Neurovestibular/Ocular Physiology

• Anatomy of the vestibular organs
• Proprioception and Exteroception
• Vestibular illusions
• Space Motion Sickness
• Artificial gravity issues
• Eye issues in space flight
Anatomy of the Ear

Vestibular System

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Vestibular Sense Organs

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Sensing Roles of Vestibular Organs

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Semicircular Canal Responses

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Orientation of Semicircular Canals

Ocular Nystagmus

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Otolith Responses

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Ocular Countertorsion

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Categories of Sensing

- **Proprioception** (internal to body)
  - “Self-Sensing”
  - Vestibular (inertial forces)
  - Muscle and tendon sensors (extension)
  - Joint sensors (angle)

- **Exteroception** (external to body)
  - Visual
  - Auditory
  - Cutaneous
Thresholds of Rotational Perception

• Rotational accelerations
  – Yaw: 0.14 deg/sec$^2$
  – Roll and Pitch: 0.5 deg/sec$^2$

• Mulder’s Constant
  – Acceleration $\times$ excitation time = 2 deg/sec
  – 5 deg/sec$^2$ $\times$ 0.5 sec $\rightarrow$ sensed
  – 10 deg/sec$^2$ $\times$ 0.1 sec $\rightarrow$ not sensed

• Rotational velocities - minimum perceived rotation rates 1-2 deg/sec (all axes)
Transfer Function of Semicircular Canals

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Thresholds of Translational Perception

- $a_x: 0.006 \text{ g}$
- $a_y: 0.006 \text{ g}$
- $a_z: 0.01 \text{ g}$
- Apparent change in direction of g vector = $1.5^\circ$
Somatogyral Illusions

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Coriolis Illusion

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Somatogravic Illusion

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Inversion Illusion

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
G-Excess Illusion

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
Vestibular Adaptation to Space Flight

- Otolith Tilt-Translation Reinterpretation (OTTR)
  - Otolith signals are interpreted as translation rather than tilt
  - Decays ~ 1 week post-flight

- Emphasis on visual and proprioceptive cues
  - Field dependent - orient in reference to nearby objects
  - Body oriented - assume world orientation is fixed by body orientation
  - Inversion illusions
Space Motion Sickness

• “Space Adaptation Syndrome”
• 2/3 of astronauts report some effects
• Symptoms
  – Primary: stomach discomfort, nausea, vomiting
  – Secondary: pallor, cold sweats, salivation, depressed appetite, fatigue
• No correlation to susceptibility to motion sickness
• Primary hypothesis: sensory conflict (Treisman’s Theory)
Progression of Space Motion Sickness

From Roy DeHart, Fundamentals of Aerospace Medicine, Williams and Wilkins, 1996
SAS Experience of First 34 Shuttle Flights

First Flight
- None: 24
- Mild: 96

Subsequent Flight
- None: 48
- Mild: 48
- Moderate: 24
- Severe: 24
SAS Experience of First 34 Shuttle Flights

First Flight %

- None
- Mild
- Moderate
- Severe

Subsequent Flight %

- None
- Mild
- Moderate
- Severe
Space Motion Sickness Countermeasures

- Preflight training
  - Desensitization
  - Autogenic feedback training (AFT)
- Pharmaceuticals
  - Oral - scopolamine/dex-amphetamine (Scopdex)
  - Transdermal - scopolamine
  - Intramuscular - promethazine
- Mechanical systems
  - Pressurized insoles
  - Load suits
  - Neck restraints
Artificial Gravity

\[ g_{\text{rotation}} = \omega^2 r \]

- Lunar gravity
- Mars gravity
- 0.5*Earth gravity
- 0.75*Earth gravity
- Earth gravity
Allowable Rotation Rates

• Select groups (highly trained, physically fit) can become acclimated to 7 rpm
• 95% of population can tolerate 3 rpm
• Sensitive groups (elderly, young, pregnant women) may have tolerance levels as low as 1 rpm
Eye Issues in Space Flight

• Early (Mercury / Gemini) astronauts reported hyperacuity on orbit (resolution of cars / trucks / boats) - not verified in controlled conditions
• Recent results indicate some astronauts have noticeable visual degradation on long-term flights - may or may not return to pre-flight conditions post-flight
• Concern for long-term human exploration - lose ability to see well prior to Mars landing?
VIIP Syndrome

- VIIP = Visual Impairment Intracranial Pressure
- Assumed to be due to fluid shift on-orbit
  - Backs of eyes (w/ retina) moved forward towards lenses
  - Choroidal folds (“stretch marks”)
  - Inflamed optic nerves
- About 60% of long-duration crew notice some visual effects
- One crew went from 20/20 to 20/100 in six months - recovered to 20/50 post-flight
- Similar to idiopathic intracranial hypertension, papilledema (optic nerve swelling) on ground
VIIP Diagnosis/Treatment

• Need to monitor intracranial pressure
  – Spinal tap
  – Direct measurement through skull
  – CT scans
  – Looking for flight-compatible bioinstrumentation

• Mitigation: reduce intracranial pressure/fluid shift
  – Lower body negative pressure
  – “Penguin” suits
  – Cerebral-spinal drainage
  – Pharmacological approaches?
References

