Human-machine interaction in virtual reality

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Physics of Motion

1) Used for tracking head/body motion

2) Used by the virtual world generator for rendering virtual scenes

3) Important for understanding vestibular function and perception

Linear motion

- Position -> velocity -> acceleration
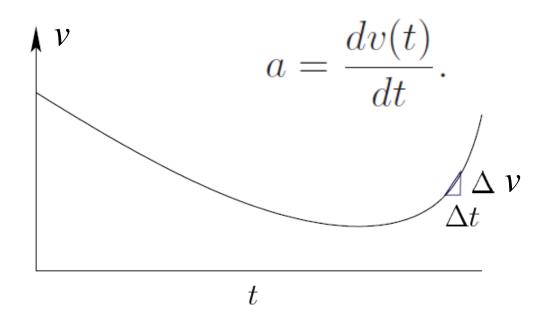
Position to Velocity

- Velocity is change in position over time

y

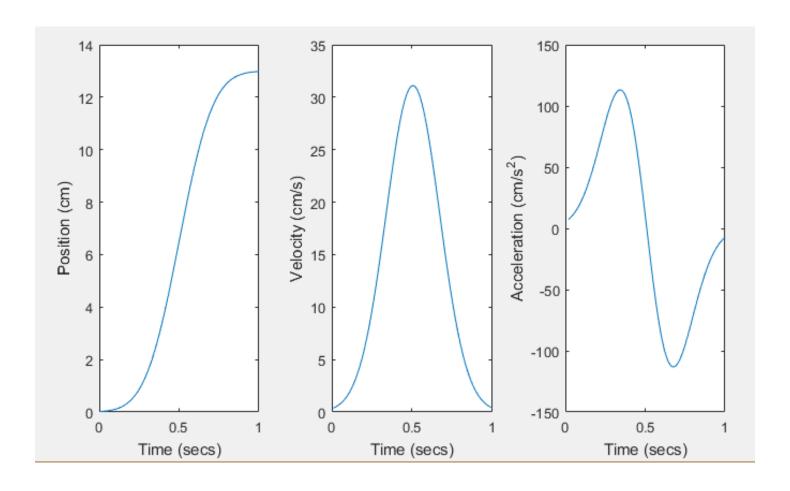- What's the name for this in calculus?

Velocity to Acceleration

- Acceleration is change in velocity over time

$$a = \frac{dv(t)}{dt}.$$

- Rate of change of acceleration?

Position to Velocity to Acceleration
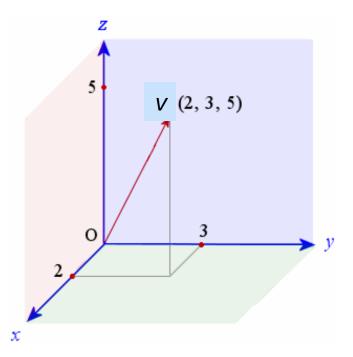
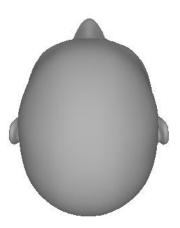- Derivatives and integrals of each other

3D Linear Motion

- Position defined by 3 coordinates (x, y, z)

- Same with velocity (v_x, v_y, v_z)

- Can be represented by a vector:

- Length is 3D speed

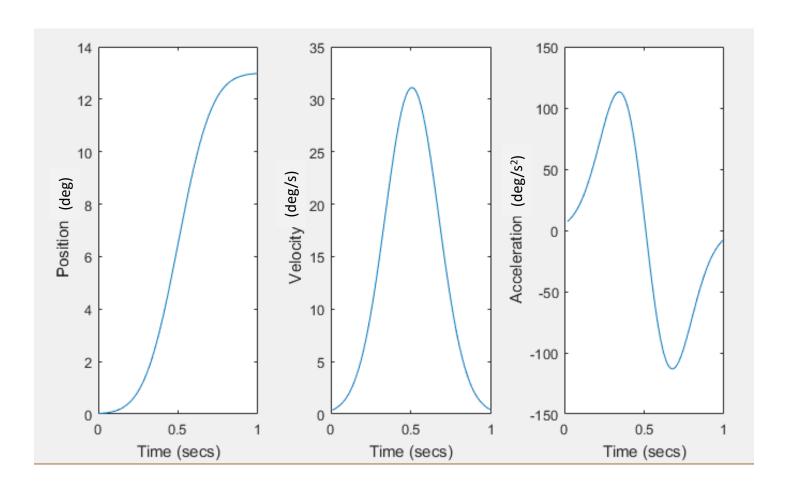$$\sqrt{v_x^2 + v_y^2 + v_z^2}$$

Angular motion

- Position -> velocity -> acceleration

Position to Velocity to Acceleration

- Derivatives and integrals of each other

Position to Velocity to Acceleration

- Angular velocity

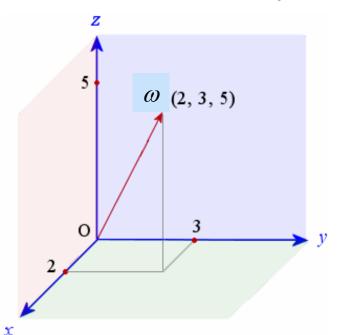$$\omega = \frac{d\theta(t)}{dt}.$$

- Angular acceleration

$$\alpha = \frac{d\omega(t)}{dt}.$$

3D Angular Motion

- Can also be represented as a vector:

- Direction is axis of rotation
- Magnitude is speed of rotation

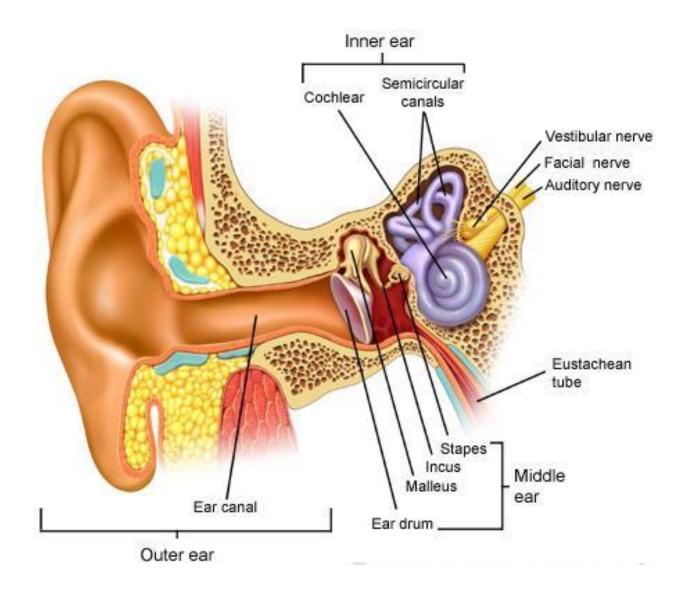$$\sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

Vestibular System

- Inertial measurement units (IMUs) in the head

- Used for:
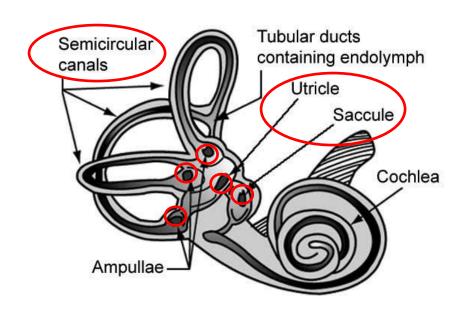
  1) Control of reflexive eye movements

  2) Balance and posture (reflexive and non-reflexive)

  3) Perception of self-motion and position

     - spatial orientation, navigation, spatial constancy, etc.

Location of Vestibular System

Vestibular Organs

- Separate organs for rotation and translation
- Transduce head <u>acceleration</u>
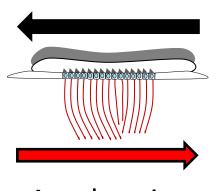
Vestibular Transduction

Semicircular Canals

- Response decays for constant velocity stimulus
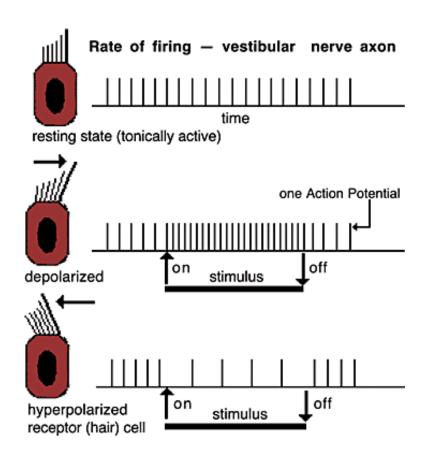- Sensitivity: 1 deg/s

Otoliths

Bending of hairs

Acceleration

- Responds to linear acceleration + gravity
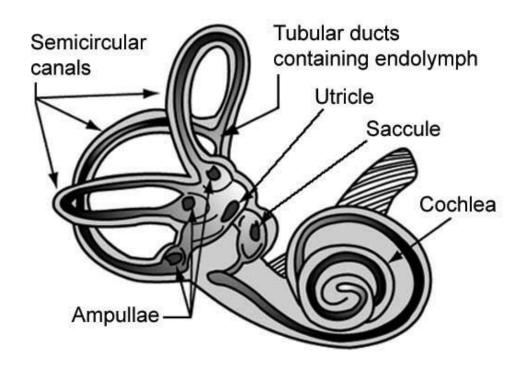- Sensitivity: 5 cm/s^2

Vestibular Transduction

- Each hair sensitive to 1D motion
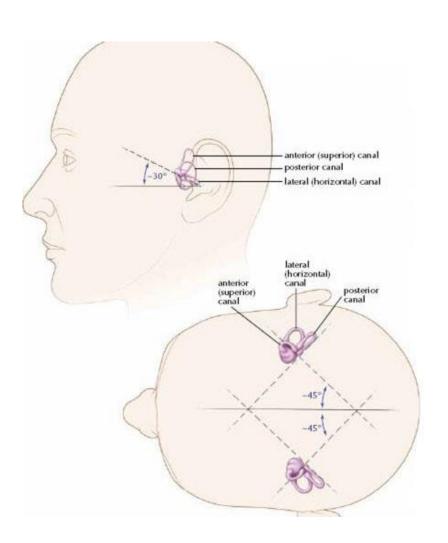
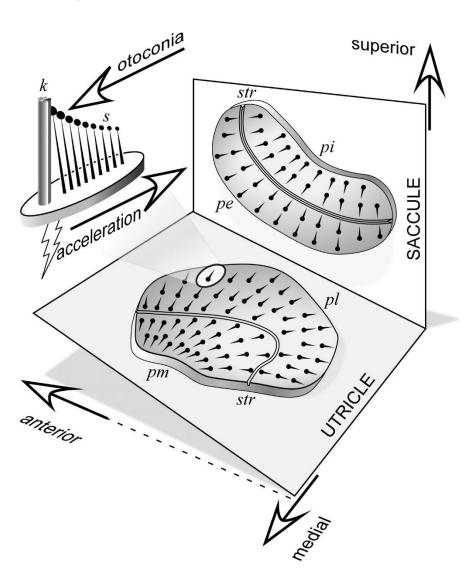# Three Canals, 3 DOF

- Horizontal, Anterior, Posterior

Three Canals, 3 DOF

- Left/right canals paired
- Respond oppositely
- "Push/pull" system
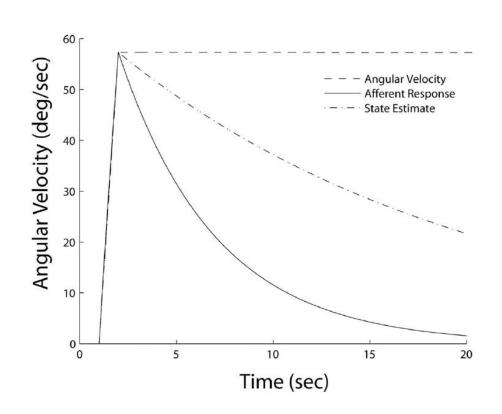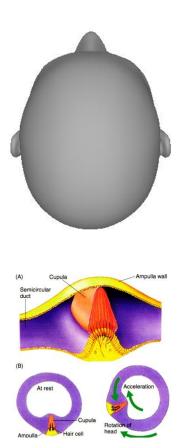 - Unilateral loss lead to sensation of spinning

Otoliths

- 2 Planes
  - Sagittal (vertical)
  - Transverse (horizontal)
- 3DOF

Vestibular Ambiguities
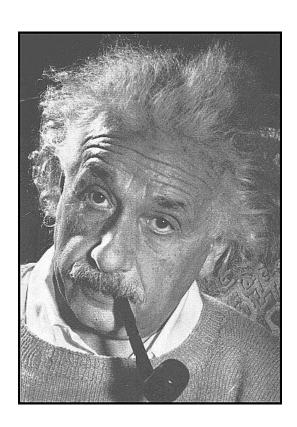
- No response to constant velocity stimulation

MacNeilage, Ganesan, Angelaki (2008) *J Neurophys.*
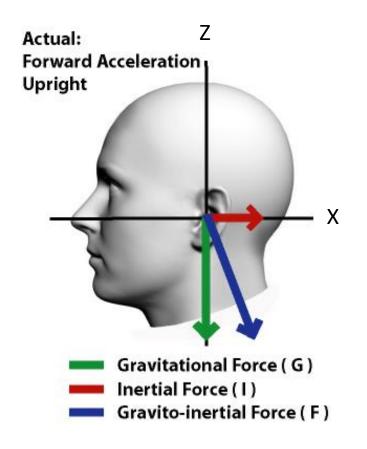
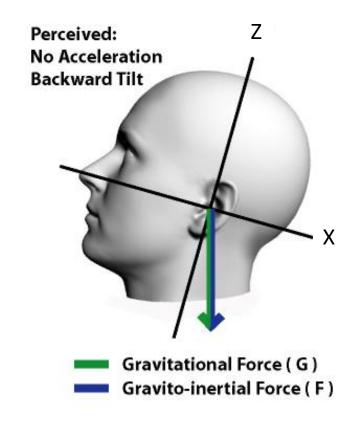# Einstein's equivalence principle

- Gravity and inertial forces due to acceleration are equivalent

- A linear accelerometer can only measure their sum

- Gravito-inertial (GI) force is the sum of forces acting on the body
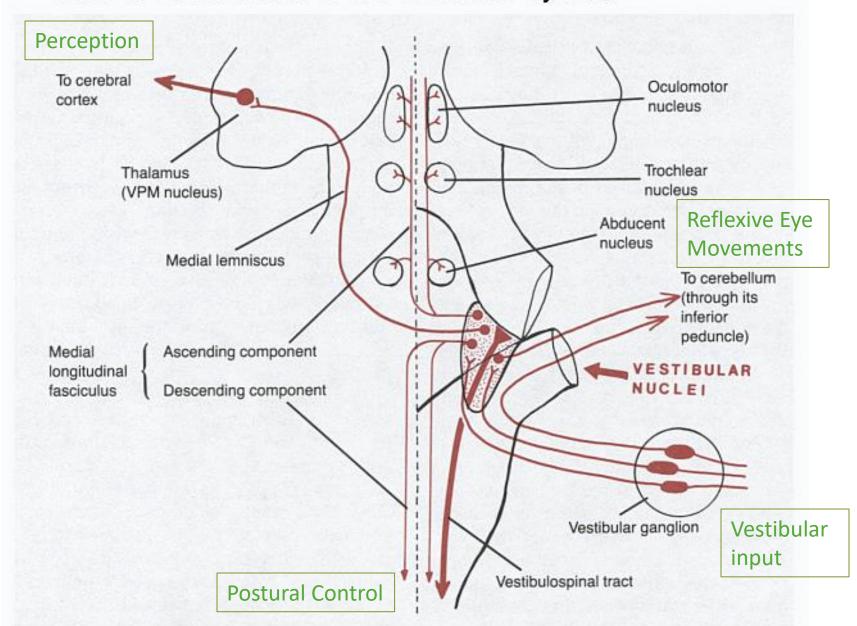
Vestibular Ambiguities

- Somatogravic illusion

MacNeilage, Berger, Banks, Buelthoff (2007) *Exp. Brain Res.*
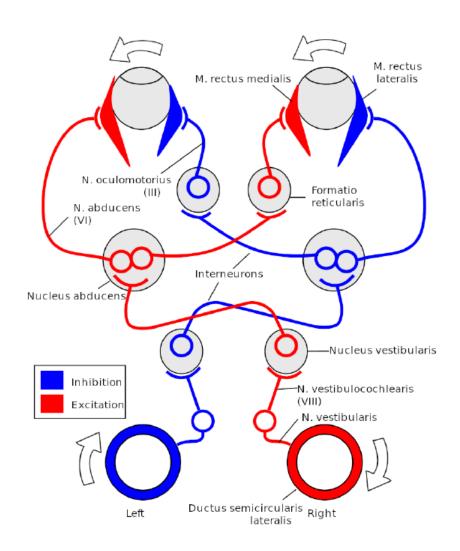
Central connections of the vestibular system

Perception

To cerebral cortex

Thalamus (VPM nucleus)

Medial lemniscus

Medial longitudinal fasciculus
{ Ascending component
Descending component }

Oculomotor nucleus

Trochlear nucleus

Abducent nucleus — Reflexive Eye Movements

To cerebellum (through its inferior peduncle)

VESTIBULAR NUCLEI

Vestibular ganglion — Vestibular input

Vestibulospinal tract

Postural Control

Vestibulo-ocular Reflex

– 3 neurons

– 2 synapses

– 10 ms

Vestibulocollic reflex

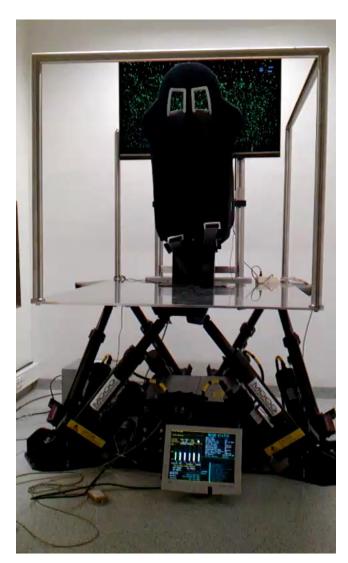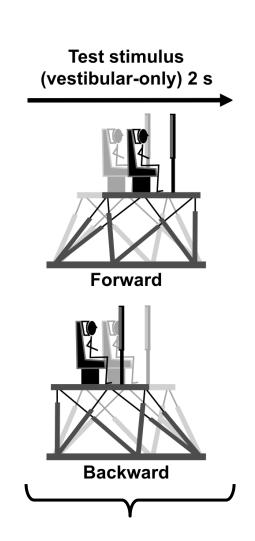# Vestibulospinal (Postural) Reflexes

- Postural reflexes:
  - Projection to "anti-gravity" muscles in the legs

Vestibular Perception

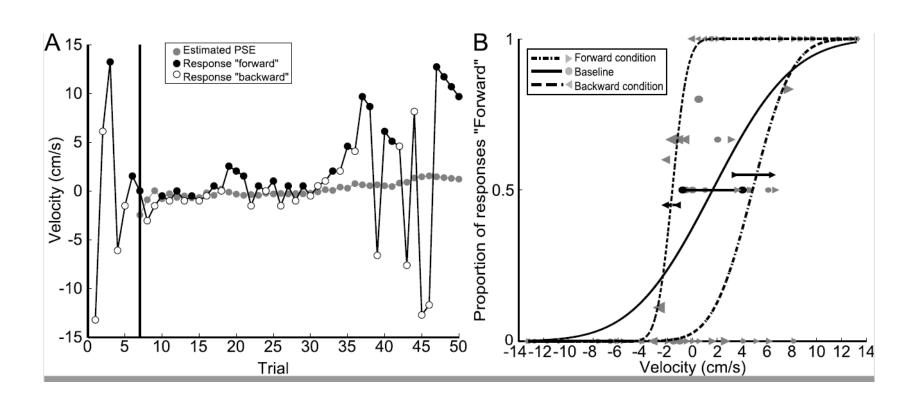**Test stimulus (vestibular-only) 2 s**

Forward

Backward

Task

Did you move forward or backward?

Vestibular Psychophysics

Vestibular Perception - Thresholds

- Rotation (angular) thresholds:
  - Did you rotate left or right?
  - Threshold: ~1 deg/s

- Translation (linear) thresholds:
  - Did you move left or right?
  - Threshold: ~5cm/s^2 , 0.005 G

Relevance for VR

- Self-motion in the real world stimulates both visual and vestibular systems

- In VR, there is often visual self-motion (optic flow) in the absence of vestibular stimulation

Vection
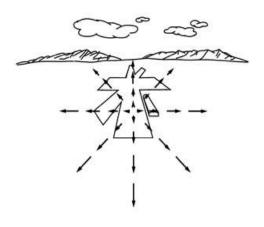
- Sense of self-motion induced by vision only

- This can lead to <u>simulator sickness</u>
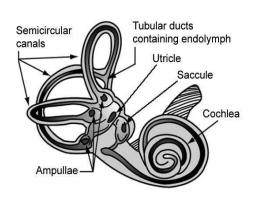
Visual-vestibular Conflict

Visual

$\neq$

Vestibular

- Causes
  - Vehicular travel
  - Visual displays
  - Vestibular dysfunction
- Consequences
  - Dizziness / vertigo
  - Nausea
  - Other physiological responses

Factors that influence vection

- Percentage of field of view covered
- Distance from center of view
- Exposure time
- Spatial frequency in visual scene
- Contrast of visual scene
- Prior knowledge
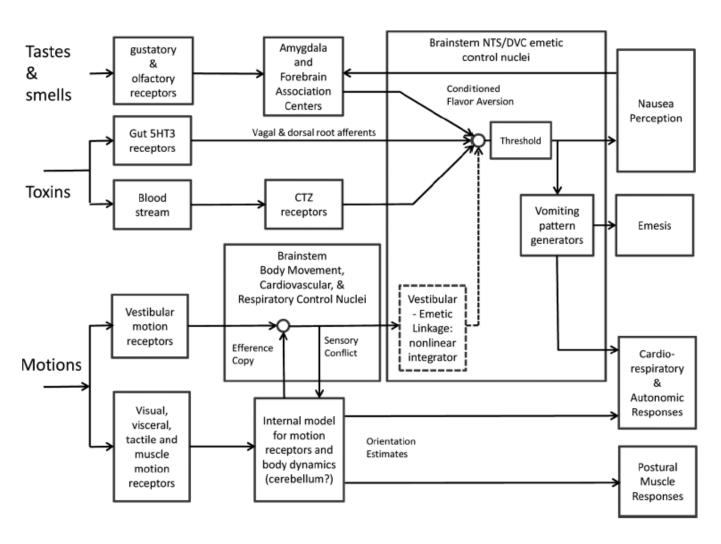- Attention
- Training and adaptation

Why does conflict lead to sickness?

- "Poison" hypothesis
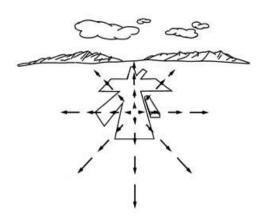
- "Anatomical coincidence" hypothesis

Why does conflict lead to sickness?

Oman 2012

How to avoid simulator sickness?

- Reduce visual optic flow
    - Reduce field-of-view, "tunneling"
    - Used by Google earth

- Artificial vestibular stimulation?
    - Galvanic vestibular stimulation (GVS)
    - Link
    - Probably not practical for VR

How to avoid simulator sickness?

- Simulate motions that are below vestibular threshold
  - i.e. constant or slowly changing velocities (low accelerations)

Factors that influence vection

- Percentage of field of view covered
- Distance from center of view
- Exposure time
- Spatial frequency in visual scene
- Contrast of visual scene
- Prior knowledge
- Attention
- Training and adaptation

How does the brain detect conflict?

- Cue comparison and cue integration covered in upcoming lecture…

- Active area of research in my lab!