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FACULTY OF ENGINEERING

Intent detection and somatosensory feedback

#03: Electromyography (EMG)

Claudio CASTELLINI, Sabine THÜRAUF

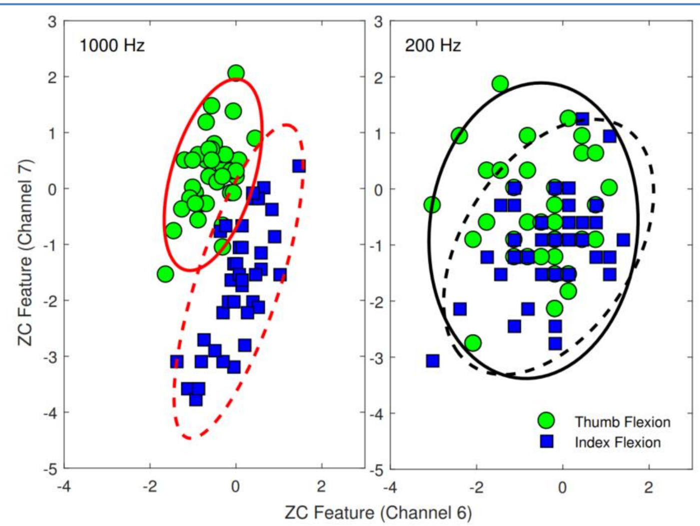


Figure 2. Differences in EMG patterns between using: (**left**) a 1000 Hz sampling rate; and (**right**) a 200 Hz sampling rate. ZC features are extracted from two different EMG channels (6 and 7) during thumb flexion (green circle markers and solid lines) and index flexion (blue square markers and dashed lines). Samples are from Subject 1 of Database 3.

EMG patterns related to two actions. Reproduced from Angkoon Phinyomark, Rami N. Khushaba and Erik Scheme, *Feature Extraction and Selection for Myoelectric Control Based on Wearable EMG Sensors*, MDPI Sensors 2018, 18, 1615

The *rubber hand illusion.* See Botvinick M, Cohen J., *Rubber hands 'feel' touch that eyes see.* Nature. 1998 Feb 19;391(6669):756. doi: 10.1038/35784. PMID: 9486643.

Lecture #03:

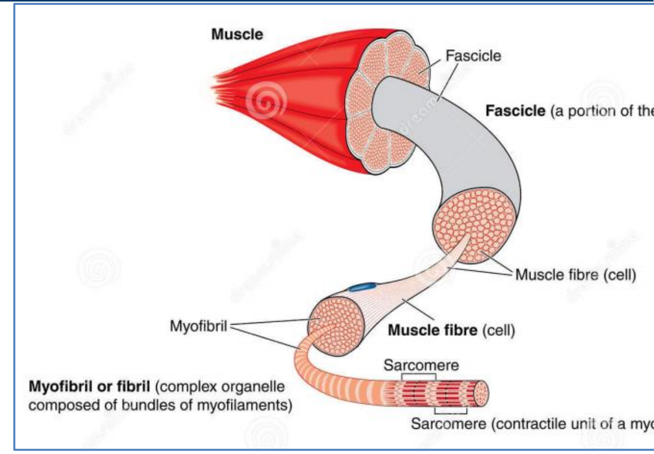
Electromyography (EMG)

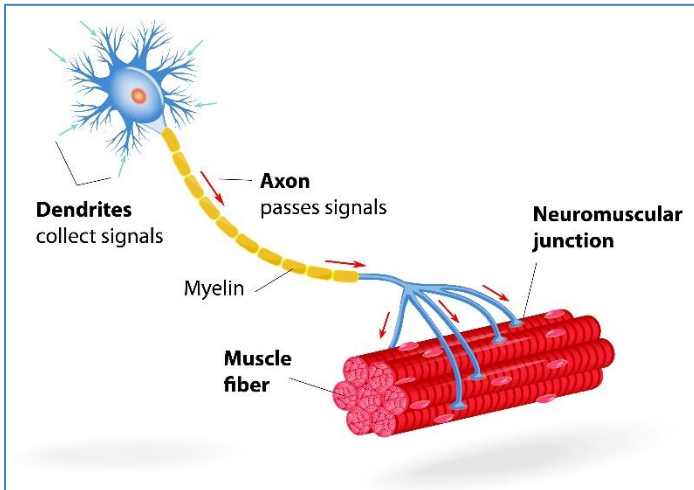
- Properties of EMG
- Measuring it
- Processing it
- Relation to intent detection
- Summary

Muscle activity / activation

- Just how does it work?
- muscles can only contract, giving rise to
  - force at the attachment to the bone, then in turn
  - torque at a joint, resulting in
  - force at the end-effector (e.g., the wrist)
- flexion / extension and stiffening up (co-contraction) enforced via
  - the agonist / antagonist mechanism
  - e.g., biceps and triceps
- basic contractile unit: the motor unit (MU), consisting of
- A motor unit consists of a single alpha-motoneuron (the motor neuron) and all the muscle fibers it innervates (controls).
  - an α-motoneuron, innervating
  - one or more muscle cells (muscle fibres)
  - at a neuromuscular junction (NMJ)
- a spike train in the α-motoneuron will cause sustained contraction of the MU.

Muscle activity / activation





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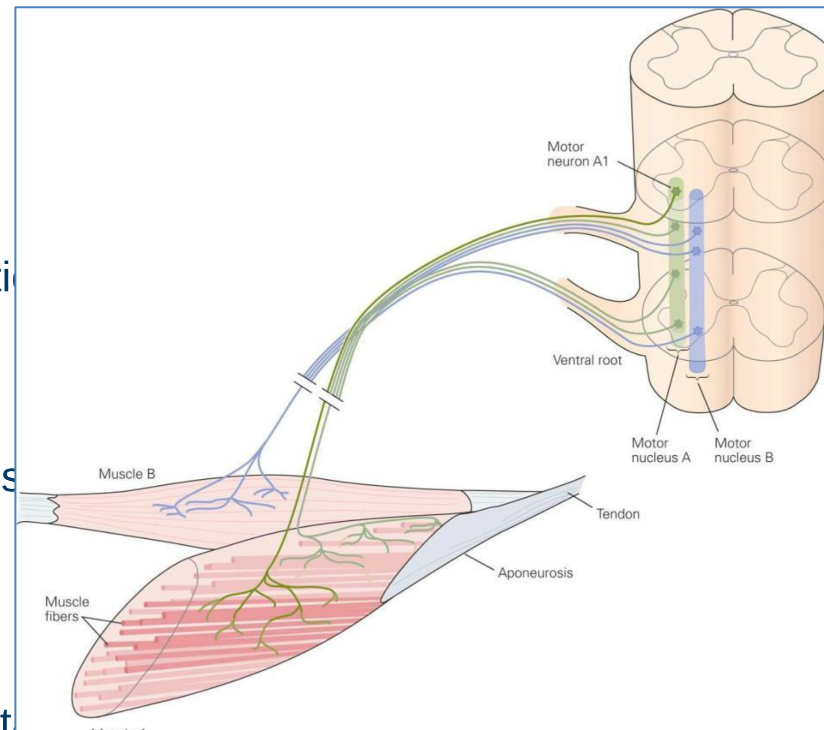


EMG

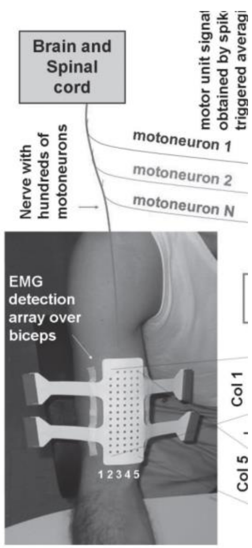
In the context of neural activity, "discharge" refers to the release of electrical impulses or action potentials by neurons. When a neuron "discharges," it means that it generates and sends out a series of electrical signals along its axon.

- so, muscle contraction (activity) is initiated by discharge of α-motoneurons
  - usually, many of them at the same time,
  - with different levels of activation,
  - carefully controlled by the CNS/PNS
- each α-motoneuron discharge causes a depolarisation wave in the cells of its MU
  - also called MUAP: Motor Unit Action Potential
- net effect: the superposition of many MUAPs on the surface of the muscle
- (Surface) electromyography is exactly all about measuring the superposed MUAPs
  - and sometimes, trying to *decompose the signal* back into its constituent MUAPs
  - The lower frequencies capture slower changes in muscle activity, while the higher frequencies capture rapid changes, such as individual motor unit action potentials.
  - Higher amplitudes indicate stronger muscle activity, while lower amplitudes indicate weaker activity

Roberto Merletti, Matteo Aventaggiato, Alberto Botter, Ales Holobar, Hamid Marateb, Taian M.M. Vieira, *Advances in Surface EMG: Recent Progress in Detection and Processing Techniques*, **Critical Reviews™ in Biomedical Engineering,** 38(4):305–345 (2010)

EMG

- surface electromyography
  - an oscillating signal related to the contraction of muscles
  - bandwidth: 15-450Hz, amplitude: 1µV-10mV



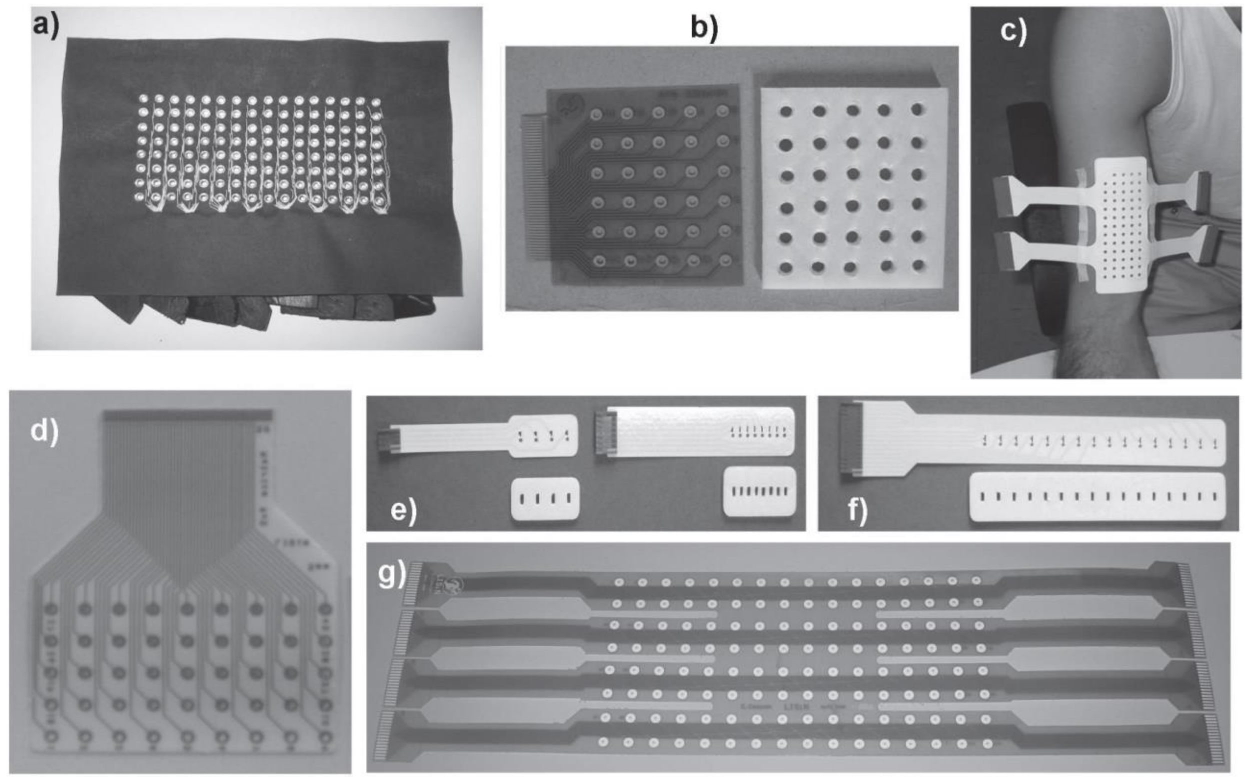


FIGURE 7. Examples of surface electrode arrays. a) Array of silver coated eyelets on cloth. Conductive gel is injected into the eyelets, b) Flexible printed circuit with 5x6 electrodes. The circuit is applied to the skin with a double adhesive foam whose cavities are filled with conductive gel through holes in the electrodes, c) array of electrodes screen printed on mylar, applied with a double adhesive foam on a biceps brachii muscle, d) another array implemented on flexible printed circuit. e) and f) linear arrays of electrodes screen printed on mylar, g) flexible printed circuit array with 128 electrodes that can bend in two directions.

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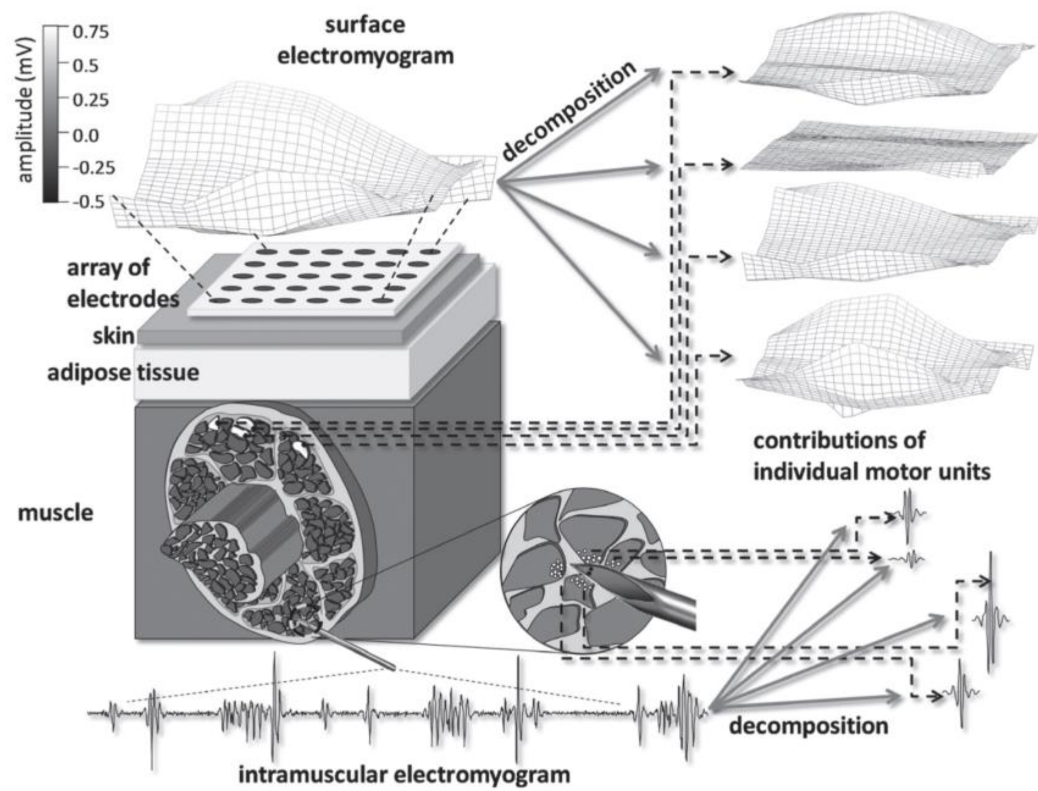

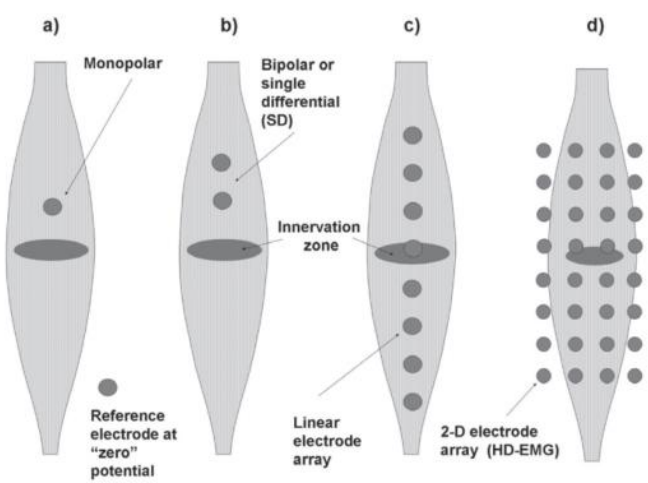

Intent detection and somatosensory feedback

1. Different electrode configurations
2. **Monopolar EMG**:
   1. In monopolar EMG, one electrode, called the active electrode, is placed over the muscle of interest, while a reference electrode is placed at a distant location, often on bony prominences or away from the muscle being measured.
   2. The active electrode detects the electrical activity (action potentials) generated by muscle fibers within the muscle of interest.
   3. The reference electrode serves as a common ground and helps to establish a baseline electrical potential against which the signals from the active electrode are measured.
   4. Monopolar EMG is useful for capturing overall muscle activity but may be more susceptible to noise and interference from surrounding tissues or electrical sources.
3. **Bipolar EMG**:
   1. In bipolar EMG, two electrodes are placed in close proximity to each other over the muscle of interest. These electrodes are typically placed parallel to the direction of the muscle fibers.
   2. One electrode serves as the active electrode, while the other serves as the reference electrode. Both electrodes detect the electrical activity generated by the muscle fibers between them.
   3. By using two electrodes close together, bipolar EMG can provide more localized and precise measurements of muscle activity compared to monopolar EMG.
   4. Bipolar EMG is commonly used in clinical settings for tasks such as needle EMG (insertion of a needle electrode directly into the muscle) and for studying the activation patterns of specific muscles during movement or tasks.

4. What is the output of an Smeg sensor - The sEMG signal is often represented as a time-series waveform, where the x-axis represents time and the y-axis represents the amplitude of the electrical signal. Each peak or fluctuation in the waveform corresponds to the firing of motor units within the muscle and the recruitment of muscle fibers during contraction.

5. The reference electrode plays a crucial role in EMG recordings by providing a stable baseline electrical potential and helping to minimize noise, artifacts, and variability in the recorded signals.

1. **Single Differential Configuration**:
    1. In a single differential configuration, two electrodes are placed in close proximity to each other over the muscle of interest.
    2. One electrode acts as the active electrode, detecting the electrical activity of the muscle fibers.
    3. The other electrode serves as the reference electrode, providing a baseline against which the signal from the active electrode is measured.
    4. The difference in electrical potential between the active and reference electrodes is recorded as the EMG signal.
    5. This configuration provides a basic bipolar setup and is commonly used for routine EMG recordings.
2. **Double Differential Configuration**:
    1. In a double differential configuration, two pairs of electrodes are used instead of one.
    2. Each pair consists of one active electrode and one reference electrode, similar to the single differential configuration.
    3. However, the two pairs of electrodes are placed slightly apart from each other, but still over the same muscle.
    4. By measuring the difference in electrical potential between the two active electrodes and the two reference electrodes separately, this configuration helps to further reduce noise and interference.
    5. The double differential configuration offers improved signal quality and enhanced noise rejection compared to the single differential configuration.
3. In summary, both single differential and double differential configurations are variations of bipolar EMG setups used to record muscle activity.

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EMG

- surface electromyography
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  - "power line 50 Hz" refers to the
  - frequency at which alternating
  - current (AC) electrical power is
  - supplied in many parts of the world.

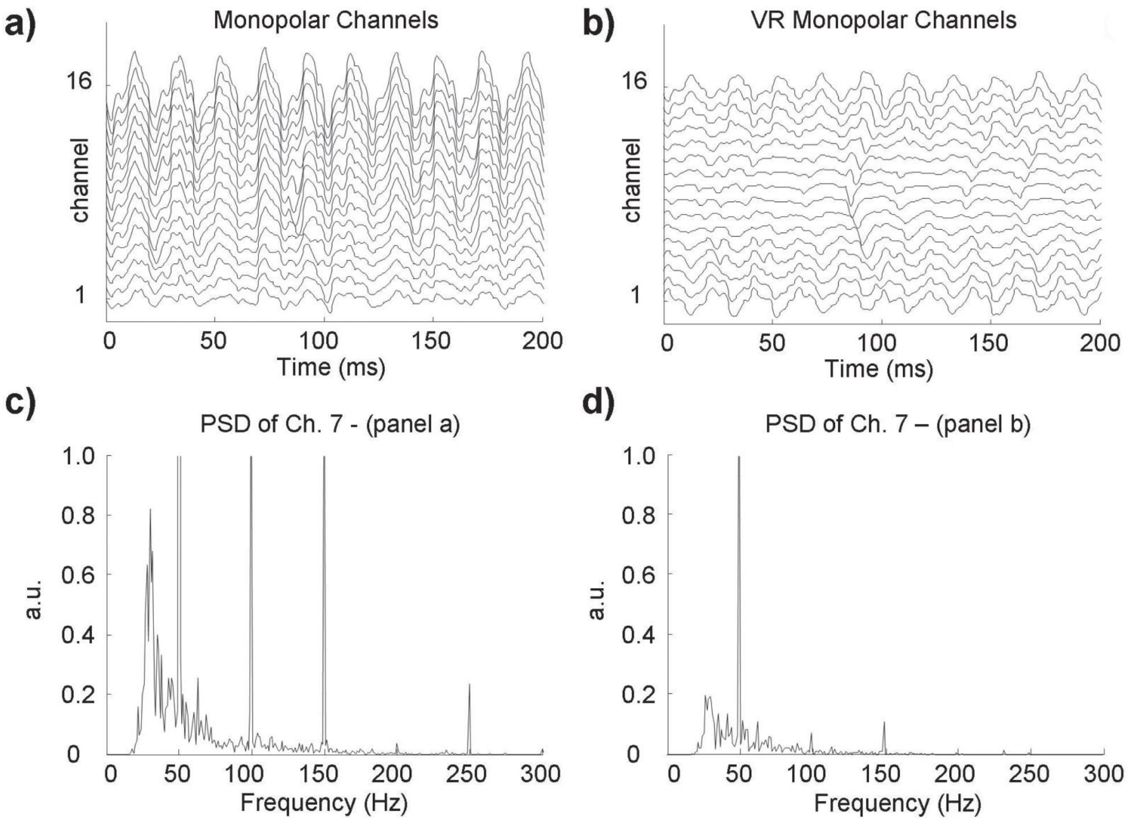

FIGURE 5. a) Example of 16 EMG channels detected with a linear array aligned with the fibers on the biceps brachii muscle. Detection with respect to a remote reference electrode (no VR). Artificial power line interference (50 Hz and four additional harmonics) was added with intensity increasing from ch 1 to ch 16. b) spectrum of ch 7. c) signals from a) measured with respect to the average of the signals in a) (VR). d) spectrum of ch. 7 of c). Note the reduction of physiological common mode signals indicated by the smaller spectral area. Arbitrary units (a.u.) are the same in b) and d).

Intent detection and somatosensory feedback

1. "frame rate" refers to the number of individual frames or images displayed or captured per second (fps).

2. Each data point plotted on the graph represents the discharge rate (y-axis) of a motor unit at a specific time (x-axis) during a muscle contraction. The higher the point is on the y-axis, the faster the motor unit is firing at that particular time. The trend shows that the firing rate of the motor units increases as force increases, and then decreases as force decreases.

3. Crosstalk in electromyography (EMG) refers to the interference or contamination of EMG signals from one muscle by signals from neighboring muscles. When EMG sensors are placed on the surface of the skin to detect muscle activity, they may pick up electrical signals not only from the target muscle but also from nearby muscles due to their proximity. In addition to interference from neighboring muscles, crosstalk can also occur between different channels of EMG recordings. For example, if multiple EMG sensors are placed on the skin surface, signals from one sensor may inadvertently influence or contaminate the signals detected by neighboring sensors.
4. To mitigate the effects of crosstalk, researchers and clinicians employ various techniques, including:

- **Selective Electrode Placement**: Careful placement of EMG sensors to minimize the proximity to neighboring muscles.
- **Signal Processing**: Sophisticated signal processing algorithms to filter out or reduce the effects of crosstalk.
- **Cross-Talk Correction**: Mathematical methods to estimate and correct for crosstalk based on the spatial and temporal characteristics of the EMG signals.
- **Normalization**: Normalizing EMG data relative to maximum voluntary contractions or other reference signals to account for variations in crosstalk across individuals and conditions.

1. The PSD represents the power per unit frequency (e.g., watts per hertz) contained in a signal. It shows how the power of the signal is distributed across different frequency components.

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EMG - decomposition

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  - bandwidth: 15-450Hz, amplitude: 1µV-10mV

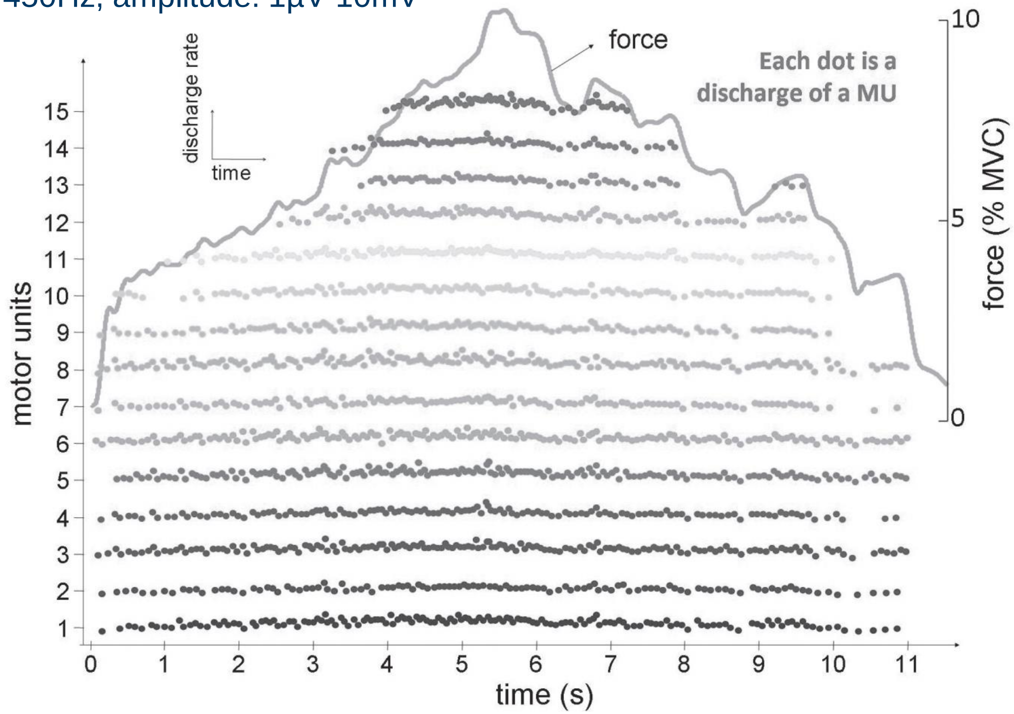

FIGURE 15. Decomposition of the HDsEMG obtained from a healthy abductor pollicis brevis muscle during its isometric contraction, from 0 to 10% MVC and back to 0% in 11 s. Each dot represents a discharge of a motor unit with the instantaneous discharge frequency (inverse of the interspike interval) indicated on the y-axis. The order of motor unit recruitment and decruitment can be seen, associated with the produced muscle force.

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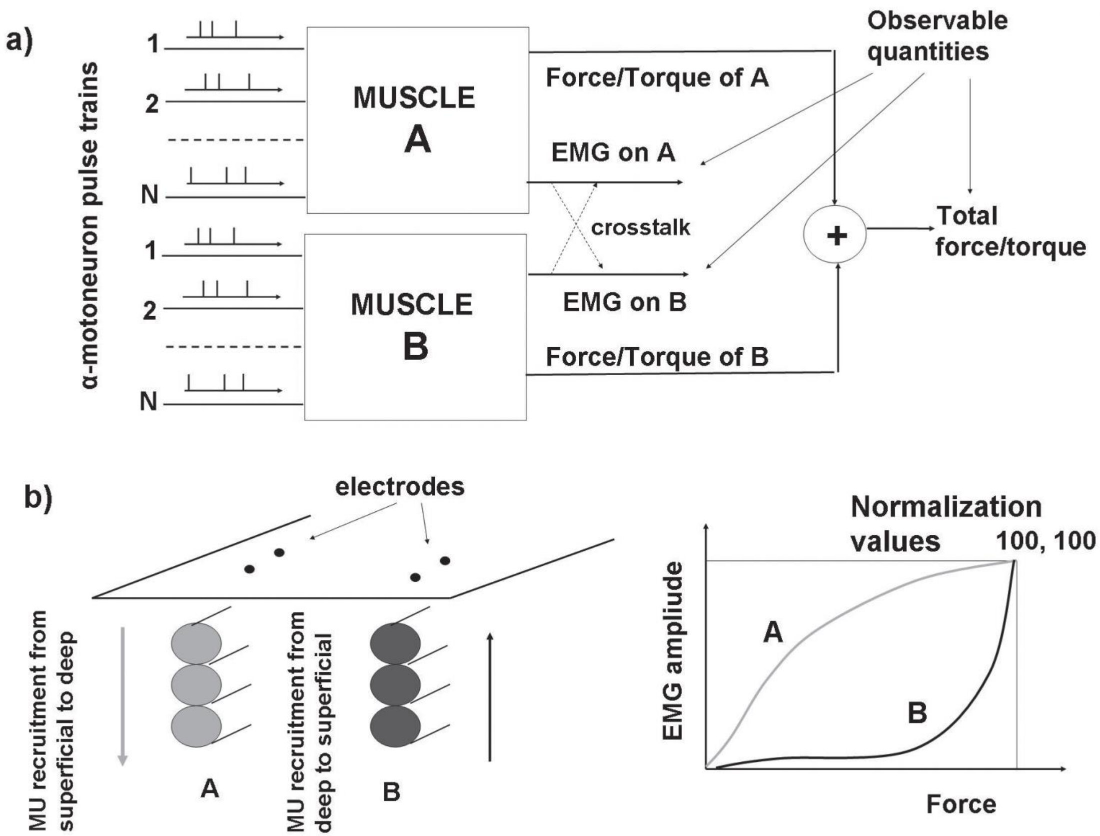

FIGURE 18. a) Example of load sharing between two muscles each producing a force or contributing to the torque at the joint. Only the total force or torque is available together with the EMG amplitude of the HDsEMG channels obtained from an electrode array. The estimation of the force/torque contributions of the individual muscles is an open problem. b) The relationship between the normalized force generated by a muscle and the normalized EMG obtained from the same muscle may be different depending on the location of the recruited motor units (MU). Two extreme cases are shown: in case a) recruitment proceeds from the most superficial to the deepest MUs, in case b) recruitment proceeds from the deepest to the most superficial MUs generating different force-EMG curves.

R. Merletti, S. Muceli, Tutorial. *Surface EMG detection in space and time: Best practices,* Journal of Electromyography and Kinesiology, Volume 49, 2019.

EMG in practice

- typical output of surface EMG sensors:

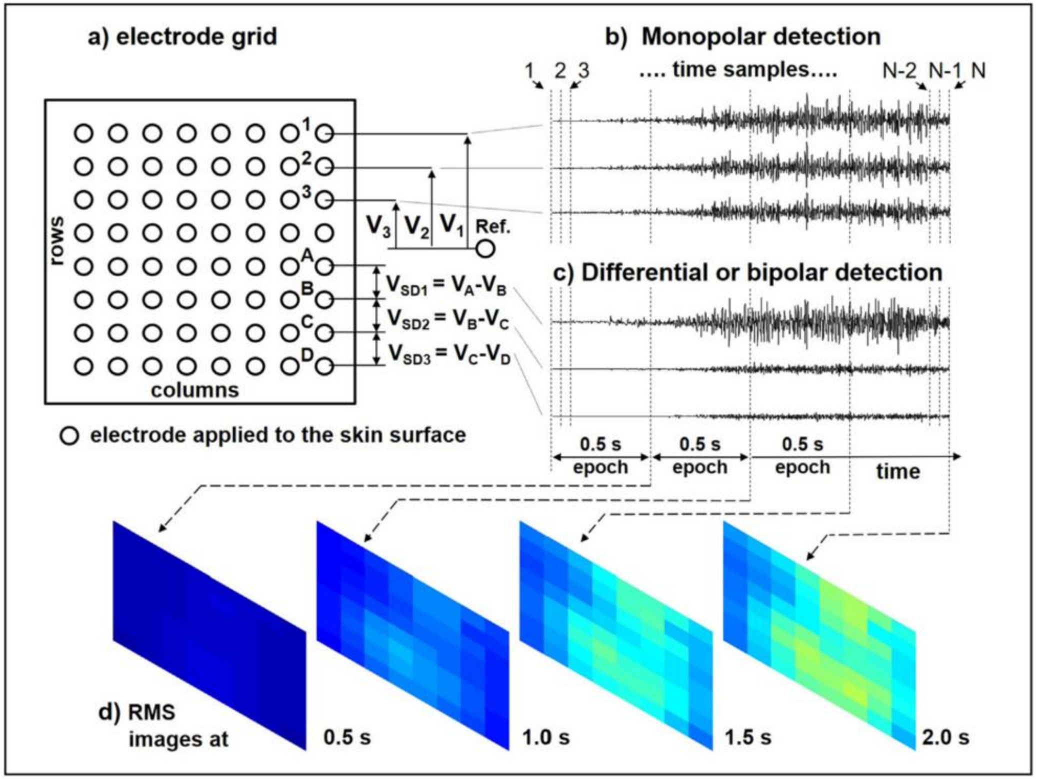

Fig.1. Surface EMG signals in space and time. (a) Schematic representation of an electrode grid of 8 rows by 8 columns applied over a muscle, (b) examples of three monopolar signals V_1 to V_3 versus time, from electrodes 1, 2, 3, measured with respect to a reference electrode, placed on an electrically inactive region, (c) examples of differential ($V_A - V_B$ to $V_C - V_D$) signals versus time. The 1, 2, 3, …, N − 1, N dashed vertical lines represent N samples of these signals in time (for clarity the samples in time are much further apart than in real conditions). Each time sample provides a map of the distribution in space. Examples of movies of instantaneous maps are available at https://www.robertomerletti.it/en/emg/material/videos/f1/to/f4/. (d) Each electrode (or pair of electrodes) provides a sample in space, which is a signal evolving in time, defining a pixel in the image. Signal features, such as the root mean square value (RMS) of each signal (pixel) may be computed over specific time intervals (time epochs or time windows or simply "epochs"). In panel d, RMS maps are monopolar with epoch = 0.5 s. Examples of movies of RMS maps are available at https://www.robertomerletti.it/en/emg/material/videos/f5/to/f19/.

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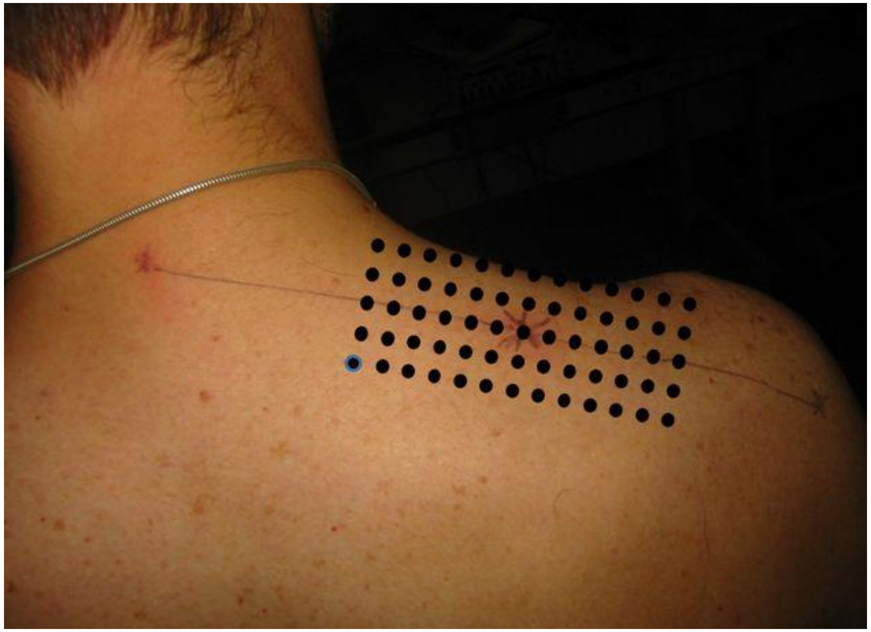
EMG in practice



- typical output of surface EMG sensors:
- Heatmap:-

- **Visualization of Muscle Activity Distribution**: Heatmaps
- allow researchers and clinicians to visualize the spatial
- distribution of muscle activity across the surface of the body.
- By displaying the intensity of muscle activity as colors on a
- two-dimensional grid, heatmaps provide a clear and
- intuitive representation of which areas of the body are more
- active during specific tasks or movements.

https://www.robertomerletti.it/en/emg/material/videos/f1/
https://www.youtube.com/watch?v=Vs6-Qd5-3gY

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EMG in practice

- typical output of surface EMG sensors:
- Extending each of the fingers produce a different activation pattern

https://www.robertomerletti.it/en/emg/material/videos/f11/

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EMG in practice

- typical output of surface EMG sensors:

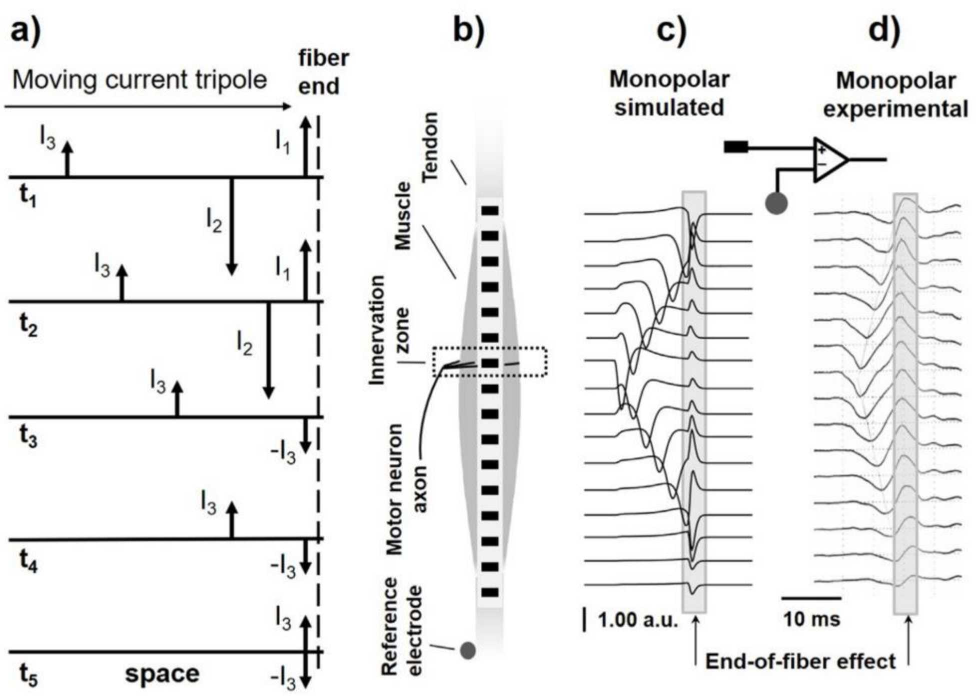

Fig. 3. The end-of-fiber effect. (a) Model of the extinction of a current tripole at the end of a single muscle fiber. As the propagating tripole reaches the fiber end, the poles stop, progressively overlap, and cancel out (see text for details). (b) Simulated MU whose fibers are all innervated and terminate at the same locations. The MU is parallel to the skin and to the electrode array, with center 6 mm below the skin. The MU has 200 fibers and its territory has a radius of 3 mm. The MU semi-length is 50 mm in the two directions. The skin and adipose layers have both 1 mm thickness. The IED is 10 mm. (c) Computer simulated monopolar signals detected by the linear electrode array indicated in b). The simulated muscle fiber conduction velocity value is 4 m/s. (d) Experimental monopolar MUAP detected over a healthy biceps brachii muscle with the same array indicated in b). The array does not reach beyond the fiber-tendon junctions. The depolarized zones, the spread of the NMJs, and the spread of the fiber-tendon junctions are likely wider than those simulated in c). Other differences may be due to the fiber conduction velocity, the volume conductor properties, the tripole approximations and the simulated point-like electrodes versus 1 mm thick, 5 mm long experimental bar electrodes.

Intent detection and somatosensory feedback

1. The "end-of-fiber effect" in the context of electromyography (EMG) refers to the phenomenon where the electrical activity detected by EMG electrodes is influenced by the position of the electrodes relative to the ends of muscle fibers.
2. Muscle fibers extend along the length of skeletal muscles and are innervated by motor neurons, with each motor neuron innervating multiple muscle fibers. At the neuromuscular junction (NMJ), which is where the motor neuron terminal meets the muscle fiber, the motor neuron releases neurotransmitters that stimulate muscle contraction.
3. The end-of-fiber effect occurs because the electrical activity at the ends of muscle fibers, near the neuromuscular junction, may differ from the activity along the length of the fiber. This can impact EMG recordings in the following ways:
4. **Signal Attenuation**: The electrical activity at the ends of muscle fibers may be weaker or attenuated compared to the activity along the middle portion of the fiber. As a result, EMG signals recorded near the ends of muscle fibers may have reduced amplitude or altered characteristics.
5. **Signal Distortion**: The complex electrochemical processes occurring at the neuromuscular junction may introduce noise or distortion into the EMG signal recorded near the ends of muscle fibers. This can make it more challenging to accurately interpret the EMG signal and extract meaningful information about muscle activity.
6. **Interference from Nearby Structures**: EMG recordings near the ends of muscle fibers may also be influenced by interference from nearby structures, such as skin, fat, or other muscles. This interference can further complicate the interpretation of EMG signals and make it difficult to isolate the activity of the target muscle.

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EMG in practice

- typical output of surface EMG sensors:

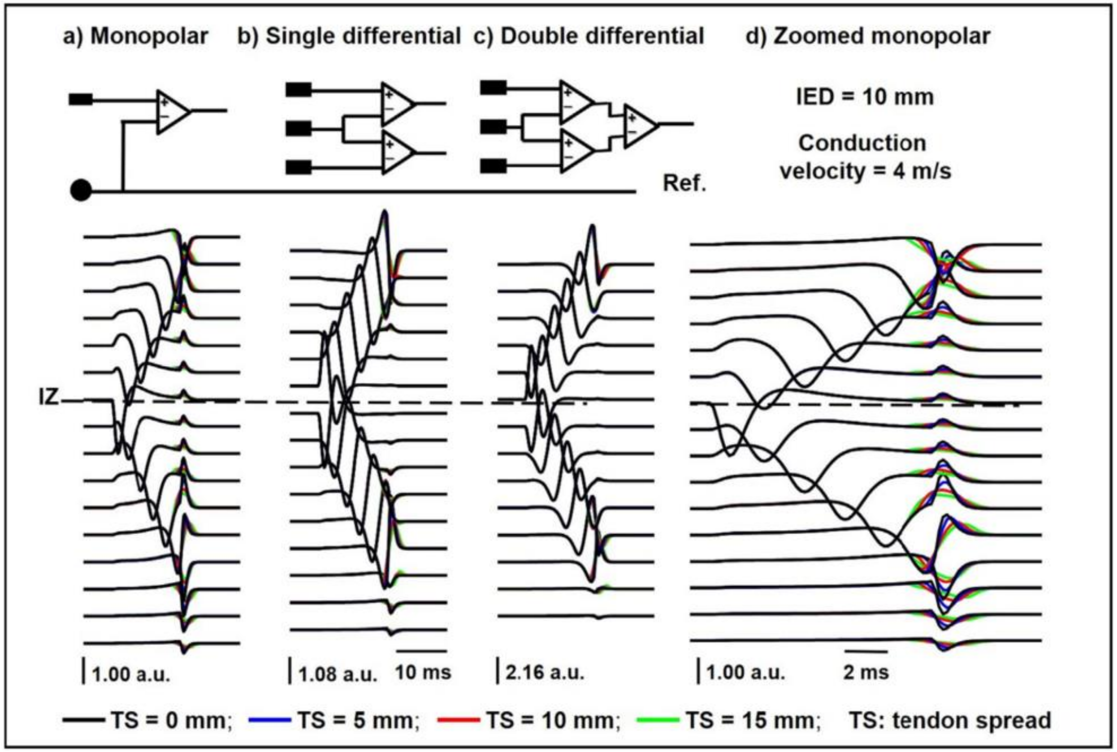

Fig. 4. Simulated action potential of a superficial motor unit as detected with a linear electrode array. All parameters of the model are the same as for Fig. 3 except for the spread of the fiber-tendon junctions (TS). Example of simulated (a) monopolar, (b) single differential (SD) and (c) double differential (DD) MUAP showing the different impact of the end-of-fiber effect, (d) time-zoomed version of the monopolar signal showing the effect of the spread of the fiber-tendon terminations. The simulated conduction velocity is 4 m/s and the spread of the NMJs is zero. The fiber-tendon junctions have a spread indicated by the different colors. The spread of the NMJs has a very similar effect. The thickness of the skin is 1 mm and adipose layers is 1 mm. The MU has radius 3 mm, with center at a depth of 4 mm in the muscle (6 mm under the skin) and is constituted by 200 fibers parallel to the skin. The MU semi-length is 50 mm in the two directions. Note the different amplitude scales: SD and DD signal amplitudes depend on the inter-electrode distance. The simulated electrodes are point-like. The a.u. units are arbitrary units that allow amplitude comparisons ; note the different scales.

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EMG in practice

- typical output of surface EMG sensors: (crosstalk)

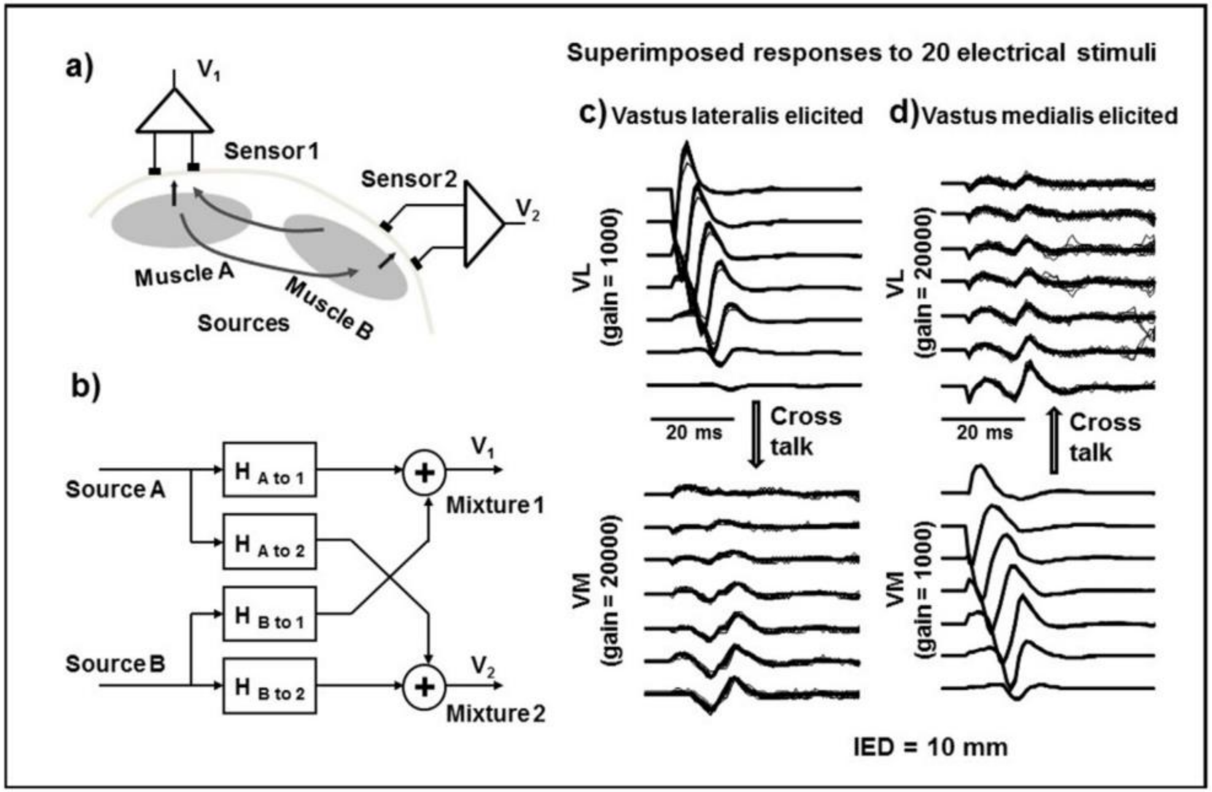

Fig. 8. Crosstalk between muscles. (a) The concept of crosstalk, (b) schematic model of crosstalk, (c) sEMG signals detected on the vastus medialis (VM) during electrical stimulation of the vastus lateralis (VL), (d) sEMG signals detected on the vastus lateralis (VL) during electrical stimulation of the vastus medialis (VM). Note the different amplifier gains and the larger crosstalk signal at the muscle-tendon region. Both electrode arrays are between the innervation zone and the muscle-tendon junction of the respective muscles. The circumferential distance between the arrays is 39 mm. $H_{A\ to\ 1}$ is the “transfer function” (that is the filter) from the source A signal to the mixture 1 signal. Fig. 8c and d are from Fig. 1 pg 685 of (Farina et al., 2002b), with permission.

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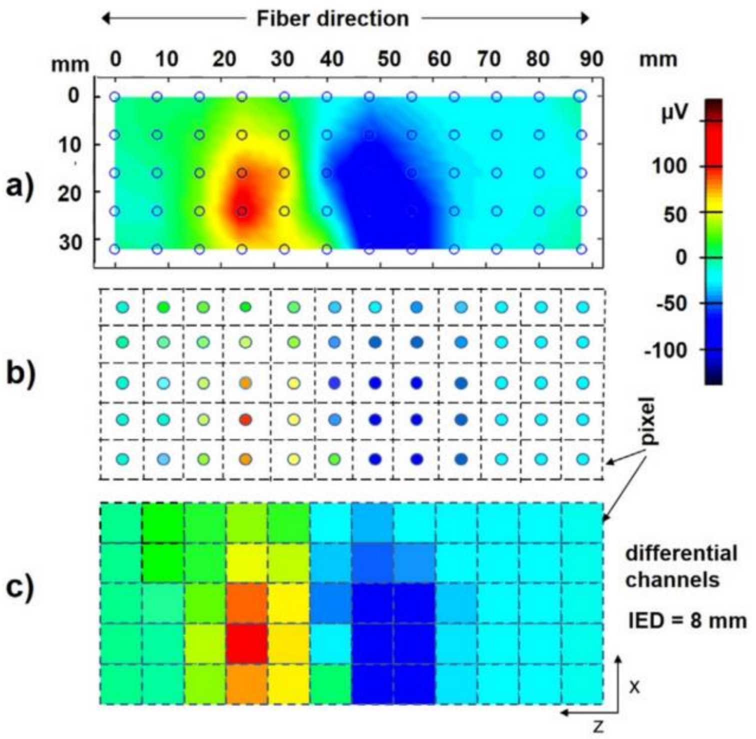
EMG in practice

- typical output of surface EMG sensors:



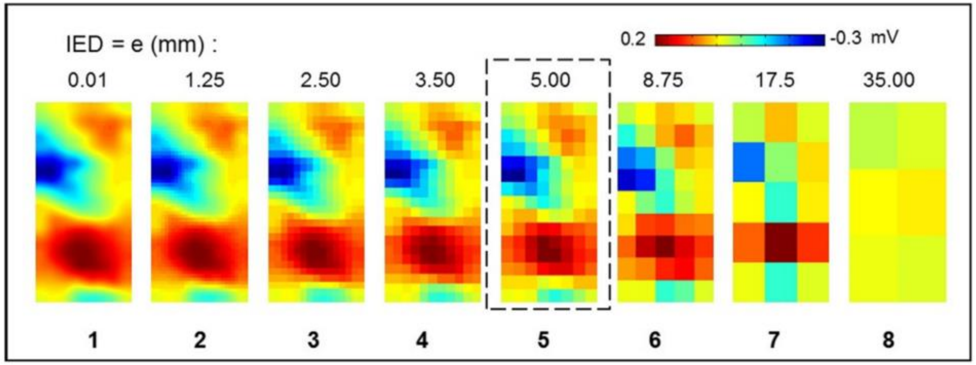


Fig. 9. Sampling sEMG images in space. (a) Instantaneous analog spatial distribution of a SD MUAP voltage, propagating along z, sampled by a grid of 5 × 13 electrodes, applied on a biceps brachii, generating 5 × 12 SD channels, (b) voltage detected by each electrode pair (channel) in the fiber direction, (c) for cosmetic reasons, the instantaneous voltage detected by each channel is usually associated with the corresponding pixel of the image. Circular electrodes have 3 mm diameter. Consider the length of this MUAP (about 60 mm) and its width (about 50 mm) in space. A similar MU placed about 50 mm lateral (in the x direction), with respect to the centerline of the array, would provide crosstalk on some of the channels. Such MU might or might not belong to the same muscle. Assuming a muscle fiber conduction velocity of 4 m/s the time duration of the MUAP detected by each channel along z would be about 15 ms.

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EMG in practice

- processing surface EMG:

- either consider the ARVs (Averaged-Rectified Values):
    - in which case there is one „feature“ per channel
    - a purely temporal feature (not spectral), monotonically related to the intensity of the contraction

- or consider features (characteristics) evaluated on a *window* of raw signal,
    - there can be several for each channel, e.g., the Hudgins features are 4 per channel
    - these are sort-of spectral features, i.e., related to the frequency content of the signal

- (very advanced, not covered here) or decompose high-density EMG into single MUAPs

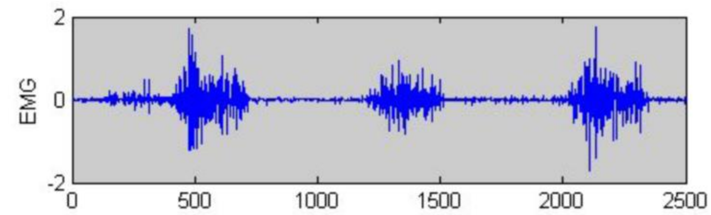
EMG in practice

- processing surface EMG: the ARVs
- either consider a time window and evaluate the root-mean-squared (RMS) signal over it, or
- first rectify, i.e., take the absolute values, then apply a low-pass filter

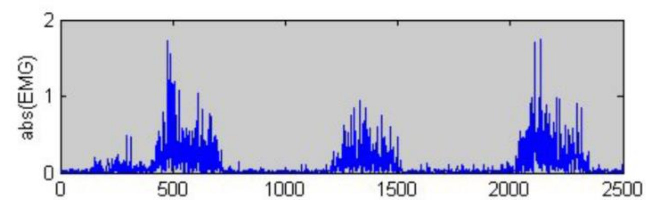
M. Zecca, S. Micera, M. C. Carrozza, & P. Dario, Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, Critical Reviews™ in Biomedical Engineering, 30(4–6):459–485 (2002)

EMG in practice

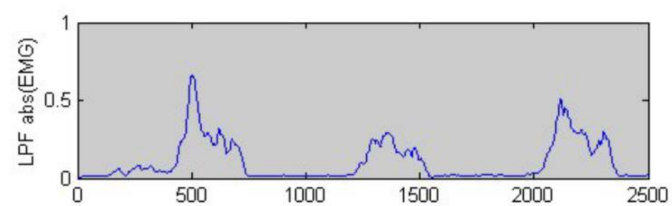
- processing surface EMG: the ARVs
- either consider a time windows and evaluate the root-mean-squared (RMS) signal over it, or
- first rectify then apply a low-pass filter -



(a) Original EMG signal



(b) Rectified EMG signal

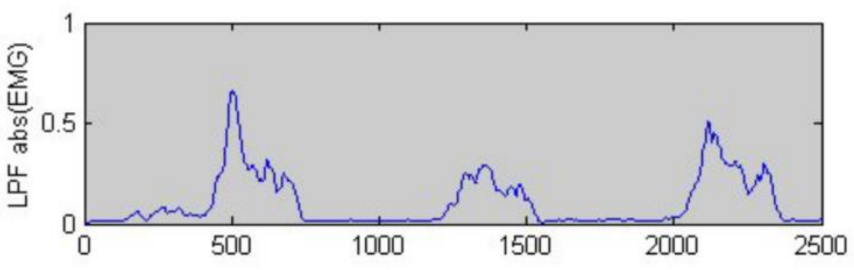


(c) Low pass filtered EMG signal

M. Zecca, S. Micera, M. C. Carrozza, & P. Dario, Control of Multifunctional Prosthetic Hands by Processing the Electromyographic Signal, Critical Reviews™ in Biomedical Engineering, 30(4–6):459–485 (2002)

EMG in practice

- processing surface EMG: the ARVs – signal from one sensor – one feature
- either consider a time window and evaluate the root-mean-squared (RMS) signal over it, or
- first rectify then apply a low-pass filter - a low-pass filter is a preprocessing step used in sEMG signal processing to remove high-frequency noise and interference while preserving the lower-frequency components related to muscle activity.
- obtain a signal which is roughly monotonically related to muscle contraction
- see demonstration with a myo!



(c) Low pass filtered EMG signal

EMG in practice

- recall our notation:

$$S = \{(\boldsymbol{x}_i, y_i)\}_{i=1}^{n} \text{ , where } \boldsymbol{x}_i \in \mathbb{R}^d \text{ and } y_i \in \mathbb{R}$$

$$X = \begin{bmatrix} \boldsymbol{x}_1^T \\ \vdots \\ \boldsymbol{x}_n^T \end{bmatrix} \in \mathbb{R}^{n \times d} \qquad \text{and} \qquad \boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} \in \mathbb{R}^n$$

EMG in practice

- with the *myo*, $d = 8$ and

$$\boldsymbol{x}_i = \begin{bmatrix} ARV_1 \\ \vdots \\ ARV_8 \end{bmatrix}$$

$$X = \begin{bmatrix} \boldsymbol{x}_1^T \\ \vdots \\ \boldsymbol{x}_n^T \end{bmatrix} \in \mathbb{R}^{n \times 8} \qquad \text{and} \qquad \boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} \in \mathbb{R}^n$$

EMG in practice

- quick digression: our dataset S is dynamic!
  - it can **and will** change over time due to new data acquisition and/or the act of discarding previous data!

- so it can **and should** be thought of as the juxtaposition of p datasets $S_i, i = 1, \dots, p$
  - where p is the number of data gatherings performed during an experiment;
  - each S_i has therefore been recorded while the user was performing a specific action
  - and so each data subset (cluster) S_i is associated to an action (not uniquely, though – think repeated actions!).

$$S = \{S_1, \dots, S_p\}, \qquad S_i = \{(X_i, \boldsymbol{y}_i)\}$$

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_p \end{bmatrix} \in \mathbb{R}^{n \times d} \qquad \text{and} \qquad \boldsymbol{y} = \begin{bmatrix} \boldsymbol{y}_1 \\ \vdots \\ \boldsymbol{y}_p \end{bmatrix} \in \mathbb{R}^n$$

B. Hudgins, P. Parker and R. N. Scott, "A new strategy for multifunction myoelectric control," in *IEEE Transactions on Biomedical Engineering*, vol. 40, no. 1, pp. 82-94, Jan. 1993, doi: 10.1109/10.204774

EMG in practice

- The Hudgins features aim to extract meaningful data from the raw EMG signals to facilitate the control of myoelectric devices by distinguishing different muscle activation patterns.

- processing surface EMG: the Hudgins features
- They are a set of parameters
- establish a time window,

- count
  - the mean absolute value (MAV)
  - the zero crossings (ZC)
  - the slope sign changes (SSC)
  - the waveform length (WL)
- along the window.
- Features are extracted from several time segments of the signal

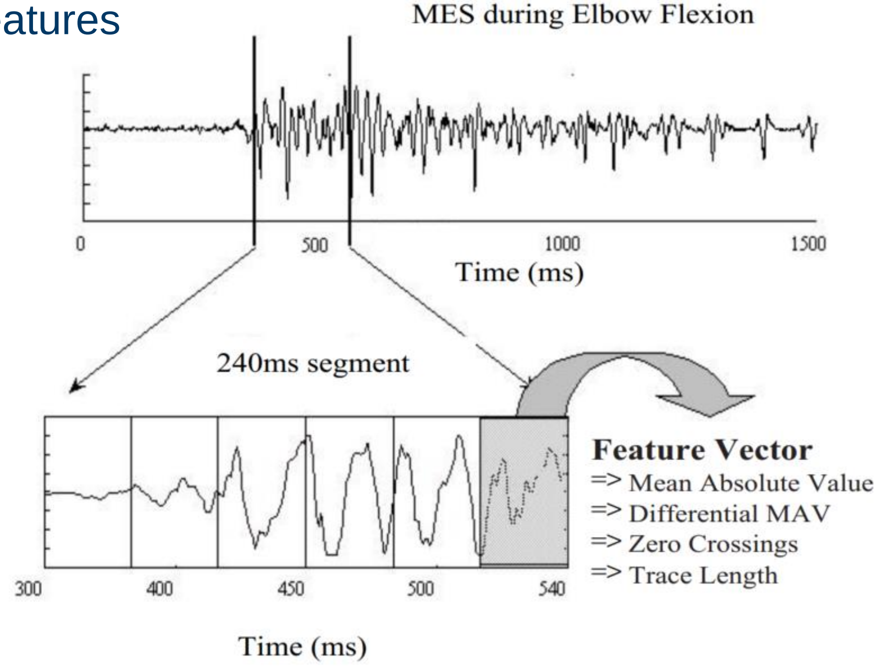


Figure 5. In Hudgins' approach, the features are extracted from several time segments of the unprocessed MES.

Intent detection and somatosensory feedback

1. **Mean Absolute Value (MAV)**:
   1. The MAV is computed by taking the average of the absolute values of the sEMG signal samples within the time window.
   2. It represents the average magnitude of muscle activation during that time period.
   3. MAV is a measure of the overall amplitude or intensity of muscle activity within the window.
2. **Zero Crossings (ZC)**:
   1. Zero crossings refer to the number of times the sEMG signal crosses the zero amplitude axis within the time window.
   2. Zero crossings provide information about the frequency of changes in the sEMG signal, indicating transitions between positive and negative phases.
   3. A higher number of zero crossings may indicate more dynamic or rapid changes in muscle activity.
3. **Slope Sign Changes (SSC)**:
   1. SSC counts the number of times the slope of the sEMG signal changes sign within the time window.
   2. It captures variations in the rate of change of the signal, indicating abrupt transitions or fluctuations in muscle activity.
   3. SSC is sensitive to changes in muscle activation patterns, such as the onset or cessation of muscle contractions.
4. **Waveform Length (WL)**:
   1. WL is calculated by summing the absolute differences between consecutive sEMG signal samples within the time window.
   2. It quantifies the overall complexity or irregularity of the sEMG waveform, reflecting the degree of variability in muscle activity over time.
   3. A higher WL value indicates a more variable or intricate sEMG waveform, whereas a lower WL value suggests a smoother or more regular waveform.

B. Hudgins, P. Parker and R. N. Scott, "A new strategy for multifunction myoelectric control," in *IEEE Transactions on Biomedical Engineering*, vol. 40, no. 1, pp. 82-94, Jan. 1993, doi: 10.1109/10.204774

EMG in practice

- the Hudgins features:
  - the mean absolute value (MAV)
  - the zero crossings (ZC)
  - the slope sign changes (SSC)
  - the waveform length (WL)
- along a time window.

1) Mean Absolute Value —An estimate of the mean absolute value of the signal, $\overline{X}_i$, in segment i which is N samples in length is given by

$$\overline{X}_i = \frac{1}{N}\sum_{k=1}^{N}|x_k| \quad \text{for } i = 1, \cdots, I \qquad (1)$$

where x_k is the kth sample in segment i and I is the total number of segments over the entire sampled signal.

3) Zero Crossings —A simple frequency measure can be obtained by counting the number of times the waveform crosses zero. A threshold must be included in the zero crossing calculation to reduce the noise induced zero crossings. Assuming a system noise of 4 μV peak to peak and a system gain of 5000, this dead zone can be calculated to be ± 10 mV measured at the input to the A/D converter. Given two consecutive samples x_k and x_{k+1}, increment the zero crossing count, ZC, if

$$x_k > 0 \text{ and } x_{k+1} < 0, \text{ or } x_k < 0 \text{ and } x_{k+1} > 0, \text{ and } |x_k - x_{k+1}| \geq 0.01\,\text{V}. \qquad (3)$$

4) Slope Sign Changes —A feature which may provide another measure of frequency content is the number of times the slope of the waveform changes sign. Once again a suitable threshold must be chosen to reduce noise induced slope sign changes.

Given three consecutive samples, x_{k-1}, x_k and x_{k+1}, the slope sign change count, SC, is incremented if

$$x_k > x_{k-1} \text{ and } x_k > x_{k+1}, \text{ or } x_k < x_{k-1} \text{ and } x_k < x_{k+1}, \text{ and } |x_k - x_{k+1}| \geq 0.01\,\text{V} \text{ or } |x_k - x_{k-1}| \geq 0.01\,\text{V}. \qquad (4)$$

5) Waveform Length —A feature which provides information on the waveform complexity in each segment is the waveform length. This is simply the cumulative length of the waveform over the time segment defined as

$$l_0 = \sum_{k-1}^{N}|\Delta x_k|. \qquad (5)$$

where $\Delta x_k = x_k - x_{k-1}$ (difference in consecutive sample voltage values).

EMG in practice

- the Hudgins features: example
- **Feature Vector=[MAV,ZC,SSC,WL]**
- **Feature Vector=[0.33,5,6,5.6]**

- along a time window. given $\hat{d}$ sensors, then in this case $d = 4\hat{d}$ and

$$\boldsymbol{x}_i = [MAV_1\ ZC_1\ SSC_1\ WL_1 \ldots MAV_{\hat{d}}\ ZC_{\hat{d}}\ SSC_{\hat{d}}\ WL_{\hat{d}}]^T$$

$$X = \begin{bmatrix} \boldsymbol{x}_1^T \\ \vdots \\ \boldsymbol{x}_n^T \end{bmatrix} \in \mathbb{R}^{n \times 4\hat{d}} \qquad \text{and} \qquad \boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} \in \mathbb{R}^n$$

EMG in practice

- the Hudgins features:
  - the mean absolute value (MAV)
  - the zero crossings (ZC)
  - the slope sign changes (SSC)
  - the waveform length (WL)
- along a time window. in the case of the *myo*, $\hat{d} = 8$, $d = 32$ and

$$\boldsymbol{x}_i = [MAV_1\ ZC_1\ SSC_1\ WL_1 \ldots MAV_8\ ZC_8\ SSC_8\ WL_8]^T$$

$$X = \begin{bmatrix} \boldsymbol{x}_1^T \\ \vdots \\ \boldsymbol{x}_n^T \end{bmatrix} \in \mathbb{R}^{n \times 32} \qquad \text{and} \qquad \boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} \in \mathbb{R}^n$$

Summary

- today:
  - muscle activity
  - biosignals related to it
- what about sEMG?
- what other kinds of signals can we use?

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