OUR EMGLAB EXPERIENCES: STRATEGIES FOR MANUAL DECOMPOSITION

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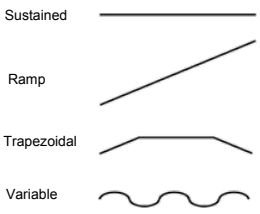
Muscles

Subjects

- Normal (ages 9 to 60)
- Cerebral Palsy
  Tibialis anterior and Gastrocnemius muscles
- Spinal cord injury: tetraplegia
  Brachioradialis muscle as a main donor in tendon transfer surgeries to restore thumb or wrist functions

Contractions

- Isometric
- Manually resisted
- Low to moderate levels

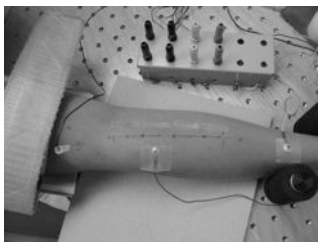


Electrodes

- Fine-wire electrodes: a pair of 50 µm-diameter stainless steel wires insulated except for 1 mm at the tip and recording surfaces offset by 2 mm
- Monopolar needles: 25 gauge, 37 mm

Montage: monopolar with surface reference

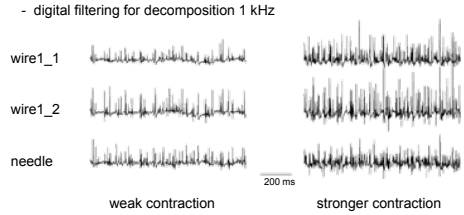
Channels: 8



EMG Signals

Recordings

- 20-s, 30-s or 100-s long epochs
- frequency band 5 Hz - 5 kHz
- sampling rate 10 kHz
- digital filtering for decomposition 1 kHz



Our Goal: Full Decomposition

To identify every discharge of every MU whose MUAP is detectable in the signal

Note: - small residual after subtracting all identified discharges
- complete discharge patterns of all identified templates

small residual

complete discharge patterns

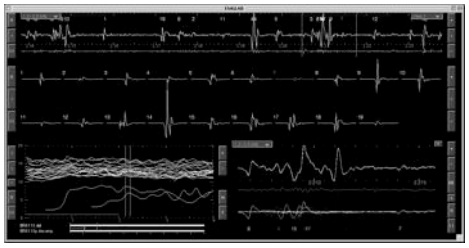
Our Goal: Full Decomposition

Our goal requires manual inspection and verification of the results from the automatic procedures and manual completion of the decomposition

Note: - complete discharge pattern of the MU with the smallest template #7 (highlighted)
- MUs #18 and #19 are newly recruited and discharge close to their thresholds

small residual

complete discharge patterns: smoothed IFRs



Decomposition Process

Manual Filling-in the Gaps

The automatic decomposition procedure identified 10 templates and sorted-out most of the activity in the signal for the first 2 s

red bar: interval in which a discharge of the highlighted template is expected

activity in the residual

gaps in the discharge patterns

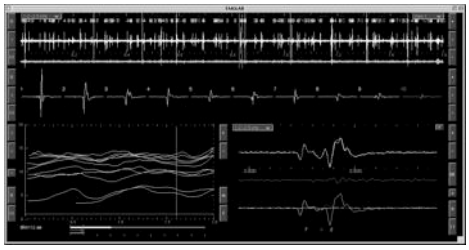
Manual Filling-in the Gaps

Full decomposition of the first 2 s is accomplished.

Note: - MU #2 was recruited 0.5 s after the beginning of the recording

no activity in the residual

smooth discharge patterns



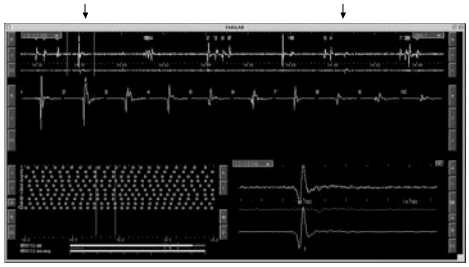
Manual Template Creation

A new MU was recruited at 13.7 s after the beginning of the recording.

Note: - it appears as a repeating activity in the residual after all the discharges of all the templates were identified.

activity in the residual

complete discharge patterns



Manual Template Creation

A new template (highlighted #11) was created manually and all its discharges were identified.

Inspection showed some small residual activity

activity in the residual

complete discharge patterns

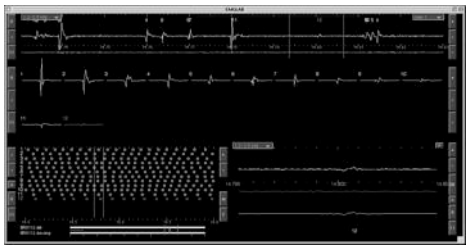
Manual Template Creation

A new template (highlighted #12) was created manually and all its discharges were identified.

Note: - discharges of #11 and #12 appear linked with a constant delay.

no activity in the residual

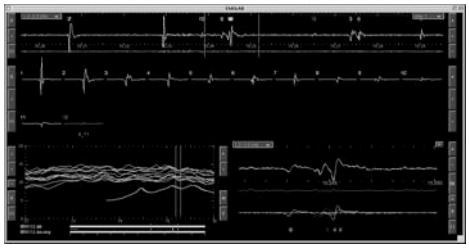
complete discharge patterns



Linked Templates: Satellite Potential

IFRs definitely show that discharges of #11 and #12 are linked.
The two templates are produced by the same MU.

Note: - template #12 was marked as a satellite of #11 and flagged not to be used in averaging of the MU waveforms from the unfiltered signal.



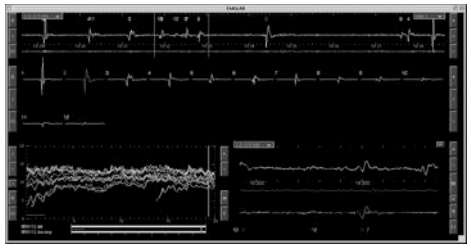
Full Decomposition Accomplished

Results

- templates : 12
- MUs : 11
- MU with satellites : 1
- recruitment: 2 MUs recruited at 0.5 s and 13.7 s

no activity in the residual

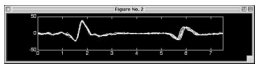
complete discharge patterns



Templates with Jitter

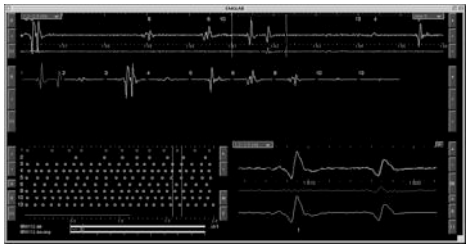
This signal was recorded by another electrode during the same contraction.

The activity in the residual is caused by an increased jitter between the two spikes of template #1.



activity in the residual

complete discharge patterns



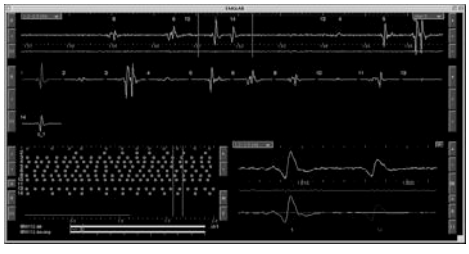
Templates with Jitter

Template #1 was divided into two components: #1 and #14.

Note: - the new template #14 was marked as a component of #1 and flagged not to be used in averaging of the MU waveforms from the unfiltered signal.

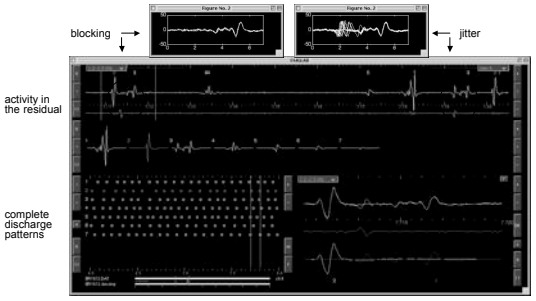
no activity in the residual

complete discharge patterns



Templates with Jitter and Blocking

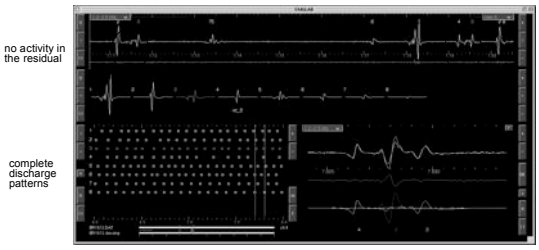
Template #3 exhibited increased jitter between the two spikes and occasional blocking of the first spike.



Templates with Jitter and Blocking

Template #3 was divided into two components:
#3 (stable) and #4 (volatile).

Note: - the gaps in the discharge pattern of the volatile component #4 show blocked occurrences.



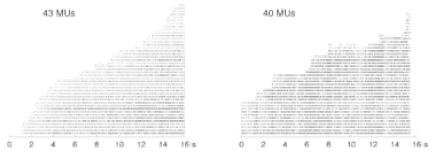
Our Studies: EMGLAB Applications

EMG methods are the only available tool to study motor control strategies (recruitment and discharge rates) and motor unit architectural organization in intact human muscles.

Our studies based on EMG decomposition using EMGLAB:

- Motor unit recruitment during ramp contractions
- Motor unit discharge rates and variability during constant-level, ramp, and trapezoidal contractions
- Muscle-fiber conduction velocity (MFCV) variability and dependence on the instantaneous inter-discharge intervals (IDIs)
- Reconstruction of the architecture of multiple motor units by analyzing MUAPs' morphological features and propagation pattern
- Investigation of the architectural origin of MUAPs with fractions, volatile components (showing increased jitter and intermittent blocking), and satellite potentials

Recruitment

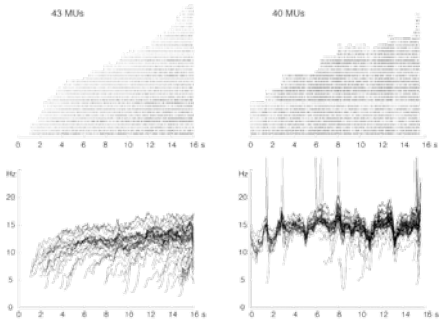


Male
Age: 36 y
Height: 175 cm
Weight: 82 kg

Male
Age: 27 y
Height: 175 cm
Weight: 79 kg

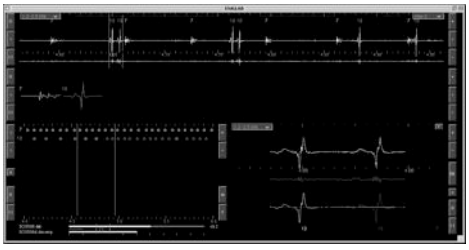
Right Brachioradialis Muscle

Discharge Rates



Doublets

Subject: SCI at C6-C7 level; injury occurred 6 years ago
Findings: Several MUs discharge with doublets for extended periods (Brachioradialis muscle)



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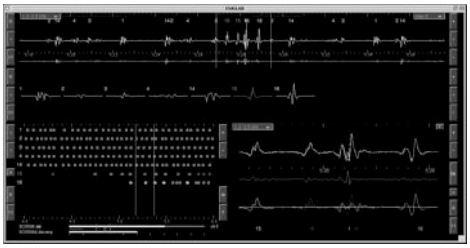
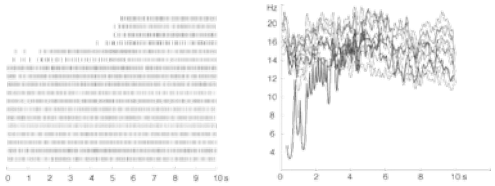
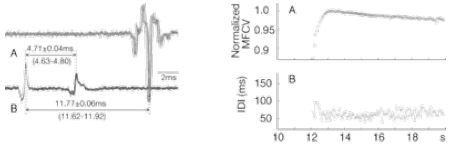


Doublets

Note: - the inter-discharge interval after a doublet is longer.



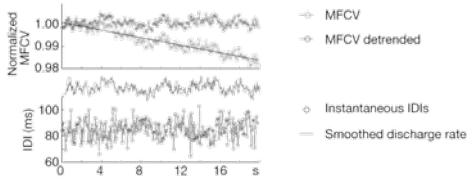
Conduction Velocity Variability



MFCV variability is quantified by measuring the inter-potential intervals (IPIs) between MU components in the same (A) or different signals (B).

At recruitment:
MFCV increases smoothly by about 10% during the first 15 to 20 discharges (A) with little influence of the instantaneous IDIs (B)

Conduction Velocity Variability



During sustained contractions:
MFCV follows closely the smoothed rather than instantaneous MU discharge rate
(Velocity Recovery Function)

Our Studies: MU Architecture

Human Brachioradialis Muscle:

An example of human series-fibered muscle

- A parallel-fibered muscle with the longest fascicles in the arm
  (Murray et al, J Biomech, 2000)
- Intrafascicularly terminating fibers
  (Feinstein et al, Acta Anat,1955)
- Several endplate zones
  (Christensen, Am J Phys Med,1959)
- Multiple extramuscular nerve branches with spatially separated muscle entry points
  (Latev & Dalley, Clin Anat, 2005)

MUAP Waveforms

MUAP waveforms

- Identified firing times for each MU are used as triggers to average from the unfiltered signal MUAP waveforms generated by this MU at different electrode sites
- The spatial organization of each MU is reconstructed by analyzing the morphological features of the MUAPs at all recording sites: locations of the endplate and the muscle/tendon junction are determined from the MUAP onset and terminal wave - both low-amplitude components

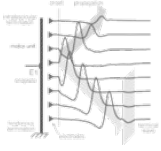
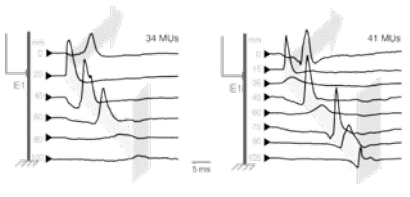


Illustration based on simulations

MU Architecture: One Endplate Zone

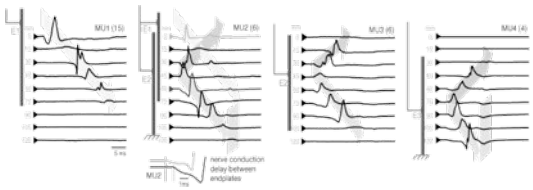
- In two subjects all the identified MUs were innervated at a single endplate zone
- All the MUs had tendonous terminations



Male subject Female subject

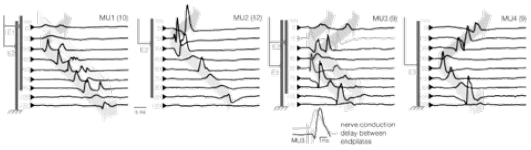
Multiple Endplate Zones

- Three endplate zones were identified in this subject: total of 31 MUs
- Some MUs were innervated in only one of the three endplate zones
- Six MUs were innervated at two endplate zones 60 mm apart
- The nerve branch between the endplate zones was myelinated based on the estimated nerve conduction velocity of 50 m/s
- MUAP propagation showed intrafascicular terminations



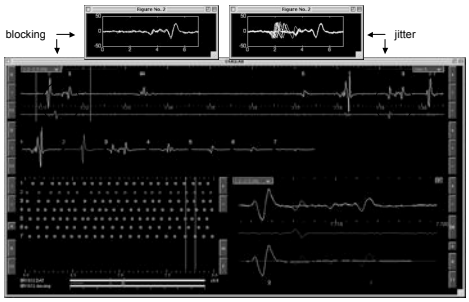
Multiple Endplate Zones

- Three endplate zones were found in this subject: total of 40 MUs
- 50% of all the motor units were innervated at two endplate zones
- 75% of all the motoneurons had branches innervating the middle endplate zone
- The propagation pattern showed some intrafascicular terminations, however the bands of muscle fibers were longer compared with the previous subject



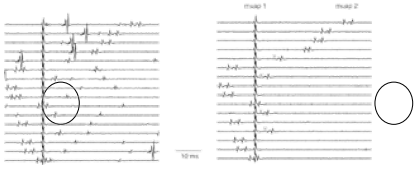
Our Studies: Template Irregularities

Two MUAPs have volatile components with similar shape that exhibit intermittent blocking and increased jitter



Hiding other Templates

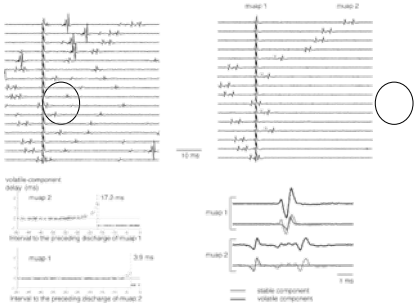
Subtracting out all the identified activity from the signal except for the discharges of the two MU highlights the irregularities.



x - blocked volatile component of muap 2

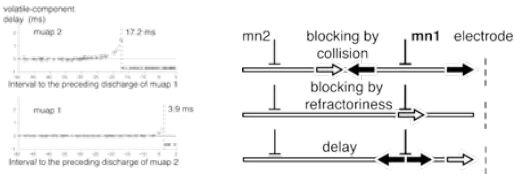
Blocking Behavior

The blocking behavior of the volatile components depends on the interval to the preceding discharge of the other MU.



Doubly Innervated Muscle Fibers

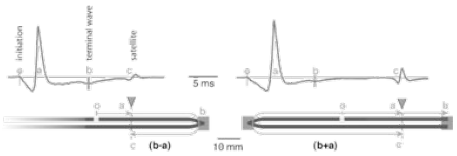
- Two MUAPs have volatile components with similar shape that exhibit intermittent blocking and increased jitter
- A detailed analysis shows that the volatile components are produced by a muscle fiber that is innervated by both motoneurons at two widely separated endplates
- The MUAP shape irregularities and blocking behavior are due to refractoriness or collision when both motoneurons try to excite the fiber at the same time



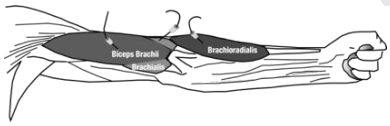
Our Studies: Satellite Potentials

Longitudinally split muscle fibers

- In normal human muscles satellite potentials always occur after the terminal wave of the MUAP
- The latency of the satellite potentials is consistent with them being generated by a retrograde propagation along a non-innervated branch of a longitudinally split muscle fiber



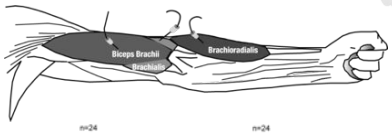
Our Studies: Multiple Muscles

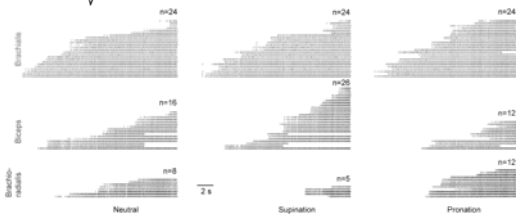


"Although they can be felt quite easily, the biceps brachii, the brachailis, and the brachioradialis have not been fully understood as far as their integrated functions are concerned.

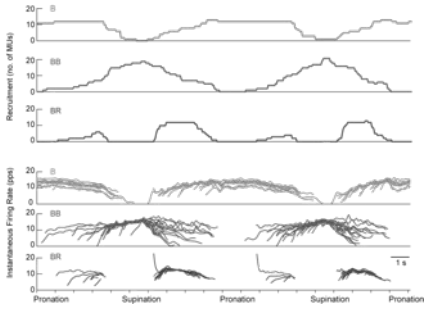
(Muscles Alive: Their Functions Revealed by Electromyography, JV Basmajian and CJ De Luca)

Elbow Flexion: Recruitment Profiles





Forearm Rotation



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