Topics covered

• EMG analysis
• Motor unit
• 3 uses of EMG
• Signal processing
• Effect of fatigue
• Noise contamination
• Sensor characteristics

• Filtering of experimental data
  – Nyquist sampling theorem
  – Why filter?
  – Types of filters
    • Butterworth filter in MATLAB
  – Picking a cut-off frequency
    • Residual analysis
    • Spectral analysis
    • “Informed decision”
Muscle terminology

• **Single Muscle Morphology**
  • Fascicle (muscle bundle)
  • Muscle fiber (muscle cell)
    • Basic structural unit
  • Myofibril (fibril)
    • Basic contractile element
  • Sarcomere (banded unit)
  • Myofilaments
    • Actin (thin)
    • Myosin (thick)
    • Crossbridge cycle resulting in contraction
    • Need for calcium

• **Motor unit**
  • Neuron
  • Muscle fibers
  • Action potential
  • Recruitment

• What type of latencies are observed with muscle
  • Why are these observed
  • How long are they

• **Huxley’s Crossbridge Model**
  • Only good for shortening
  • 3 regions of attach/detachment
  • Supports $F = f(v)$
Muscle modeling and behavior

• **Hill muscle model**
  - Three components
    • CEC, PEC, SEC
  - What each represents
  - How each component relates to observed behavior
    • Length-tension
    • Force-velocity

• **Hill equation for force-velocity relationship**
  \[ F = \frac{(F_0b - av)}{(b + v)} \]
  - What are parameters
  - When is it applicable/what can it represent
  - Problems

• **Muscle power**
  - Know how to compute
  - Applicable for what behavior
  - Know how to determine maximum power
Review: Hill (1938) Equation for Force and (shortening) Velocity

\[ F = \frac{(F_0 b - av)}{(b + v)} \]

where

\[ a = \text{coefficient of shortening heat (units of force)} \]

\[ b = a \frac{v_0}{F_0} = \text{constant (units of velocity)} \]

- For CEC part of muscle model
- Based on internal thermodynamics of muscle
- Produces F – V (shortening) curve
Review: Problems with Hill Equation

1. Data (Edman, 1979) suggest that the Hill equation overestimates \( F_0 \) by 25% and \( v_0 \) is underestimated.
   
   • However, Hill equation is good first approximation for relationship between force and shortening velocity.

![Graph showing force-velocity relationship](image.png)

**Figure 2.7.27** Schematic illustration of the difference between theoretical estimation and experimental determination (e.g., Edman, 1979) of the force-velocity relationships.

2. Not applicable to eccentric contraction (lengthening)
Review: Muscle Power

- Can get instantaneous power as function of velocity

\[ P(v) = F(v) \cdot v \]

- Maximum power:

\[ v(\text{at } P_{\text{max}}) \approx 0.31v_o \]

\[ F(\text{at } P_{\text{max}}) \approx 0.31F_o \]

\[ v = 0.31v_o \]
Review: Muscle Power

• Values @ $P_{\text{max}}$ derived from:
  • take derivative of power equation with respect to $v$
    $$P(v) = F(v) \cdot v$$
    $$\Rightarrow \frac{dP}{dv} = \frac{dF}{dv} v + F$$
  • Insert Hill’s equation

• And find $P = P_{\text{max}}$ when $\frac{dP}{dv} = 0$
Muscle behavior

- Length-tension relationship
- Three curves:
  - Active
    - How shape relates to sarcomere behavior
  - Passive
    - Know shape, starting point
  - Total
    - How to sum active + passive
    - How it changes with activation level

- Force-velocity relationship
- Shape
  - Eccentric part
  - Concentric part
  - Isometric part
  - How it changes with activation level
b) Whole muscle behavior:

- **Active tension:**
  - Due to active components (CEC)

- **Passive tension:**
  - Due to passive components (PEC + SEC)

- **Total tension:**
  - Active + Passive

- Total (and active) curves change with: **activation level**
Review: Force – Velocity Relationship

- Created during isotonic conditions
- Shortening: concentric contraction
- Lengthening: eccentric contraction
- Greater force during lengthening than shortening

FIGURE 2-7. The muscle force-velocity curve for skeletal muscle obtained using sequential isotonic contractions such as those shown in Figure 2-6. The threecircled numbers represent the force and velocity data from the three corresponding contractions in Figure 2-6. Note that force increases dramatically upon forced muscle lengthening and drops precipitously upon muscle shortening.
EMG terminology and considerations

- What does it measure
- What are 3 uses of EMG
- Signal processing
  - Full wave rectification
  - Linear envelope
  - Timing
- Fatigue
  - What is effect
  - How to detect
- Noise contamination
  - How to reduce
  - What to consider
- Sensor characteristics
  - Placement (orientation, distance)
  - Why need a reference electrode
The amplitude of the sEMG signal is proportional to the force produced by the muscle.

Three main uses of EMG:
1. Qualitative assessment of force
2. Activation timing
3. Fatigue
Signal processing

Raw data (original)

Full wave rectified (Absolute value)

Linear envelope (Low Pass Filter)

EMG (Volts or mV)

Timing (Threshold)
During progressing contractions the sEMG signal expands in the time domain and compresses in the frequency domain.

In **isometric** constant-force contraction, the frequency compression may be measured monitoring the Mean or Median Frequencies via the Fourier Transform.
16: Where to Locate the EMG Sensor for a High-Fidelity Signal?

- Underlying muscle
- Innervation Zones
- Direction of muscle fibers (bars perpendicular to fibers)
- Orientation arrow
- Tendon
20: Noise Contamination

- **Physiological Noise**
  - EKG, EOG, respiratory signals, etc.
    - Reduced by judicious location of the sensor and by rotation of the sensor

- **Ambient Noise**
  - power line radiation (50, 60 Hz)
    - Removed by differential detection
  - Cable motion artifact
    - Removed by high quality technology

- **Baseline Noise**
  - Electro-chemical noise (skin-electrode interface)
    - Reduced by effective skin preparation
  - Thermal noise (property of semiconductors)
    - Reduced but not eliminated by modern technology

- **Movement Artifact noise**
  - Movement of electrode with respect to the skin (induced by force transients or movement of the skin)
  - This is the most obstreperous noise
    - Reduced by effective skin preparation and filtering
**Recommendation:**

**Detecting the sEMG Signal**

- **Active Sensor of High quality signal**
  - Reduces cable artifact
  - Reduces noise contamination

- **Differential detection**
  - Reduces ambient electrical noise

- **Fixed Inter-electrode spacing (Preferably 1 cm)**
  - Maintains constant frequency bandwidth
  - Reduces cross-talk

- **Effective Electrode-Skin preparation for sEMG sensor and Reference electrode**
  - Reduces Noise contamination
  - Reduces ambient electrical noise
  - Reduces movement artifact

- **Locate sensor in the belly of the muscle**
  - Reduces cross-talk
  - Increases signal to noise ratio
  - Do not place sensor on the tendon or on the innervation zone
Reference electrode

- A reference electrode is used to create a relative “ground” for the EMG signals

**Connecting the Reference Electrodes:**

- Be sure to clean and, if necessary, shave the skin prior to affixing the Reference Electrode.
- Only one Reference Electrode is required when collecting EMG signals.
- The site should be an electrically inactive area on the skin surface (e.g., ASIS, sternum, clavicle)
- Attach 1\textsuperscript{st}, **BEFORE** sensor electrodes.
Sensor electrodes – key points

- Place sensor in the middle of the belly of the muscle
  - effective electrode-skin contact will provide great benefits in assuring a high quality signal.
- Align arrow parallel to muscle fibers
- Before attaching electrode, use electrode as probe to find best signal strength.

Method of application:

1. Shave excessive hairs
   - or hair can be moved aside or sensor can be placed over hair.
2. Clean skin with alcohol to remove skin debris. Allow alcohol to evaporate. Clean electrode surfaces.
3. In most cases (depending on skin type) no electrolyte is required.
4. Attach sensor-skin interface. Press hard to assure maximal adhesion to the skin.