Electromyography: Physiology

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Nervous System

- **Central Nervous System** *(cerebellum, cerebrum, brain stem, spinal cord)* – conscious control, motor programs

- **Peripheral Nervous System** *(afferent and efferent motor nerves, various sensory organs)* – reflex control, sensory feedback
  - **Somatic nervous system** – connect with skeletal muscles

- **Muscles can be excited (contracted) by either system**

- E.g., messages can travel from motor cortex directly to \( \alpha \)-motoneurons via pyramidal nerve cells in spine,

- Or a stretched muscle (tendon tap) can send a message via Ia-afferent nerves attached to muscle spindles directly to \( \alpha \)-motoneurons to cause a reflex contraction
Central Nervous System

Pyramidal nerves (or corticospinal nerve tract)
- carry messages from motor cortex to grey matter (anterior or ventral horns) in spinal cord
- fastest conduction speeds
- most cross from one side of brain to opposite side of body at the medulla oblongata
- synapse directly with alpha-motor nerves but most synapse through interneurons
Peripheral Nervous System

Efferent nerves
- excite muscles to contract directly (alpha motoneurons) or indirectly (gamma motoneurons)

Afferent nerves
- carry sensory messages to brain or to motor nerves

Muscle Spindles
  » sense stretch and velocity

Golgi Tendon Organs
  » sense force in the tendons

Interneurons
- carry messages from one nerve to another
  - usually inhibitory
Muscle Spindles

Muscle spindles (γ-efferent nerves)

- have excitable muscle fibres called intrafusal fibres that allow spindle excitability to be modulated
- in parallel with muscle fibres
- act primarily to excite muscles to contract via direct connection with alpha motor nerves and indirectly relax muscles to inhibit contractions of opposing muscles
Muscle Spindles

• Muscle Spindles (Ia- and II-afferents)
  – When a muscle is stretched, spindles send messages to the spinal cord via Ia-afferent nerves that can cause the same muscle to respond with a contraction, called the stretch or myotatic reflex
  – Ia-afferents sense both muscle length and velocity changes
  – Secondary II-afferents sense degree of stretch but not velocity
Golgi Tendon Organs

Golgi Tendon Organs (Ib-afferent nerves)
- located in tendons and thus are able to sense tension changes
- in series with muscle fibres
- transmit signals to brain via Ib-afferent nerves
- act primarily via interneurons to prevent tearing of muscle by inhibiting contractions
Reflexes (Examples)

Stretch Reflex (monosynaptic, myotatic) are fastest skeletal reflexes since there are no interneurons

- cause a stretched muscle to contract
Reflexes (Examples)

Flexion Reflex *(nociceptive withdrawal reflex)* use an interneuron and act to cause flexor muscles to contract after a painful or hot stimulus.
Reflexes (Examples)

Crossed-extensor Reflex. -occur to extensors causing relaxation when a flexor is contracting

Tonic Neck Reflex. -flexion of neck facilitates flexor muscles of extremities; neck extension does vice versa

Long-loop Reflex (AKA functional stretch reflex, transcortical reflex). -acts like the stretch reflex but takes longer and is trainable. Is part of the reason that prestretching a muscle (via a counter-movement) creates a stronger contraction.
Motor Unit

• One \( \alpha \)-motoneuron plus all the muscle fibres it enervates

• Innervation ratio varies with number of fibres per motor unit (large leg muscles have many fibres per motoneuron for stronger responses, facial and eye muscles have few fibres and therefore permit finer movements but weaker contractions)
All-or-none and Orderly Recruitment

- **All-or-none rule** – once a motoneuron fires all its muscle fibres must fire.

- **Graded muscle responses** occur because of orderly recruitment of motor units, i.e., lowest threshold motor units fire first followed by next lowest threshold. Highest threshold and strongest motor units fire last.
Motor Unit Action Potential

- When an action potential reaches the muscle at localized motor points (innervation points) the sarcoplasmic reticulum and t-tubule system carry the message to all parts of the muscle fibre.
Motor Unit Action Potential

- A rapid electrochemical wave of depolarization travels from the motor point causing the muscle to contract
- Followed by a slower wave of repolarization and a brief refractory period when it cannot contract
- The wave of depolarization can be sensed by an electrode and is called the electromyogram (EMG). The repolarization wave is too small to detect.
Electrodes

• A surface electrode detects the wave of depolarization as it passes below.
• As the wave approaches, the voltage increases; as it passes underneath the voltage goes to zero; finally as it departs the voltage reverses polarity and gradually declines.
• This yields a biphasic signal.
• The biphasic signals are so small that other electrical signals from the environment (called interference) mask them.
• Solution is to use a differential amplifier.

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Differential Amplifier

- Subtracts one signal from another.
- By placing two electrodes in series over the muscle, the wave of depolarization passes under each electrode one after the other but with a slight delay.
- Subtracting the two electrode signals from each other makes any common signal disappear and identical biphasic signals that arrive at different times become a triphasic signal.
- This is what we call the electromyogram (EMG).
Differential Amplifier

- EMG1 under electrode 1

- EMG2 under electrode 2 has a slight delay

- EMG1–EMG2 is the triphasic EMG signal
Electromyogram

• Each motor unit’s wave of depolarization may be detected by the electrode pair and will have approximately the same shape if the electrode stays at the same place with respect to the muscle. Thus, it is possible to detect the recruitment of single motor units.

• In most contractions, however, there are many motor units some large, some small, some close and some far from the site so it is usual impossible to tell how many are firing and which fibres are firing (large vs. small).

• But, EMGs may be used to roughly estimate the level of recruitment and the timing of muscle contractions.
Electromyogram cont’d

- Except in very special situations it is NOT possible to use EMGs to estimate the level of FORCE in a muscle.
- It is also NOT suitable to compare the magnitude of one muscle’s EMG compared to a different muscle even in the same person.
- The magnitude of the EMG depends on many factors unrelated to the force and therefore is a relative measure for each muscle.
- Thus, EMGs are often normalized to specific values such as the muscle’s maximal voluntary contraction (MVC) or to some standard load.
EMGs and Vertical GRFs of Gait Initiation