Sensorimotor Control

Day 1
- Introduction (SCOTT)
- Whole-Body Postural Control (TING)
  - Motor redundancy
  - Mechanical-Neural Control

Day 2
- Upper Limb Movements (SCOTT)
  - Primary Motor Cortex
  - Optimal Feedback Control
- Mathematics of Optimal Feedback Control (CREVECOEUR)
- Muscle Synergies (TING/SCOTT)
COSMO: Sensorimotor Control

Dr. Stephen Scott
Botterell Hall, Room 219
e-mail: steve.scott@queensu.ca

The 3 Bs of Motor Control

Introduction
1. The Limb Matters Damn it!
2. Somatosensory System
3. Motor Circuits

Brains

Biomechanics

Behaviour
Behaviour

Reach for a cup

Navigate crowded pub

Reach up and stop a puck wearing hockey equipment

Get a touchdown
Perspectives on the Motor System

Limb-centric

Brain-centric
The Motor System

Equally Important & Intimately Linked
Properties of the Motor Periphery

1. Motor Units
2. Muscle Mechanics
3. Limb Mechanics
4. Muscle Anatomical Action
Final Common Motor Output
Motor Unit = 1 motoneuron + innervated muscle fibres
Two ways to Increase Muscle Force Output

Increase Firing Rate  Motor Unit Recruitment

(A) Single muscle twitches (5 Hz)  (B) Temporal summation (20 Hz)

(C) Unfused tetanus (80 Hz)  (D) Fused tetanus (100 Hz)

NEUROSCIENCE, Fourth Edition, Figure 16.8

NEUROSCIENCE, Fourth Edition, Figure 16.9
Muscle Mechanics

Muscle Force-Length Relationship
Muscle Mechanics

Muscle Force-Velocity Relationship

Isometric Force (V=0)

Force Output

F0

Lengthening

0

Shortening

Vmax

Velocity

Power Output

Force

Power = Force * Velocity

Force-Velocity

Velocity of Shortening

Pedalling Velocity

80

120
Musculoskeletal Anatomy

Biceps
Brachialis
Brachioradialis

Muscle Anatomical Action
Limb Mechanics

\[ \tau_s = I_s \ddot{\theta}_s \]
\[ \tau_s = I_s \ddot{\theta}_s \]

\[ \tau_e = \ddot{\theta}_e \left( I_e + \frac{m_e l_e^2}{4} \right) + \dot{\theta}_e \left( I_e + \frac{m_e l_e^2}{4} + \frac{m_e l_e l_s}{2} \cos(\theta_e) \right) + \left( \frac{m_e l_e l_s}{2} \dot{\theta}_e^2 \sin(\theta_e) \right) \]

\[ \tau_s = \ddot{\theta}_s \left( I_s + I_e + m_e l_e l_s \cos(\theta_e) + \frac{m_e l_e^2 + m_s l_s^2}{4} + m_e l_e^2 \right) + \dot{\theta}_e \left( I_e + \frac{m_e l_e^2}{4} + \frac{m_e l_e l_s}{2} \cos(\theta_e) \right) - \left( \frac{m_e l_e l_s}{2} \dot{\theta}_e^2 \sin(\theta_e) \right) - \left( m_e l_e l_s \dot{\theta}_e \dot{\theta}_s \sin(\theta_e) \right) \]
Uncoupling of Joint Motion and Torque
Neuroscience 324: Systems Neuroscience
Motor Systems I: Limb Biomechanics

1. Motor Units
2. Muscle Mechanics
3. Limb Mechanics
4. Muscle Anatomical Action
Somatosensory System

For perceiving properties of objects

- Lateral Motion (Texture)
- Pressure (Hardness)
- Static Contact (Temperature)
- Unsupported Holding (Weight)
- Enclosure (Global shape)
- Contour Following (Global shape)

For motor action

Lederman, Psychology, Queen’s University
Cutaneous Receptors

Merkel’s Discs

Free Nerve Endings

Meissner’s Corpuscle

Hair Follicle Receptor

Pacinian Corpuscle

Ruffini’s Ending

Free Nerve Endings: Pain, Temperature
All Other Receptors: Touch
Muscle Spindles:
Muscle length and velocity

Intrafusal muscle fiber

Extrafusal muscle fibers

Capsule (connective tissue) surrounding spindle

Axons of γ motor neurons

Group I and II afferent axons

Axon of α motor neuron

Golgi Tendon Organs (GTOs)
Muscle force

Extrafusal muscle fibers

Capsule

Axonal Ib afferent

Axon

Collagen fibrils

Tendon

*NEUROSCIENCE, Fourth Edition, Figure 9.7*
Somatosensory Humunculus
Somatosensory Cortex Important for Motor Skills

Lesion in Somatosensory Cortex

ipsilateral hand

Contralateral hand
Somatosensory Cortical Processing

Proprioception:
- Position sense,
- Kinesthesia (sense of motion),
- Sense of effort

Touch:
- Stereognosia (identify objects)
- Graphesthesia (letters written on hand)
Parietal area 5

Distal-type neurons

(a) (b) (c) (d)
Before tool-use After tool-use Passive holding

Proximal-type neurons

(e) (f) (g)
Before tool-use After tool-use
Somatomotor System

Cortex: Voluntary Control

Lateral Motor System

Medial Motor System

Brainstem: Postural Control

Spinal Cord: Basic Reflexes and Locomotor Pattern
Spinal Circuits

Basic Reflexes

- Cutaneous afferent fiber from nociceptor (Aδ)
- Motor neuron
- Extensor muscle
- Flexor muscle
- Stimulated leg flexes to withdraw
- Opposite leg extends to support
- Cutaneous receptor

Basic Locomotor Pattern

(C)

- Extensors
- Flexors

(stance)  (swing)

Level of transection of spinal cord

*NEUROSCIENCE, Fourth Edition, Figure 16.15 (Part 3)*
Reticulospinal Tract

Primary somatic sensory cortex
Primary motor cortex
Premotor cortex

Cerebrum

Brainstem

Reticular formation
Reticulospinal tract

Medullary and Pontine

Spinal cord

Integration of Postural Control with Voluntary Motor Action and Locomotion

Biceps EMG

Gastrocnemius EMG

Time (ms)

TIME (ms)

NEUROSCIENCE, Fourth Edition, Figure 17.4
Corticospinal Tract

- Internal capsule
- Cortex
- Corticospinal and corticobulbar tracts
- Cerebral peduncle
- Midbrain
- Red nucleus
- Trigeminal motor nucleus (V)
- Hypoglossal nucleus (XII)
- Pontine fiber bundles
- Middle pons
- Middle medulla
- Pyramid
- Pyramidal decussation
- Caudal medulla
- Lower motor neuron
- Ventral corticospinal tract
- Lateral corticospinal tract
- Spinal cord
Primary Motor Cortex

Largest contribution to corticospinal tract

Betz cells (large corticospinal cells)

Corticomotoneurons
- directly synapse on motoneurons
- predominantly distally limb musculature

Motor Humunculi
- large face and hand representations

Volitional motor control
- highly dextrous movements

Contralateral

Blumenfeld
Figure 6.2
Corticospinal Tract:
Motor Regions target Intermediate and Ventral Horn
Sensory Regions target Dorsal Horn

Supplementary Motor Area
Premotor Cortex
Primary Motor Cortex
Central Sulcus
Somatosensory Cortex
Parietal Area 5
Posterior Parietal Cortical Areas
- Multi-Sensory Integration
- Motor Planning

Somatosensory Cortex
Parietal Association Cortex

Visual Information (where)

Blumenfeld Figure 6.1

Patient dwgs
dorsal Premotor Cortex
Mirror Neurons: cells that only fire when someone else is acting
Supplementary Motor Area
- motor imagery
- bimanual
- motor sequences

Premotor Cortex
- selection of action
- sensory to motor associations
- green light/proceed, red light/stop
- observation of action

Blumenfeld
Figure 6.1
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1. The Limb Matters Damn it!
2. Somatosensory System
3. Descending Motor Systems

The 3 Bs of Motor Control

Brains

Behaviour

Biomechanics