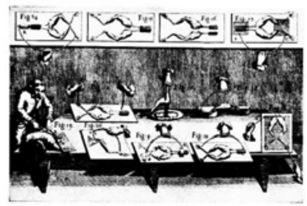
Kinesiological Electromyography

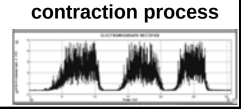
Electromyography

Electromyography (EMG) involves the study of the electrical signals associated with the activation of muscle - originated in 1792 with work of Galvani



Galvani's Experiments on "Animal Electricity"

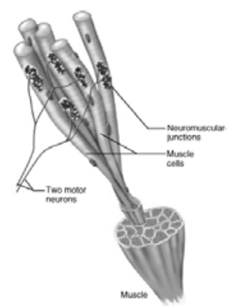
EMG signal arises from the flux of charged particles (ions) across the muscle membrane during excitation-contraction process



Electromyography

- Why use EMG? What questions can it potentially help us answer?
  - When during a movement is a muscle active?
  - How active is a muscle during a movement?
  - Is a muscle active primarily during shortening or lengthening?
  - Has a muscle fatigued during an activity?
  - How much force is a muscle generating?
- EMG must usually be combined with other data (temporal, kinematic, kinetic) to be of much use

Basic Concepts



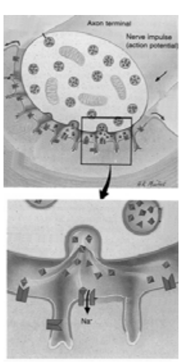
(a)

Motor Unit

One α-motoneuron and all the muscle fibers that it innervates

The motor unit is the functional unit of the neuromuscular system

Basic Concepts



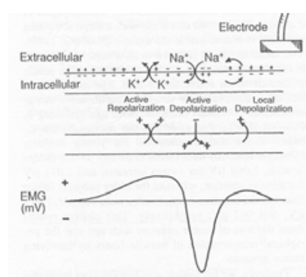
Neuromuscular Junction

Synaptic junction between one axon of an α-motoneuron and the corresponding muscle fiber

Acetycholine released from axon terminal into synaptic cleft, binds with receptor sites on motor end plate of muscle

May lead to generation of an action potential that propagates outward from motor end plate along muscle membrane

Basic Concepts

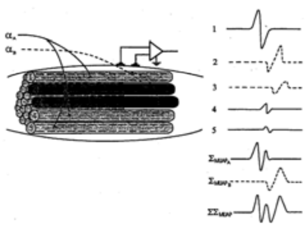


Muscle Fiber Action Potential (MFAP)

A single moving dipole associated with changes in membrane potential due to propagation of action potential along muscle membrane

The moving dipole is the basis for EMG, and triggers the contraction process

Basic Concepts



Motor Unit Action Potential (MUAP)

The algebraic sum of all MFAP in a motor unit

Each muscle fiber has a unique MFAP: affected by; size & location of fiber, surrounding tissue, etc

Each muscle fiber makes a contribution to MUAP

Basic Concepts

Motor Unit Action Potential (MUAP)

Muscles can have 100’s of motor units with 1000’s of fibers each, resulting in a very complex signal

e.g., Henneman reported cat gastrocnemius has > 1000 fibers/MU and > 300 MU/muscle

The two following summations exist in the recorded EMG signal

EMG = ΣMUAP’s and MUAP = ΣMFAP’s

Basic Concepts

Two primary strategies used by CNS to increase muscle force:

Recruitment - activation of previously silent motor units

Rate Coding - previously active motor units are stimulated at a higher rate

Both processes will result in more force, and larger EMG amplitude, but not necessarily in a linear manner

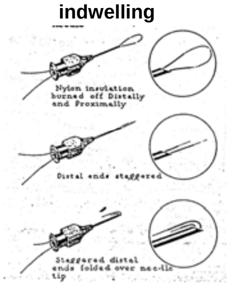
Electrodes

Electrode types

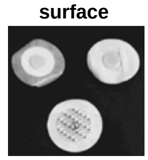
- Indwelling - Needle or fine-wire; inserted into muscle of interest
  - smaller pick-up zone than surface electrodes
  - more selective, can be used for motor unit studies
  - can be used to reach deep muscles
- Surface - placed on the skin with adhesive over muscle of interest
  - larger pick-up zone, may be more representative of whole muscle activation
  - more susceptible to cross-talk
  - can only be used with superficial muscles

Electrodes

indwelling



surface



Typically made from silver-silver chloride (minimal resistance to current flow)

Electrodes

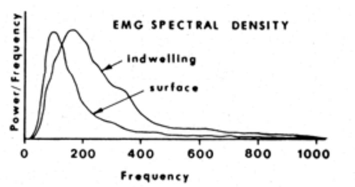
Amplitude & Frequency Characteristics of EMG Signals

	Indwelling	Surface
Amplitude (mV)*	0.05 - 5	0.01 - 5
Total Freq Range (Hz)	0.1 - 10000	1 - 3000
Primary Freq Range (Hz)	40 - 400	20 - 200
Min Sampling Rate (Hz)	800	400
Preferred Samp Rate (Hz)	2000	1000

*Low EMG signal amplitude requires amplification before recording

Electrodes

Frequency characteristics of EMG signals recorded with different electrodes



Other signals may be present that overlap with EMG spectrum: ECG (1-100 Hz), power line hum (60 Hz), movement artifact (0-10 Hz)

Recording the EMG

Objective when recording an EMG signal

Obtain a signal that is:

- **An undistorted representation of ΣMUAP's**
- **Free of noise and artifact**
- **Stable and reliable**
- **Has a minimum of cross-talk from other muscles**
- **Has a high signal-to-noise ratio**

Recording the EMG

Signal is dependent on:

- **Amount and type of interspersed tissue**
- **Electrode size**
- **Electrode spacing**
- **Electrode position over the muscle**
- **Amplifier characteristics**

Noise arises from

- **Other biosignals (e.g., ECG)**
- **Power line hum**
- **Electrode movement**
- **Cabling artifact**
- **Amplifier**

Recording the EMG

<u>Electrode placement</u> - should be between innervation zone and distal tendon, or between two innervation zones; long axis of electrode should be parallel to muscle fibers

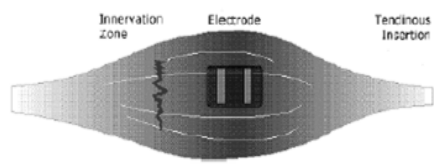


Figure 4: The preferred electrode location is between the motor point (or innervation zone) and the tendinous insertion, with the detection surfaces arranged so that they intersect as many muscle fibers as possible.

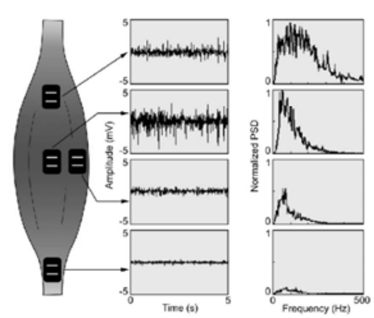
Recording the EMG

Electrode placement

- **Do not place electrode near myotendonous junction**
- **Do not place electrode at innervation zone (motor point); this was a commonly recommended location to put the electrode for many years**
- **Approximate innervation zone locations and fiber orientations can be obtained from atlases**
- **In the absence of better information, place the electrode just distal to mid-point of muscle belly**

Recording the EMG

Effect of electrode placement on signal characteristics



Recording the EMG

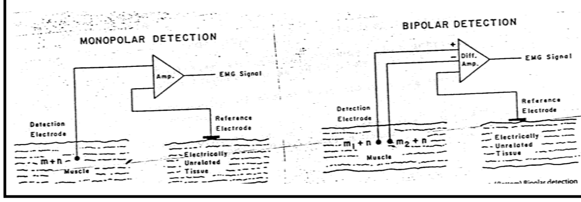
Amplifier Considerations

- EMG amps come in two configurations
  - Single-ended
  - Differential
- Major amplifier characteristics that affect signal quality are:
  - System gain
  - Input impedance
  - Frequency response
  - Common-mode rejection

Recording the EMG

Single-ended amplifier - recorded EMG voltage at electrode is referenced to a distant ground electrode

Differential amplifier - recorded EMG voltage is difference between signal on two electrodes after comparison with reference ground electrode



Recording the EMG

Amplifier Gain

- The low amplitude of EMG signals (< 5 mV) necessitates amplification to the order of volts (e.g., ×100, ×1000, ×10,000)
- Gain setting is typically user selectable
- Preamplifiers - some electrodes have built-in amplifiers to boost signal at recording site
  - Increases signal-to-noise ratio
  - Minimizes movement artifact

Recording the EMG

Amplifier Input Impedance (Resistance)

- Amp input impedance must be high relative to skin-electrode impedance; otherwise signal amplitude will be attenuated
- Minimum input impedance for sEMG is 1 MΩ; commercial systems typically 10-100 MΩ
- Mathematically we want $V_{INP} \approx V_{EMG}$, or

$$\frac{V_{INP}}{V_{EMG}} \approx 1.0$$

Recording the EMG

Amplifier Input Impedance (Resistance)

- Example 1 - poor EMG circuit
  - $R_{Skin1} = R_{Skin2} = 10{,}000\ \Omega$ (minimal skin prep)
  - $R_{INP} = 80{,}000\ \Omega$ (low by today's standards)
  - $R_{TOT} = 10{,}000 + 10{,}000 + 80{,}000 = 100\ k\Omega$

  Current (I) due to a 2 mV signal (Ohm's Law V=I·R)
  - $I = V_{EMG} / R_{TOT} = (2\times10^{-3}\ V) / (1\times10^{5}\ \Omega) = 2\times10^{-8}$ amps
  - Thus, $V_{INP} = I \cdot R_{INP} = (2\times10^{-8}\ amps)(8\times10^{4}\ \Omega) = 1.6$ mV

  The 2 mV signal has been attenuated by 20%
  This is not good!

Recording the EMG

Amplifier Input Impedance (Resistance)

- Example 2 - better EMG circuit
  - $R_{Skin1} = R_{Skin2} = 1{,}000\ \Omega$ (substantial skin prep)
  - $R_{INP} = 1{,}000{,}000\ \Omega$ (higher input impedance)
  - $R_{TOT} = 1{,}000 + 1{,}000 + 1{,}000{,}000 = 1.002\ M\Omega$

  Current (I) due to a 2 mV signal (Ohm's Law V=I·R)
  - $I = V_{EMG} / R_{TOT} = (2\times10^{-3}\ V) / (1.002\times10^{6}\ \Omega) = 1.9962\times10^{-9}$ amps
  - Thus, $V_{INP} = I \cdot R_{INP} = (1.9962\times10^{-9}\ amps)(1\times10^{6}\ \Omega) = 1.996$ mV

  Now the 2 mV signal has been attenuated by at trivial 0.2% - This is much better!

Recording the EMG

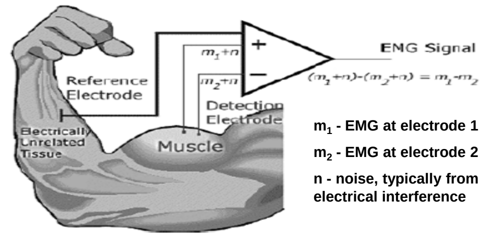
Amplifier Frequency Response

- Every amplifier has a bandwidth (range) over which it amplifies signals with limited distortion
- Above and below this range the amplification will be less than desired
- Recommended frequency response for EMG
  - Surface 10-1000 Hz
  - Indwelling 20-2000 Hz

Recording the EMG

Amplifier Common-Mode Rejection Ratio

- Differential amp set-up allows common noise to be removed from recorded EMG signal



m_1 - EMG at electrode 1

m_2 - EMG at electrode 2

n - noise, typically from electrical interference

Recording the EMG

Amplifier Common-Mode Rejection Ratio

- CMRR is a measure of how well common signals are rejected in a differential set-up
- CMRR of 1000:1 means all but 1/1000 of a common signal will be removed from recording
- Minimally acceptable CMRR for EMG
  - 10,000:1
- Typical CMRR for commercial EMG amps
  - 20,000-100,00:1

Recording the EMG

Amplifiers - a final note

- EMG amps commonly have one or more hardware filters; these are analog filters that are applied before A/D conversion
  - High-pass filter - for removing movement artifact; common cutoff frequency of 10-20 Hz
  - Low-pass filter - to prevent aliasing during the A/D conversion process; common cutoff frequency of 500-1000 Hz
  - Band-pass filter - equivalent to a high-pass followed by a low-pass filter

Processing the EMG

The recorded EMG signal can be processed in a bewildering number of ways - these are some of the most common:

- DC bias removal
- Full-wave rectification
- Linear envelope
- Temporal analysis
- Root-mean-square
- Average amplitude
- Peak amplitude
- True mathematical integration
- Frequency analysis

Processing the EMG

After data have been DC-bias corrected, full wave rectified, and possibly low-pass filtered, the two most common means for quantifying EMG signal strength are average amplitude and root mean square (RMS) value

Average amplitude is the mean value of the rectified signal over a specified period of time, and represents the area under the curve for this time interval

RMS value is the square root of the average power of the EMG signal over a specified period of time

Processing the EMG

<u>Amplitude Normalization</u>

- **Many factors affect amplitude of EMG signal**
- **There is little basis for comparing absolute EMG values across subjects, or even between muscles within a subject**
- **Normalizing EMG signal amplitude to a reference condition improves validity of such comparisons**
  - Data during trials are then expressed as a percentage of value from the reference condition

Processing the EMG

Common Normalization References:

- Maximal isometric voluntary contraction
- Submaximal isometric voluntary contraction
- Peak EMG amplitude during activity
- Average EMG amplitude during activity

Yang and Winter (1984) found the last two methods greatly reduced inter-subject variability, but at the expense of a meaningfulness of EMG amplitude (no longer related to some standard level of effort)

Applications of EMG

There are numerous uses of EMG in human movement; some of the most common are:

- **Temporal Analysis (on-off timing)**
- **EMG - Muscle Force Relation**
- **Muscle Fatigue Assessment**

EMG - Temporal Analysis

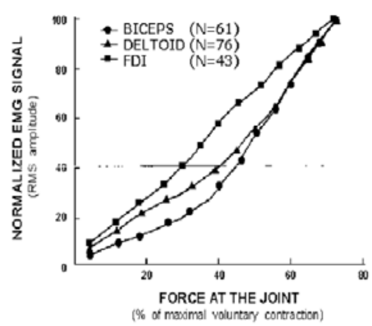
EMG Onset Time Determination

- **Common approach is to use a threshold above which EMG is considered to be 'on'**
  - Determine a 2-3 SD window of the resting EMG signal (represents baseline noise)
  - EMG signal must exceed this threshold for a minimum time (e.g., 20-50 ms) to be considered on
  - Similar approach is used to determine 'off' time

EMG - Muscle Force Relation

- **In 1952 Lippold reported a *linear* relation between EMG amplitude of ankle plantar-flexors, and the torque produced by these muscles for isometric contractions**
- **Numerous studies have confirmed these results, while just as many have reported a *nonlinear* relation between EMG and isometric muscle force/torque**
- **For nonlinear case, EMG increases faster than muscle force**

EMG - Muscle Force Relation



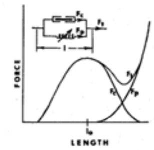
Note linear relation for FDI and nonlinear relations for deltoid and biceps

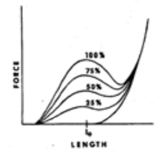
EMG - Muscle Force Relation

- Under non-isometric conditions, factors other than neural drive affect EMG amplitude and muscle force production
- EMG signal affected by
  - location of muscle fibers under electrode
  - change in muscle temperature / subject sweating
- Muscle force affected by
  - force-length relation
  - force-velocity relation

EMG - Muscle Force Relation

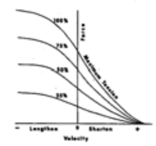
force-length relation

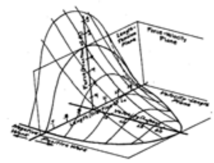




active force-length relation at different activation levels

force-velocity relation at different activation levels

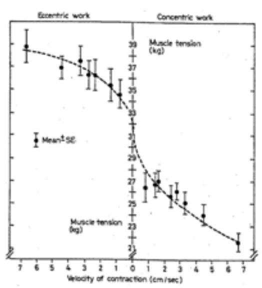


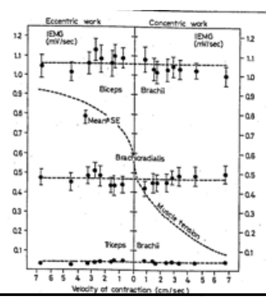


combined force-length -velocity relation

EMG - Muscle Force Relation

Data from Komi (1973) suggest that force-velocity and force-length factors are the major determinants of the dynamic EMG-force relation (other factors can not be ruled out though)

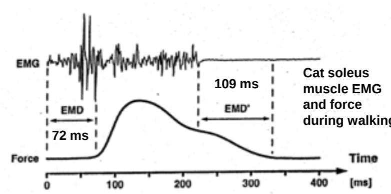




EMG - Muscle Force Relation

Electromechanical Delay

- Build-up of muscle force trails the detection of EMG by some finite time period
- Same thing happens with the cessation of EMG at end of a period of activity



EMD values have been reported to range from 10-100+ ms

Equipment used may play a role

EMG - Fatigue Assessment

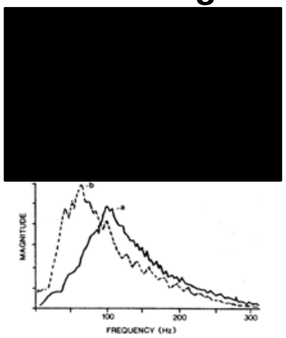
What is muscle fatigue? (multiple definitions exist)

- Working definition: failure to generate or maintain the required or expected force, resulting from muscular activity, and reversible by rest
- Major application of EMG in fatigue research is analysis of median (or mean) frequency
  - Median frequency shifts to the left (lower frequencies) with muscular fatigue

EMG - Fatigue Assessment

- The major physiological change with fatigue, perhaps affecting frequency content of the EMG signal is a decrease in muscle fiber conduction velocity
- Some have argued that certain faster motor units drop out, but this is arguable
- Increased synchronization of MU firing may also result in decreased median frequency

EMG - Fatigue Assessment



From time ‘a’ to time ‘b’ the muscle has fatigued, causing a shift in median frequency of PSD and a small increase in peak signal power

Frequency Domain

Again, I wish to acknowledge Brian Umberger, PHD for significant contributions to these slides