Postural Control, Sensory Systems
Biomechanics Lecture
Posture

Posture:
• The orientation of the body relative to the environment
• An inverted pendulum in the field of gravity
Which way is up?

• All animals need to know where ‘up’ and ‘down’ are for movement and balance.

• A *sense of the force of gravity* is essential: an internal construction based on multiple sensory information (visual, somatosensory, vestibular)
Sources of Problems to Posture

- High centre of mass (CoM)
- Multiple joints
- Small support area
Postural Sway: CoM or CoP

Spontaneous Displacement

- Quiet stance with no perturbation
- Spontaneous sway in the Centre of Pressure
Postural Sway: COM or COP
Spontaneous Displacement

Noise or an active search process?

Postural sway *increases* under these conditions:

- closed eyes (importance of a reference frame)
- standing on a narrow support (not *too* narrow)
- age, disorder

Sway *decreases* under these conditions:

- light finger touch (to virtually any part of the body)
- holding an object connected to the external world
Mechanisms that help maintain posture if there is a Perturbation

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Time Delay</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>APAs</td>
<td>&lt; 0 ms</td>
<td>Based on a prediction of a perturbation</td>
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<tr>
<td>Muscle elasticity</td>
<td>0 ms</td>
<td></td>
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<tr>
<td>Monosynaptic rflx</td>
<td>30 ms</td>
<td>Poorly controlled</td>
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<tr>
<td>Polysynaptic rflx</td>
<td>50 ms</td>
<td>Low gain</td>
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<tr>
<td>Preprogrammed rn</td>
<td>70 ms</td>
<td>Approximate correction</td>
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<tr>
<td>Voluntary action</td>
<td>150 ms</td>
<td>Late</td>
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Postural Reflexes

• Any movement of the CoG, even if not immediately threatening to balance, is detected by *afferent* input and opposed by the *contraction of postural* muscles

• Postural reflexes often involve the contraction of *many muscles* all over the body and are therefore more complex than the simple stretch reflex.

• Responses can be initiated by input in *somatosensory, visual or vestibular* pathways.

• The same response can be elicited by *any one* of the inputs OR inputs from one channel may *modulate* the responses due to stimulation of another.

• Different balance strategies may be used dependent on *context, age,* or any *pathology*
Sensory Input and Control

**Sensory Input** activates **postural reflexes** that:

1) Activates supporting musculature

2) Activates muscle synergies to produce correction to perturbation and maintains posture
Role of Sensory Input in Postural Control

Purpose:

- Provides the CNS with information about the direction and magnitude of De-Stabilizing Torques
- Monitors the effects of Internal Stabilizing Torques

Components:

1. Vision
2. Somatosensory
3. Vestibular
1. Visual Input

- **Visual input**: provides information about self vs external movement

- **Visual stimuli** (eye’s retina – thalamus – V1)
  - to parietal-temporal-occipital association cortex (orienting movements in space)
  - to temporal lobe (detecting movement in the environment)
  - to brainstem (coordination of eye/head movements)
  - to other cortical areas, forming

- **Slow system** for movement correction (~200 ms)
Postural Sway Increases With Eyes Closed
Motion of Visual Field Affects Posture

If a standing subject looks at a screen that displays a certain pattern, an accelerated movement of the pattern \textit{towards} the subject induces a sensation of \textbf{moving forward} and a corresponding \textbf{backward sway} of the body.
2. Somatosensory inputs

SENSORY INPUT FROM

- **Muscle Spindles:**
  - length of muscles crossing ankle and joints of foot
- **Joint Receptors:**
  - ankle joint position
- **Golgi Tendon Organs:**
  - variations in tension in leg and foot muscles
- **Mechanoreceptors:**
  - sole of foot for knowledge of distribution of support; light touch with hand
- **Proprioceptors:**
  - providing information about current inter-segmental relationships

Corrections to posture from somatosensory inputs can take ~100 ms

Sensory input to brain via dorsal column medial lemniscal to SI and spinal cerebellar pathways to cerebellum
Importance of tactile information from the feet

- Anaesthesia of the tactile afferents from the feet in dogs
- When the dog was placed on a moving platform it had difficulty resisting the perturbations to balance

Problems of balance in patient groups: diabetics with neuropathy
- Distal sensory neuropathy occurs in 50% of long-term diabetics
- Sensory loss from the feet causes problems with:
  1. Balance and gait, with increased incidence of falls
  2. Excessive postural sway, worsened if no vision
  3. Delayed responses to surface perturbations
  4. Poor scaling of the amplitude of postural reflexes
Light touch and postural sway

- Light touch - input from cutaneous afferents in the fingertips - reduces postural sway, particularly in A-P direction but also M-L direction.
Effect of touch on balance in a patient with diabetic neuropathy

Fig. 3. Medio-lateral (A) and antero-posterior (B) angular velocity of a DM-PN patient and of a control subject (C and D respectively), during stance on foam surface with eyes closed. (Presented are 5–6 s in the middle of a 40-s long trial). X-axis tick marks denote 1 s.
Somatosensory loss and balance

- Ian Waterman: sensory neuropathy below the neck
- Normal vestibular system
- Reliance on visual information for walking and other movements
The sense of gravity

• The brain’s understanding of how the force of gravity moves things
• Particular importance of the vestibular system

• How a ball falls through the air, and how we know when it will arrive in our hands.
• How our body falls

Prediction of our own trajectories and the trajectories of objects moving in the environment
3. Vestibular System - The Inner Ear

The Vestibular System provides information about:

- Head Linear Acceleration (the otolith organs)
- Head Rotation, angular accelerations
- Head Position (semi-circular canals)

Patients with a loss of vestibular function:

- can function almost normally…. 
- so, vestibular system works in conjunction with other sensory systems
The sense of balance

• The vestibular system of the brain and inner ear provides signals related to the **orientation of the head with respect to gravity**

• **Main structures:**

  **Otolith:** Linear movements
  **Semicircular canals:** Angular movements

Locked in the bony structure of the inner ear in close association with the auditory organ, the cochlea, the vestibular organs form two functional units. The two otolith organs sense linear acceleration and its gravitational equivalent, and the three semicircular canals sense rotational movement in space. The hair cells of the utricle and saccule form a two-dimensional array with their cilia embedded in a membrane of dense calcium crystals known as otoliths (‘ear stones’). Movement of the membrane by gravitational or inertial forces maximally activates those hair cells that are aligned with the movement. With the two organs oriented at right angles to each other, the direction of linear acceleration is spatially encoded in three dimensions and the magnitude of the acceleration is encoded by the firing rate. As the head rotates, the inertial force of the fluid in the semicircular canals deflects the cilia of hair cells aligned with the canals, modulating the firing of the afferent nerves. With the three semicircular canals aligned at right angles to each other, rotation in any direction can be resolved.
Standing on a bus

- The otolith organs contribute to a signal of the vertical that the brain’s balance system uses to align the body with gravity.

- The signal of the direction of gravity is also used to align an internal representation of the external space so passenger and trees perceived as upright.

- As the bus leaves the stop, the otolith organs report the total gravito-inertial vector (I), which is tilted due to the addition of a component caused by acceleration.

  - This otolith signal is the correct one for appropriate balance control.

  - Other sensory signals to correctly perceive the world.
Interactions with other systems

• Identical rotations of head evoke identical vestibular signals but the brain interprets the signal according to input from other senses

• If the other senses report the neck, trunk and pelvis turning but the feet remain stationary, vestibular signal contributes to an overall perception of turning.

• When on a swivel chair, vestibular signals alone are sufficient to perceive turning
Galvanic Vestibular Stimulation

- GVS is a technique to understand and isolate the *vestibular contribution to balance*
- Achieved by attaching surface electrodes to the mastoid processes
- Bipolar stimulation applied: a vestibular perturbation to balance
- **Experience of falling towards the cathode** electrode
- The virtual signal of head movement by GVS effects whole body motor control: leading to **reflex EMG responses** in the whole body
- The reflex responses are **dependent on environment**, and concurrent input from other sensory sources.
Sway responses to GVS

• Subjects stood in the central point with the head turned in 1 of 5 positions
• Feet always pointed straight ahead
• Whole-body sway trajectories towards the anodal electrode
EMG responses to Galvanic Vestibular Stimulation (GVS)

- After onset of a step current, short and medium latency EMG responses are observed in upper limb, trunk and lower limb muscles
- Short and medium latency responses are in opposite directions
- Bigger stimulation for a short-latency response
- EMG responses are inverted in antagonist muscles
- EMG will change dependent on other sensory input
Sway responses to GVS

- Sway responses for the pelvis, trunk and head for GVS at 0.5 mA
- Upward traces are with anode-right GVS
- Downward traces are with anode-left GVS
- Body moves towards the anodal side after stimulation
- Greatest tilt always in the head
Falls and the elderly

• Aging often accompanied by a reduction in the ability to control automatic movements, including posture and gait

• 1.8 million falls in the US amongst an elderly population result in medical treatment

• Sixth leading cause of death in over 65 age group
Control of Posture with Aging

• Concurrent loss of strength and reduction in balance exaggerates functional impairments

• All sensory systems (vestibular, visual and somatosensory) decline with age

• Elderly fallers have greater AP sway and EMG activity in leg muscles than young adults during quiet standing

• Response of elderly to balance perturbations slower and involves greater muscle activity
Movement Control in the Elderly

• Postural stability more reliant on sensory (visual cues)

• With eyes-closed, increase in postural sway and asymmetry of loading between the legs

Fig. 3. Limb load asymmetry (LLA) factor (mean ± SD) while standing with eyes open (EO) and eyes close (EC) in young and elderly groups.
What Is Necessary to Maintain Posture?

- Adequate perception of a reference point or reference vertical
- Light touch reduces postural sway, even at very low-contact forces.
- Timely generation of appropriate muscle torques
- Control of posture under external and internal perturbations
Recommended Reading