Course goal

- Explain the processes involved in neural communication that allow for cell-cell signaling, muscle force production, involuntary and voluntary movement, and locomotion.

Action Potential Generation & Signaling

Vocabulary

Ohm's Law (V=IR)	current (I)	resistance (R)
conductance (g)	potential difference (V)	capacitance (C)
time constant (tau)	length constant (lambda)	patch-clamp
voltage-clamp	reversal potential	

By the end of the course, students are expected to achieve the following set of principles and learning goals:

1. **Current is generated and flows around electrical circuits.**
   a. Using Ohm's Law, calculate and predict how current, resistance/ conductance, and potential difference change in relation to each other.
   b. Interpret/create graphical relations among the variables in Ohm's Law.
   c. Predict how potential difference, number of charges, and capacitance change in relation to each other.
   d. Draw an electrical circuit that includes each of the following variables and identify the analogous structure in the cell membrane.
      i. conductor
      ii. capacitor
      iii. battery
      iv. current generator
      v. switch
      vi. pump
   e. Given a diagram of an electrical circuit (in series or in parallel) determine the direction of current flow.

2. **Ion channels and driving forces establish equilibrium potentials (Ex) and the resting membrane potential (Vm).**
   a. Calculate the net driving force or the equilibrium potential for an ion, and the resting membrane potential of a cell.
   b. Given a scenario, determine the direction (inward or outward) of the electrical, chemical, and/or net driving forces.
   c. Given a set of data predict the direction of the current (net or ionic) due to electrical, chemical and net driving forces.

d. Given a change in the following variables predict how each influences current flow across the membrane.

   i. net driving force
   ii. permeability
   iii. equilibrium potential
   iv. resting membrane potential

3. Passive neuron properties influence current (I) and the change in membrane potential (ΔVm).

a. Given a set of data, analyze and predict the relations among membrane potential, membrane conductance, current, and the involved ion channels.

b. Predict how differences in size and charge distribution between neurons influence their electrical properties.

c. Calculate time constant, length constant, input resistance and/or input capacitance to determine when and where signals will decay in a neuron.

d. Predict and/or analyze how differences in the passive properties of neurons influence current, membrane potential, time and length constants and local graded potentials.

4. An action potential is generated and propagated when the change in membrane potential exceeds voltage threshold.

a. Distinguish between data obtained with the patch-clamp and voltage-clamp techniques.

b. Graph, predict and/or analyze voltage-clamp data to:

   i. calculate input conductance
   ii. determine the amplitude, direction, and type of currents.

c. Given a scenario, identify the influence of concentration gradients, membrane permeability and voltage gated ions channels on the:

   i. action potential
   ii. rate of action potential generation
   iii. refractory state

d. Given a scenario, determine the factors that can modulate the different phases and propagation of an action potential. Consider the influence of concentration gradient, net driving forces, membrane permeability, and active ion transport

e. Compare and contrast intracellular and extracellular stimulation and recordings of action potentials.

5. **Signaling between neurons occurs via synaptic contacts.**
   a. Compare and contrast the structure, function, and signal characteristics of electrical and chemical synapses.
   b. Given a scenario, identify the type of ion channel in a given functional region of a neuron.
   c. Predict and/or analyze reversal potential data.
   d. Determine how changes in the factors that control neurotransmitter release in the synaptic cleft influence postsynaptic activity.
   e. Explain how activation of ligand-gated receptors can elicit different responses in postsynaptic neurons.

6. **Neuronal properties and signals can be modulated.**
   a. Compare and contrast metabotropic and ionotropic receptors.
   b. Describe changes mediated by second messengers and predict how these influence pre- or postsynaptic excitability and function.
   c. Given a scenario/data, determine how the activity of pre- or post-synaptic neurons has been modulated.
   d. Identify the mechanisms responsible for altering the effectiveness of synaptic transmission.

Motor Units and Muscle Action

Vocabulary

recruitment threshold
orderly recruitment
rate coding
force task
position task

1. **The motor unit is the final common pathway for the neuromuscular system.**
   a. Explain why the motor unit is described as the final common pathway.
   b. Given data on motor unit anatomy, calculate innervation numbers and predict motor unit forces.
2. **Motor units exhibit a range of physiological properties.**
   a. Distinguish between the methods used to measure motor unit properties (speed, strength of contraction, fatigability).
   b. Given data on motor unit properties (speed, strength of contraction, fatigability), determine the type of motor unit.
   c. Describe the distribution of properties across a motor unit population.
   d. Defend or refute the statement that type I muscle fibers are slow twitch and type II muscle fibers are fast twitch.
   e. Given data on multiple muscle fibers, motor units, or muscles, explain any difference in force they exert.
3. **Muscle force is controlled by motor unit recruitment and rate coding.**
   a. Predict and/or analyze how the following (individually or collectively) influence muscle force production and/or contraction speed.
      i. input conductance (resistance) of a motor neuron
      ii. recruitment threshold of the motor unit
      iii. orderly recruitment
      iv. rate coding
4. **Motor unit properties are adaptable.**
   a. Given data from a force or position task, determine the factors that influence the variation in the time to failure for motor units..
   b. Predict how motor unit recruitment and rate coding are modulated to accommodate changes in the force capacity of muscle (for example: during fatiguing contractions.
   c. Given adaptations in motor unit anatomy and physiology during aging, training (exercise), and/or neurological diseases, predict the changes that would occur in clinical measures of neuromuscular function.

Spinal Reflexes

Vocabulary

muscle spindles	group 1a afferent	group 1b afferent
tendon organs	Hoffmann (H) Reflex	state dependent modulation
phase dependent modulation	feedback control	feedforward control

1. **Muscle force is controlled by feedback and feedforward signals.**
    a. Given data on a movement, predict whether a performance involved either feedback or feedforward control.
2. **Sensory receptors provide feedback about muscle force and length.**
    a. Distinguish between the type of feedback provided by tendon organs and muscle spindles, and explain why/how each sensor provides its type of feedback.
    b. Explain how the feedback provided by muscle spindles can be modulated, and describe when and why this occurs.
3. **Reflex pathways provide rapid feedback to motor neurons and interneurons.**
    a. Given a scenario, describe/draw the pathway by which stretch of a muscle alters the motor neurons innervating agonist and antagonist muscles, and how this pathway can be modulated.
    b. Given a scenario, describe how feedback transmitted by group Ia and Ib afferents influences motor neuron activity.
    c. Explain how variation in stimulus intensity influences the amplitude and duration of M waves and Hoffmann (H) reflexes
4. **Afferent feedback is modulated during voluntary contractions.**
    a. Given data on a movement, predict whether or not it would involve state- or phase-dependent modulation of reflexes.
    b. Given changes in the amplitude of the H reflex, determine the strength of modulation by the afferent input.
    c. Given data on changes in reflex responses during a prescribed task, predict the changes responsible for altering the reflex response.
5. **Reflexes are adaptable.**
    a. Determine if the difference in time to failure between the force and position tasks is caused by adjustments in the spinal cord or motor cortex.
    b. Explain why the change in the amplitude of the H reflex during the position task differs from that during the force task.
    c. Identify interventions that can be used to improve muscle function in individuals with a spinal cord injury.
    d. Analyze data on the amplitude and timing of M waves and H reflexes to determine the underlying neuromuscular disease.

Locomotion

Vocabulary

locomotor rhythm	half-center model	descending input
sensory input	visual	vestibular

1. **Locomotion is controlled by patterns of neural activity produced by a locomotor neural network.**
   a. Describe the different modes or gates of locomotion.
   b. Explain the biomechanical differences in the motor programs for walking and running.
2. **The essential locomotor rhythm is produced by the spinal cord.**
   a. Identify the experimental conditions underlying the conclusion that the locomotor rhythm is produced by the spinal cord.
   b. Illustrate a model that shows the interaction of reflex pathways receiving continuous input to allow for alternating activation of muscles.
   c. Describe the conditions that enable a human to recover the ability to walk after a spinal cord injury.
3. **Central pattern generators are networks of neurons that produce rhythmic outputs.**
   a. Explain how differences in neuronal properties can contribute to locomotor rhythms.
   b. Given a neural circuit that can produce an alternating rhythm (half-center model), determine the interactions or activity among the neurons required to produce a locomoter rhythm.
4. **Locomotor rhythms are modulated by descending and sensory inputs.**
   a. Given a scenario, explain how feedback from muscle spindles and tendon organs can influence the locomotor cycle.
   b. Describe how descending or sensory input systems (visual or vestibular) can influence locomotion.
   c. Defend the statement that changes in locomotion are produced by changes in the patterns of neural activity and not in the neural networks that produce the patterns.
   d. Distinguish the roles of the basal ganglia and the cerebellum in the control of locomotion.

Voluntary Actions

Vocabulary

target-centered coordinate system	fixation-centered coordinate system	difference vector
cross education		

1. **There are direct and indirect descending pathways to the spinal cord.**
   a. Given the connections within the motor system, describe the types of signals needed to perform a voluntary action.
2. **Neural networks compute difference vectors, develop motor plans, and adjust activation signals to perform reaching and pointing actions.**
   a. Given data on the location of a target and a fixation-centered coordinate system, calculate the difference vector to reach the target.
   b. Describe the input-output functions of the networks that transform a difference vector into a motor plan.
   c. Identify the origin of the error signal when the movement does not go as planned and describe how the adjustment is generated.
   d. Analyze patterns of EMG activity to infer the motor strategies used to perform reaching, pointing, and grasping actions.
3. **Increases in muscle strength always involve adaptations in the activation of muscle by the nervous system.**
   a. Defend or refute the statement that the strength of a muscle depends on more than just its size.
   b. Given data on reflexes and evoked responses, identify the source of the adaptations in the nervous system that accompany increases in muscle strength.
   c. Predict the types of changes in muscle activation that can influence the strength of the muscle.
   d. Determine how transcranial magnetic stimulation can be used to identify the mechanism of action responsible for cross education.