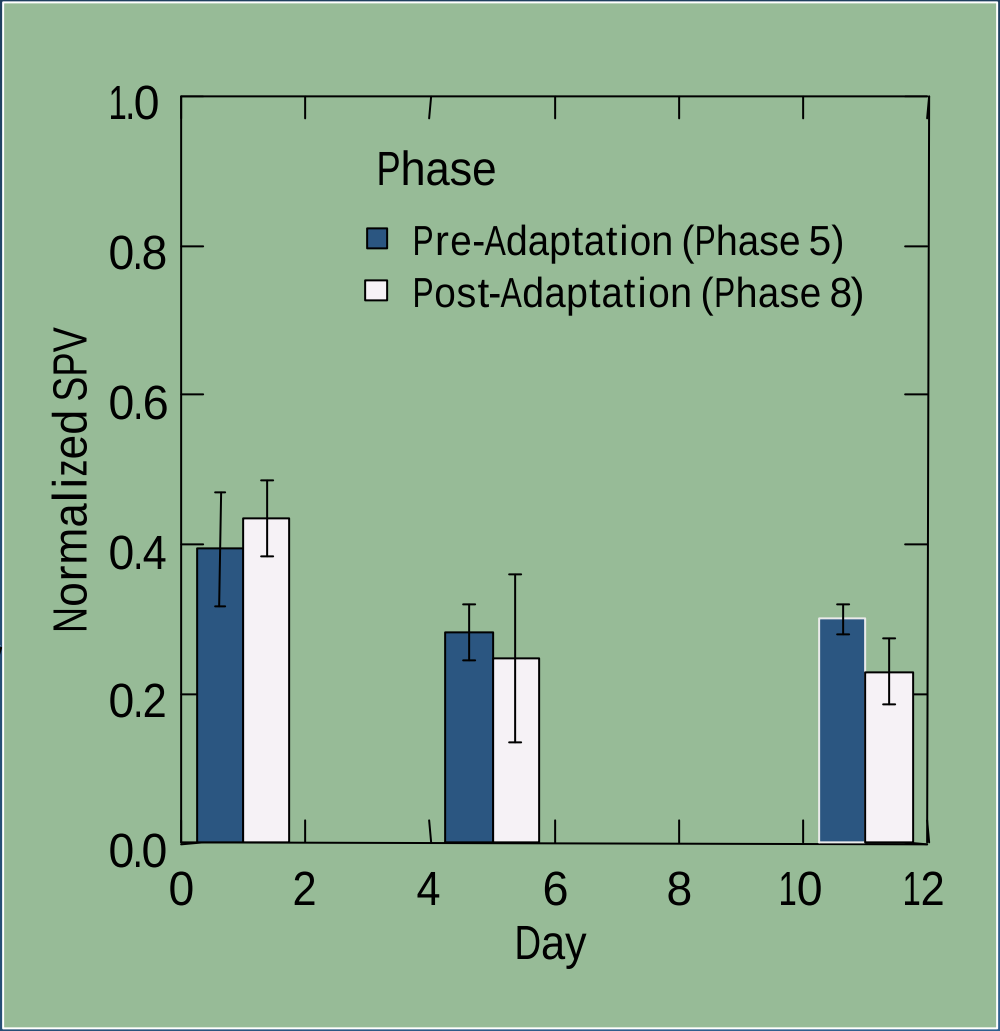
* same direction as pitch head movement

Persistence of Illusory Tilt



Pilot Study

- **One subject exposed for 12 consecutive days….**
- **Vertical eye responses did not decrease significantly more than *n=8* results**
- **Motion sickness symptoms were negligible by Day 12**
- **Illusory tilt was negligible by Day 12**



Conclusions

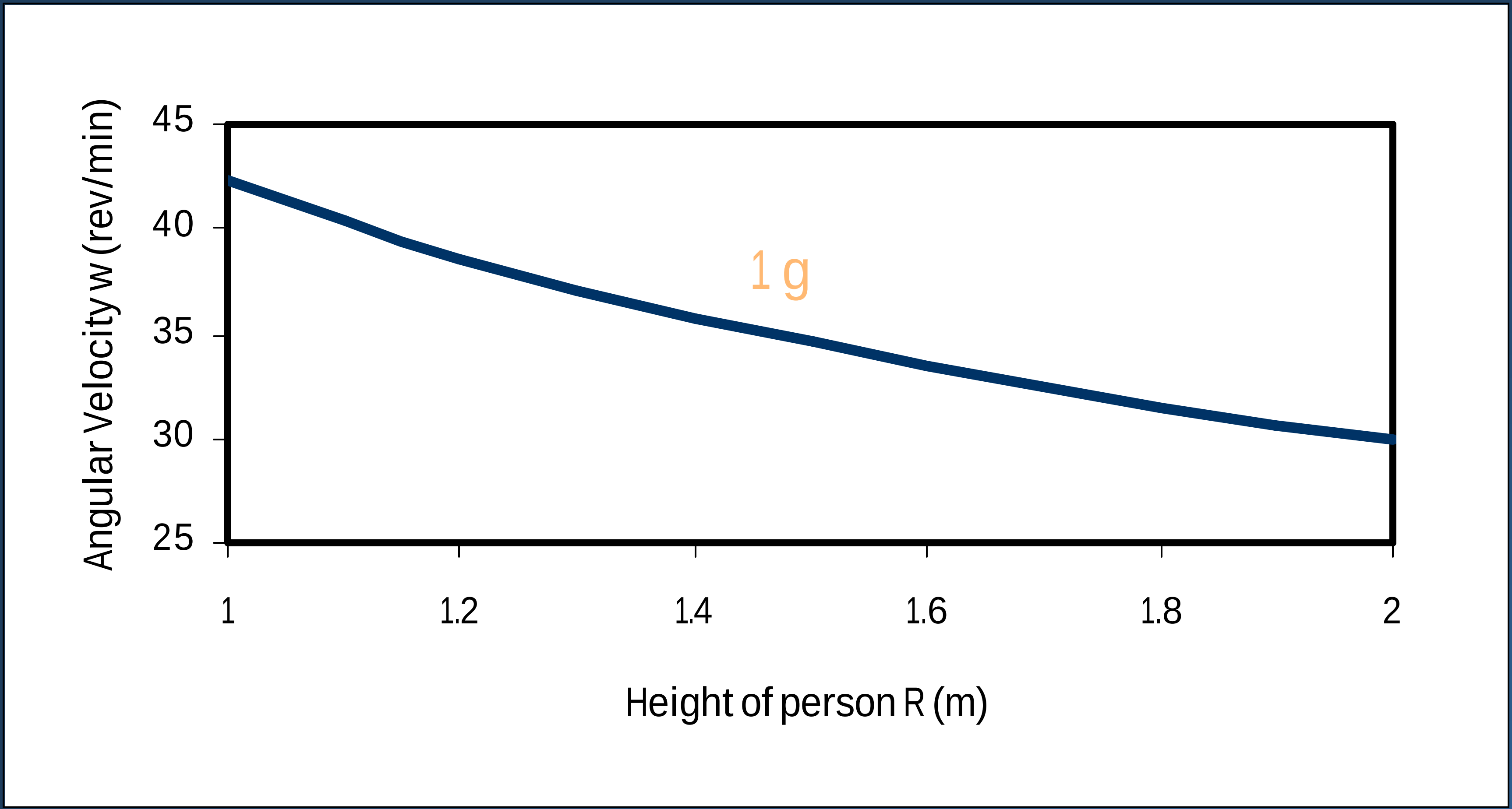
At 23 rpm:

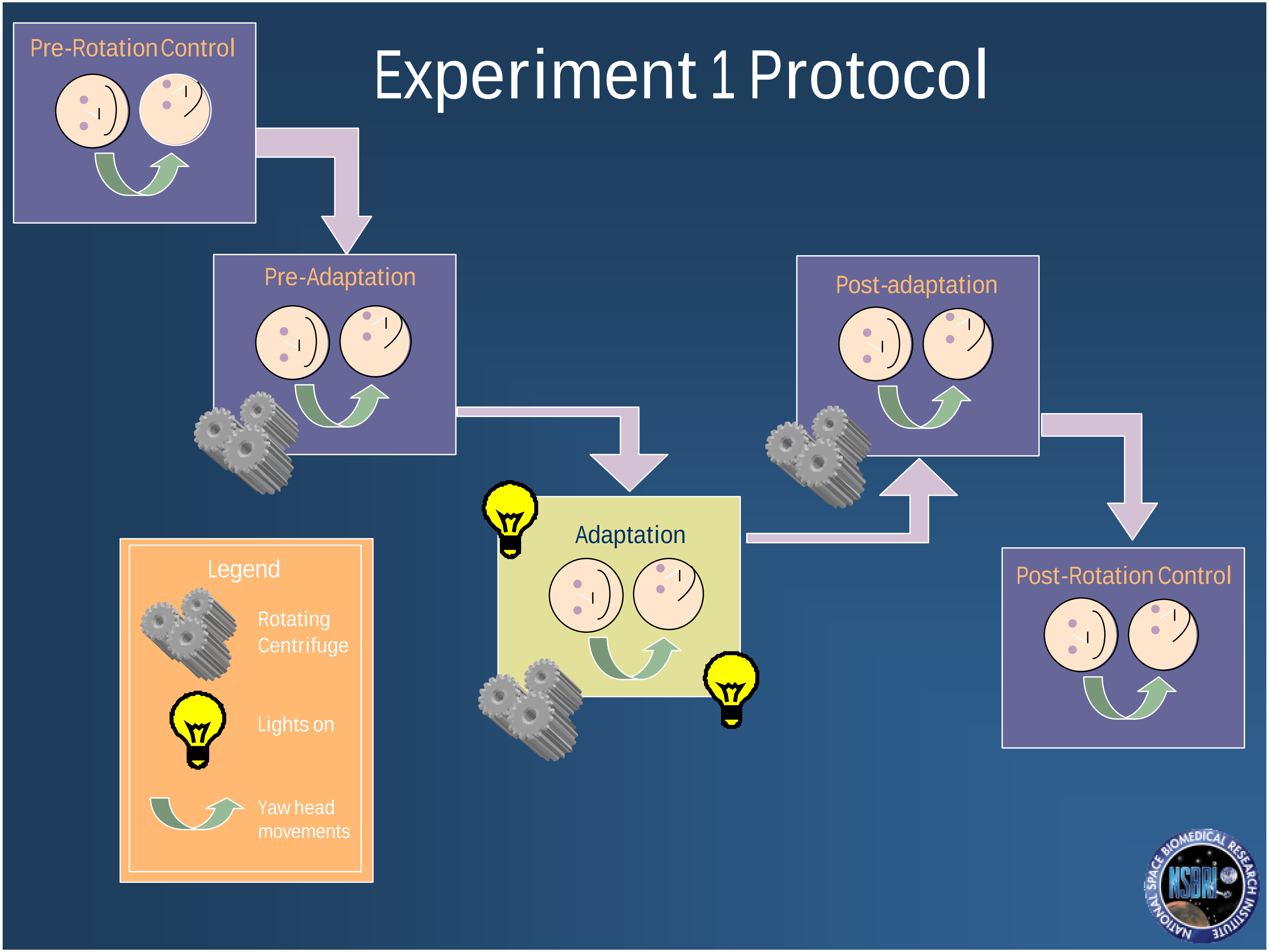
- Head movements during short-radius centrifugation have disturbing side-effects, not all of which can be predicted by a semicircular canal model
- All side effects are subject to partial adaptation
- Generalization of adaptation to different head-movements and to different rotating environments remain to be investigated

Acknowledgements

This work was jointly supported by the National Space Biomedical Research Institute through a cooperative agreement with the National Aeronautics and Space Administration (NCC 9-58)

1-g Level (at feet) for Short-Radius Centrifuge: Angular Velocity vs. Subject Height




Experiment 1 Protocol
Pre-Rotation Control
Pre-Adaptation
Adaptation
Post-adaptation
Post-Rotation Control
Legend
Rotating Centrifuge
Lights on
Yaw head movements
NATIONAL SPACE BIOMEDICAL RESEARCH INSTITUTE
NSBRI

Normalized Slow Phase Velocity Calculation

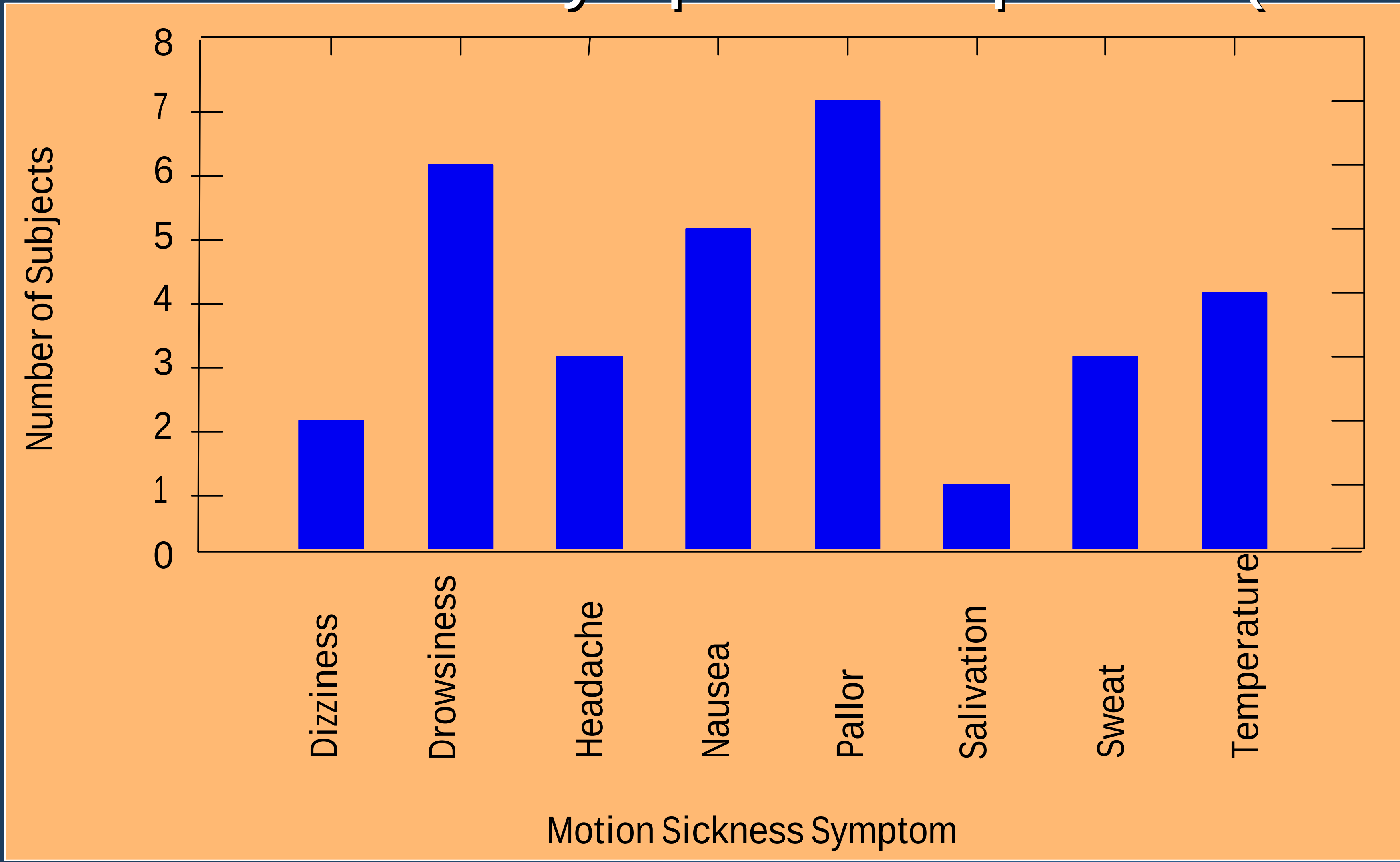
Normalized SPV was calculated by dividing the magnitude of the SPV response (A) by the stimulus; in this case, the stimulus was represented as the product of the sine of the magnitude of the head movement in radians times the angular velocity of the rotating environment (23 rpm equals 138 degrees/second).

Normalized SPV=

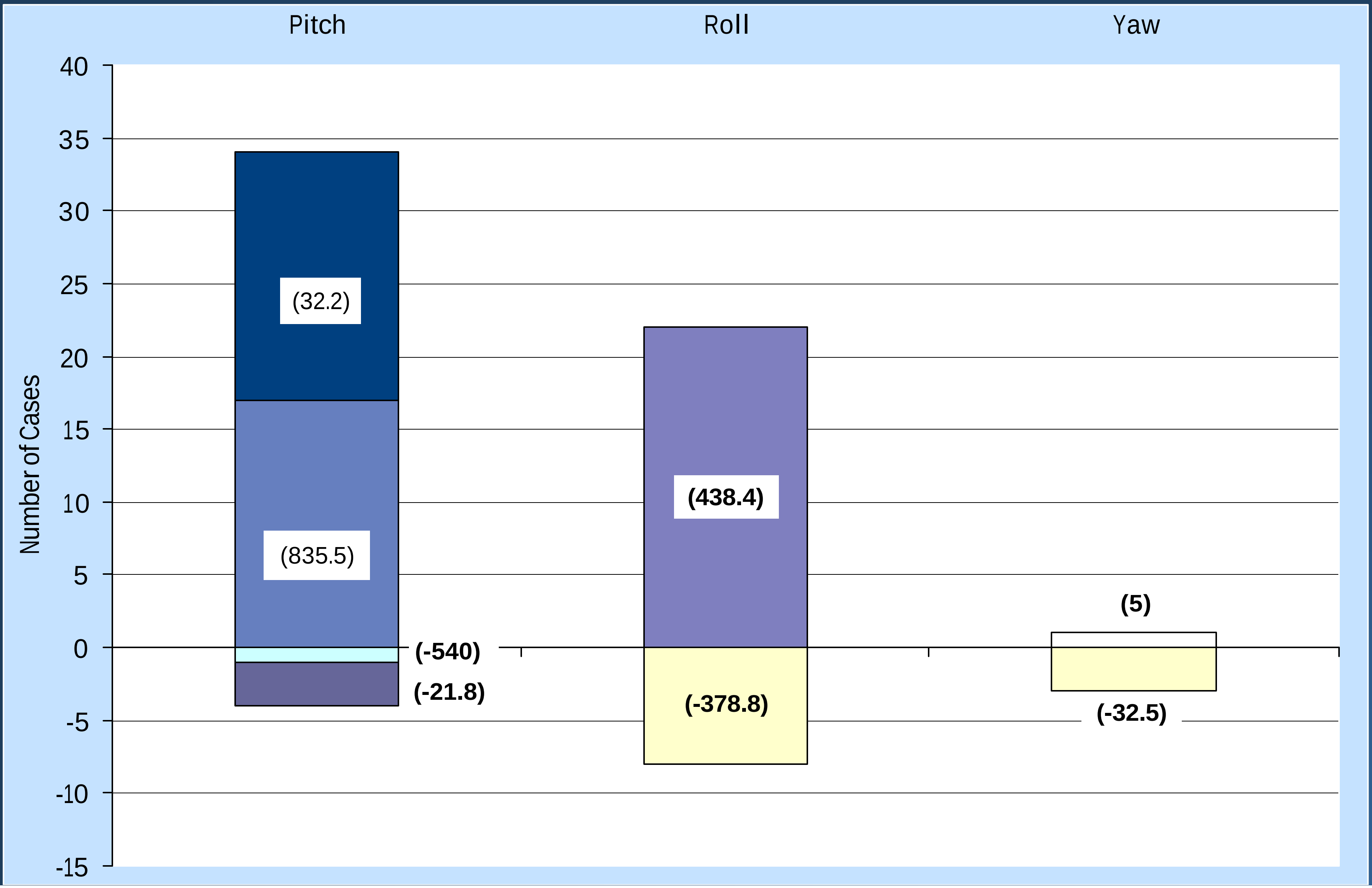
A/[sin(head movement* P /180)*138]

where, A is the magnitude of the exponentially decaying curve fitted to the SPV envelope in degrees/second

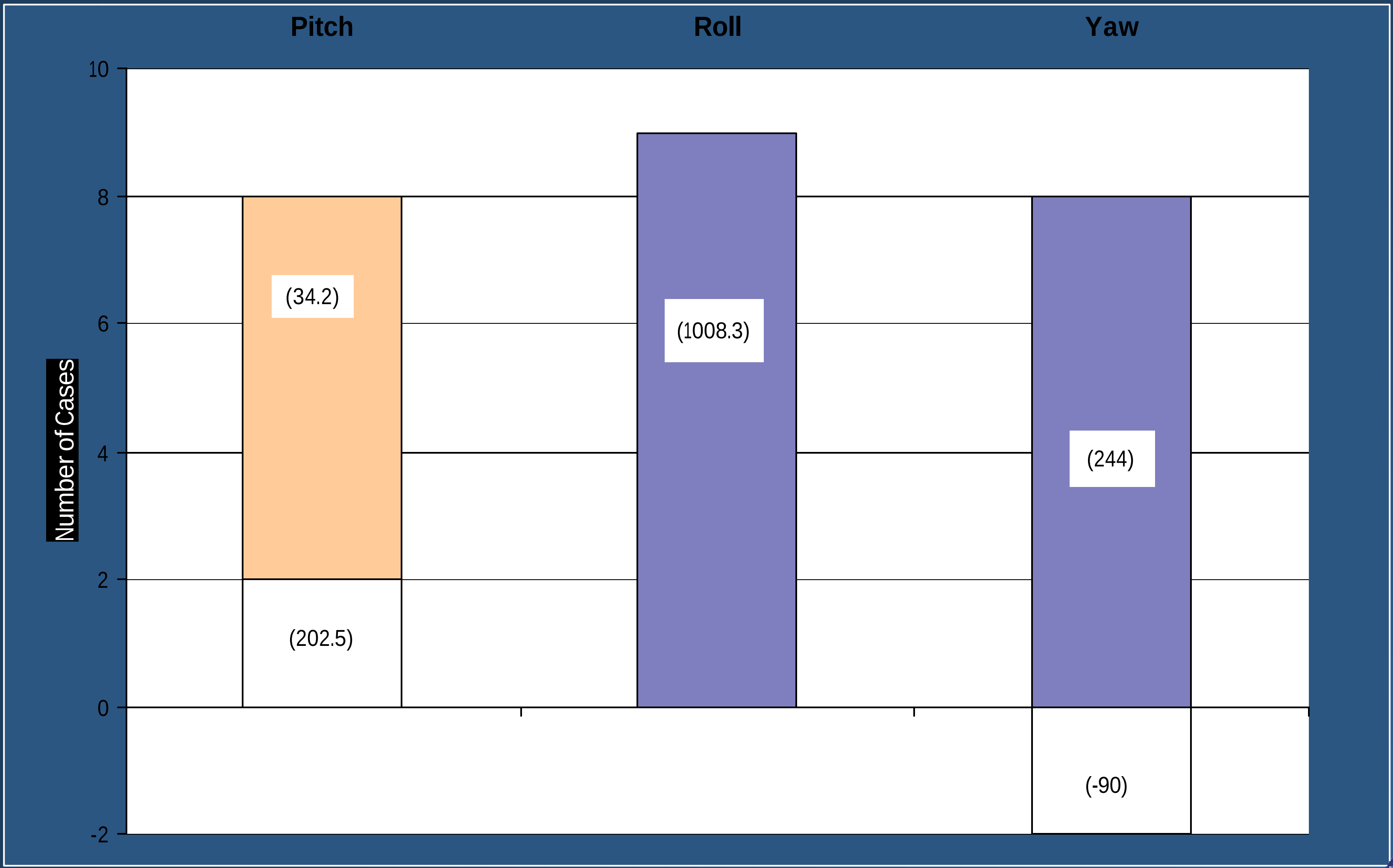
Motion Sickness Symptoms Reported (n=8)

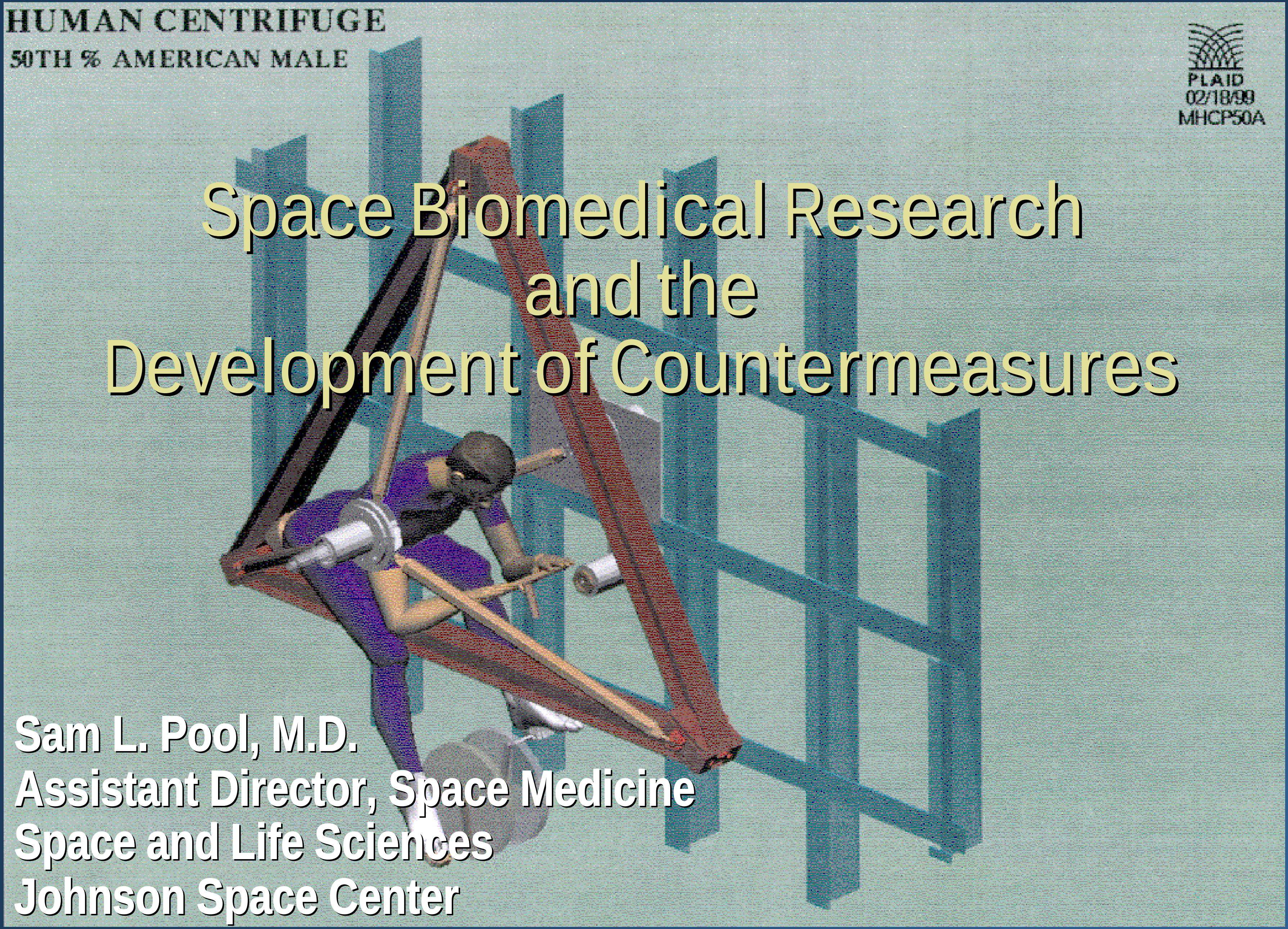


Perceived Motion for Counterclockwise Yaw Head Movement



Perceived Motion for Pitch Forward Head Movement





Space Biomedical Research and the Development of Countermeasures

Sam L. Pool, M.D.
Assistant Director, Space Medicine
Space and Life Sciences
Johnson Space Center

Potentially Debilitating Effects of Microgravity

- Bone Demineralization – Osteoporosis
- Impaired Fracture Healing – Non Union
- Renal Stone Formation & Soft Tissue Calcification
- Orthostatic Intolerance (on return to gravity)
- Cardiac Arrhythmias
- Dehydration (on return to gravity)
- Decreased Aerobic Capacity
- Impaired Coordination
- Muscle Atrophy (Loss of Strength)
- Radiation Sickness
- Increased Cancer Risk
- Impaired Immune Function
- Behavioral Changes & Performance Decrements
- Medical Treatments at Risk

Potentially Debilitating Effects of Microgravity

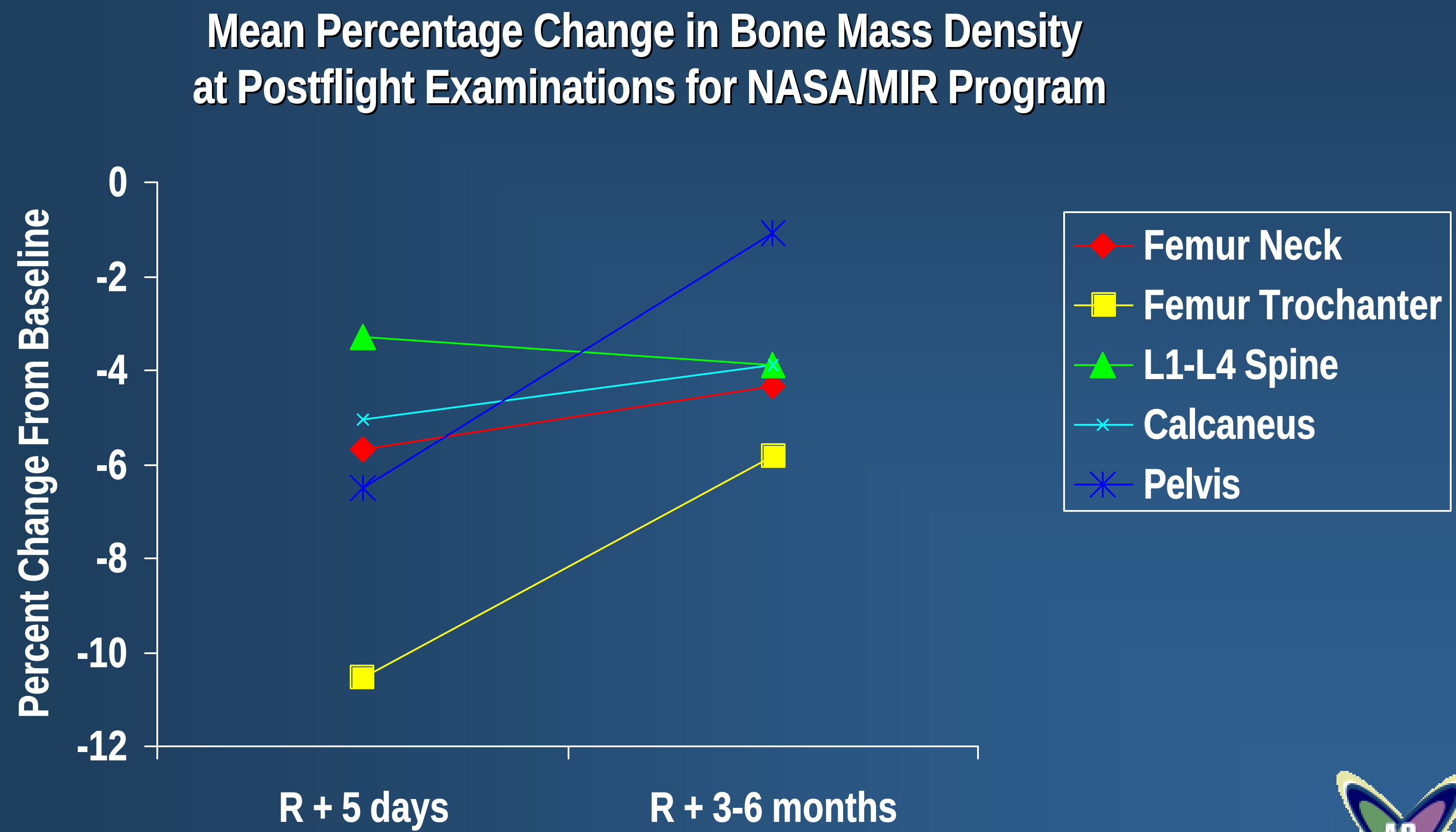
Bone Demineralization – Osteoporosis

Countermeasures:	Effectiveness:
Aerobic Exercise	Minimal
Resistive Exercise	TBD
Medication	TBD

Impaired Fracture Healing – Non Union; Renal Stone Formation; Soft Tissue Calcification

Countermeasures:	Effectiveness:
Aerobic Exercise	TBD
Resistive Exercise	TBD
Medication	TBD

Potentially Debilitating Effects of Microgravity



Genitourinary System

Sensitive Information

Total *n*	Rate per 14 days	Genitourinary System
10	0.21	Urinary incontinence
7	0.04	Inability to urinate
3	0.01	Painful urination
2	0.01	Concentrated or “dark” urine
1	0.02	Irregularity of menses

*** Urinary tract infections reported as ‘Infectious Diseases’.**

Orthostatic Intolerance (on return to gravity); Dehydration (on return to gravity)

Countermeasures:	Effectiveness:
Aerobic Exercise & LBNP	Minimal
Fluid & Na Cl Load	Partially Effective
Liquid Cooled Garment	Partially Effective
Anti-g Suit	Partially Effective

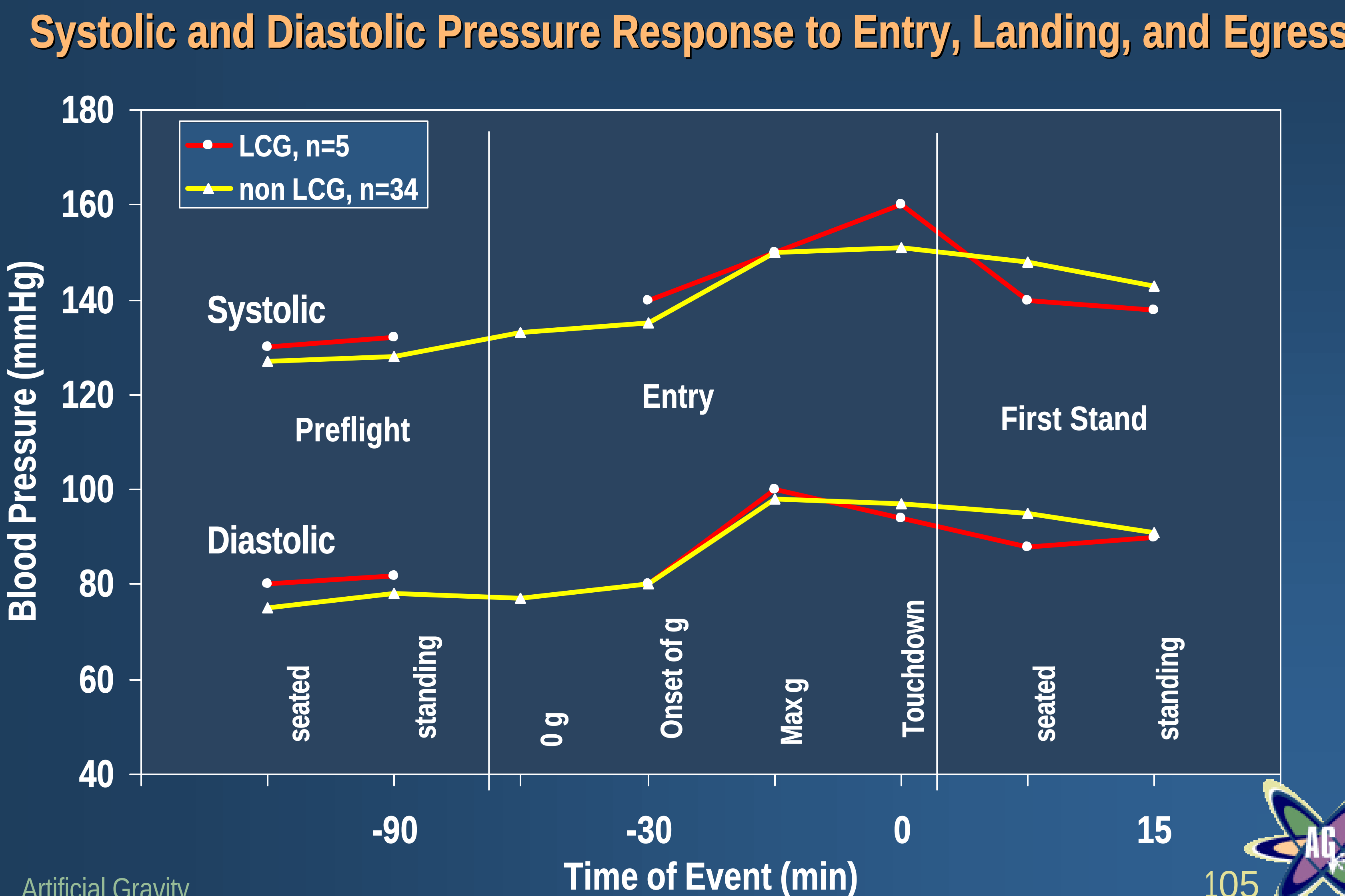
Cardiac Arrhythmias

Countermeasures:	Effectiveness:
Medications	TBD
Acute Cardiac Life Support	TBD

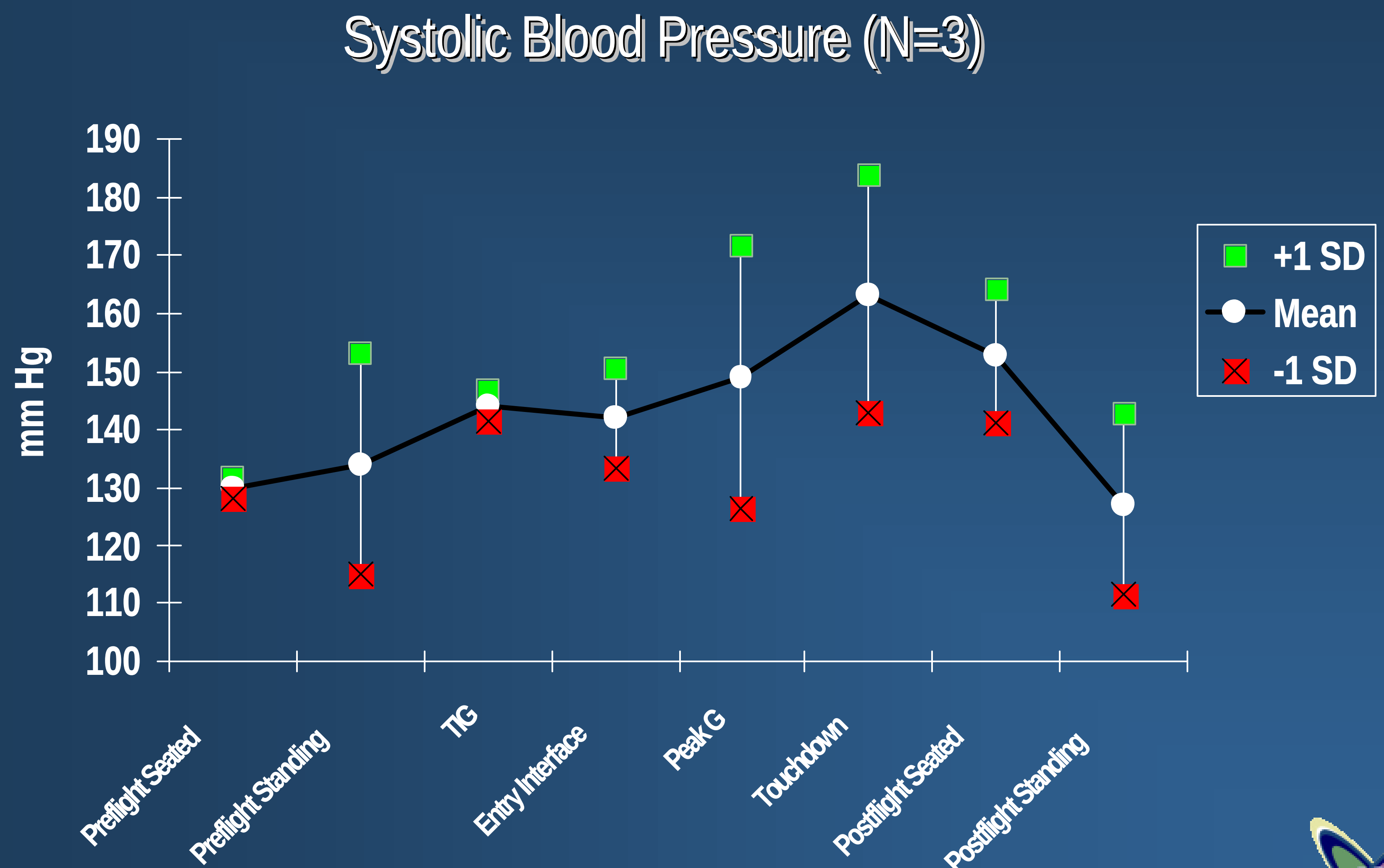
Decreased Aerobic Capacity

Countermeasures:	Effectiveness:
Aerobic Exercise	Moderately Effective

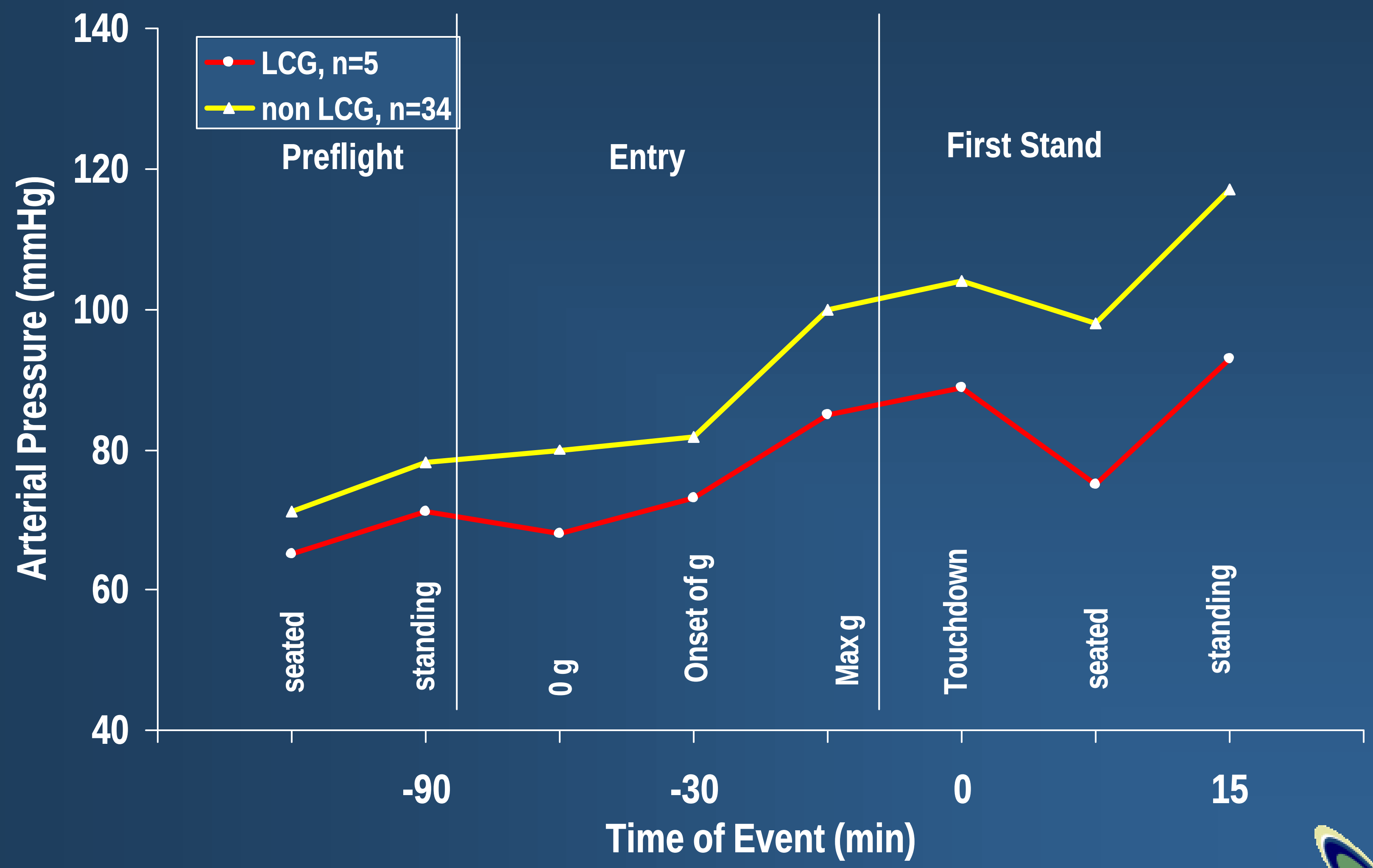
Systolic and Diastolic Pressure



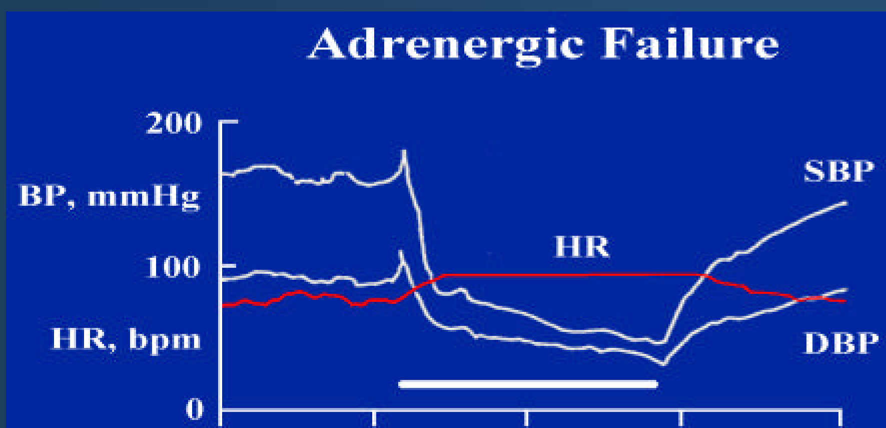
Preflight and Entry Monitoring

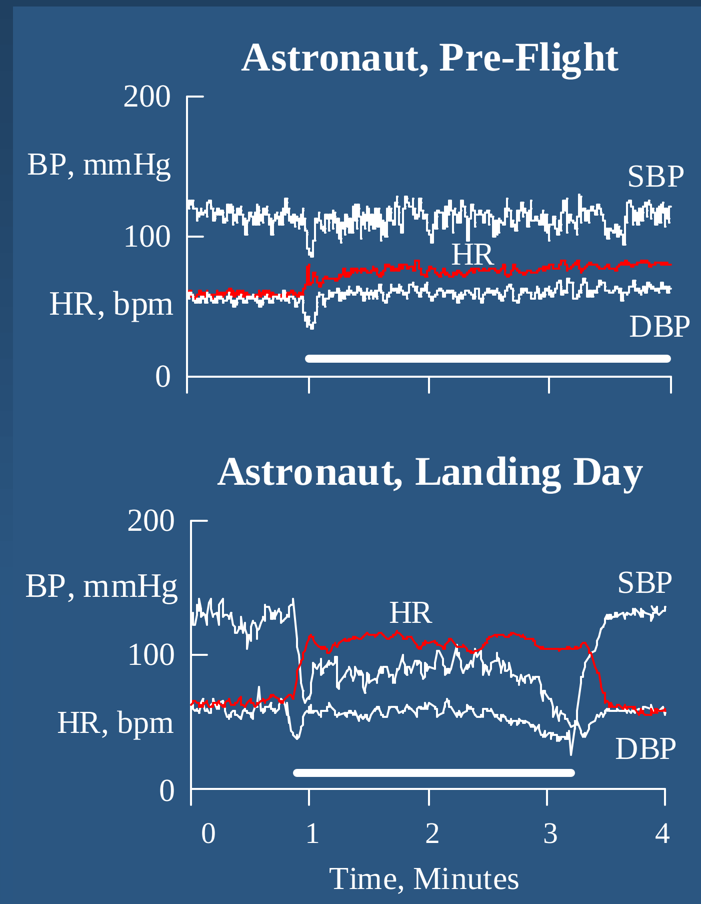


Heart Rate Response to Entry, Landing and Egress



P. A. Low, 1993


Adrenergic Failure
200
BP, mmHg
100
HR, bpm
0
SBP
HR
DBP

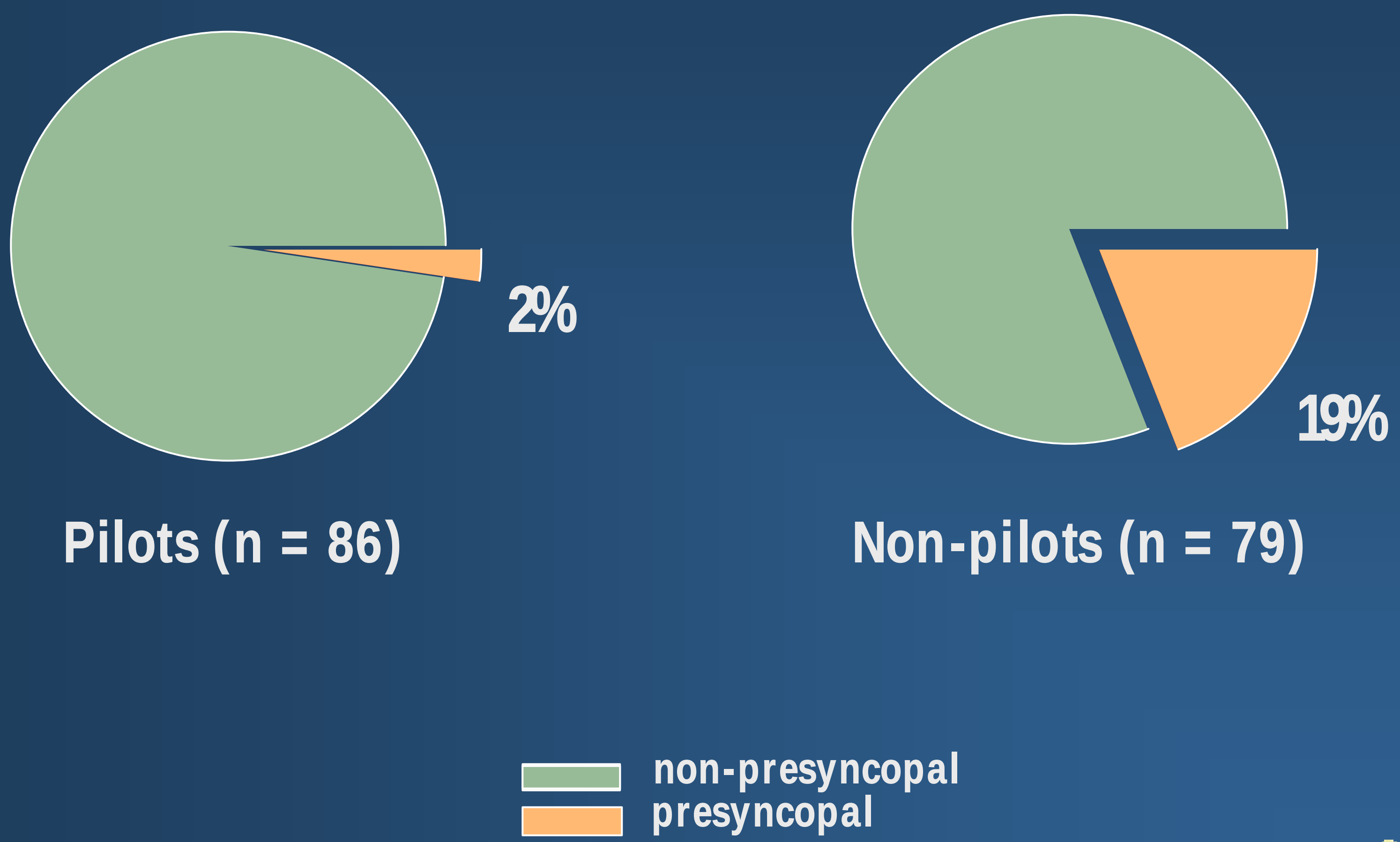

Astronaut, Pre-Flight
200
BP, mmHg
100
HR, bpm
0
SBP
HR
DBP
Astronaut, Landing Day
200
BP, mmHg
100
HR, bpm
0
SBP
HR
DBP
0
1
2
3
4
Time, Minutes

Orthostatic Hypotension

Occurrence of Orthostatic Hypotension
(Shuttle Missions)

Orthostatic Hypotension		Pre-Challenger Mission	Post-Challenger Mission
Pre-Egress - Missions	%	25%	52%
	%	6.4%	13.1%
Crewpersons In Clinic - Missions	%	12.5%	38.5%
	%	3.2%	10.4%
Crewpersons Number of Missions		24	25
Avg.. Mission Duration (Days)		6	7

Operational Stand Test



Impaired Coordination

Countermeasures:	Effectiveness:
None	

Muscle Atrophy (Loss of Strength)

Countermeasures:	Effectiveness:
Aerobic Exercise	Minimal
Resistive Exercise	TBD

Radiation Sickness & Increased Cancer Risk

Countermeasures:	Effectiveness:
Shielding	TBD
Medication	TBD (Minimal)

Nervous System and Sense Organs

Sensitive Information

Total *n*	Rate per 14 days	Nervous system and sense organs
188	0.59	Headache
78	0.25	Eye irritation, dryness, redness
26	0.10	Sensory changes (e.g., tingly, numbness, unusual sensations)
18	0.06	Ear problems
5	0.02	Myoclonic jerks (associated with sleep)
4	0.01	Subconjunctival hemorrhage
2	0.01	Sty in eye

Musculoskeletal System

Sensitive Information

Total *n*	Rate per 14 days	Medical Event
30	0.1	Shoulder/trunk muscle pain
29	0.1	Back muscle pain
29	0.1	Leg/foot muscle pain
20	0.06	Hand/arms muscle pain
10	0.03	Muscle cramp
9	0.03	Neck muscle pain
5	0.02	General muscle pain, fatigue

Impaired Immune Function

Countermeasures:	Effectiveness:
None	

Behavioral Changes & Performance Decrements

Countermeasures:	Effectiveness:
Screening (select out)	Substantial
Screening (select in)	TBD
Training (coping skills)	TBD

Medical Treatments at Risk

Countermeasures:	Effectiveness:
Develop Evidence Base	TBD

In-flight Medical Events (7 US Crew)

Sensitive Information

Total *n*	Rate per 100 days	Medical Event
7	0.74	Musculoskeletal
6	0.63	Skin
4	0.42	Nasal congestion, irritation
2	0.21	Bruise
2	0.21	Eyes
2	0.21	Gastrointestinal
1	0.11	Hemorrhoids
2	0.21	Psychiatric
1	0.11	Headaches
1	0.11	Sleep disorders

Medications

Most commonly used during NASA/Mir Program

Medication	Number Dispensed
Sudafed	131
Ambien	81
Restoril	68
Benadryl	60
Ascriptin	55
Tylenol	37
Dulcolax	32
Motrin	28
Seldane	18
Entex LA	13
Afrin	9

Behavioral Health

Sensitive Information

Total *n*	Rate per 14 days	Symptoms
15	0.05	Stress/tension
12	0.04	Anxiety/annoyance
2	0.002	Decreased concentration
2	0.01	Mood elevation/depression
2	0.01	Malaise, fatigue
1	0.004	Drug-induced hallucinations