Electromyography

Electromyography is a seductive muse.
-- Carlo DeLuca, J Appl Biomechanics, 1997

EID424
Bioengineering Applications in Sports Medicine
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Prof. Kremenic

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Electromyography

- EMG
- Measurement of the electrical signals produced by muscle tissue
  - Quantify muscle activity
  - Very low-level signals
- Applications
  - Clinical
  - Research

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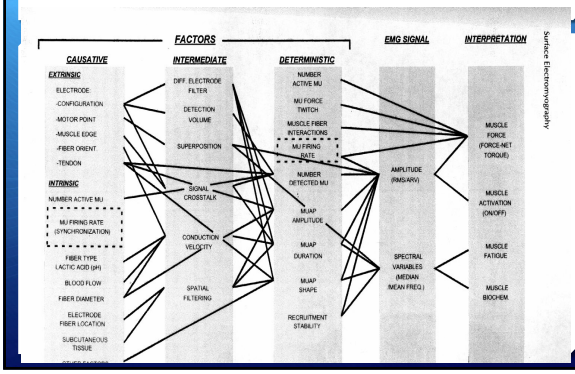
Many Factors Affect EMG



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EMG Acquisition

- Electrodes
- Amplifiers
- A/D conversion
  - Typically 12 or 16-bit
- Analysis
  - Amplitude measures
  - Timing measures
  - Frequency measures

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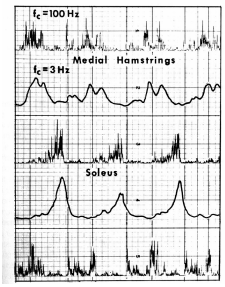
Olde School EMG

- Often used polygraph equipment
- Counting boxes on graph paper



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EMG Amplifiers

- Differential amplifier
- Must be low-noise, high-gain
  - EMG very small signal (~100's of uV)
- Subject must be isolated from power supply!
  - Battery powered
  - Optical isolation
  - Transformer
- Expensive

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EMG Electrodes

- Typically Ag-AgCl alloy
- 2 per muscle
  - Differential amp
  - + 1 ground for system [usually]
- Surface
- Invasive
  - Needle
  - Fine wire

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Surface EMG Electrodes

- Easiest to use
- Non-invasive
  - Does not require special training/certification
- Samples entire muscle
  - Picks up signals from motor units beneath electrodes
- Relatively good reproducibility
- Good skin prep essential!

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Surface EMG Skin Prep

- All things between electrodes and muscle distort signal
  - Skin
  - Fat
  - Hair
  - Oil
  - Lotion
- Minimize impedance between electrode and muscle

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Surface EMG Skin Prep Procedure

- Shave if necessary
- Abrade skin
  - Remove layer of dead skin (and some live)
  - Exfoliate
- Clean with alcohol pad
  - Ouch
  - Be nice and do this first
- Apply electrodes

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Surface EMG Electrodes

- Many types/shapes/sizes
  - Single
  - Bar
  - Array
- Reusable
  - Must be kept clean
  - Require application of electrolyte gel to ensure good contact
  - Tape/glue to skin

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Surface EMG Electrodes

- Disposable
  - Use once
  - Pre-gelled/glued
  - More commonly used

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Pre-amplified Electrodes

- Surface electrode with amplifier built-in
  - Active vs passive pickups for guitar
- Amplify signal at source
  - Bigger signal relative to noise picked up by electrode leads, artifact from wires moving
- Requires power
  - More cumbersome
- Not cheap

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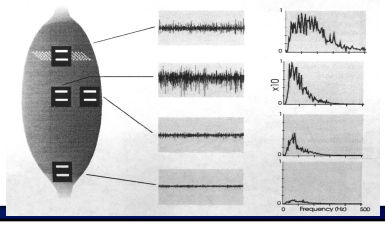
Surface Electrode Orientation

- Pair of electrodes must be placed along direction of muscle fibers
  - Measure the AP as it propagates along the fibers
  - Try to avoid innervation zone of muscle



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Invasive EMG Electrodes

- Not distorted by skin/fat/hair/sweat/etc.
- Can pick up signals from deep muscles
- Samples small number of motor units
  - Single motor unit?
- Requires certification
  - Training/certification requires medical background

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Invasive EMG Electrodes

- Confirm correct placement by stimulating through electrode
  - Remove and replace if not correct
  - "Poke and hope" technique [DeLuca]
- Needle electrodes
- Fine-wire electrodes
- Ouch

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Needle Electrodes

- Very thin needle
- Typically "Teflon"-coated
  - Slides in and out easily
- Exposed conductor only at end
- Mostly used for stimulation
  - Used for acquisition only when little or no motion involved

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Fine-Wire Electrodes

- Very thin wires inserted into needle
- Insulated except at tip
- Tip bent, sticking out of needle
- Needle inserted, removed
  - Barbed end of wire remains

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Pros and Cons

- Surface
  - Relatively reproducible
  - Gives idea of function of entire muscle
  - Easy to use
  - Signal distorted by intervening tissue
- Fine-wire
  - Hard to duplicate placement
  - Only samples a few motor units
  - Requires training, long setup
  - No intervening tissue
  - People don't like holes in their skin

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EMG Testing Procedure

- Pair of electrodes per muscle
  - Differential amplifiers
  - Orient along direction of muscle fibers
- Stimulator?
  - Apply strong enough current to cause nerve/muscle to depolarize, generating action potential

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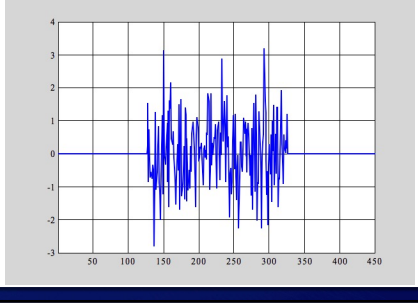
So What's It Look Like?

- Surface EMG interference pattern



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EMG Interference Pattern

- Result of many action potentials
  - Different amplitudes (intervening tissue)
  - Out of phase
  - Some add, some subtract
- For signal processing purposes, can be treated as a stochastic (random) process
  - Band-limited Gaussian noise
  - Zero-mean, variance a function of amplitude
  - More on this later

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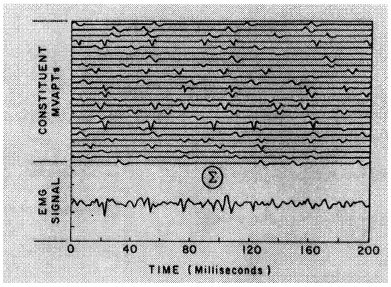
Origin of EMG Interference Pattern



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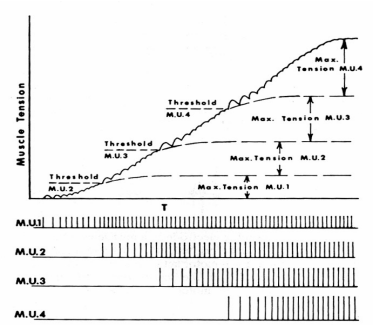
Motor Unit Recruitment



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Factors Affecting EMG

- Skin prep
  - Reduce skin impedance
  - More signal to amplifier
- Electrode distance
  - Farther apart → larger amplitude
  - Standardize!
- Electrode size
  - Larger electrodes → more motor units

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Comparing EMG

- Take great care
  - Different muscles have different properties
    - Fiber type composition
    - Length/tension
    - Force/velocity
    - Etc…
  - Side-side, day-day in same person difficult
    - Differences in placement, orientation of electrodes
  - Between people almost impossible
    - As above
    - Also differences in size, strength

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EMG Normalization

- Enables comparison
- Normalize to maximal voluntary isometric contraction (MVC)
  - Most common
  - Easiest conceptually
  - Activity should isolate muscle in question as best possible
  - Really max effort?
  - Any relation to task being performed?

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EMG Normalization

- Normalize to standard activity
  - Gait
  - Lift standard weight
- Normalize to data being analyzed
  - Max in that activity is 1.0

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EMG Crosstalk

- Pick up unwanted signal from nearby muscle
- Difficult to identify
  - Cross-correlation? Not really
- Double differential amplifier
- Minimize with proper electrode spacing, good skin prep

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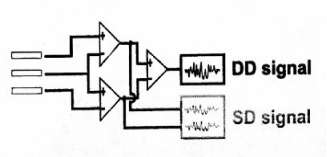
Double-Differential Technique

- Crosstalk should be similar in each single-differential signal
- Another difference should eliminate crosstalk



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Clinical EMG

- What neurologist/orthopaedist/physiatrist is referring to when referring a patient for an EMG
- Evaluating something specific
  - Nerve injury
  - Muscle weakness
  - Carpal tunnel syndrome

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Clinical EMG

- Usually involves testing of one muscle/set of muscles or nerve
- Usually involves stimulation of a motor nerve

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Nerve Conduction Studies

- Evaluate health of nerve by measuring its conduction velocity
  - Speed with which AP propagates along its axon
- Typically:
  - EMG electrodes placed on muscle
  - Nerve innervating muscle stimulated at several locations

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Nerve Conduction Studies

- Stimulate motor nerve
- Pick up response at muscle
  - Compound muscle action potential (CMAP)
  - M-wave

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Nerve Conduction Studies

- Measure distance between sites of stimulation
- Based on distance between sites and latency of response, conduction velocity along nerve can be estimated
  - Amplitude, duration also of interest
- Must have at least two sites!
  - Only one site means time spent for signal to cross neuromuscular junction and propagate across muscle included
  - Much slower than nerve conduction speed

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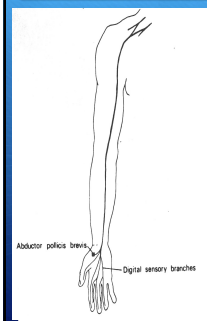
Nerve Conduction Studies



- Median nerve

NORMAL VALUES (MOTOR)

Segment	*Distal Latency or NCV*	*Amplitude (mV)*	*Reference*
Wrist to abductor pollicis brevis	3.9 ± 0.37 (3.4–4.5) msec	11.8 (7–17)	[2, 3]
Elbow to wrist	49.0 ± 3.9 (45.1–54.4) m/sec	11.8 (7–17)	[2, 3]
Axilla to elbow	56.3 ± 5.1 (50.0–68.3) m/sec	11.8 (7–17)	[2, 3]
Erb's to axilla	65.1 ± 6.1 (57.1–76.2) m/sec	11.8 (7–17)	[2, 3]
Erb's to elbow	62.9 ± 6.0 (51.0–76.0) m/sec	11.8 (7–17)	[3, 4]

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F-Wave

- Stimulus travels distally to muscle and proximally to motor neuron cell body
  - *Orthodromically* and *antidromically*, respectively
  - Orthodromic response is M-wave
  - Neuron can fire to activate muscle in response to antidromic stimulus
    - Latency, amplitude, duration of interest

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Hoffman-Reflex (H-Reflex)

- Stimulate nerve
  - Some axons being stimulated are sensory nerve fibers from *muscle spindles*
    - Sense muscle fibers stretching
  - These stimulate motor neuron to activate muscle

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H-Reflex

- Measure of motor neuron, spinal cord excitability
- Amplitude of reflex, latency useful
- Commonly measured in soleus muscle in back of leg
  - Long nerve makes it easier to measure
  - In shorter nerve, can be swamped out by initial motor response

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H-Reflex

- Very low stimulus gives no response
- Gradually, evoke H-reflex
- At maximal H-reflex, start of M-wave response
- As M-wave increases, H-reflex goes away

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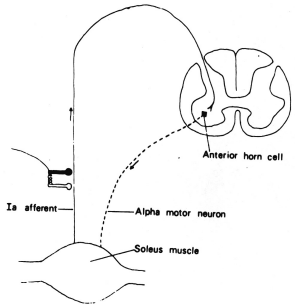
H-Reflex



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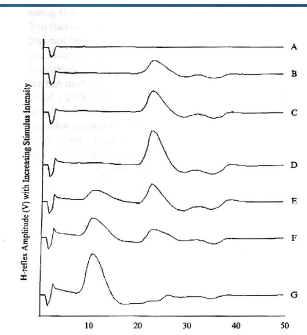
H-Reflex Recruitment Curves



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Research Applications of EMG

- Measure activity of muscles during various activities
- Relate amount/type/timing of activation to the activity being performed
- Holy grail: relate measured EMG activity to force being exerted by muscle
  - Pretty much impossible

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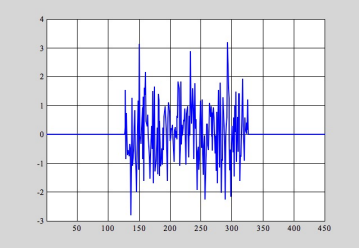
Typical Surface EMG Tracing

- Surface EMG interference pattern
- More or less band-limited, Gaussian noise



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EMG Measurements

- Amplitude measurements
- Timing measurements
- Frequency measurements

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EMG Amplitude

- Larger amplitude means more motor units recruited (mostly)
- Amplitude *qualitatively* related to force generated in muscle contraction
  - Many other factors related to force generation
    - Other motor units that are not measured
    - Type of motor units (I, II)
    - Other muscles acting synergistically
    - Co-contraction of antagonist muscles
    - Pennation angle of muscle

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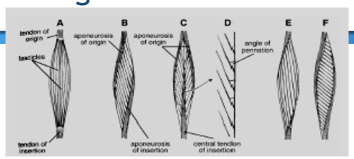
Pennation Angle



- Angle of muscle fibers
  - Greater cross-sectional area
  - Force-generating capacity is proportional
  - Exert greater force
- Remember:
  - Want electrodes placed along direction of muscle fibers in order to measure propagation of AP along fibers

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EMG Amplitude

- Raw EMG requires some form of processing
  - Otherwise, average amplitude is 0
- Typically
  - Rectified
  - Rectified and smoothed (RMS)
    - Sometimes referred to an integrated EMG (iEMG)
- Don't forget to normalize!!!!

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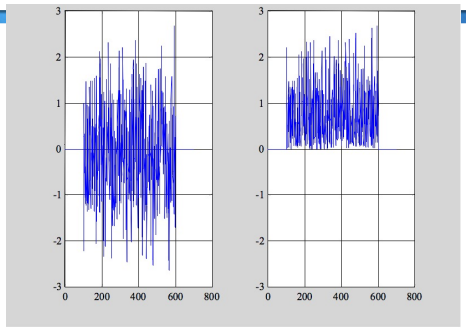
EMG Amplitude: Rectification



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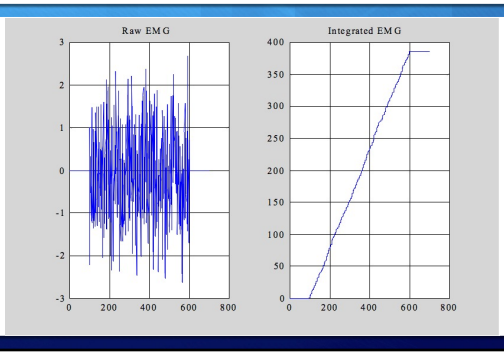
EMG Amplitude: Not What Is Meant by Integrated EMG



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EMG Amplitude: Smoothed, Rectified EMG

- Rectify EMG
- Smooth result by either
  - RMS of every xxx pts
    - Number of points should be related somehow to the activity being studied
  - Low-pass filter
  - Integrate (and reset integrator!)

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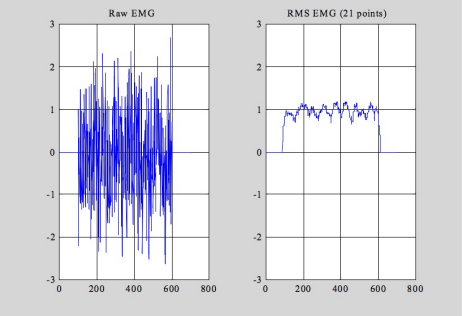
EMG Amplitude: Soothed, Rectified EMG



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EMG Timing Measurements

- When is muscle activated?
  - Does it turn on when it should?
  - On entire time it should?
- When are agonist/antagonist activated relative to each other?
- Amount of smoothing *very* important
  - Don't want to miss events, or trigger incorrectly
- Volumes of papers written about best way to determine when muscle is turned on
  - How to pick threshold?

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EMG Frequency Content

- Very different between
  - Surface
  - In-dwelling
- Beware noise at 50/60 Hz
  - Don't forget harmonics
  - Lots of signal as well
  - Many systems include notch filter

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Wire/Needle EMG Frequency Content

- Can range from 20 Hz-several kHz
  - Typically not much more than 1 kHz

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Surface EMG Frequency Content

- Typically 20-500 Hz
  - Almost entirely done by 300 Hz

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EMG Filters

- Highpass filter
  - Typically 10-20 Hz
    - No EMG frequency components below 10 Hz
  - Mainly to remove motion artifact
    - Noise created by wires, electrodes moving

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EMG Filters

- Lowpass filter
  - ≤ half sampling frequency
    - Ideally, well under
    - Limited by frequency content of EMG signal
    - Int Soc of Electrophysiology and Kinesiology (ISEK) recommendations:
      - > 350 Hz for surface
      - > 450 Hz for wire
      - > 1500 Hz for needle
  - Anti-aliasing
  - Remove high frequency noise

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EMG Frequency Measurements

- Mean frequency
- Median frequency
- Derived from power spectral density (PSD) computed via fast Fourier Transform (FFT)

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EMG Mean Frequency

- Centroid of the first moment of the power spectrum:
  - $\Sigma [f G(f)] / \Sigma [G(f)]$
- Can be adversely affected by high-frequency noise

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EMG Median Frequency

- Frequency which divides area under power spectrum in half
- Typically lower than mean frequency

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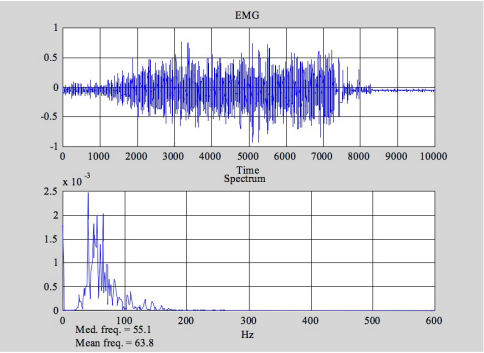
EMG Mean and Median Frequency



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Factors Affecting EMG Frequency Content

- Interesting stuff:
  - Conduction velocity
  - Muscle diameter
    - These are essentially the shape of the action potentials
  - Slight effect of firing rate
- Bad stuff:
  - Skin
  - Fat
  - Electrodes

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Beware: EMG is Not Stationary

- If body is moving, muscle is moving under electrodes
  - Source of signal changing
- Over time, EMG changes with fatigue
- Only short periods of isometric contractions may be considered stationary!
- Can only legally apply Fourier Transform to stationary signals

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Moving Screws Everything Up

- With movement:
  - Muscle fibers/motor units beneath electrodes move
    - Change shape
    - Change location relative to electrodes
  - At different joint angles more/less/different motor units may be active to maintain the same force level

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EMG and Fatigue

- Fatigue
  - Inability to maintain the required force
  - Peripheral causes
    - Metabolic processes
    - Issues in muscle, neuromuscular junction
  - Central causes
    - Failure of central nervous system to drive muscle
    - Not motivation

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EMG and Fatigue

- In sub-maximal isometric contractions
  - EMG amplitude *increases* with fatigue
    - More motor units recruited to perform same work
  - EMG mean/median frequency decreases with fatigue
    - Decrease of AP conduction velocity along muscle fiber with build-up of metabolites
    - Power spectrum compresses, becomes more skewed
    - Motor unit synchronization

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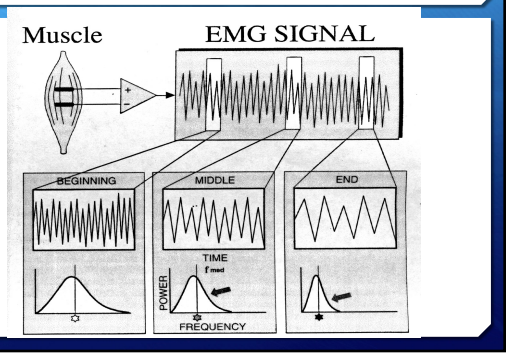
EMG and Fatigue



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Fatigue

- Women more fatigue-resistant than men
- Elderly more fatigue-resistant than young
- Differences in:
  - Fiber type
  - Strength
  - Blood flow
  - …

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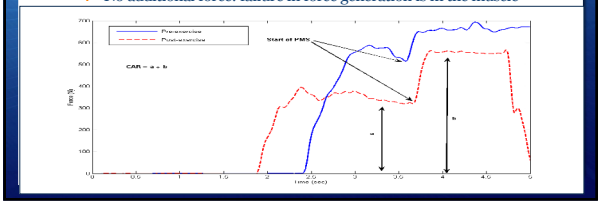
Peripheral vs Central Fatigue

- Central activation ratio (CAR)
  - Subjects performs maximal voluntary contraction, measure force
  - Supramaximal stimulus superimposed
    - Additional force: muscle can be driven further; fatigue is failure of nervous system drive
    - No additional force: failure in force generation is in the muscle



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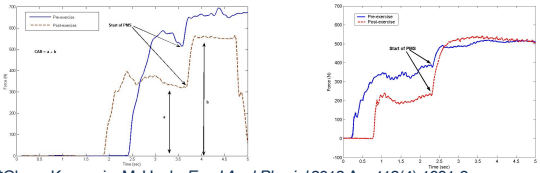
Cutting Edge [as in, still unexplained]*

- Distance cycling
  - Two hours
    - Interspersed sprints (every 20 min), 3k time trial at end
  - Men: central and peripheral fatigue
  - Women: central fatigue only



*Glace, Kremenic, McHugh. *Eur J Appl Physiol* 2013 Apr;113(4):1091-8.

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Strange EMG Changes…

	Men	Women	Sig?
VL amp	Unchanged	Unchanged	0.629
VM amp	Unchanged	↓ 31%	0.021
RF amp	Unchanged (↓ 12%)	↓ 17%	0.569
VL Mean freq	Unchanged	Unchanged	0.369
VM Mean freq	Unchanged	Unchanged	0.757
RF Mean freq	↑ 26%	Unchanged (↑ 5%)	0.097

- Most research done with fatigue uses pretty high-level contractions
  - Cycling is *extremely* low-level
  - Different mechanism/motor unit rotation strategy

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Newer EMG Application: Magnetic Stimulation

- Magnetic stimulator
  - Think Faraday's Law
    - Induce current in wire with magnetic field around wire
  - Replace "wire" with "nerve"
  - Painless, especially compared with electrical stimulation
- Stimulation of peripheral nerves
- Stimulation of nerve roots at spinal level
- Simulation of motor cortex
  - Recently, FDA-approved for treatment of depression

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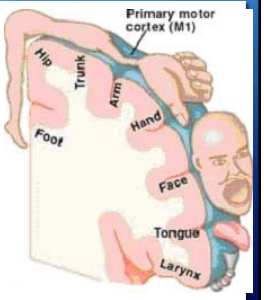
Transcranial Magnetic Stimulation

- Stimulate motor cortex of brain
- Measure response at muscle
- Evaluate entire conduction path
- Typically done using arm, hand muscles



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Transcranial Magnetic Stimulation

- Motor evoked potentials (MEP)
  - Stimulate, measure size of AP response
  - Measure *central motor conduction time* (CMCT)
    - Also stimulate nerve root in spinal cord
  - Often easier to evoke while subject is performing a contraction
    - Cortex more *excitable*
  - Site of fatigue?
- Silent period after MEP during active contractions

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Bathroom Reading

- Basmajian, DeLuca CJ. *Muscles Alive*. Baltimore: Williams and Wilkins, 1985.
- DeLuca CJ. The Use of Surface Electromyography in Biomechanics. *J Appl Biomech*, 1997, 13:135-163.
- Kamen G, Caldwell GE. Physiology and Interpretation of the Electromyogram. *J Clin Neurophysiol*, 1996, 13(5):366-384.

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