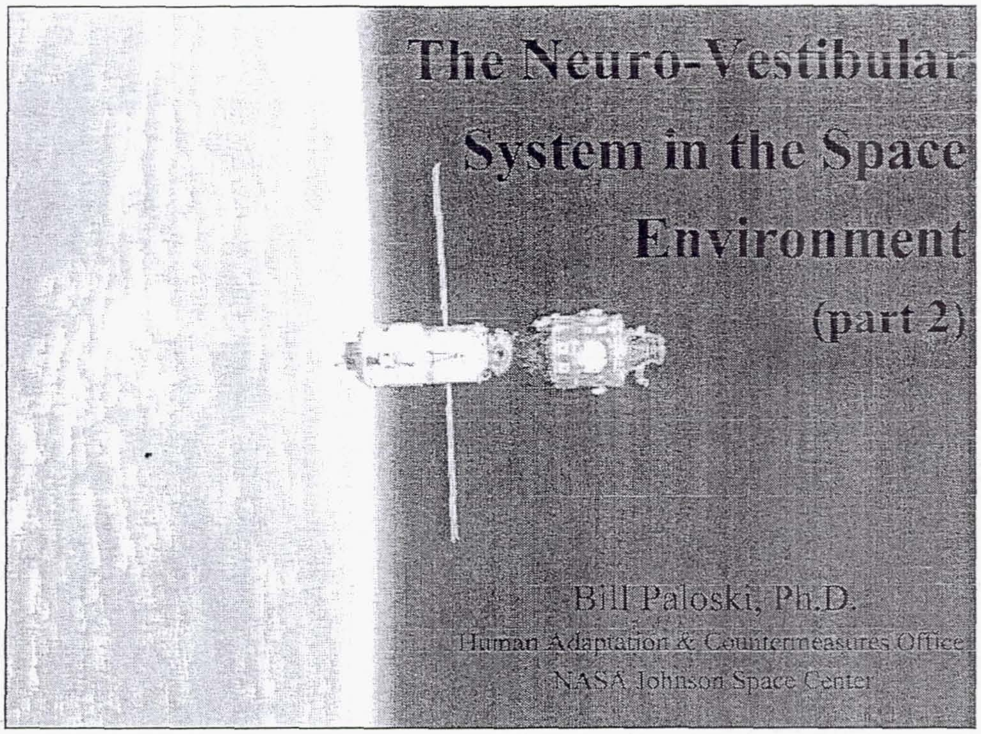
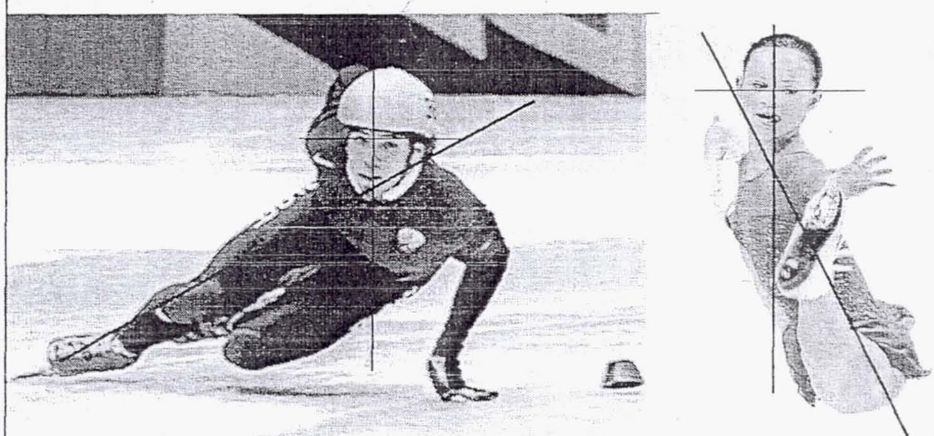


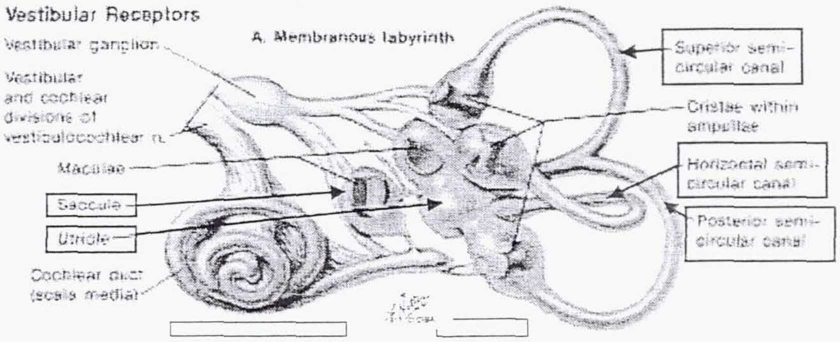
The Neuro-Vestibular System in the Space Environment (part 2)

Bill Paloski, Ph.D.
Human Adaptation & Countermeasures Office
NASA Johnson Space Center

Gravity provides the CNS a fundamental reference for estimating spatial orientation and coordinating movements in the terrestrial environment.



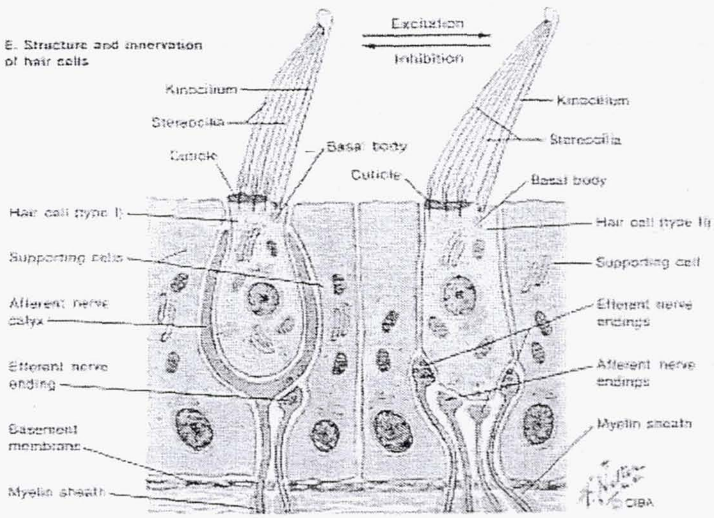
Peripheral Vestibular System



Otolith Organs:
Sensitive to linear motion (and gravity)

Semi-circular canals:
Sensitive to rotational motion

Hair Cell Anatomy



Otolith Physiology

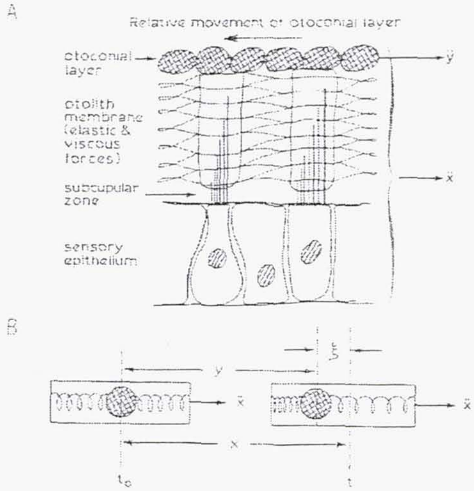
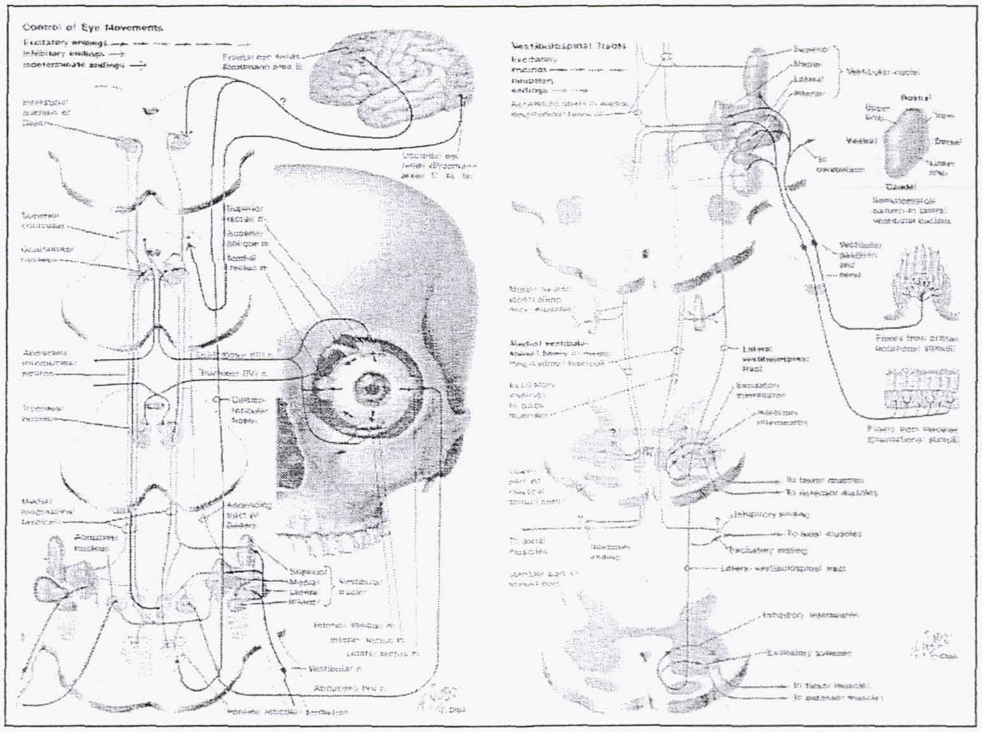
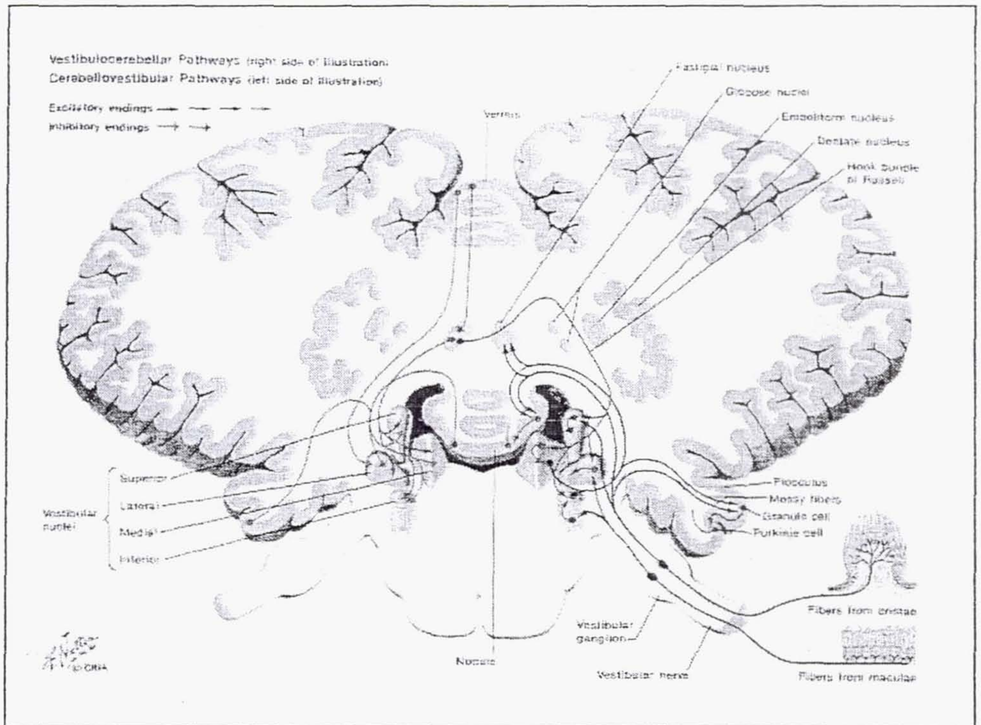


Fig. 3-9. A: Presumed mechanical linkages between the macular epithelial cells and overlying structures. B: Elementary mechanical analogy. $\ddot{x}$, Linear acceleration of head relative to space; $\ddot{y}$, acceleration of otoconia relative to space; ξ, relative displacement of otoconia and macula; t_0, position of end organ at commencement of acceleration; t, position after time t.

Benson, 1982

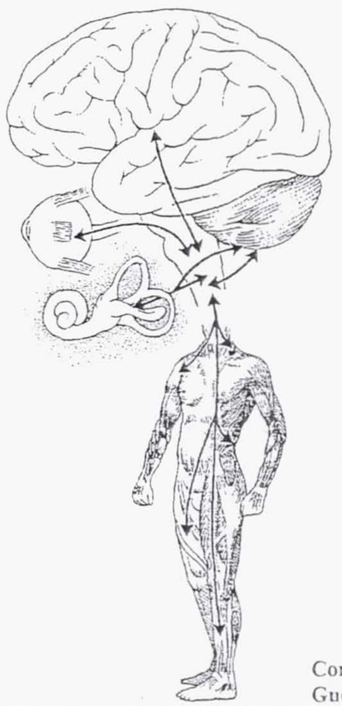




Spatial Orientation
and
Balance Control

Require

Central Integration
of
Sensory Information



Correia & Guedry, 1978

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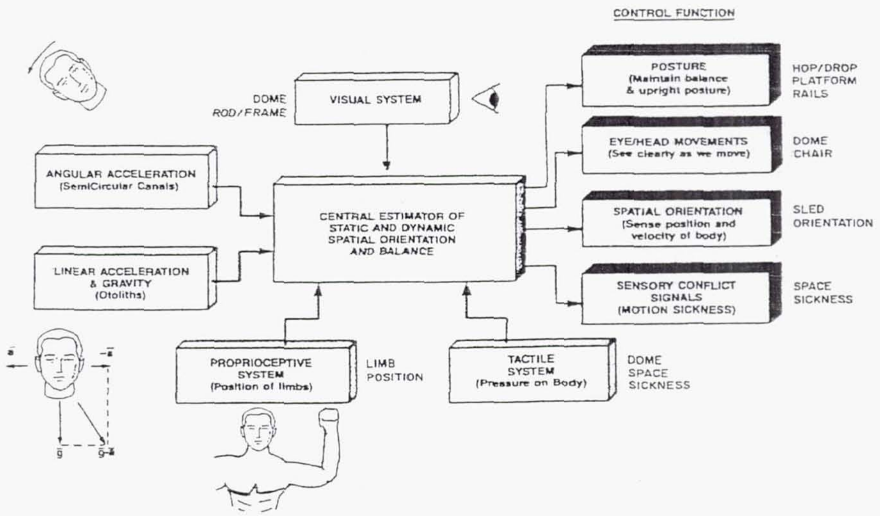
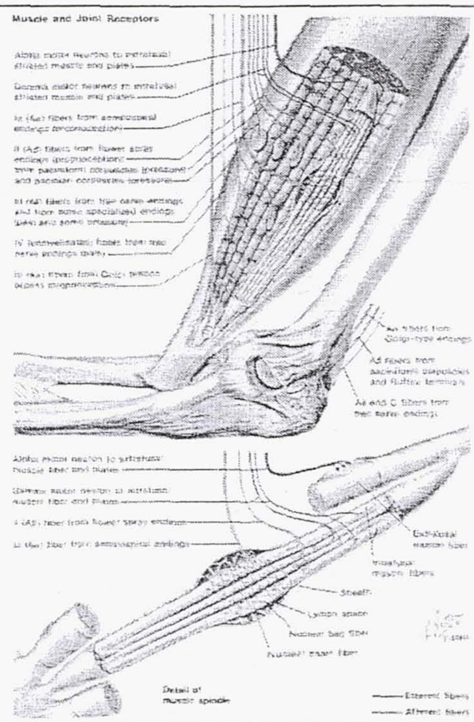


Fig. 1. Scope of the MIT/Canadian Spacelab 1 experiments, by experiment short name, relative to a schematic representation of the role of the vestibular and other senses in control of posture, eye movements and perception of orientation. Experiment short names are keyed to Table 1

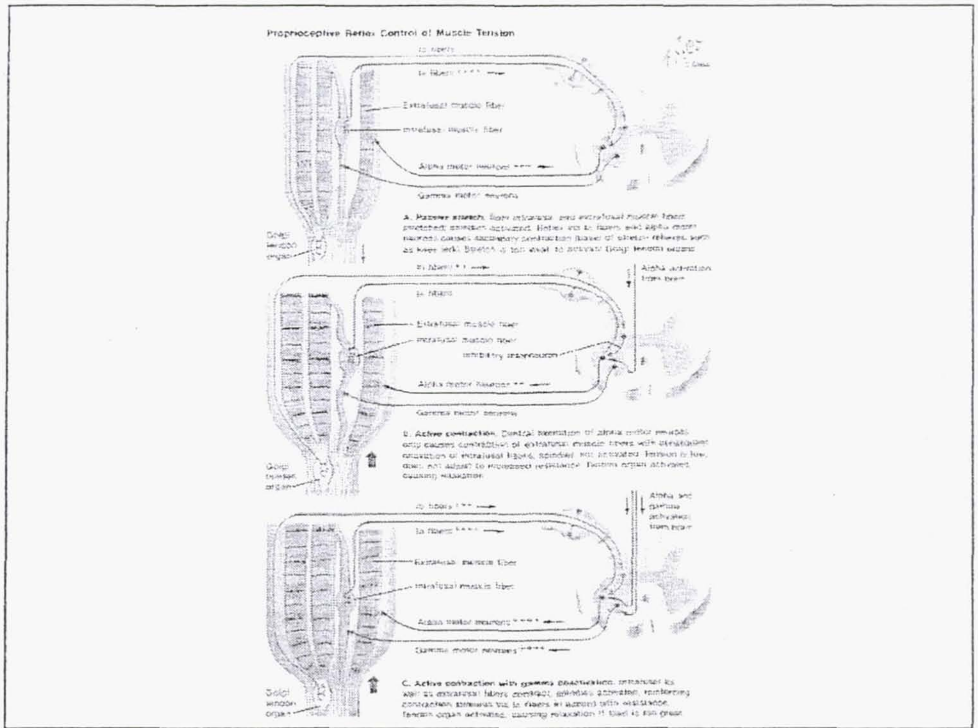
Young et al., Exp Brain Res, 1986

Brain is a black box

Proprioceptive Function



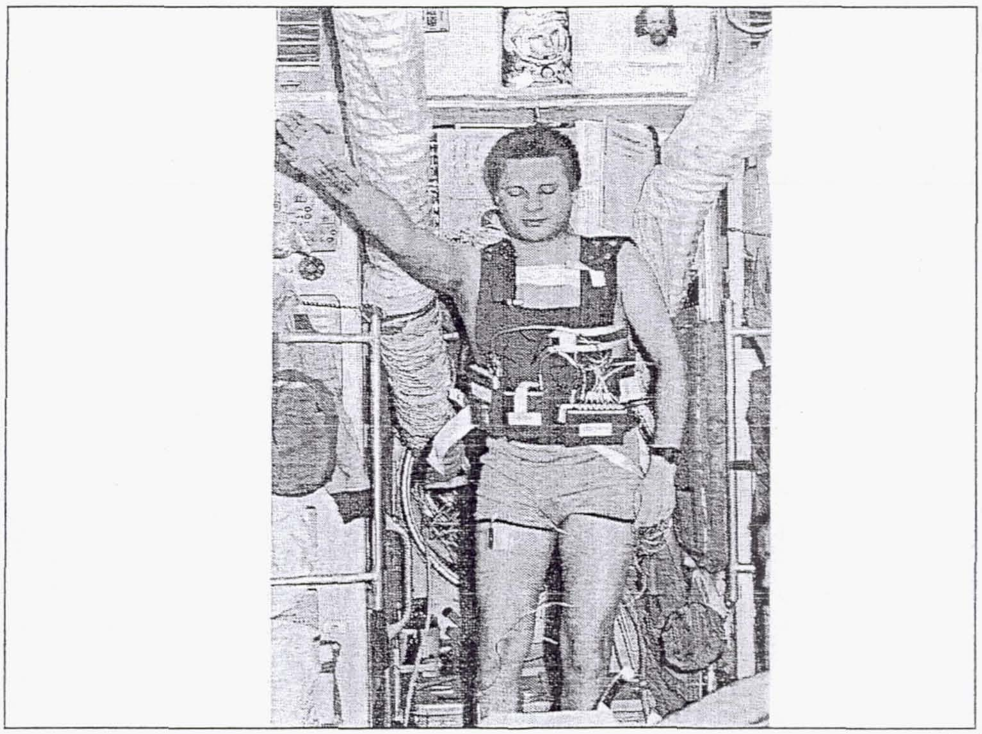
Bed Test
- lie still
- forget arms
- brain forgets where hands are.



H-Reflex
Motor (muscle) tone modul in descend. column.

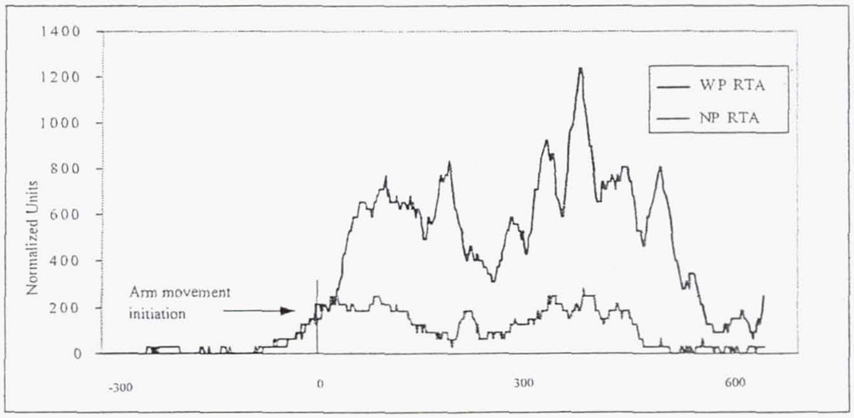
measured in Knee

Walk on Ice in Street Shoes is similar to walking Postflight.



Modulating by pressure on bottom of Feet.

During Space Flight Postural Muscles can be Activated with Foot Pressure

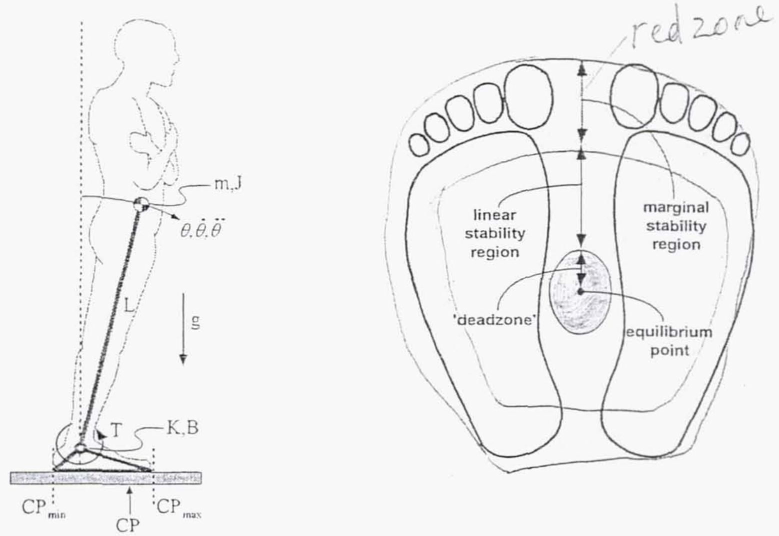


Courtesy of J. Bloomberg

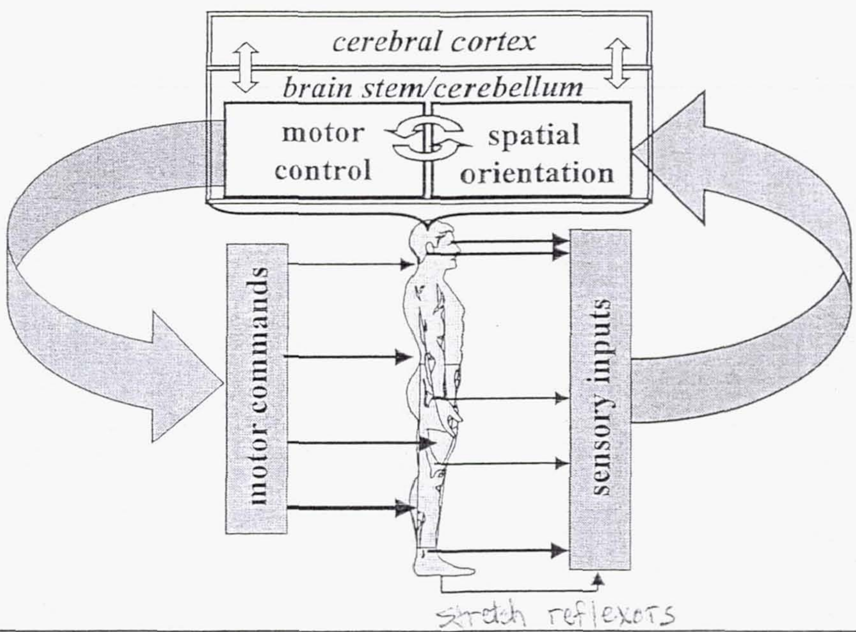
Neurolab mission

Postural Stability

Base of Support

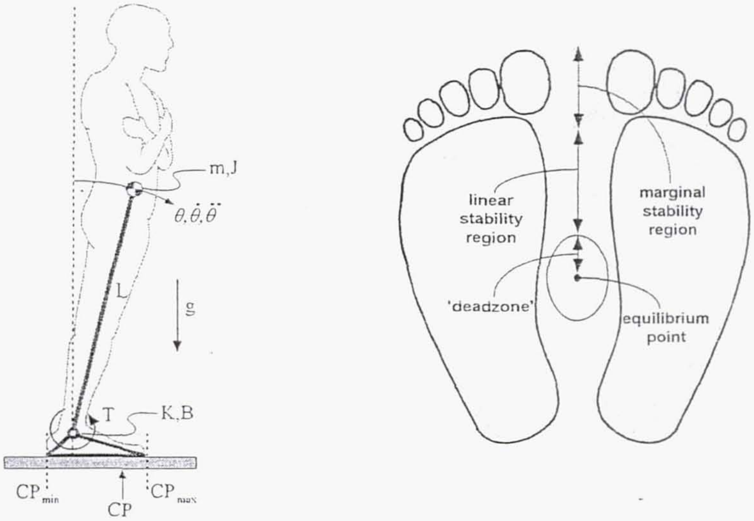


Human Sensory-Motor Balance Control



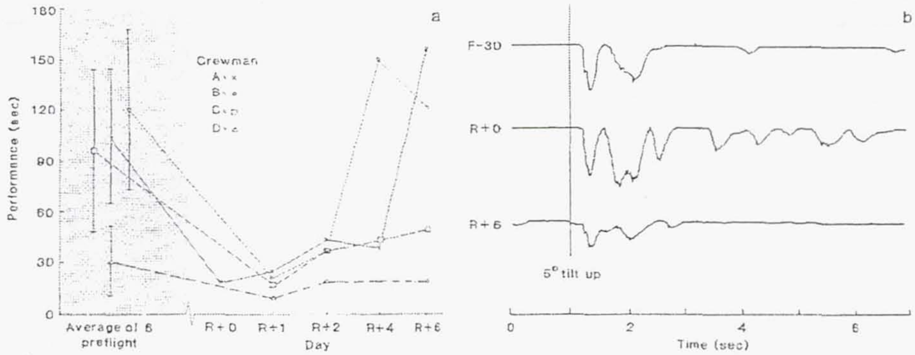
Perturbation Experiment

Postural Stability



Move base of support back 5cm.

Tib. Anterior EMG



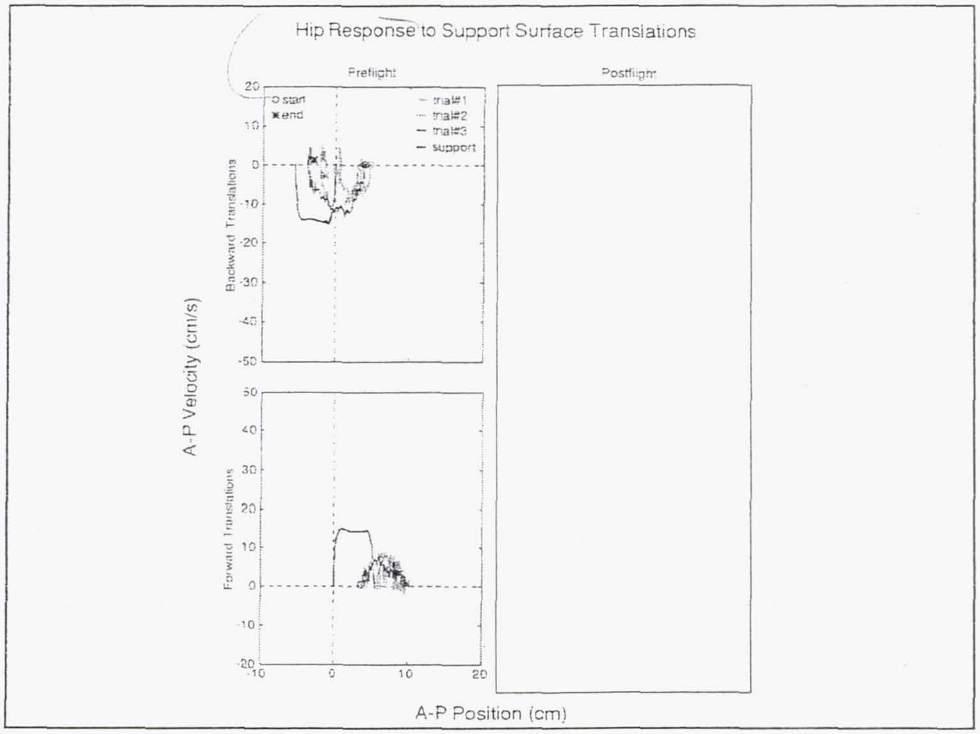
5° tilt up.

Fig. 2. Posture control with eyes closed, showing marked decrements immediately after flight for standing on a 5.7-cm rail or responding to an unexpected toe-up tilt of a posture platform (6). In (a), modified sharpened Romberg test measured total time standing on rail for the best three of five 1-minute trials. In (b), filtered EMG activity (arbitrary units) from the tibialis anterior muscle of one subject during the first eyes-closed 5° toe-up tilt shows, for R + 0, increased magnitude and duration of the late response. The drop in magnitude below the preflight value was seen for R + 0 but not for the other three subjects.

Young et al., Science, 1984

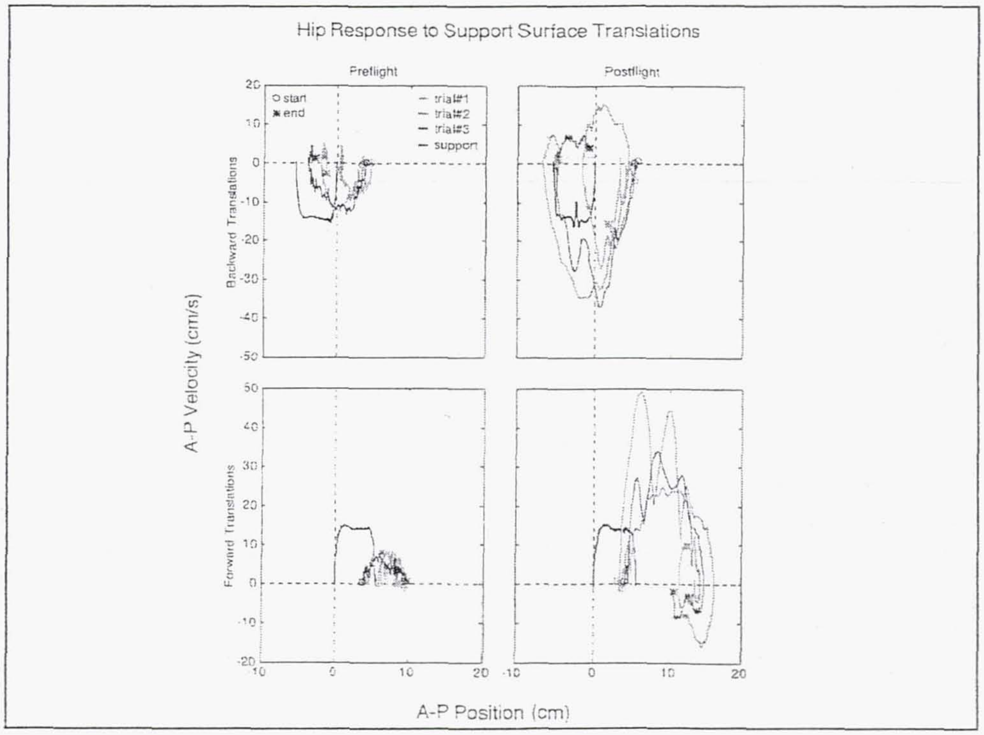
7 day mission

R+0 @ 4hrs.



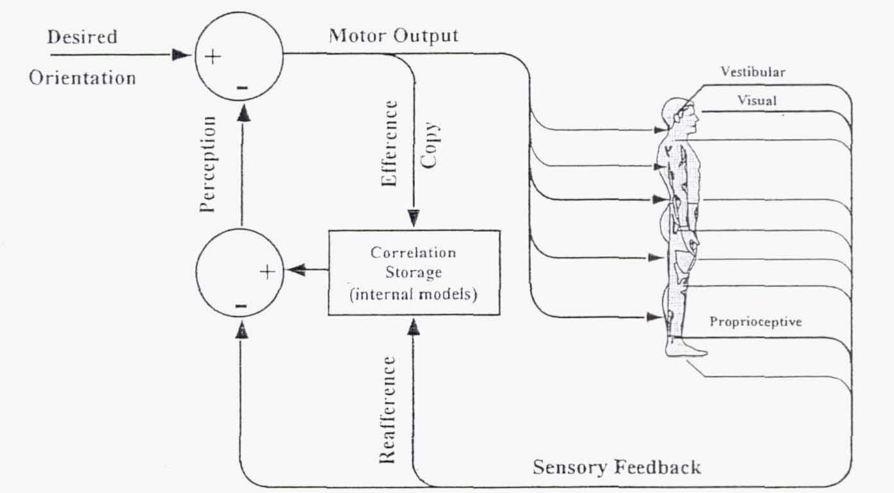
3 Trials

Translated base of support
. backwards
. forwards
. backwards



Adaptive Neural Control of Upright Stance

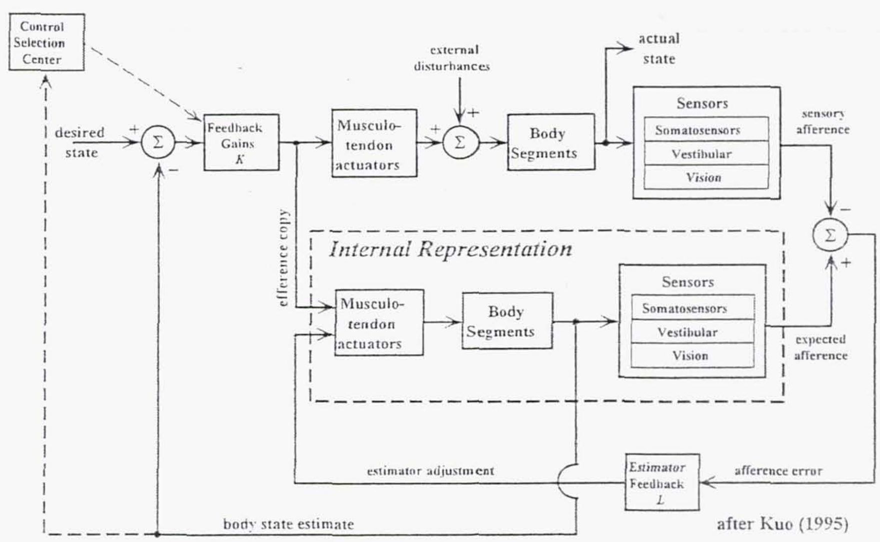
Internal Model



based on Hein and Held (1962)

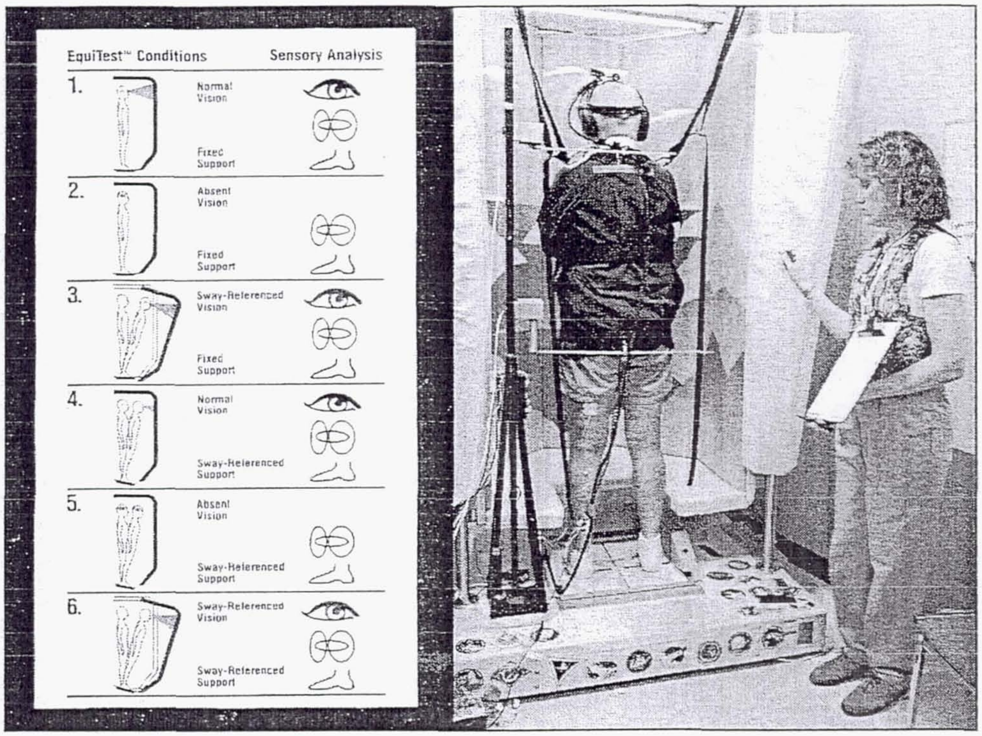
Dual Adaptation : wearing glasses.

Adaptive Posture Control Model



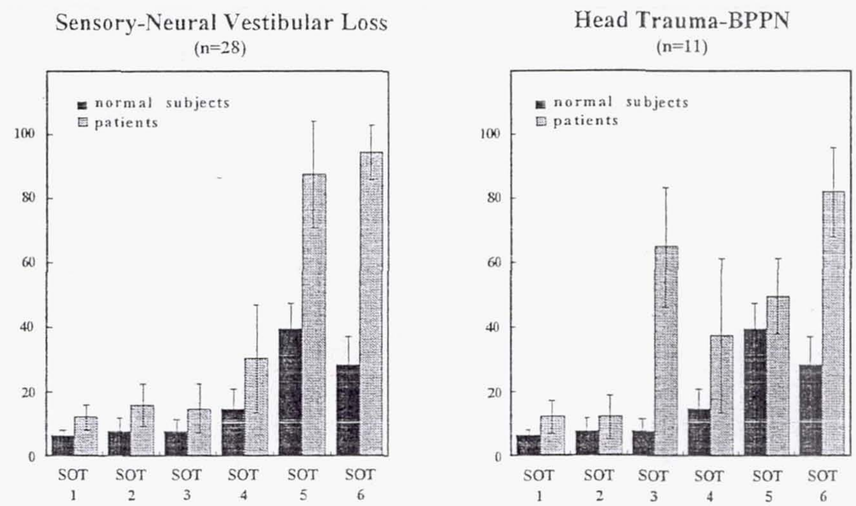
after Kuo (1995)

Posture Platform



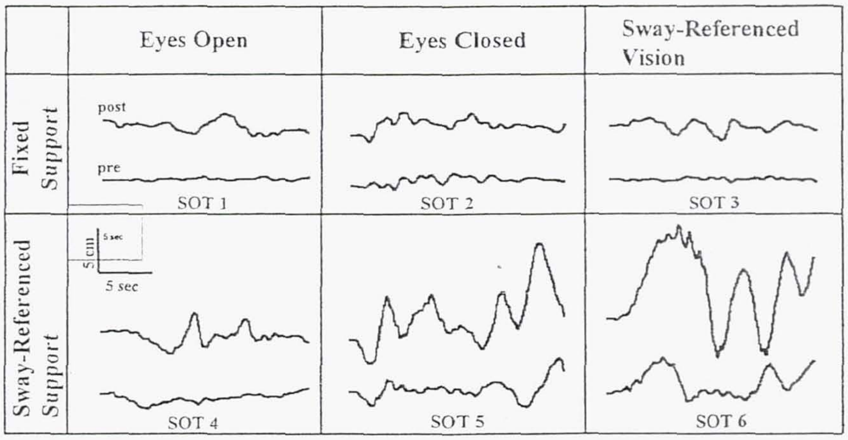
Patient Balance Test Performances

(redrawn from Black et al. 1988)



Bilateral Deficient People

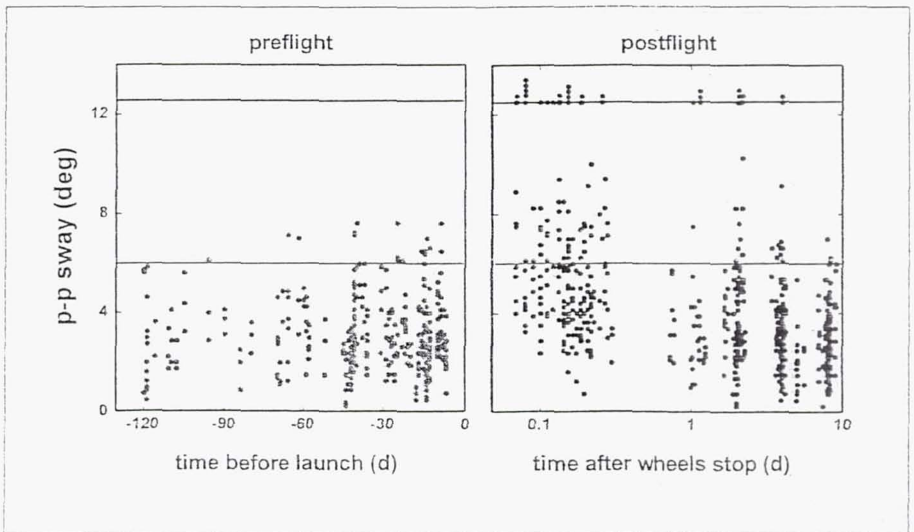
Typical Astronaut Performance



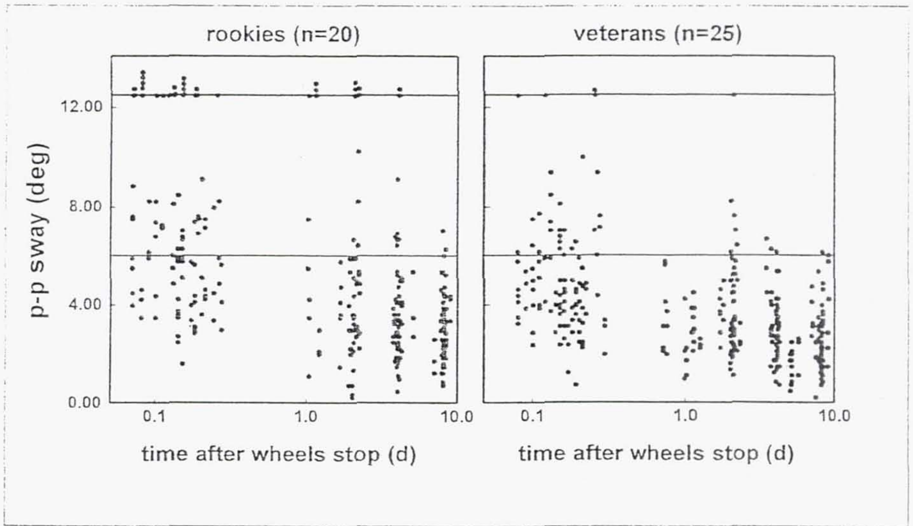
Paloski, et al., 1997

Raw Sway Data From SOT 6

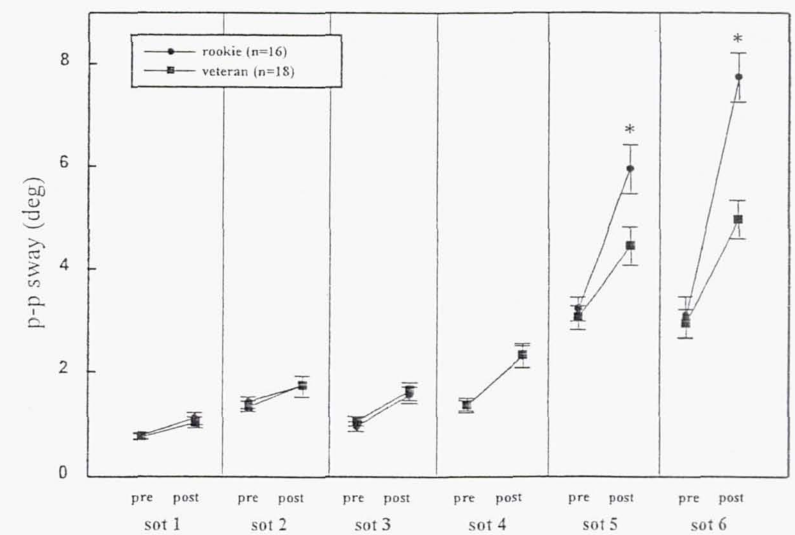
~~(n = 45 subjects)~~



Postflight Sway Data from SOT 6



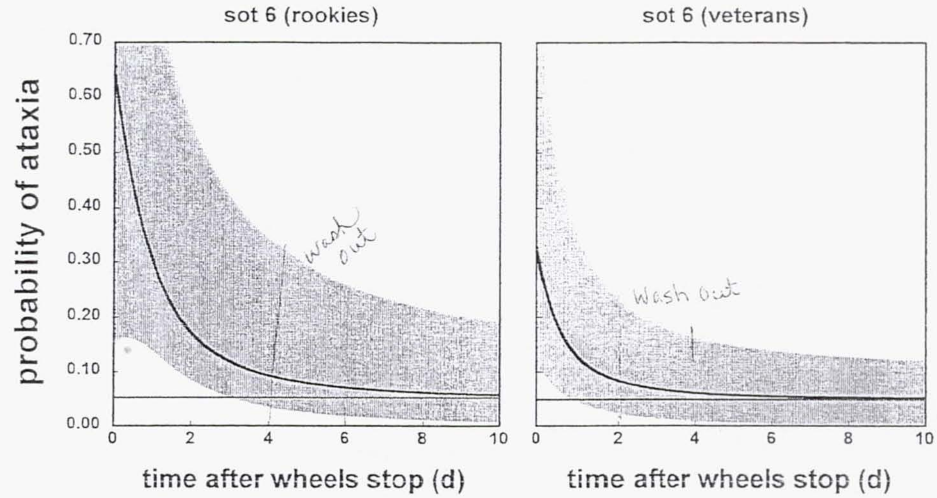
Landing Day Performance

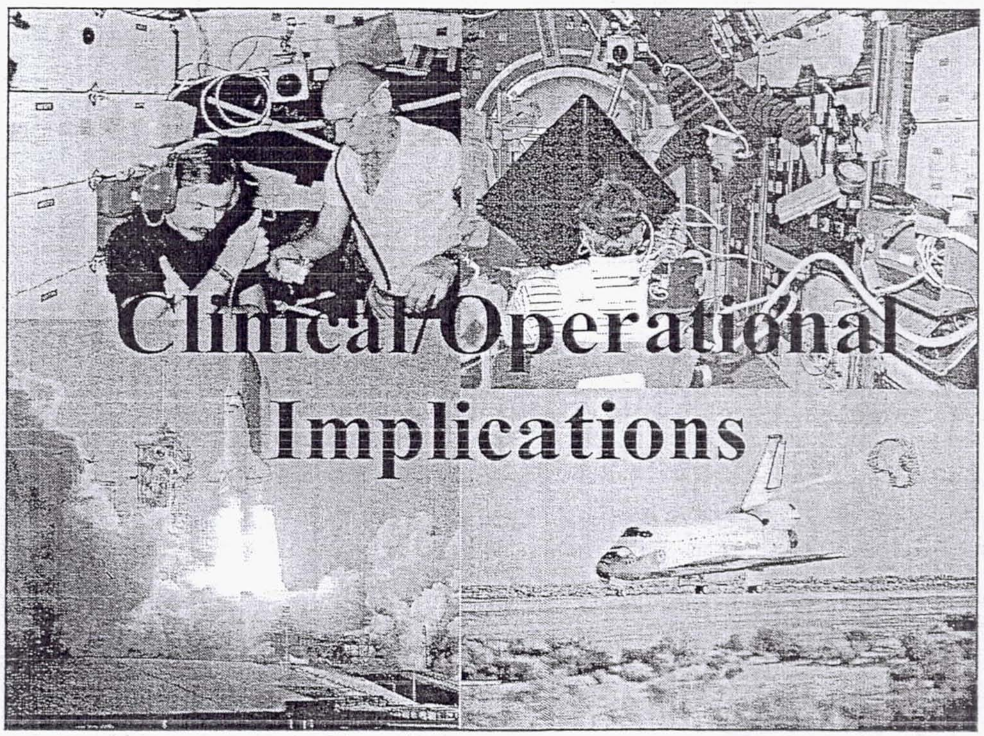


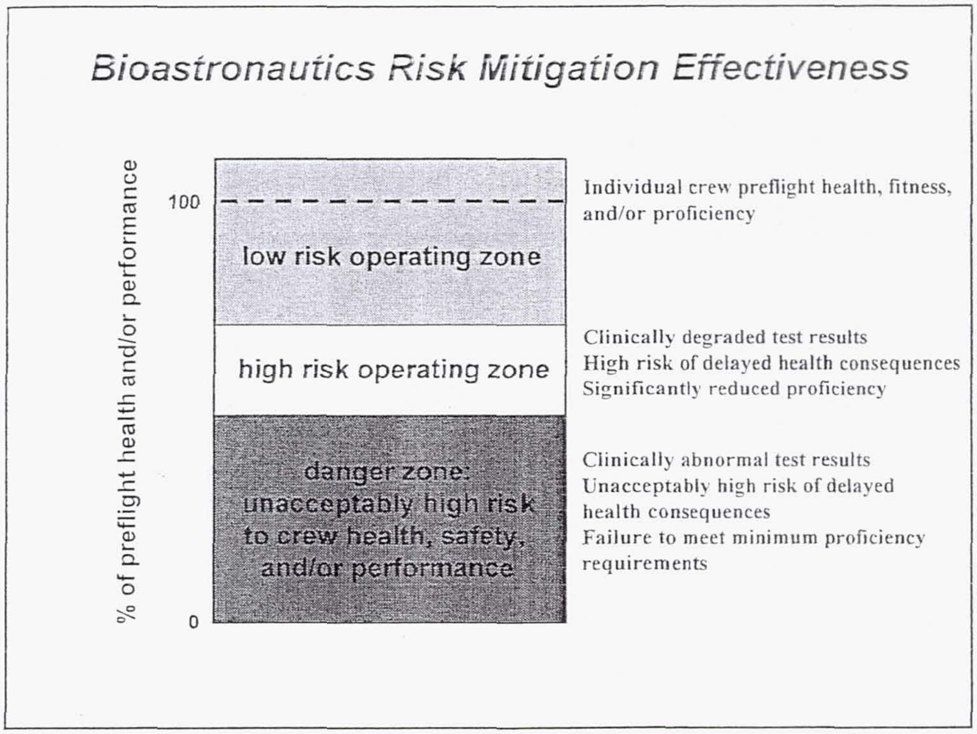
Something learn btw. flights

Dual Adaptation

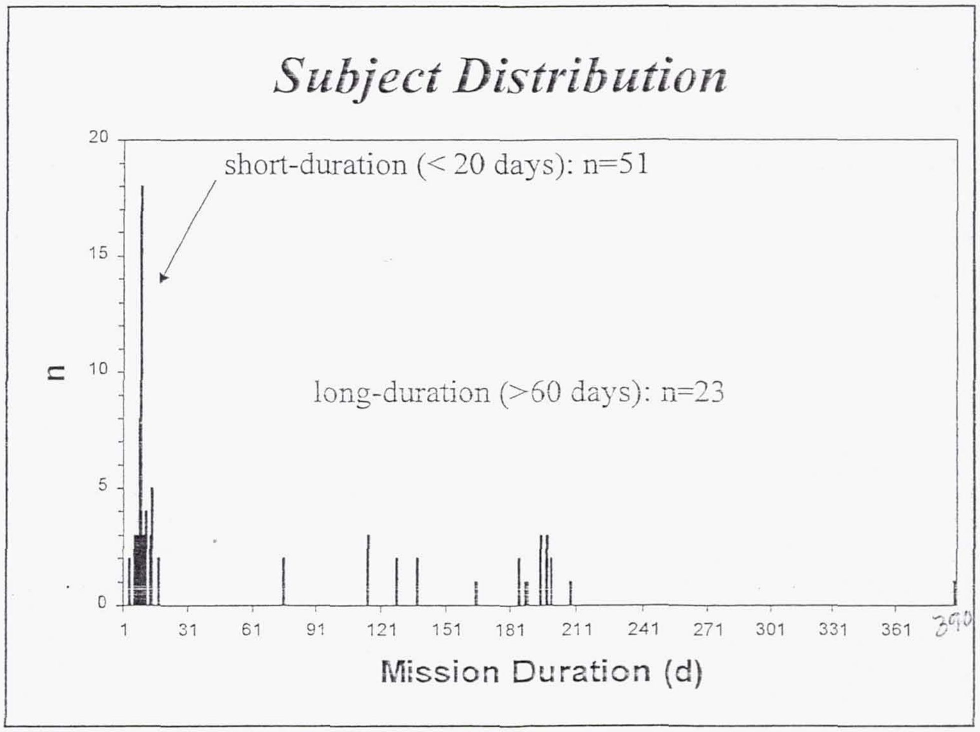
Risk of Ataxia Following Space Flight







Variable based on Task Type



Data Analysis

Statistical Model for EQ Scores: The normalized latent EQ scores (scale of 0 to 1) for each SOT are modeled as Beta distributions: $y \sim B(p, q)$. The density of y is:

$$\boxed{f(y) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} y^{p-1}(1-y)^{q-1}}$$

Fall Model: The conditional probability of a fall given latent EQ score is modeled as:

$$P(\text{fall} \mid y) = G(y) = (1-y)^r \quad \text{or} \quad P(\text{fall}) = \frac{\Gamma(p+q)\Gamma(r+q)}{\Gamma(q)\Gamma(r+p+q)}$$

where p, q and r depend on independent variables (mission duration and time after landing):

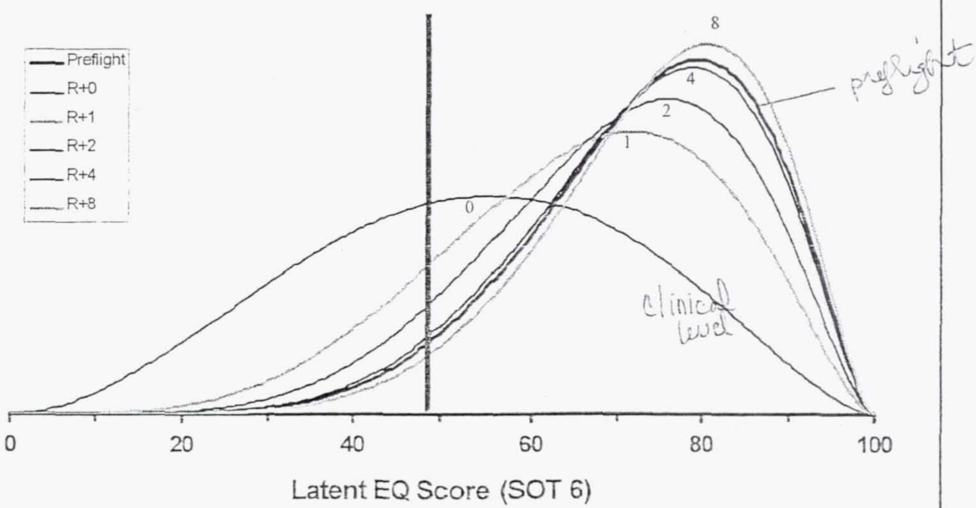
$$\log r = C_5 + C_6 \frac{\delta}{1+t} + C_7 \frac{\delta \log(dur)}{1+t}$$

$$\log q = C_4 \text{ (fixed for all conditions)}$$

$$\log p = C_0 + C_1\delta + C_2 \frac{\delta}{1+t} + C_3 \frac{\delta \log(dur)}{1+t}$$

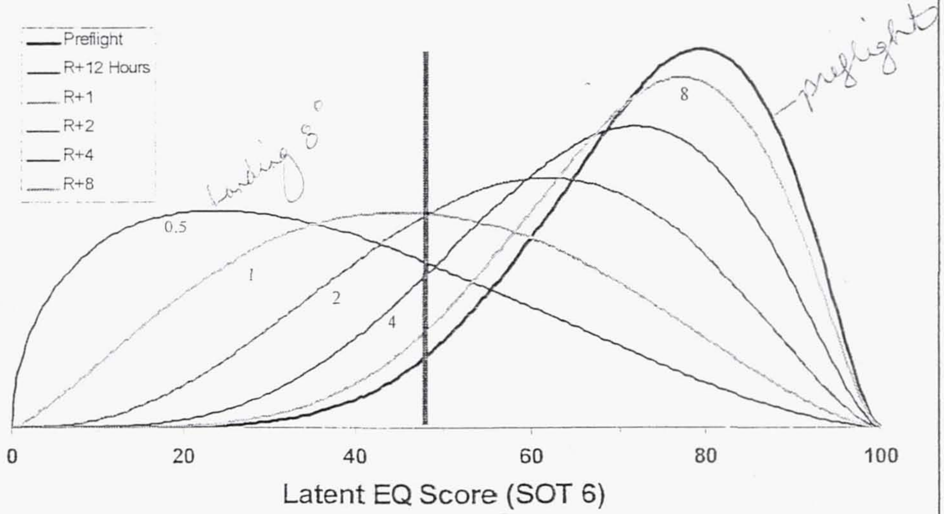
where δ = 0 preflight; 1 postflight, dur = mission duration (days), t = time after landing (days) for postflight only, and $C_0, \ldots, C_7$ are coefficients estimated from the data

Performance Distributions Following 10-day Missions



4-8 days to return to preflight levels

Performance Distributions Following 180-day Missions



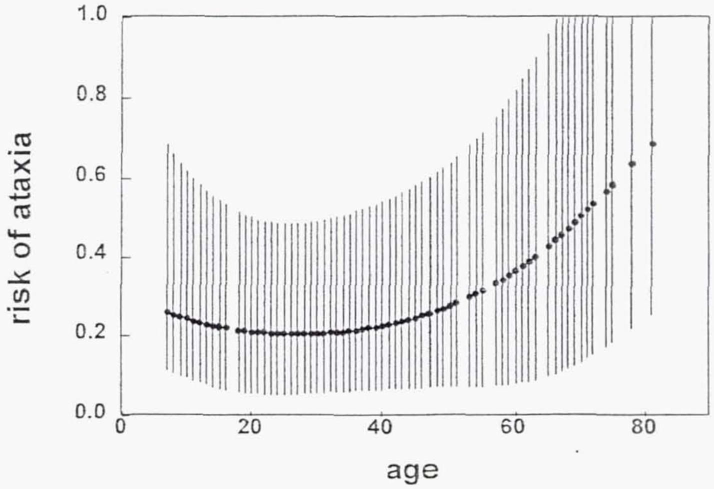
8-10 days to recover.

According to the NIH:

- There are more than 30,000,000 people over age 65 in the U.S. (Bureau of Census, 1992)
- Vestibular disorders account for 20–25% of falls in the elderly that lead to hospitalization (Brockelhurstet al., 1991)
- Of the elderly people hospitalized because of falls (over 200,000 per year with hip fracture alone), 40% die within one year (Rubenstein, 1983)

Risk of Falling in Normative Population

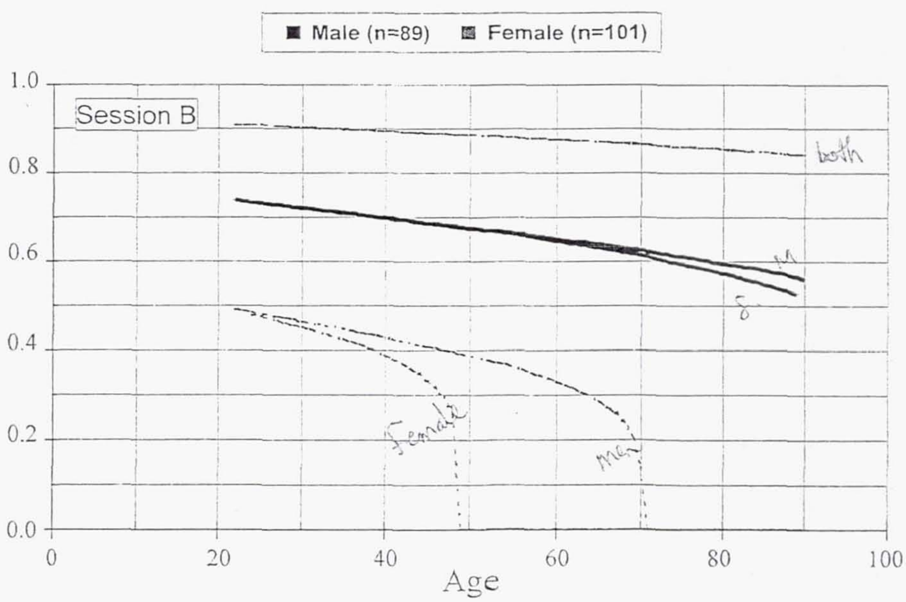
(SOT 6 data from Peterka and Black, 1990)



7-50 yrs maintain posture

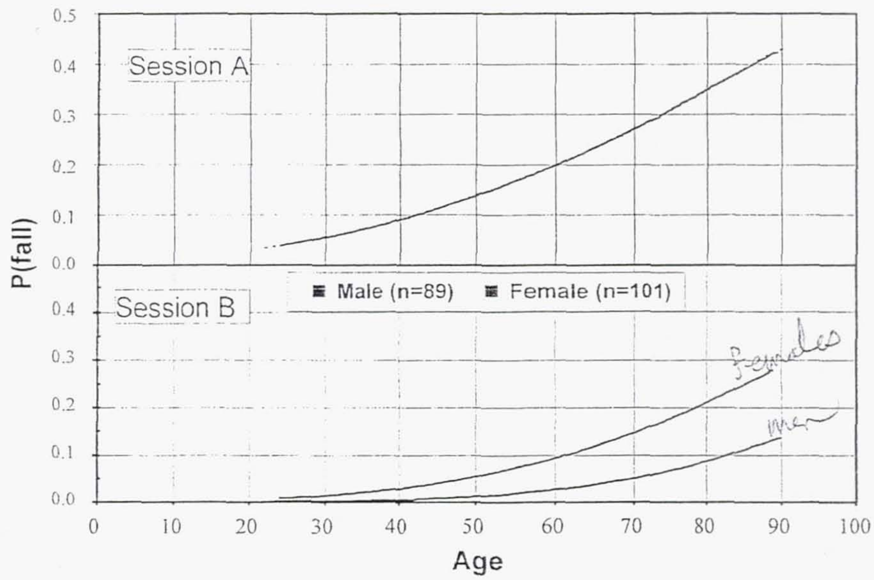
70-80 yr olds ↑ fall

SOT 6 Performance: EQ



20-90 years

SOT 6 Performance: Falls



Probability of falls

multi-system countermeasure?

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

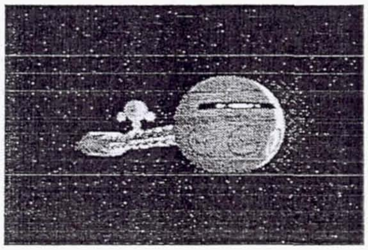
Option 2: Rotational AG

$$F_{\text{centrifugal}} = -m\, r\omega^2$$

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

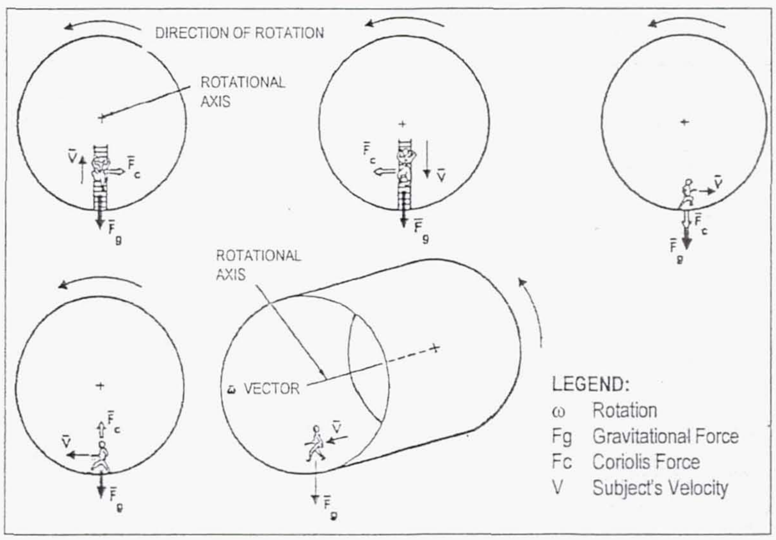
Precedent from the Past:
2001



movie

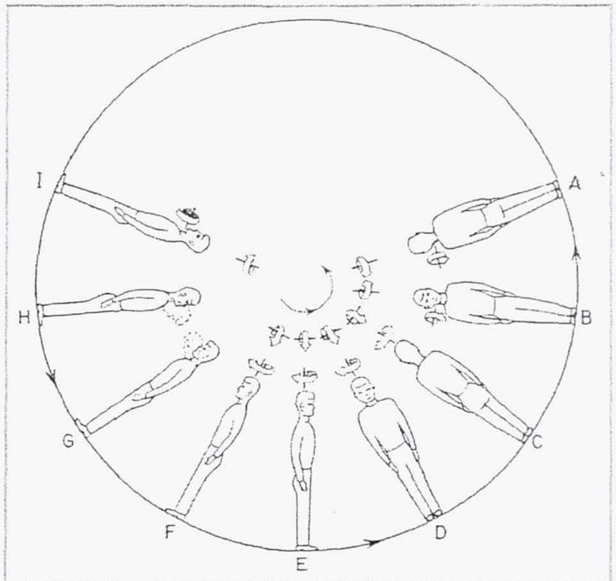
Kubrick, 1968

Physics and Physiology



from Stone, 1970

Physics and Physiology



Objectives

1. Discuss the role of gravity in spatial orientation and balance control.
2. Review the anatomy and physiology of the neuro-vestibular system.
3. Examine the disruption and recovery of sensory-motor function following space flight.

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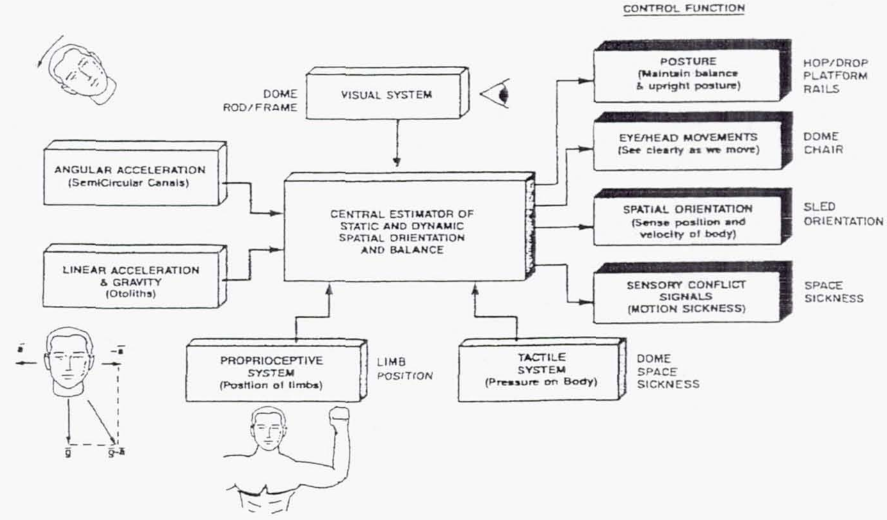
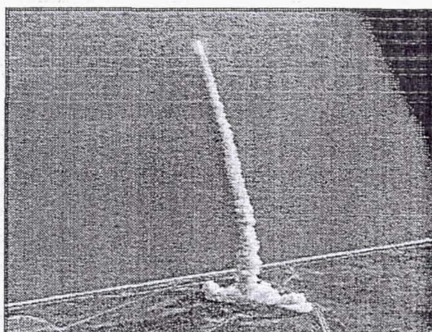


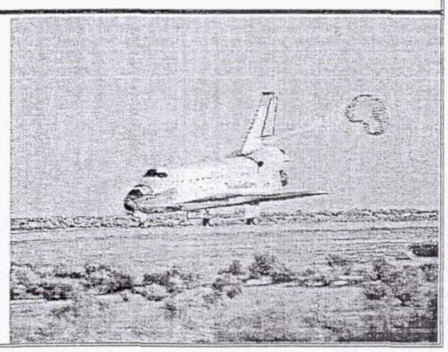
Fig. 1. Scope of the MIT/Canadian Spacelab 1 experiments, by experiment short name, relative to a schematic representation of the role of the vestibular and other senses in control of posture, eye movements and perception of orientation. Experiment short names are keyed to Table 1

Young et al., Exp Brain Res, 1986

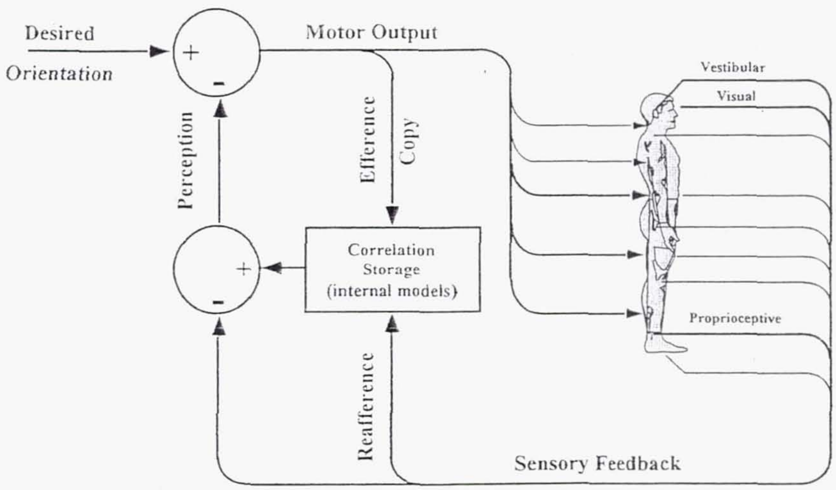


Insertion into orbit removes the fundamental CNS spatial reference and triggers neuro-adaptive processes that optimize performance for the microgravity environment.

Return to Earth reintroduces this reference and triggers neuro-adaptive processes that return performance to terrestrial norms.

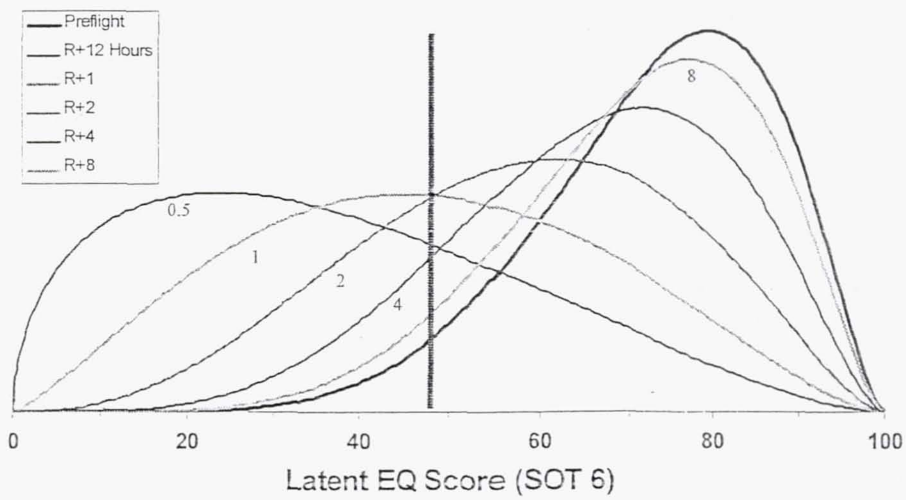


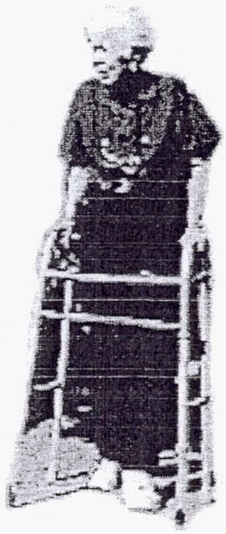
Adaptive Neural Control of Upright Stance



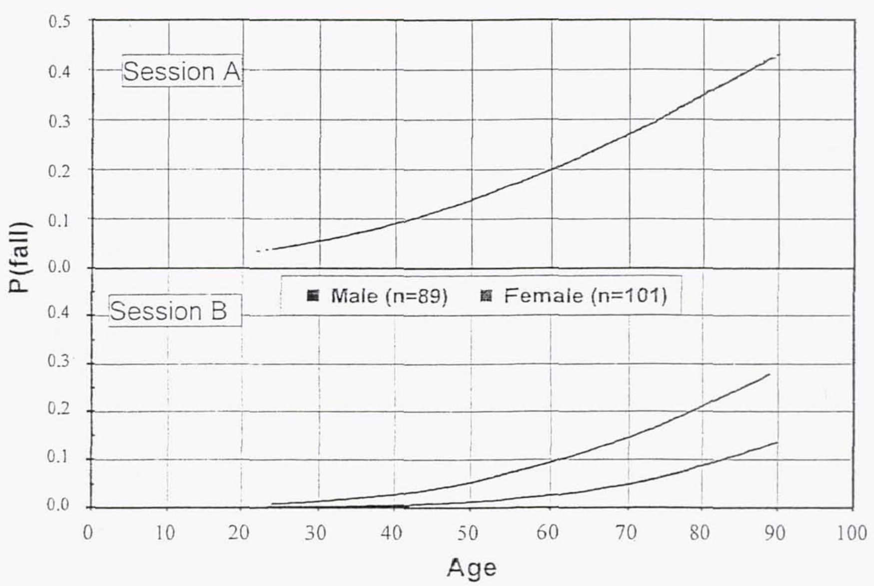
based on Hein and Held (1962)

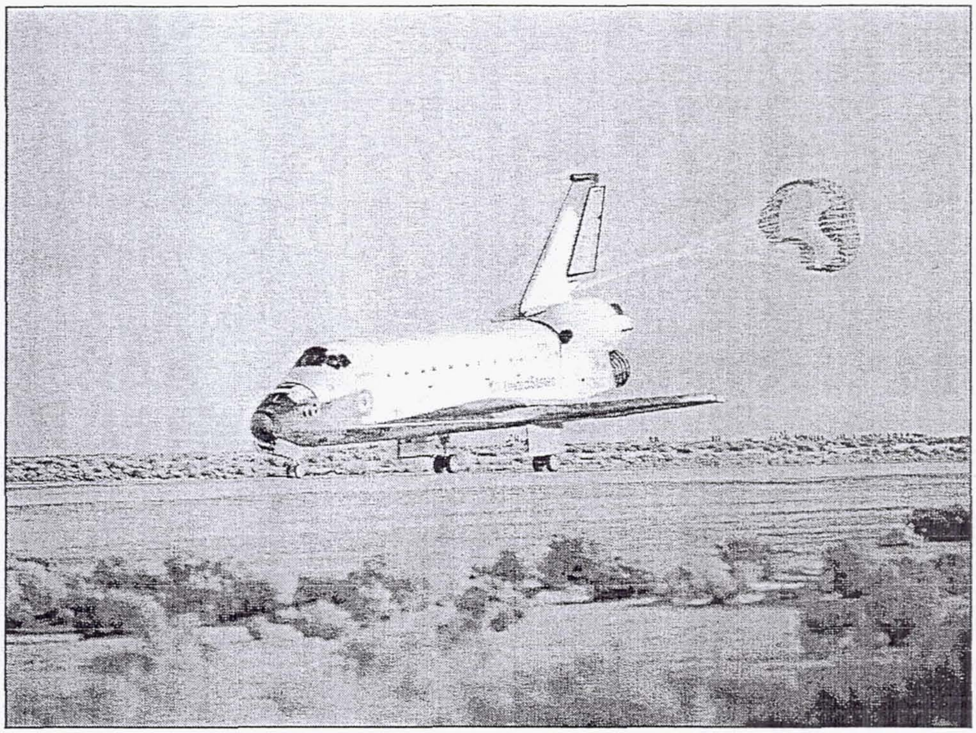
Performance Distributions Following 180-day Missions





SOT 6 Performance: Falls





Forward work to facilitate the next steps in human exploration of space…

- Identify sites and mechanisms of sensory-motor adaptation.
- Determine interactions between sensory-motor adaptation, autonomic system function, and musculo-skeletal function.
- Assess functional risk of sensory-motor adaptation to the success of future missions.
- Develop adequate countermeasures to mitigate the untoward functional risks.

Ground-based venues are unlikely to serve as adequate analogs. Space-based experiment platforms will be required, possibly including animal and human centrifuges to provide artificial gravity.