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Imaging the Behavior of Motor Units by Decomposition of the EMG Signal

Carlo J. De Luca

Delsys Inc.

Boston, MA, USA

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Acknowledgments

- **Collaborators**

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  R. Srivastava

- **Support**

  NIH
  Liberty Mutual Ins. Co.
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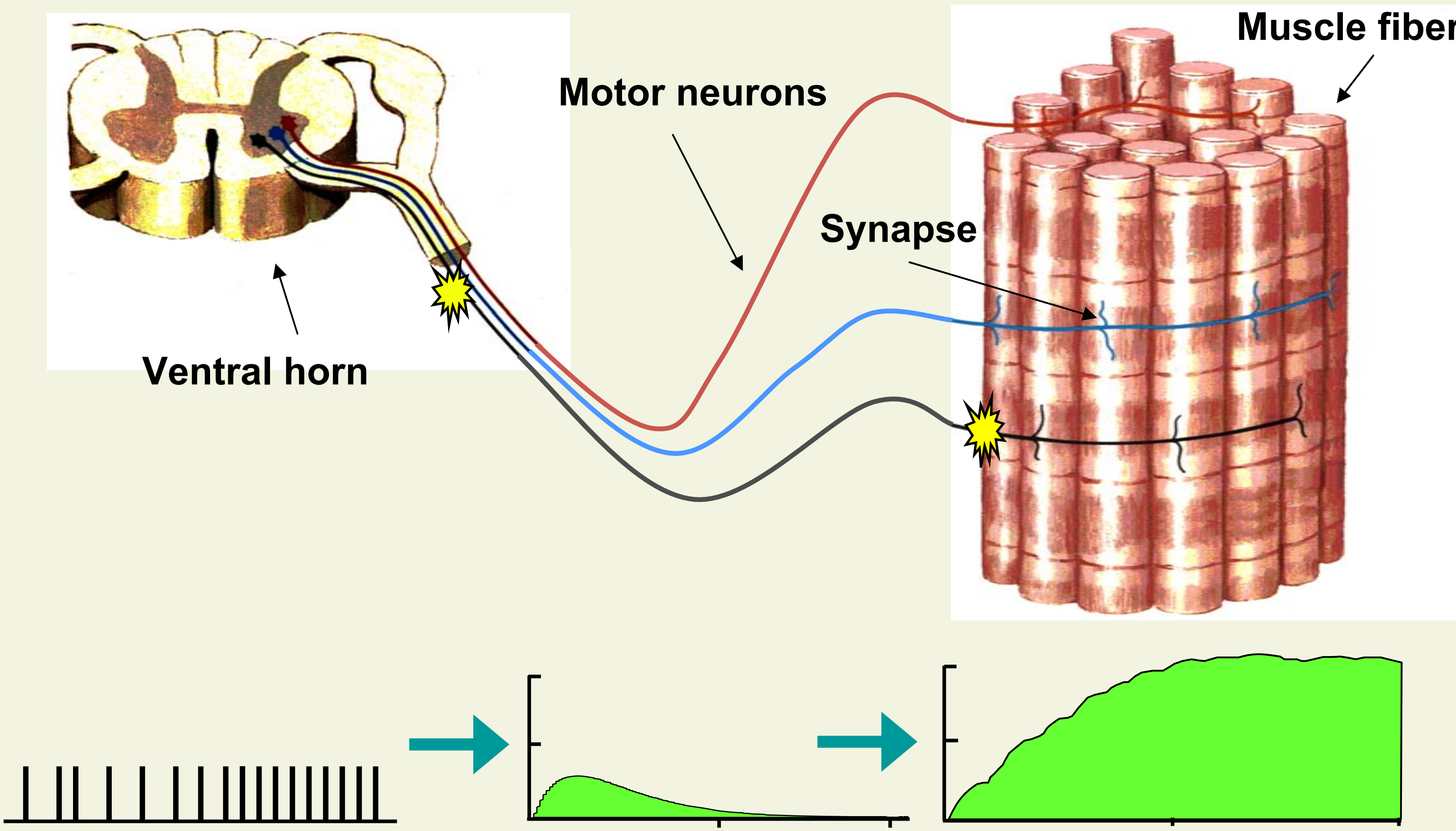
  V. A. Rehab R & D
  Rehabilitation Services Administration
  United Cerebral Palsy Res. & Ed. Foundation
  C.A. Dana Foundation
  Hearst Foundation

 ISBN: 978-0-9798644-2-1

Motor Units and Force



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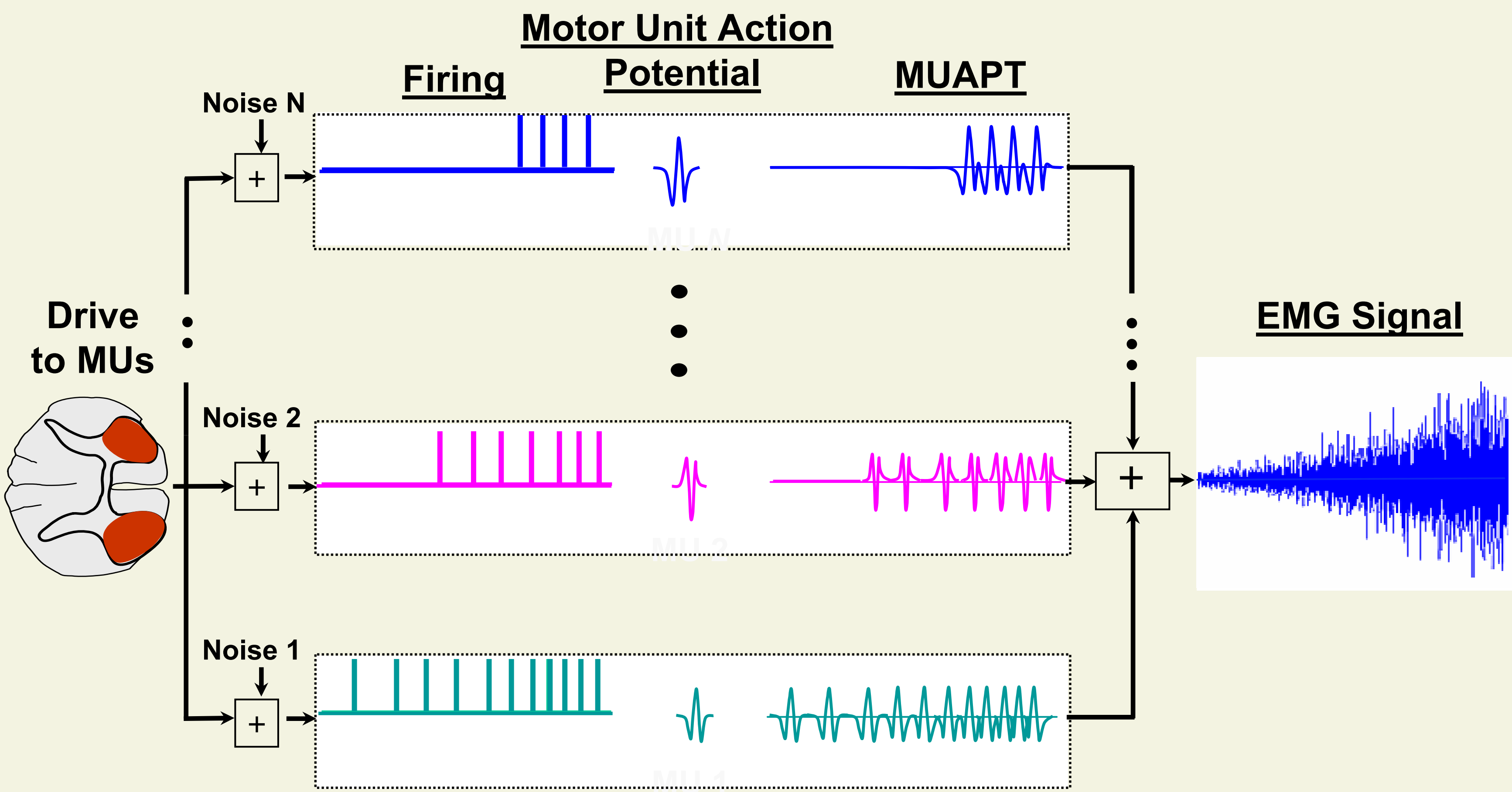
Motor Unit Control and the EMG Signal



De Luca CJ and Erim Z. Common drive of motor units in regulation of muscle force. *Trends in Neuroscience*, 17: 299-305, 1994.

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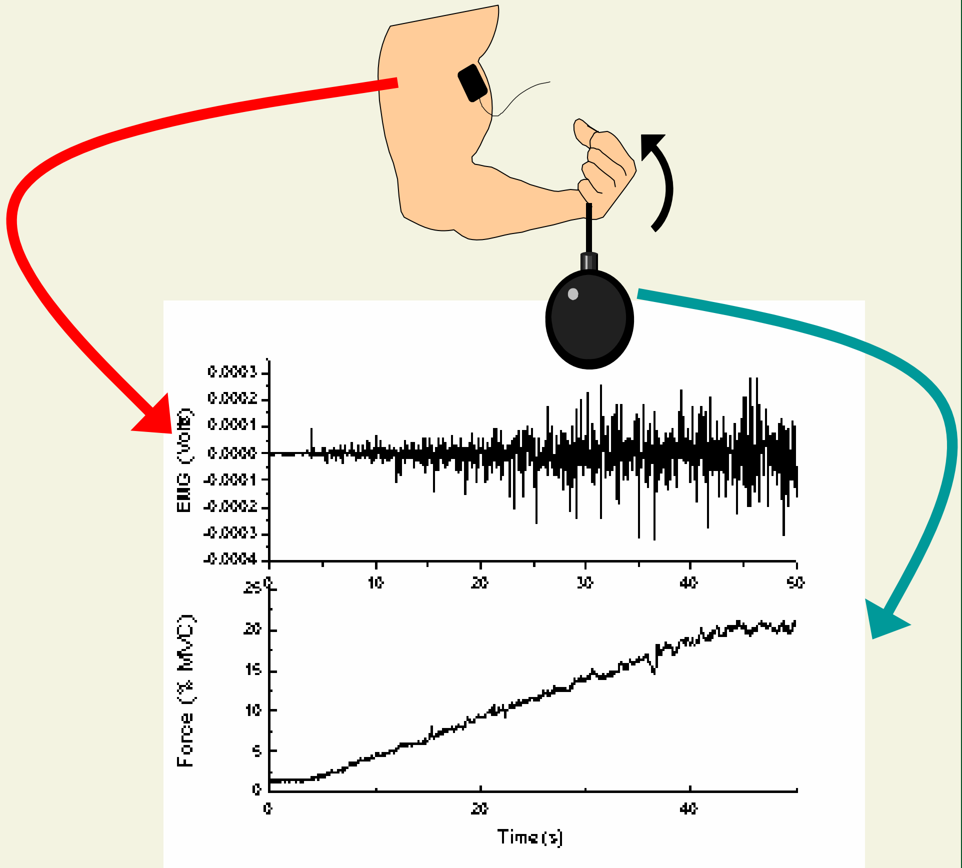
The sEMG Signal and Force

The amplitude of the sEMG signal is proportional to the force produced by the muscle



De Luca CJ. The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13: 135-163, 1997.

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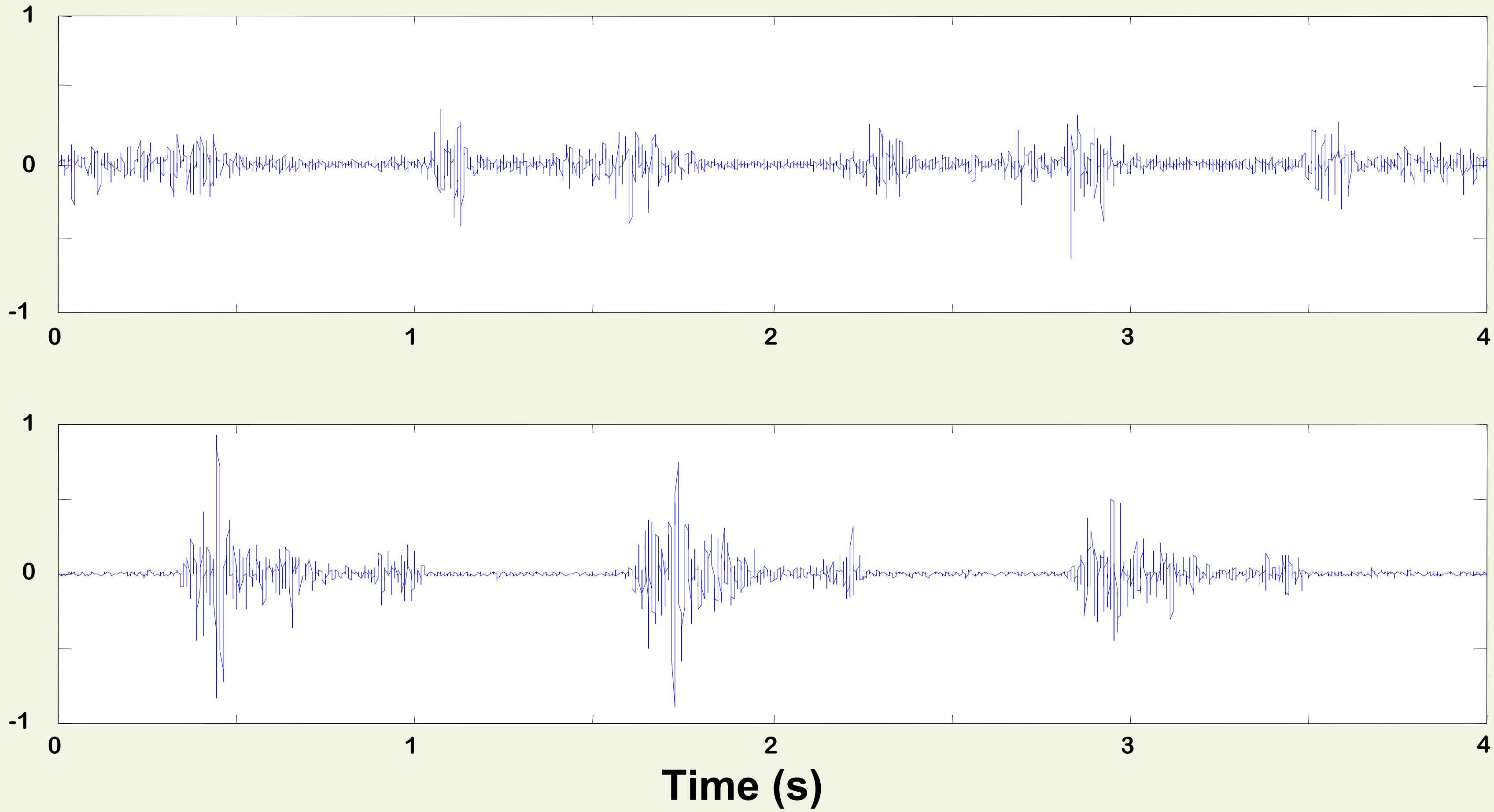
Amplitude



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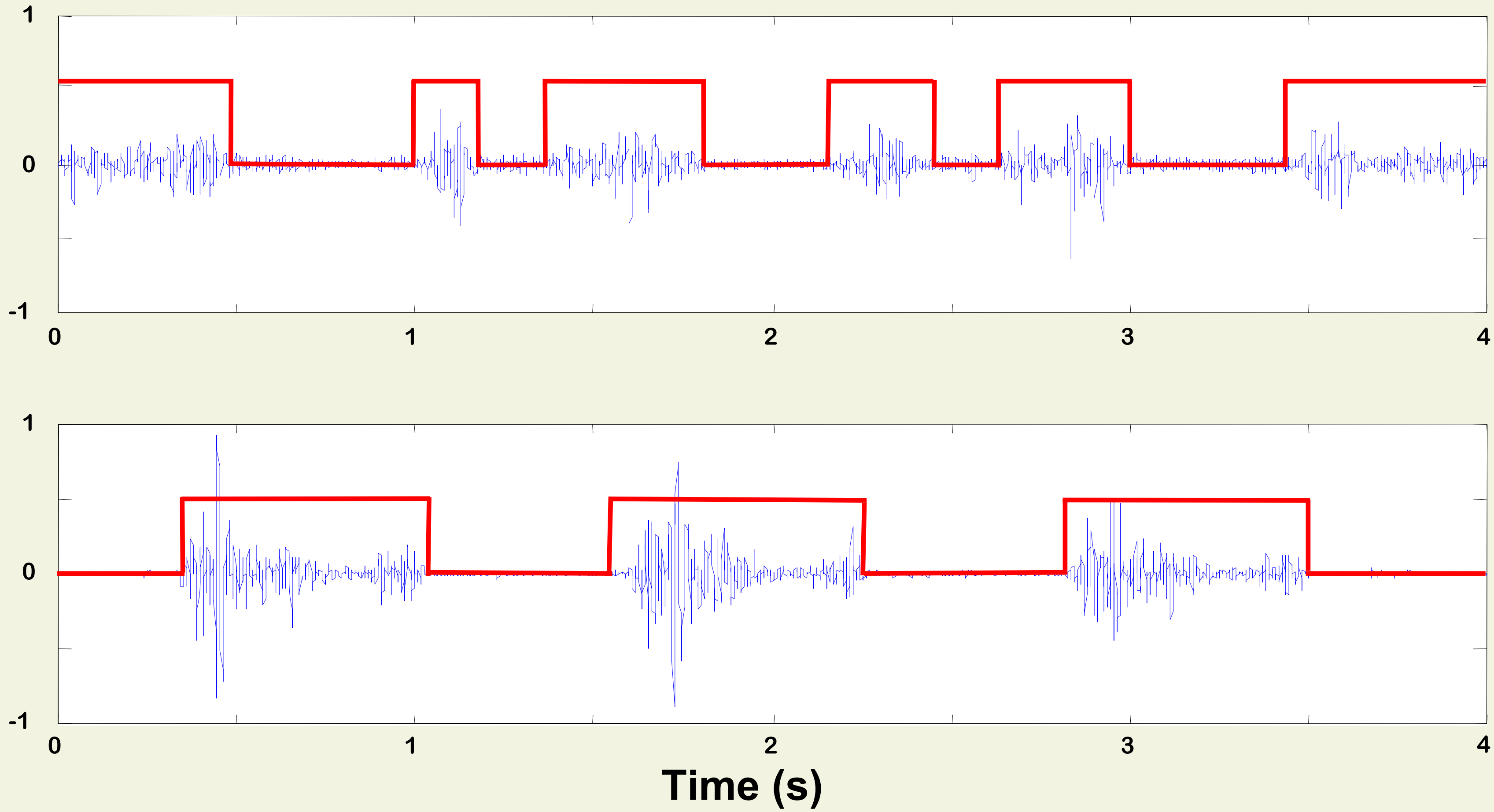
Activation Timing



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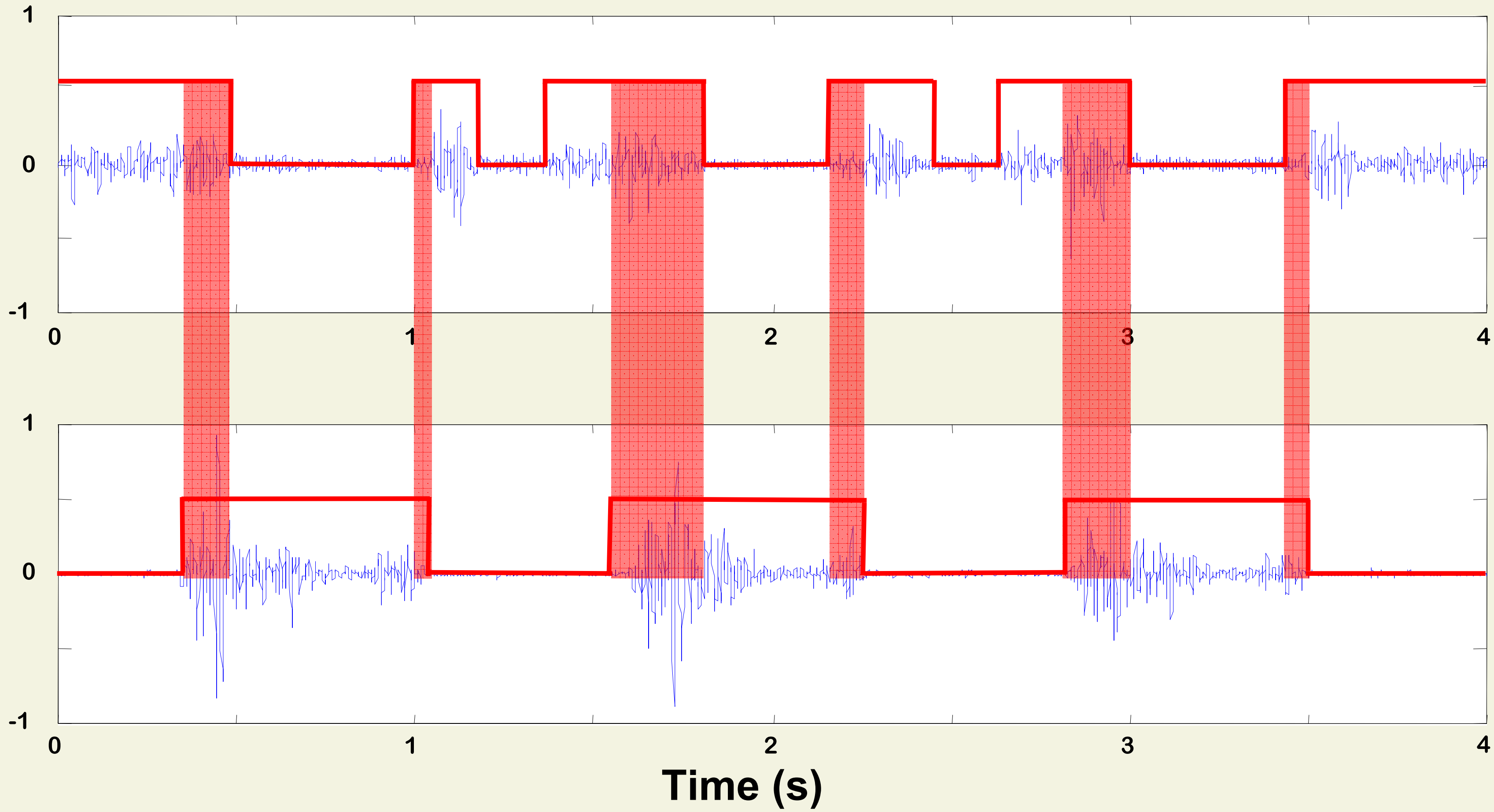
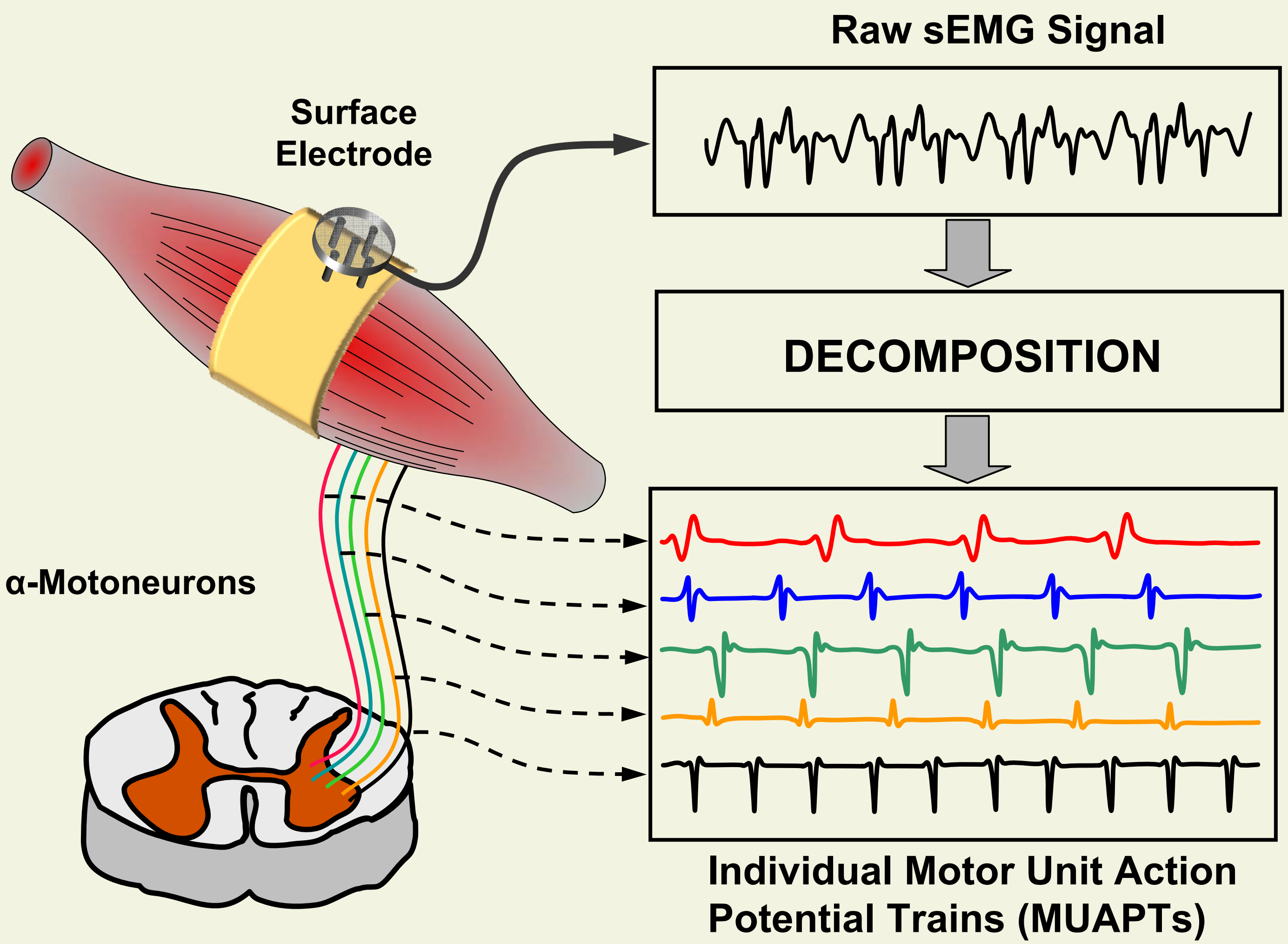
Co-Contraction



Decomposition of the sEMG Signal



What does EMG Decomposition (dEMG) provide?

- **sEMG provides a behavioral image of the whole muscle**

- **dEMG provides a behavioral image of the muscle cells**
  - Automatic, accurate identification of the firings of up to 30 concurrently active motor units
  - Automatic detection of MU recruitment and derecruitment

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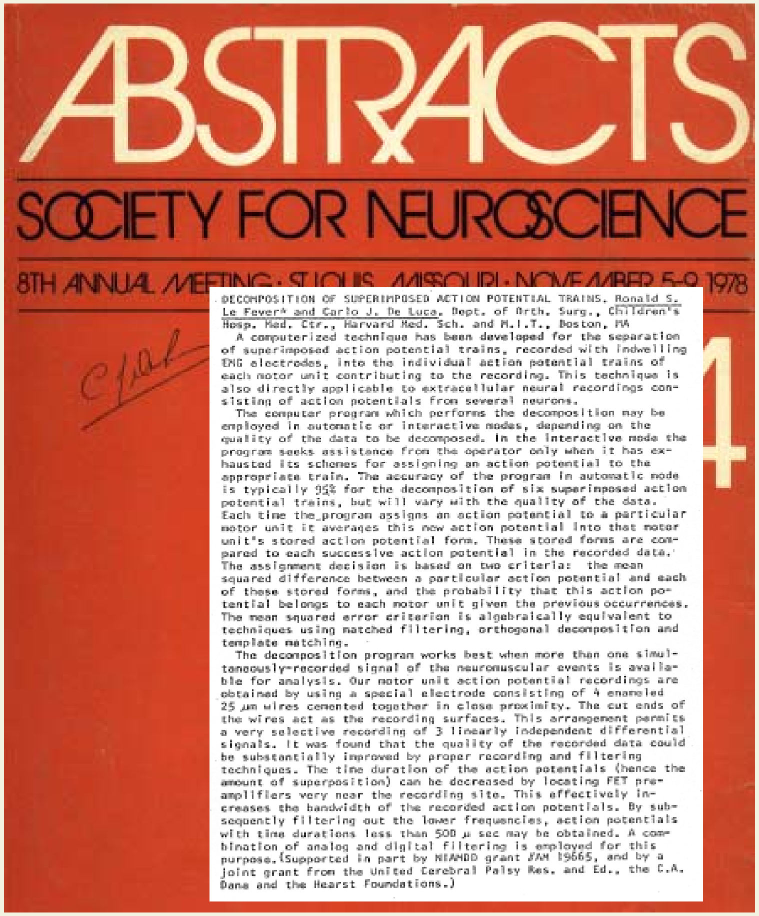
Why bother ?

- **Provides new parameters for studying and assessing motor control within a muscle and among muscles**
  - Firing rates
  - Correlation of motor unit firings
  - New motor unit recruitment
  - Synchronization of firings

- **Enables non-invasive, more intricate investigations in motor control**
  - Latency between MU firing and force
  - Firing-by-firing interaction amongst motor units within a muscle and across muscles

Precision Decomposition 1.0 1978



DECOMPOSITION OF SUPERIMPOSED ACTION POTENTIAL TRAINS. Ronald S. Le Fever* and Carlo J. De Luca. Dept. of Orth. Surg., Children's Hosp. Med. Ctr., Harvard Med. Sch. and M.I.T., Boston, MA

A computerized technique has been developed for the separation of superimposed action potential trains, recorded with indwelling EMG electrodes, into the individual action potential trains of each motor unit contributing to the recording. This technique is also directly applicable to extracellular neural recordings consisting of action potentials from several neurons.

The computer program which performs the decomposition may be employed in automatic or interactive modes, depending on the quality of the data to be decomposed. In the interactive mode the program seeks assistance from the operator only when it has exhausted its schemes for assigning an action potential to the appropriate train. The accuracy of the program in automatic mode is typically 95% for the decomposition of six superimposed action potential trains, but will vary with the quality of the data. Each time the program assigns an action potential to a particular motor unit it averages this new action potential into that motor unit's stored action potential form. These stored forms are compared to each successive action potential in the recorded data. The assignment decision is based on two criteria: the mean squared difference between a particular action potential and each of these stored forms, and the probability that this action potential belongs to each motor unit given the previous occurrences. The mean squared error criterion is algebraically equivalent to techniques using matched filtering, orthogonal decomposition and template matching.

The decomposition program works best when more than one simultaneously-recorded signal of the neuromuscular events is available for analysis. Our motor unit action potential recordings are obtained by using a special electrode consisting of 4 enameled 25 µm wires cemented together in close proximity. The cut ends of the wires act as the recording surfaces. This arrangement permits a very selective recording of 3 linearly independent differential signals. It was found that the quality of the recorded data could be substantially improved by proper recording and filtering techniques. The time duration of the action potentials (hence the amount of superposition) can be decreased by locating FET preamplifiers very near the recording site. This effectively increases the bandwidth of the recorded action potentials. By subsequently filtering out the lower frequencies, action potentials with time durations less than 500 µ sec may be obtained. A combination of analog and digital filtering is employed for this purpose. (Supported in part by NIAMDD grant AM 19665, and by a joint grant from the United Cerebral Palsy Res. and Ed., the C.A. Dana and the Hearst Foundations.)

Characteristics

- Analysis on 3 channels
- Automatic decomposition 65%
- Operator assisted editing up to 100%
- Effective Sampling rate of 50 k Hz for alignment resolution
- Maximum Aposteriori (MAP) Receiver - template matching
- Action Potential shape adaptation to small changes
- Action Potential superposition resolution

LeFever, RS and De Luca, C J. Decomposition of action potential trains. Proceedings of 8th Annual Meeting of the Society for Neuroscience 229, 1978.

The sEMG Precision Decomposition System
-- Block Diagram

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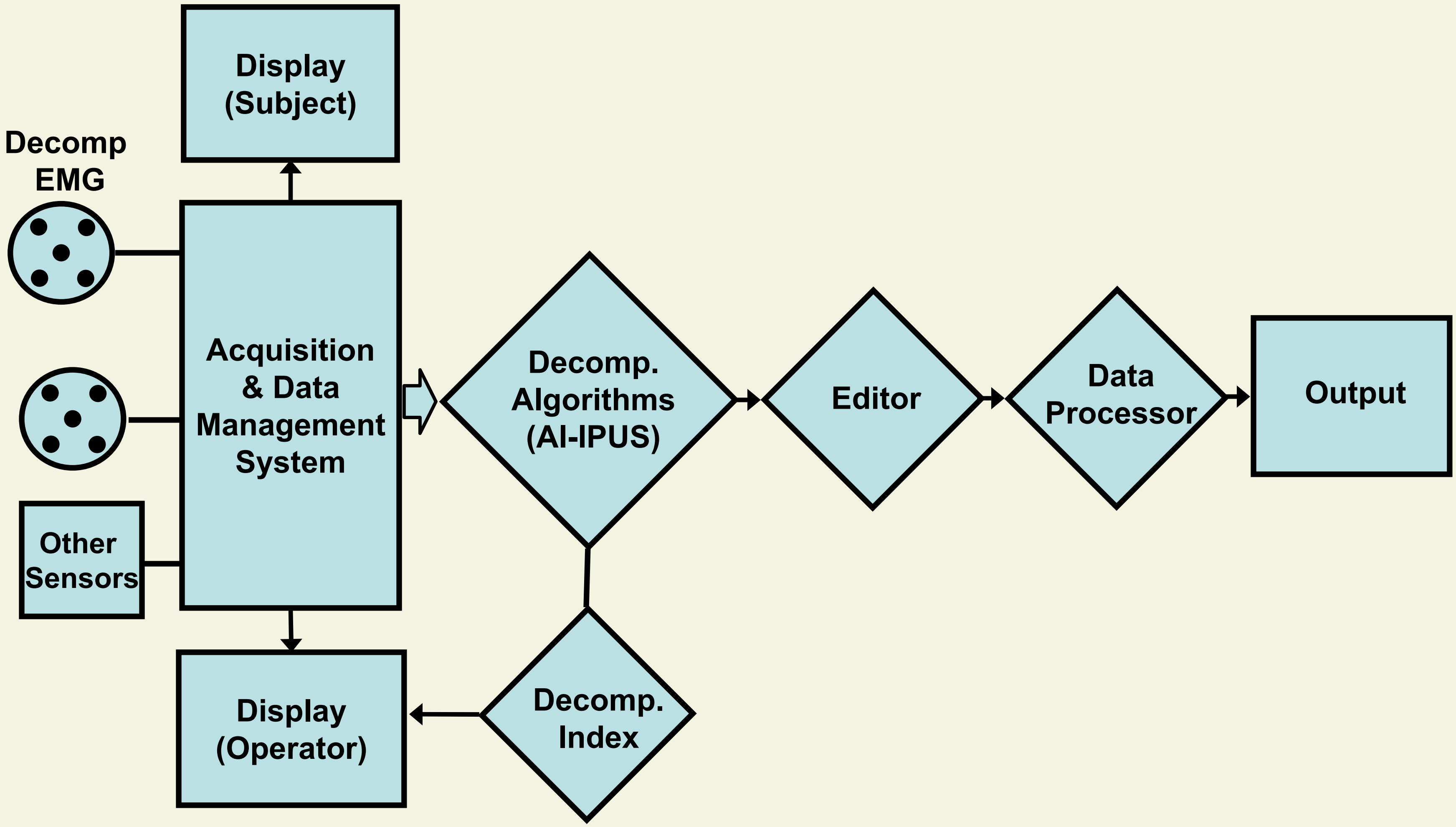
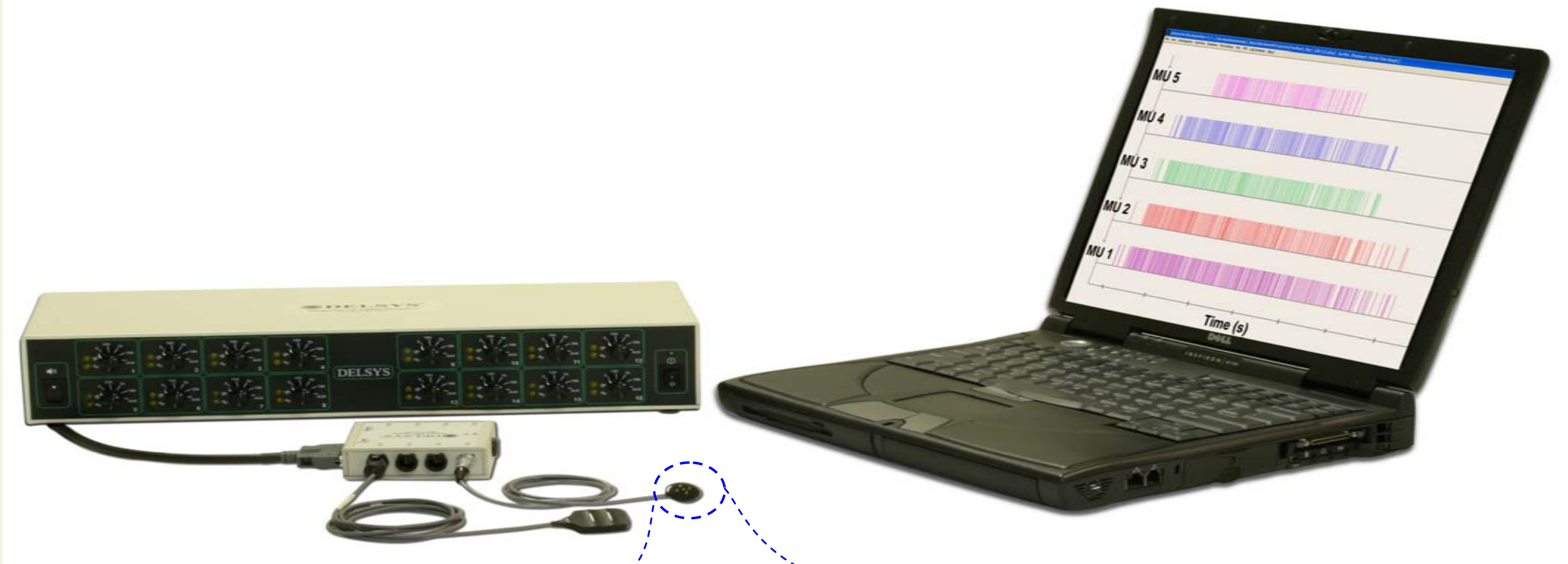


The sEMG Precision Decomposition System

-- Device



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Film

Play Film

– Large (58 MB)
– Small (2MB)

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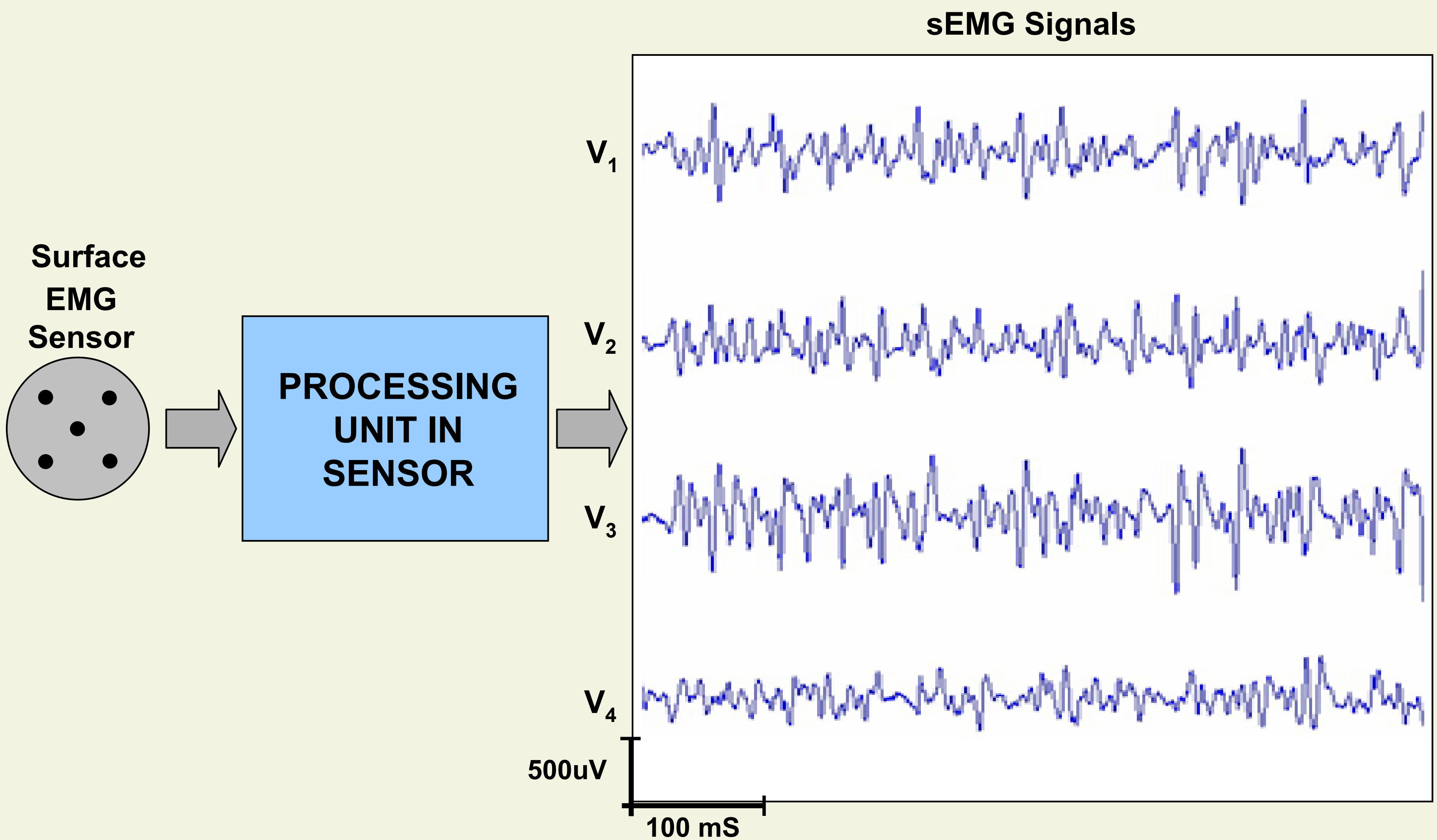
Detection Technique
-50% MVC; FDI



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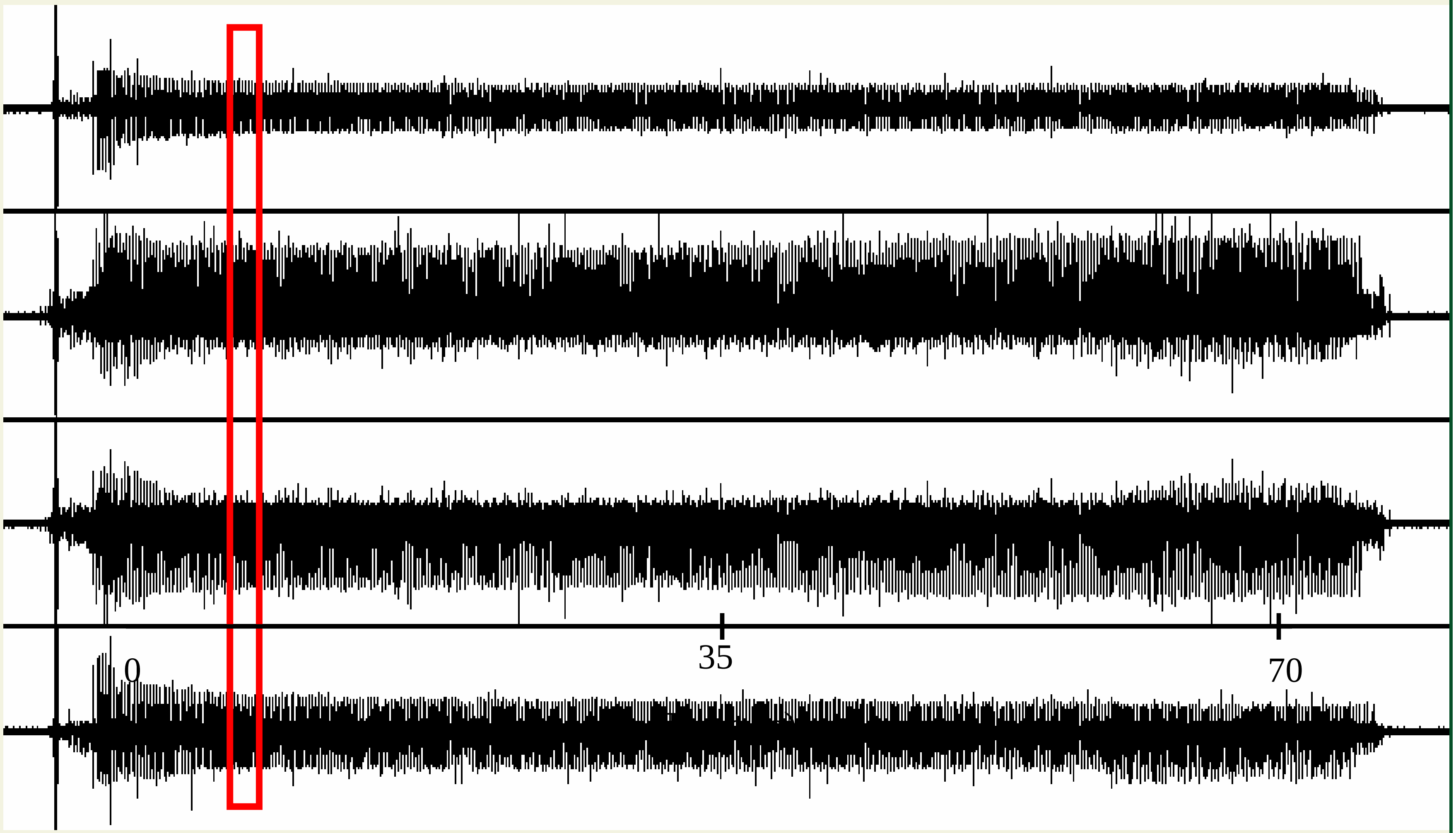
4 channels of EMG Signal



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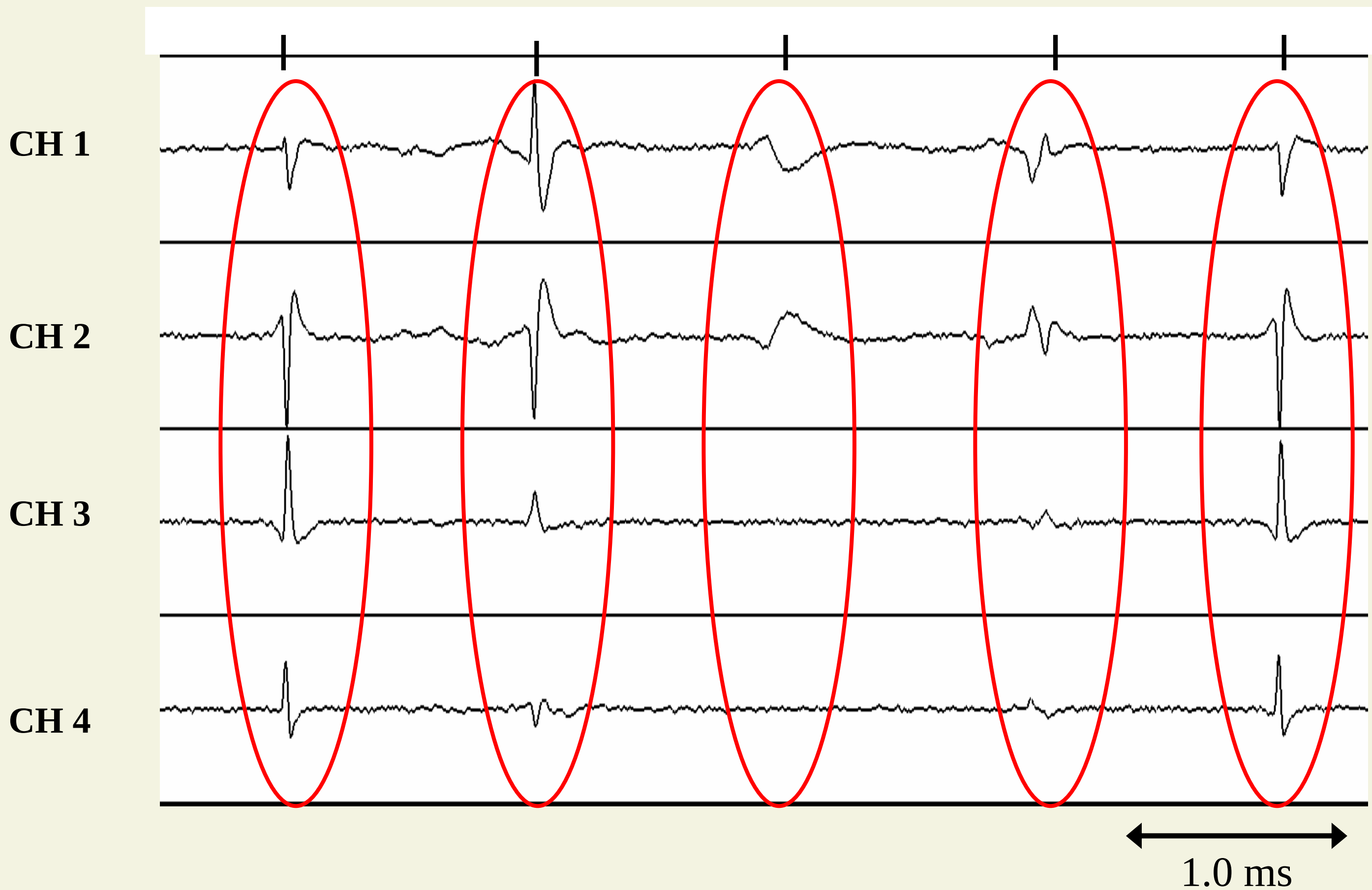
Expanded view of segment

Motor Unit Action Potentials (MUAPs)



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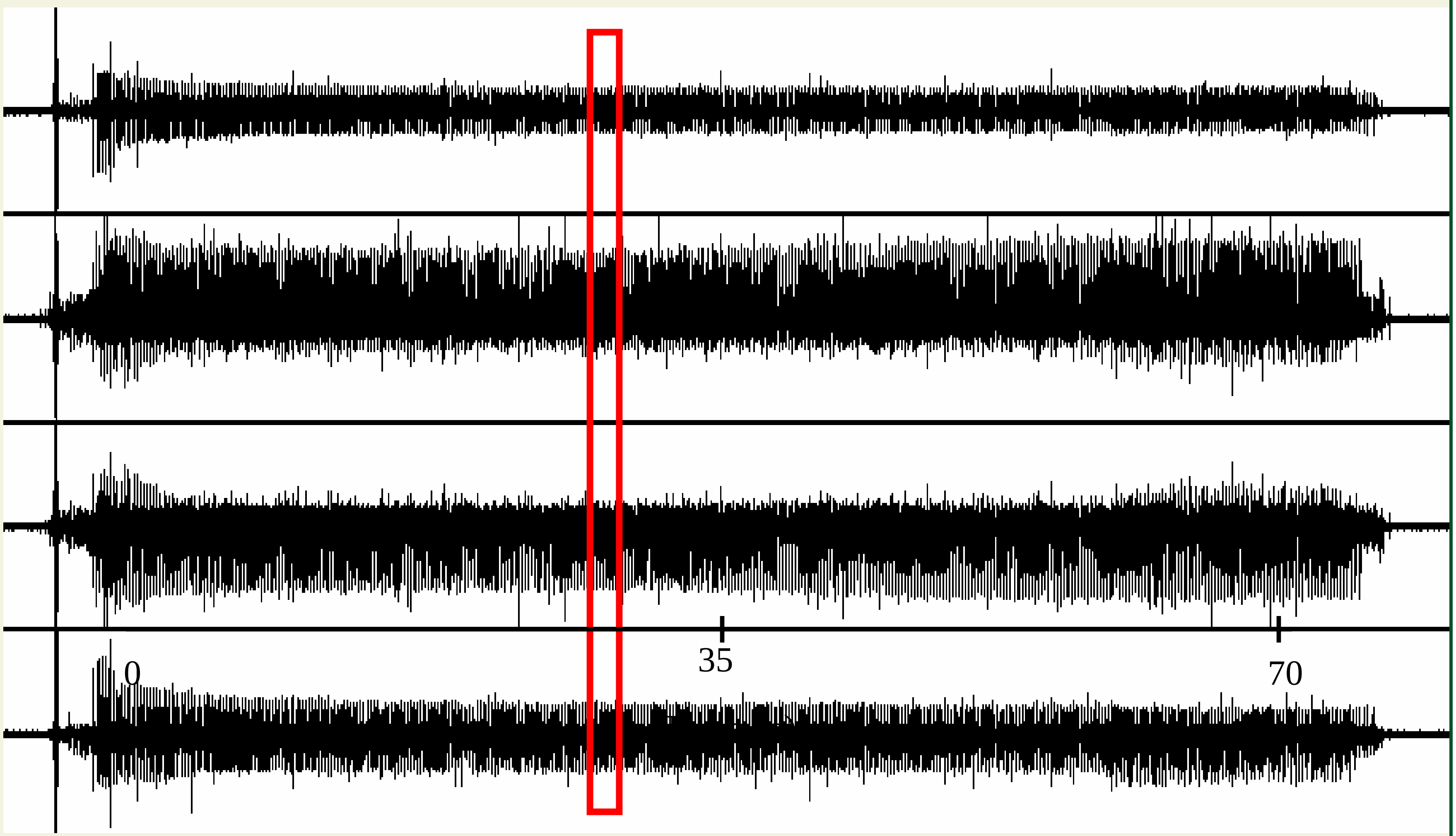
A more complex segment



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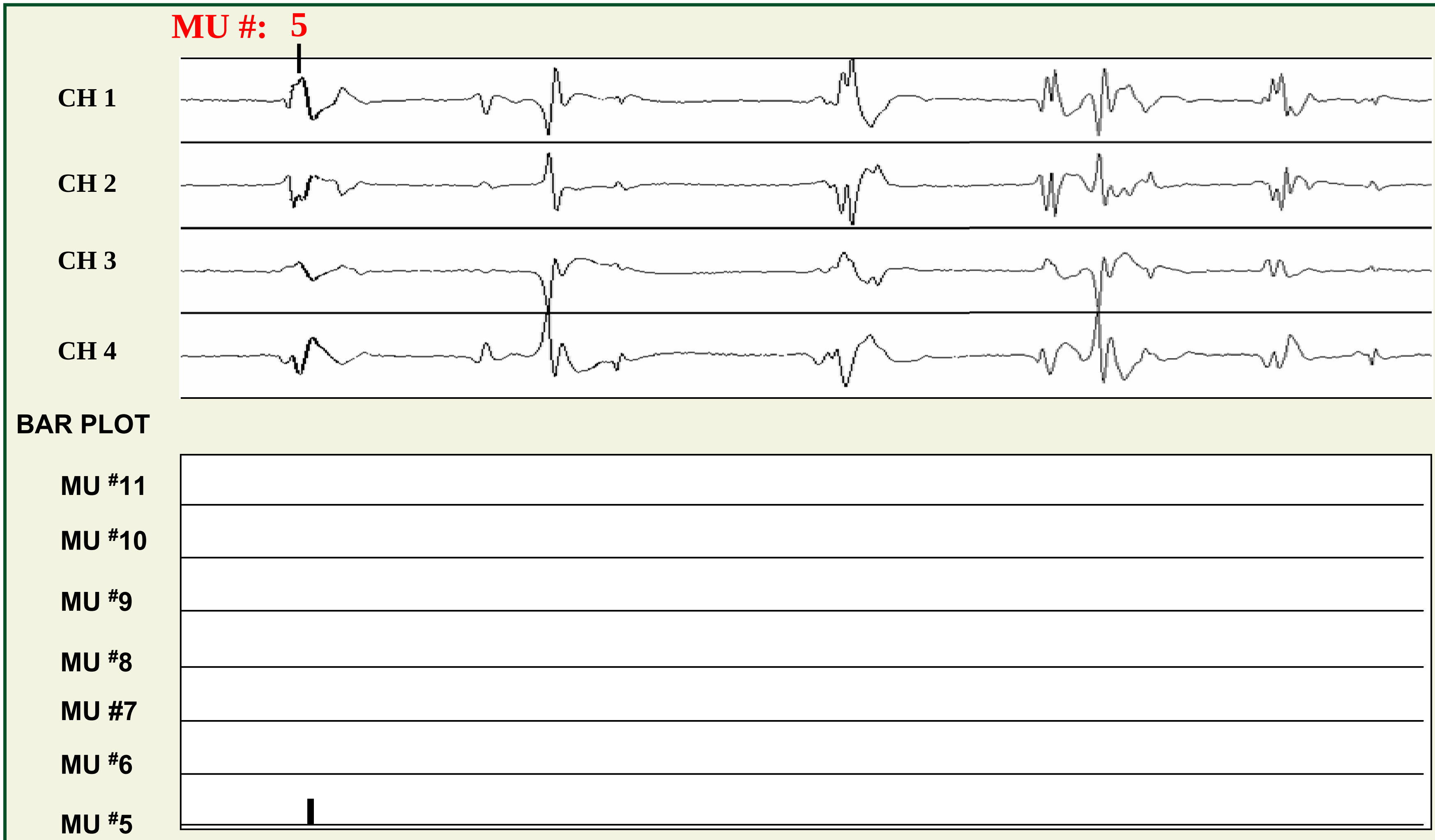
Superpositions



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Superpositions

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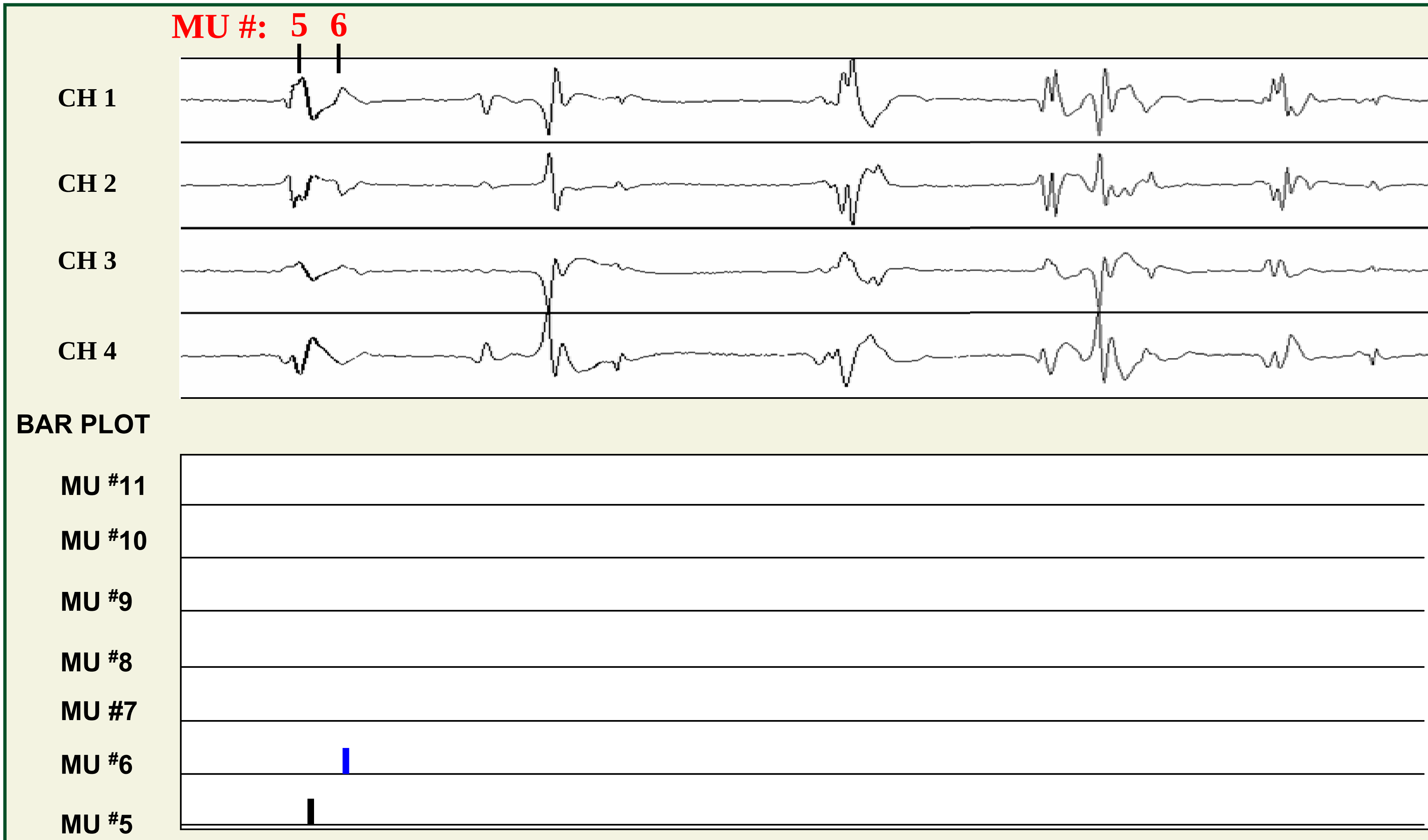

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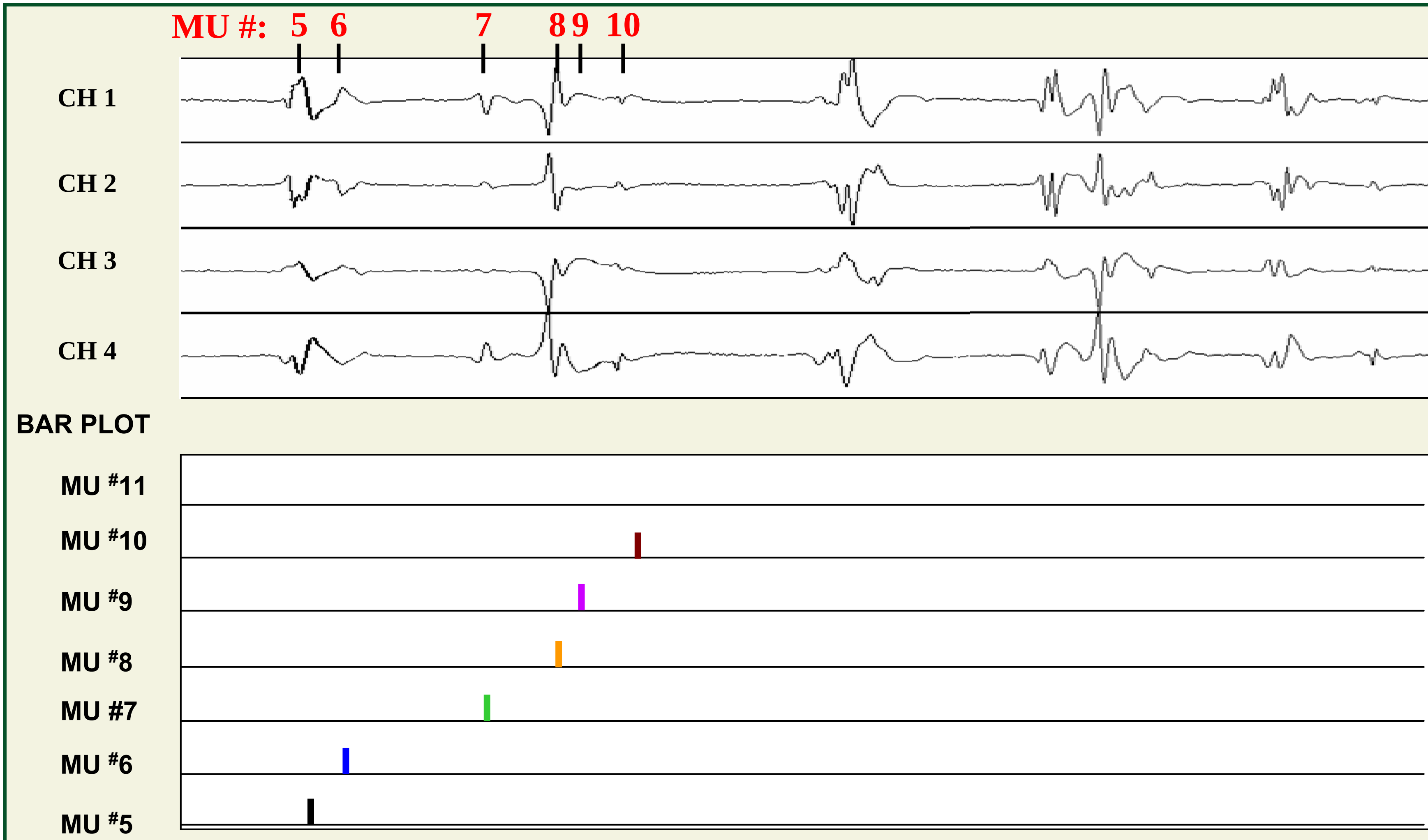
Superpositions



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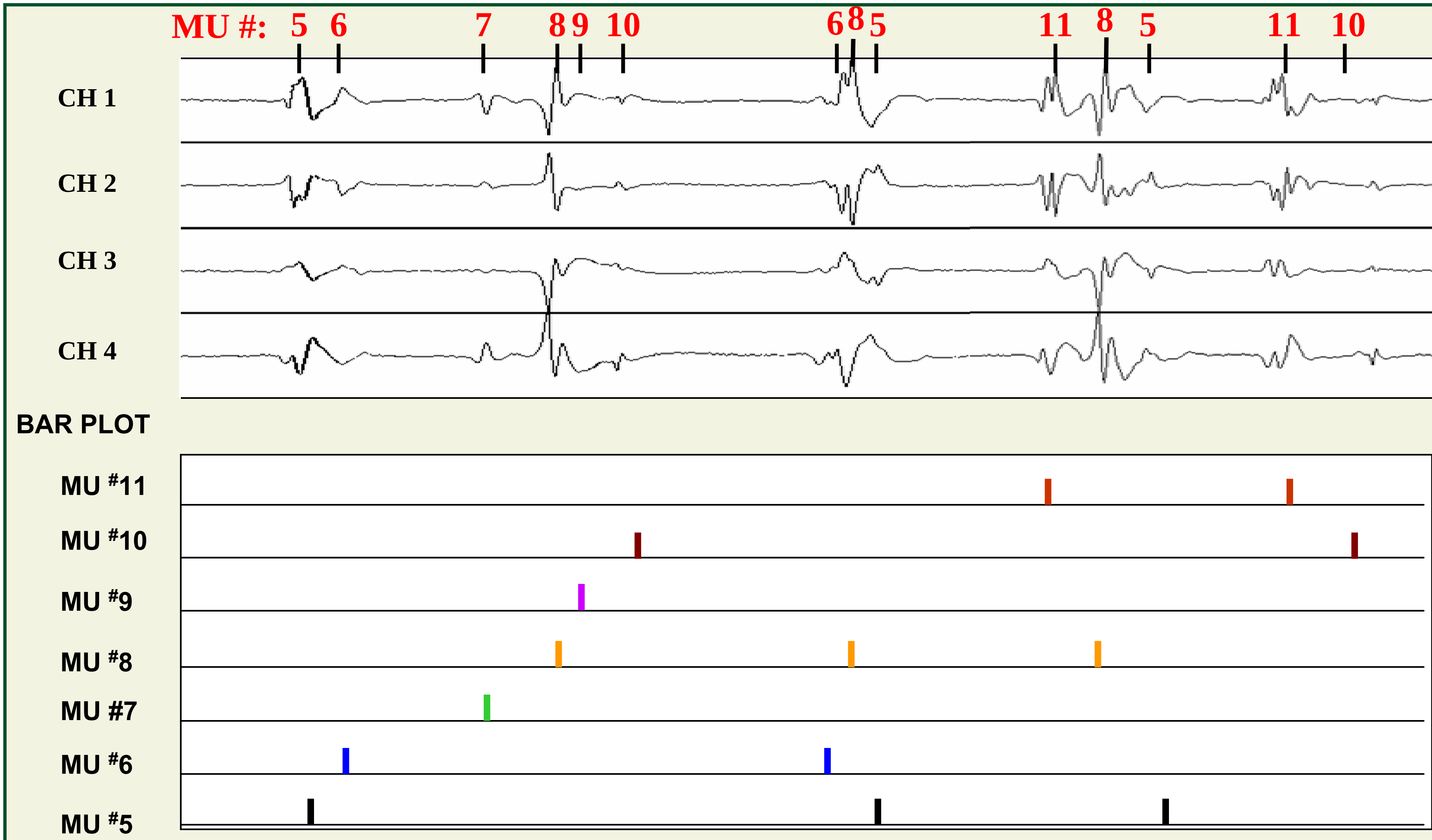
Superpositions



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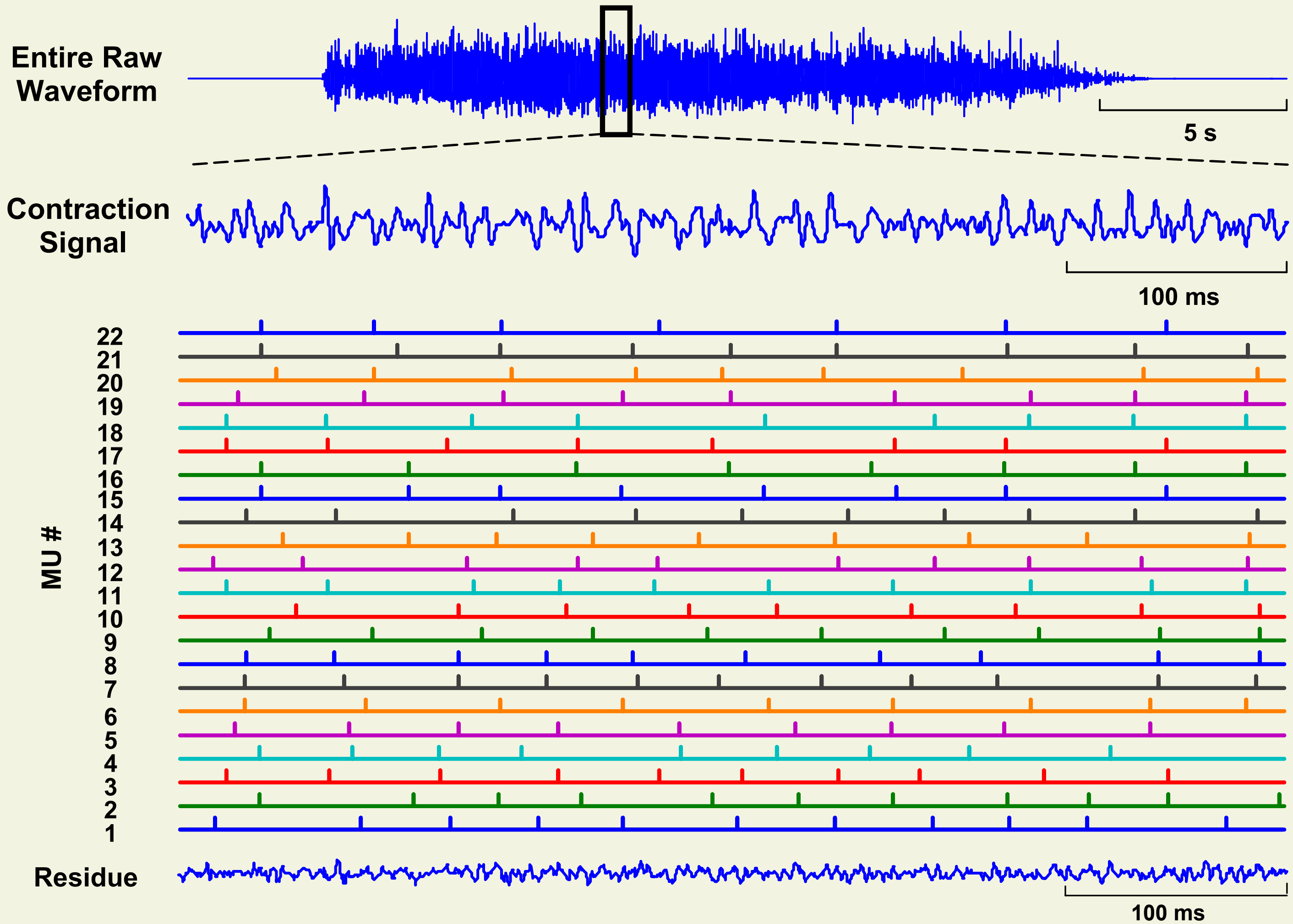
sEMG Decomposition Sample – FDI 80% MVC



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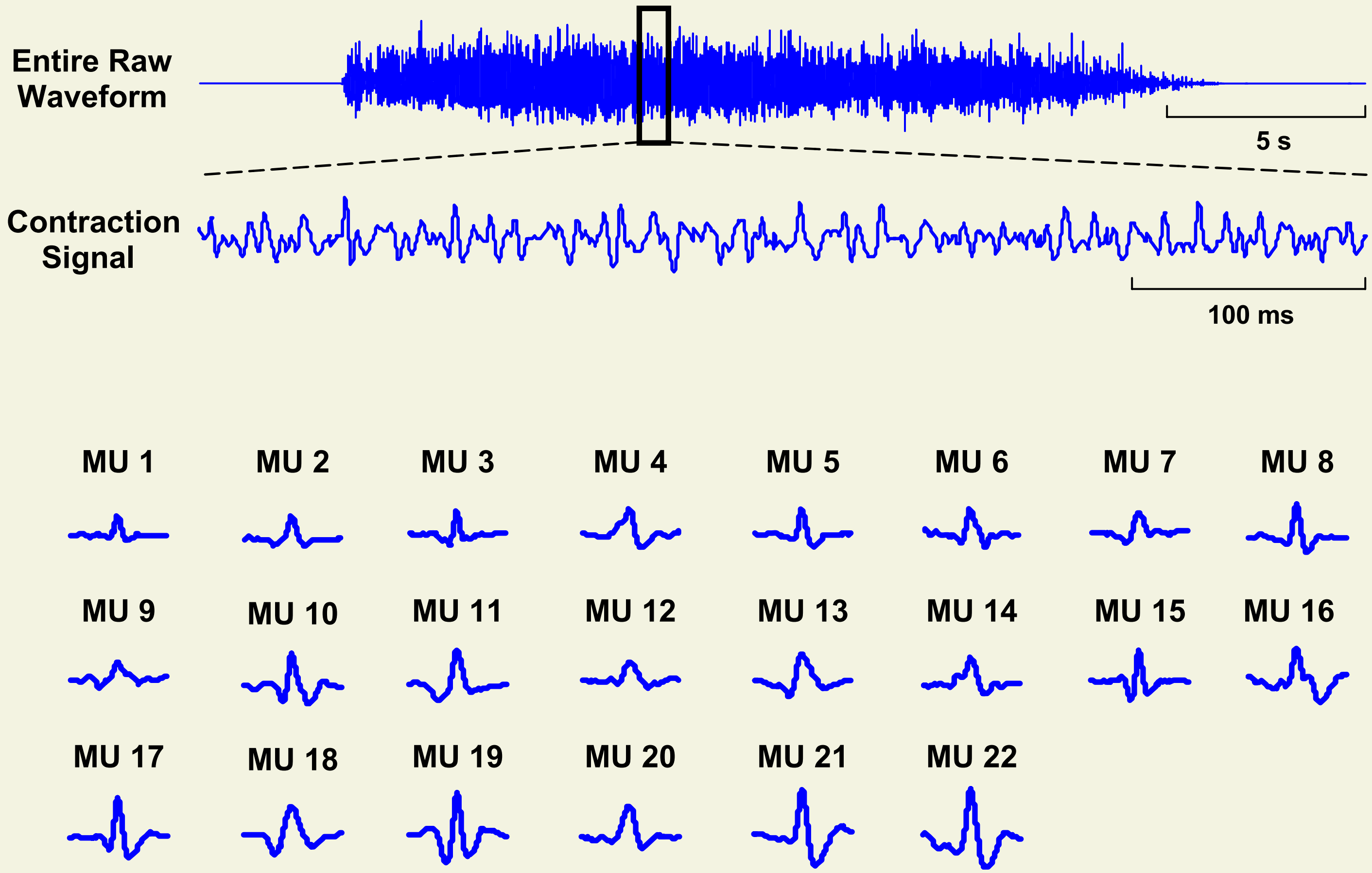
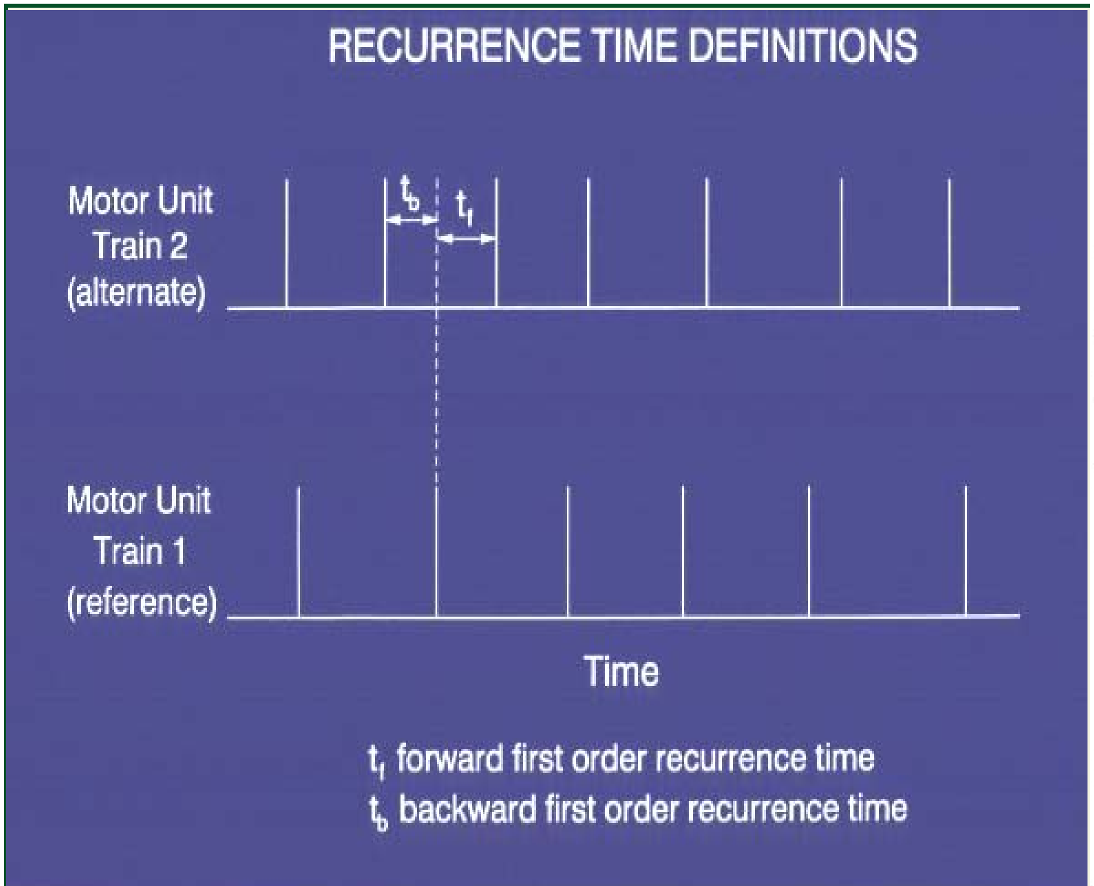
sEMG Decomposition Sample – FDI 80% MVC

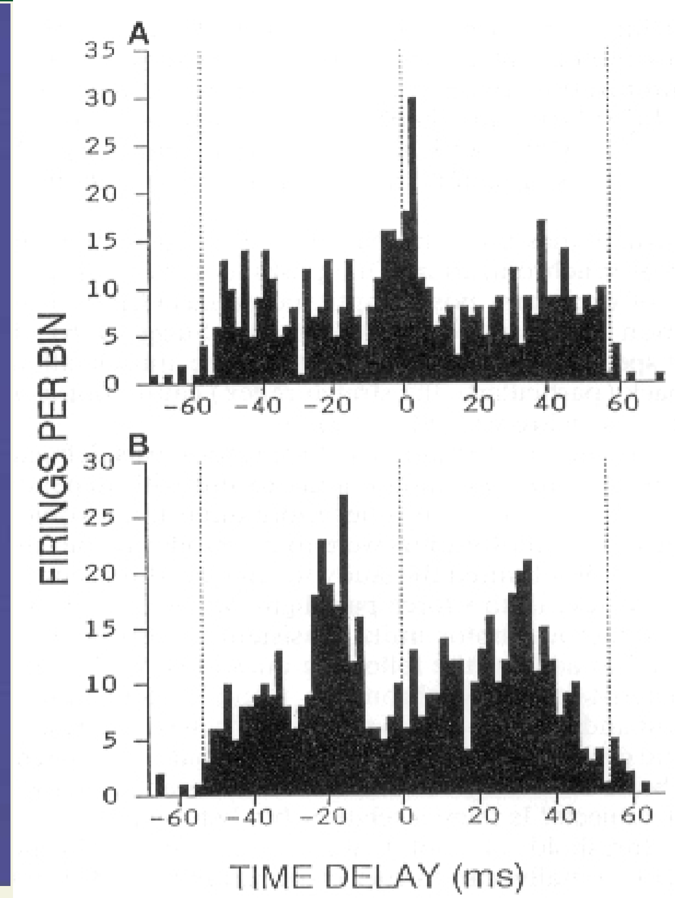


Performance

- **Accuracy of decomposition**
  - This IS the CRITICAL factor
  - 90% automatic
  - 97 to 100 % with editor
- **Number of Motor Units**
  - Up to 30+ MU
- **Contraction Level**
  - Up to 100% MVC
- **Yield**
  - Over 95% of contractions

Synchronization of MU firings





De Luca CJ, Roy AM, and Erim Z. Synchronization of motor unit firings in human muscles. *Journal of Neurophysiology*, 70: 2010-2023, 1993.

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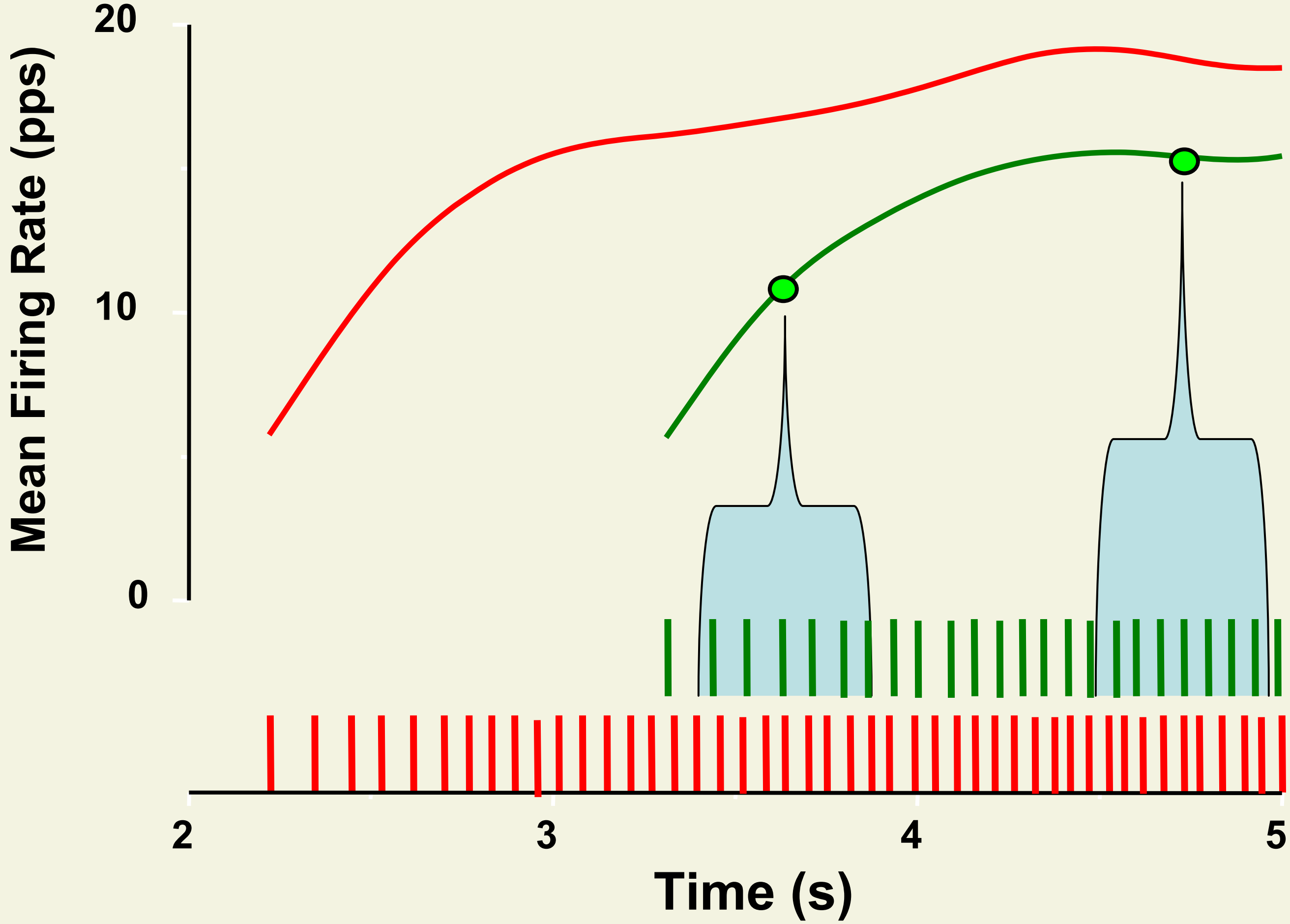
Calculation of firing rate



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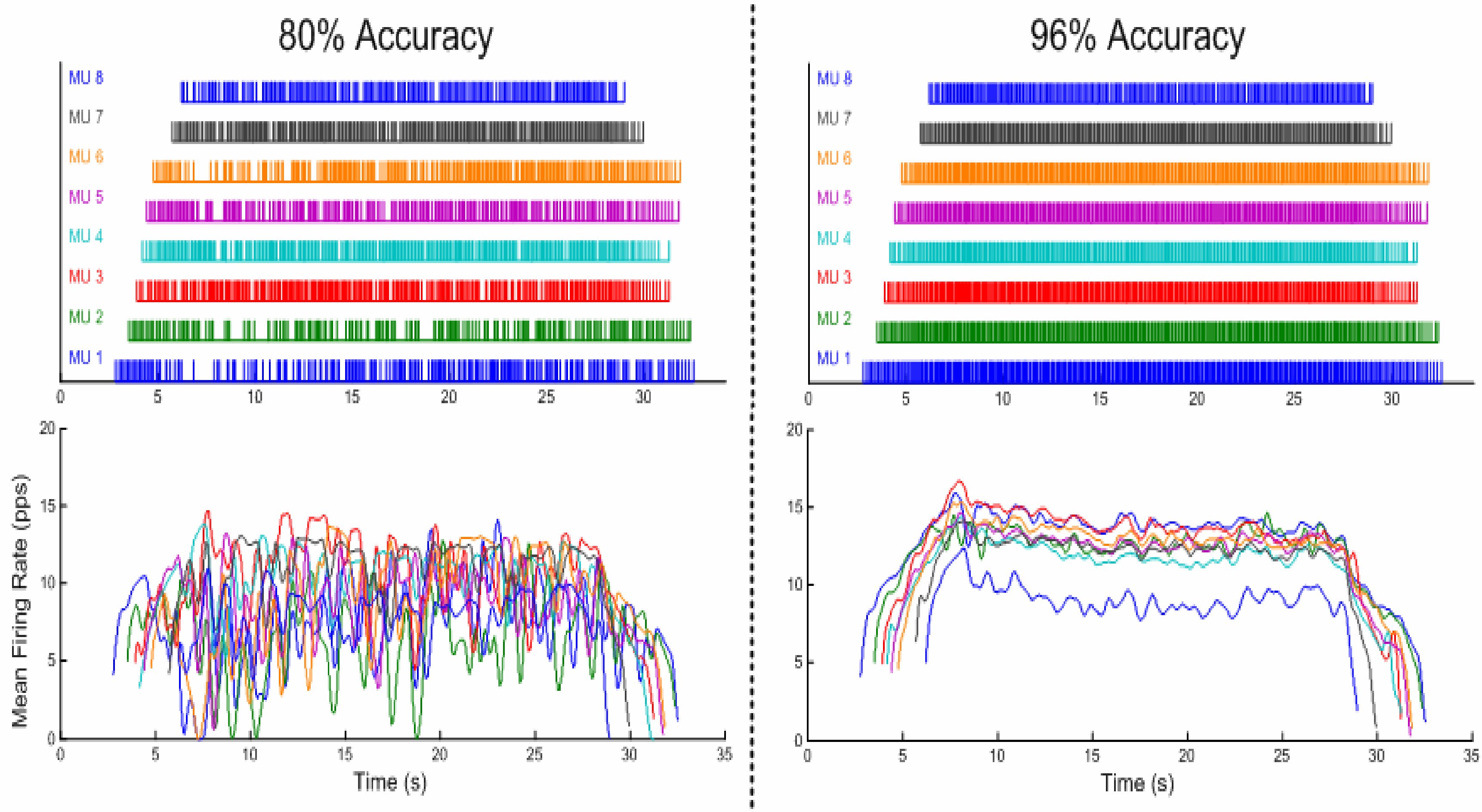
Accuracy is critical !!



Nawab SH, Wotiz RP, and De Luca CJ. Decomposition of indwelling EMG signals, J. Applied Physiology, 2008

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Examples of New Findings

Normal state

- Synchronization of MU firings
- Common Drive of MU firings
  - Within muscle
  - Across muscles
- Onion Skin
- control properties vary across muscles
- Motor unit substitution

Altered states

- Fatigue
- Aging
- Microgravity
- Cerebellar stroke

MU Firing Rates and Muscle Twitch Response

VL; 20% MVC

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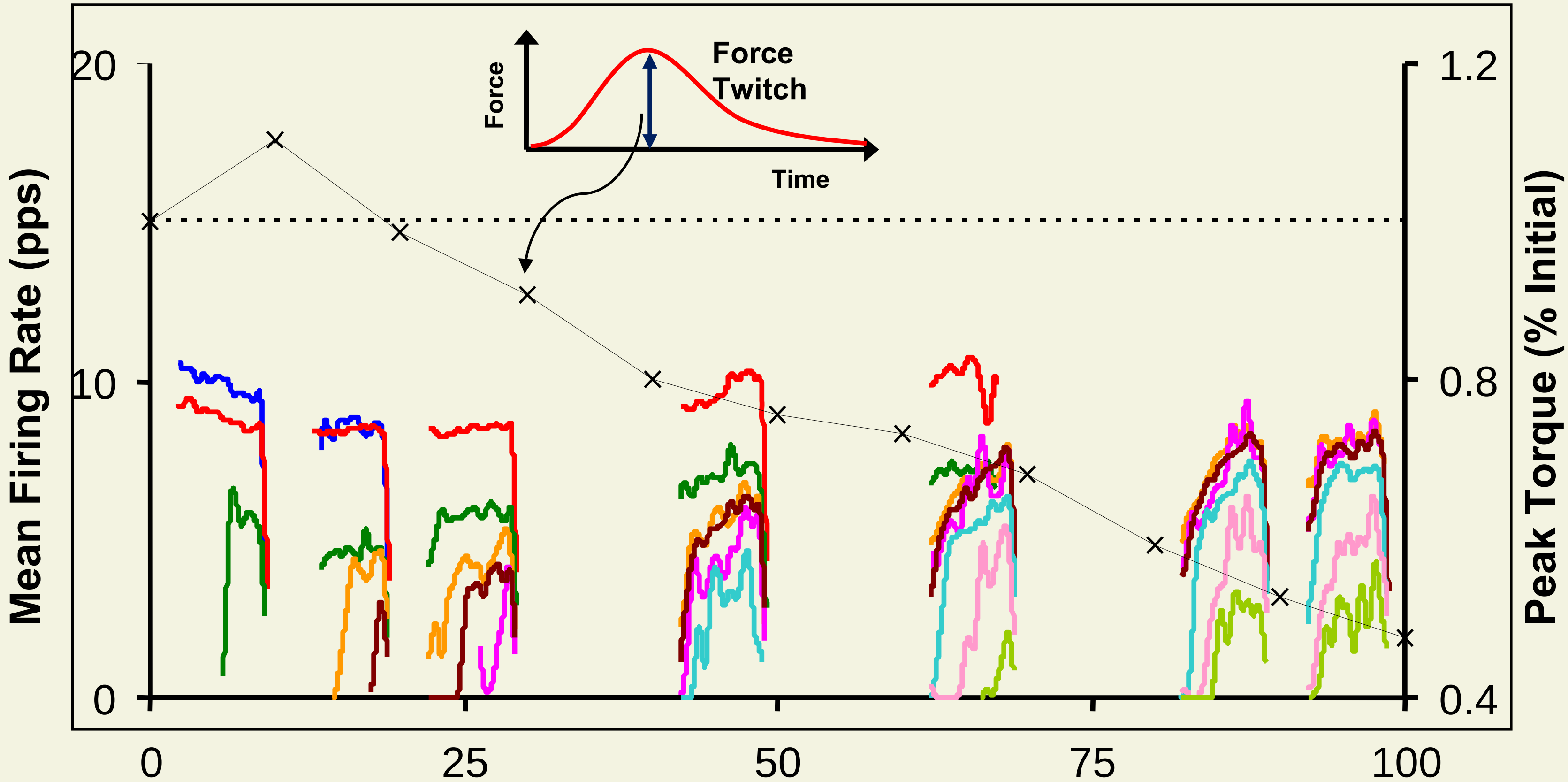
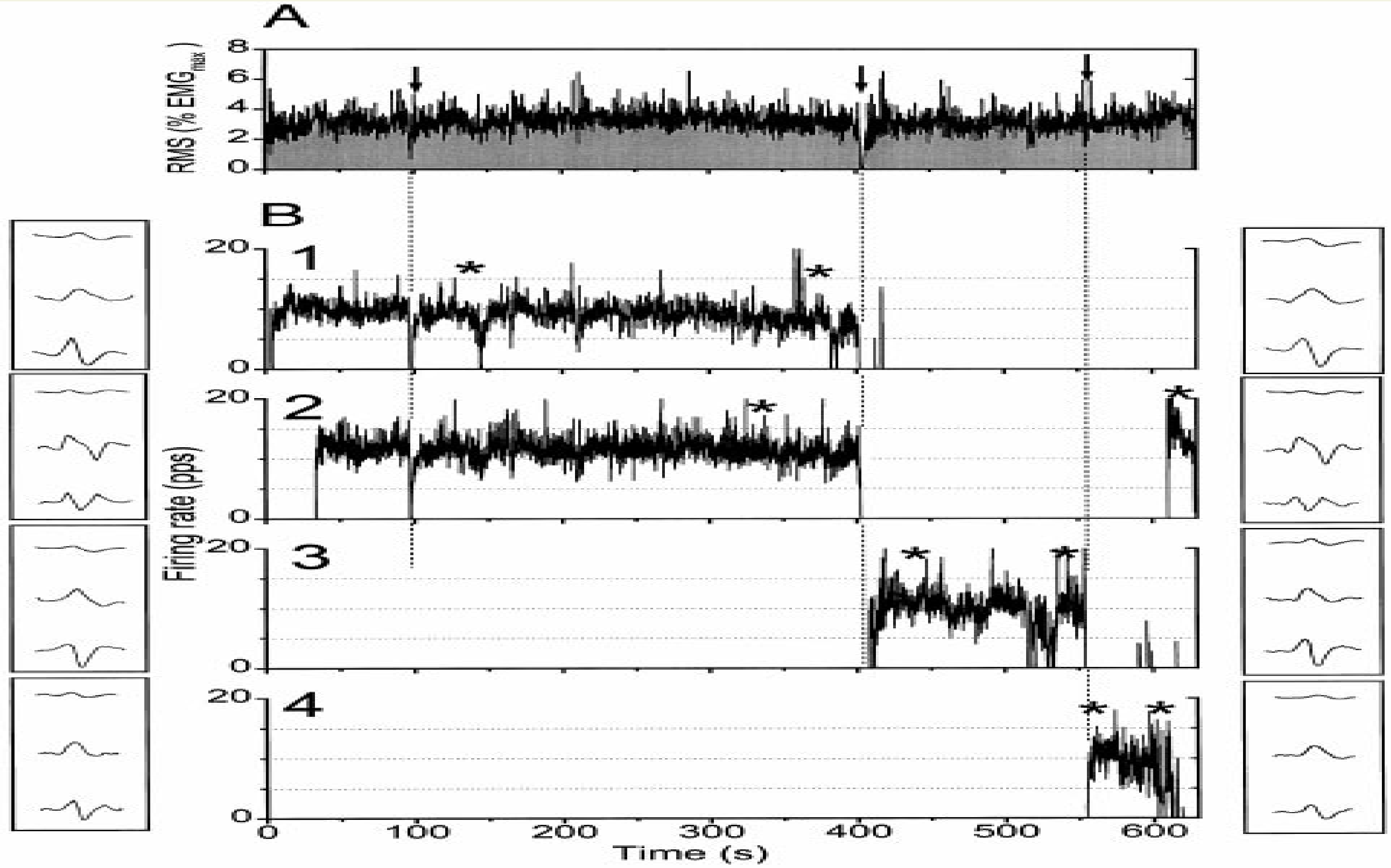


Adam A and De Luca CJ. Firing rates of motor units in human vastus lateralis muscle during fatiguing isometric contractions. ***Journal of Applied Physiology*****, 99: 268-280, 2005.**

MU Substitution
(Trapezius Muscle)



Westgaard RH and De Luca CJ. Motor unit substitution in long duration contractions of the human trapezius muscle. *Journal of Neurophysiology*, 82: 501-504, 1999.

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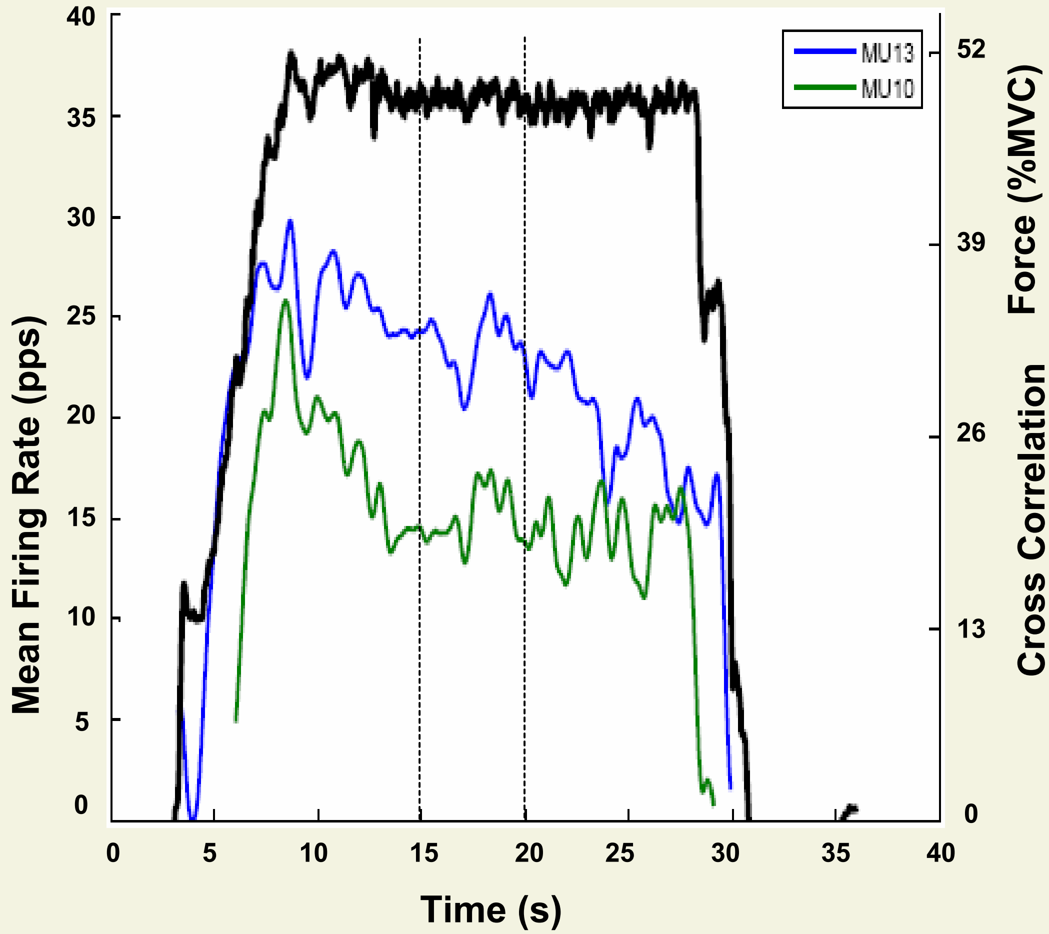
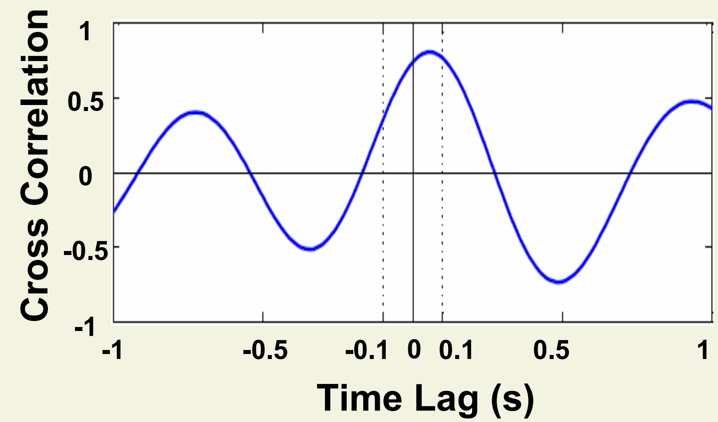
Common Drive
Cross-Correlation of Firing rates





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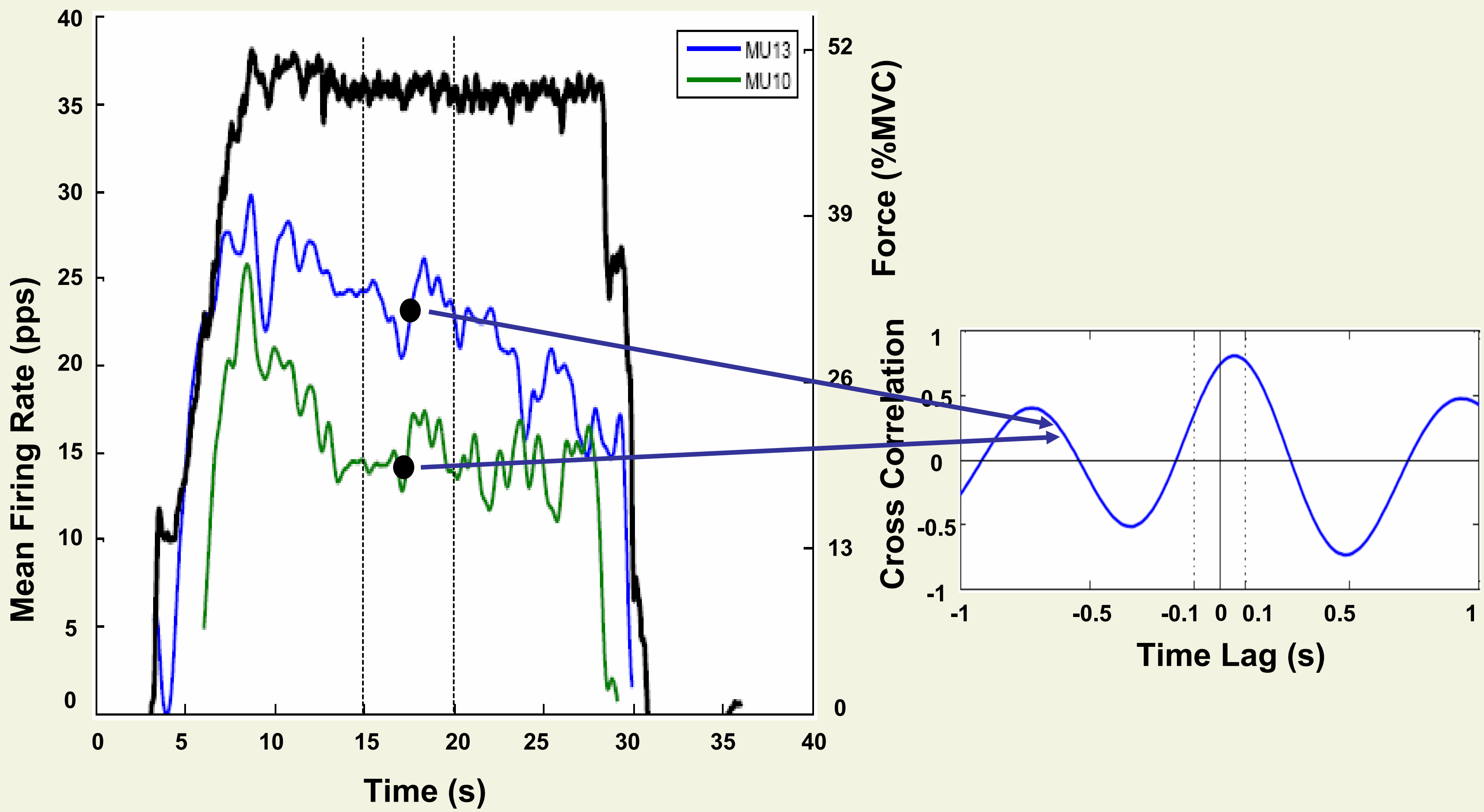

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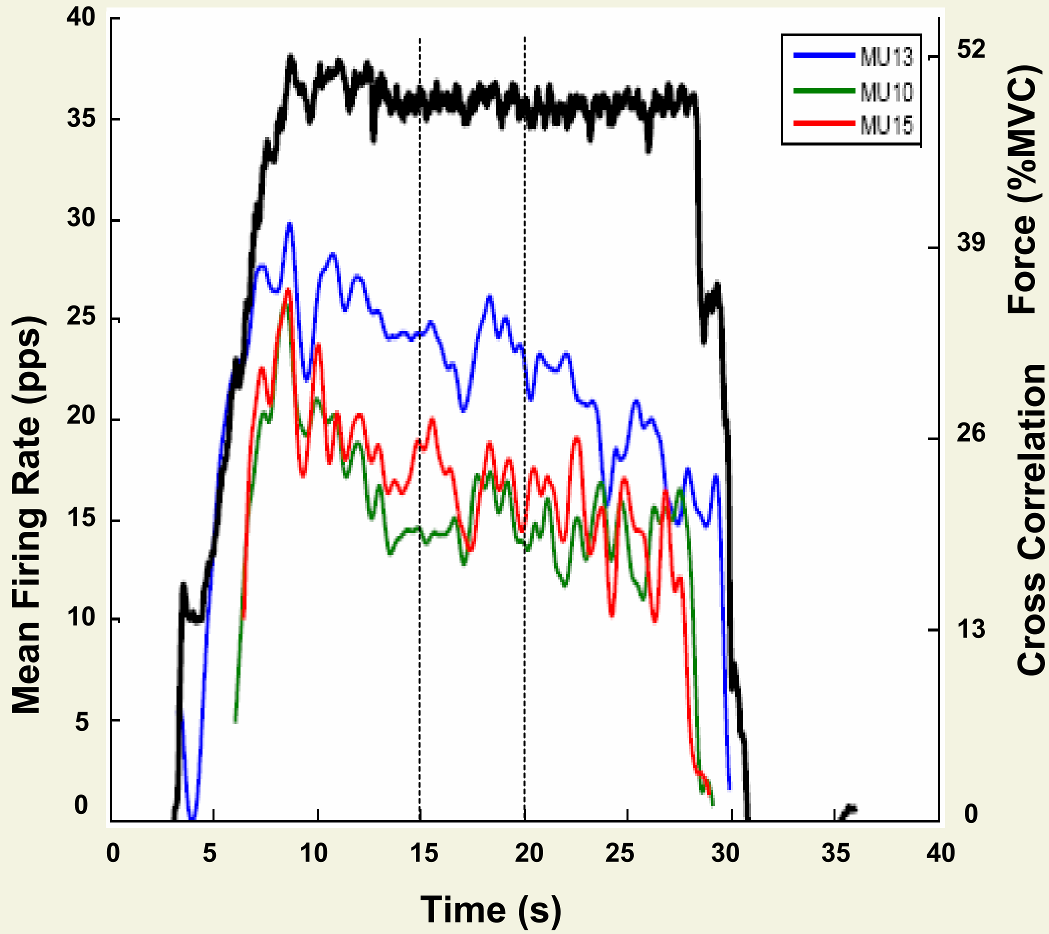
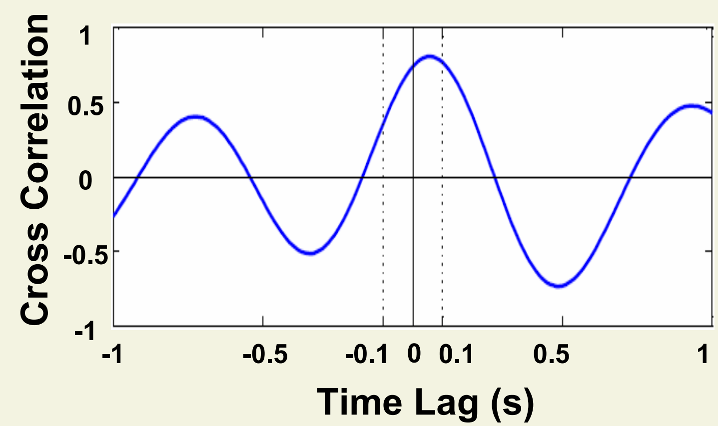
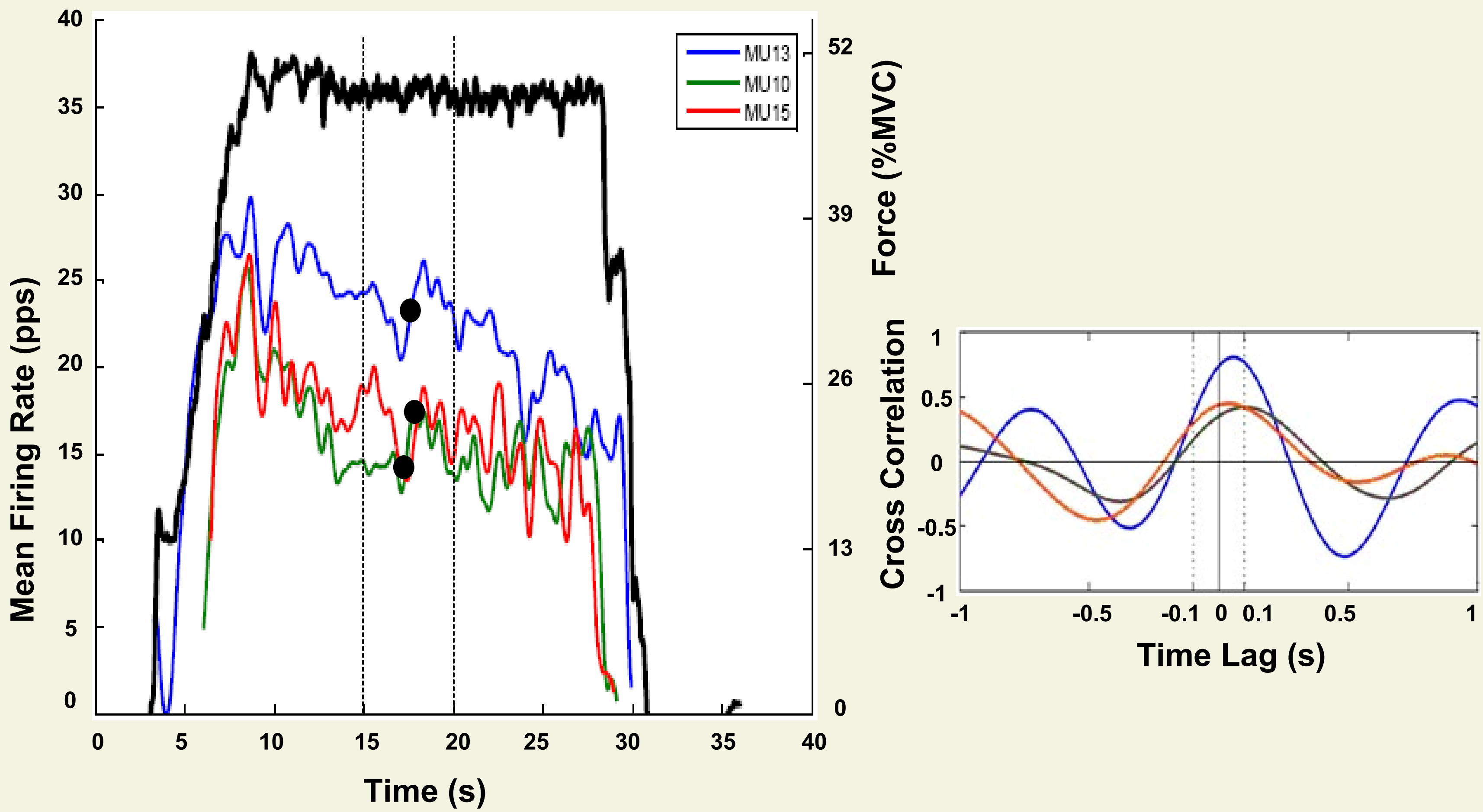
Common Drive
Cross-Correlation of Firing rates





Common Drive
Cross-Correlation of Firing rates



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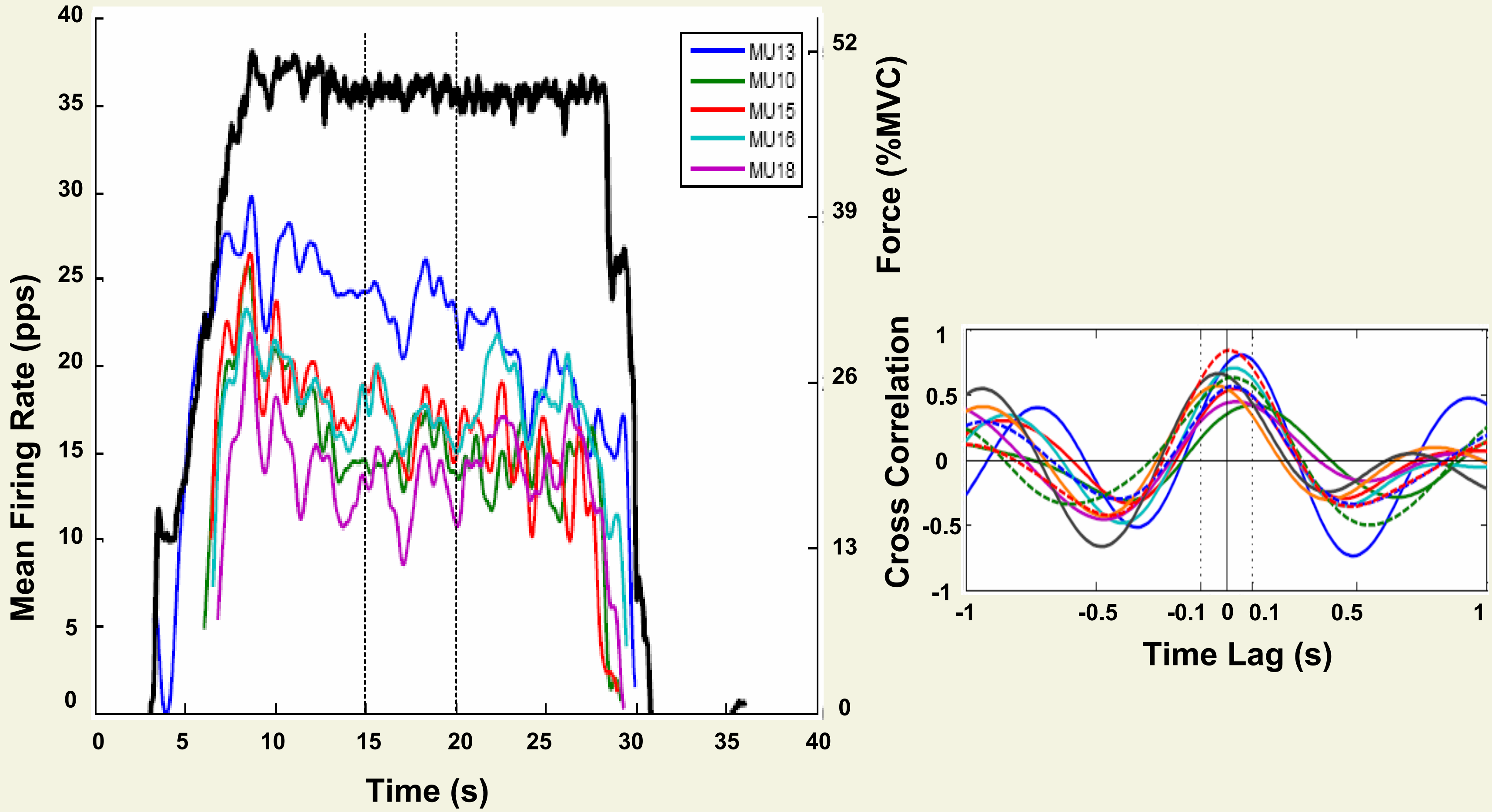
Common Drive
Cross-Correlation of Firing rates



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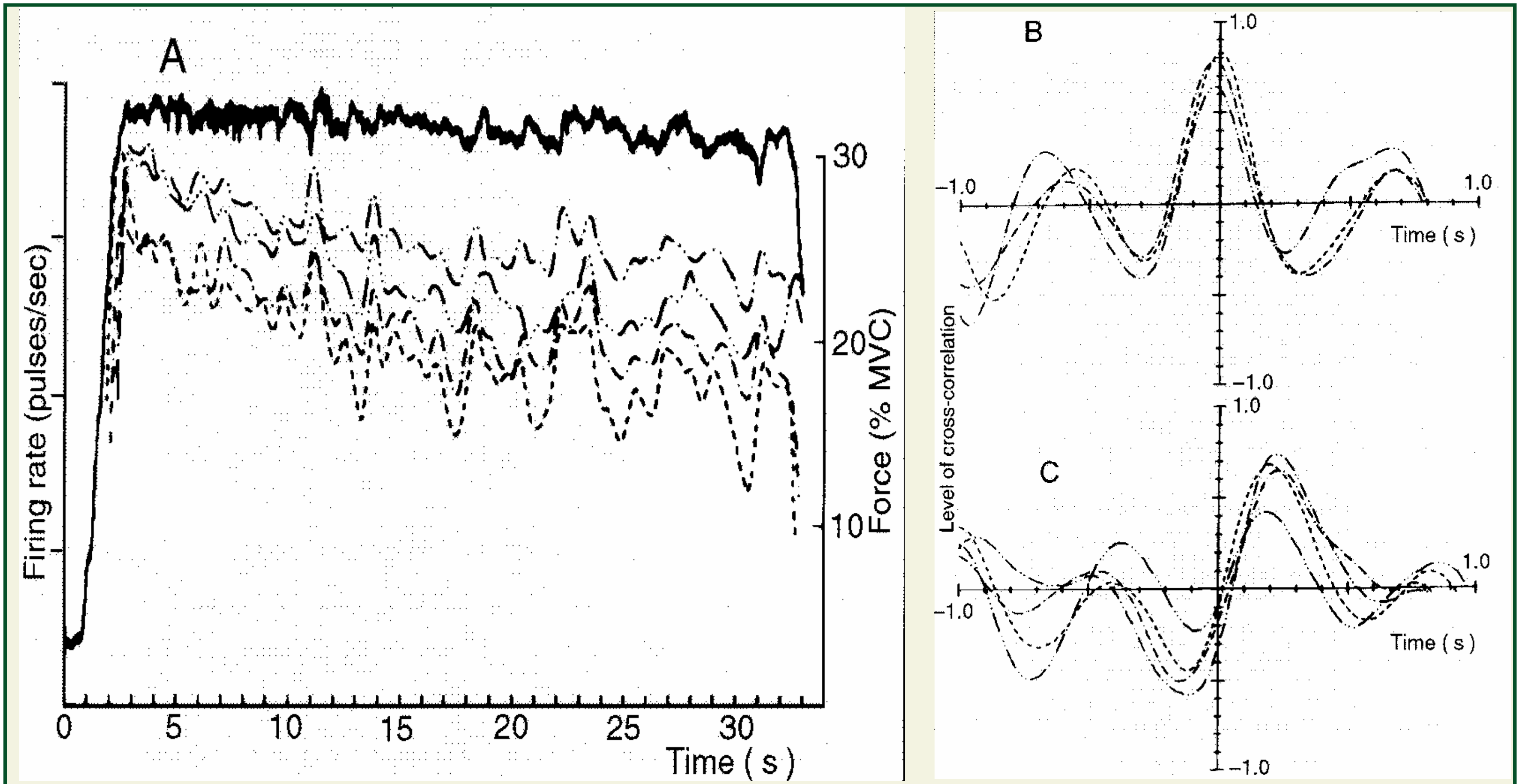
Common Drive



De Luca CJ, LeFever RS, McCue MP and Xenakis AP. Behavior of human motor units in different muscles during linearly-varying contractions. *J Physiol* 329: 113-128, 1982.

Common Drive Between Muscles

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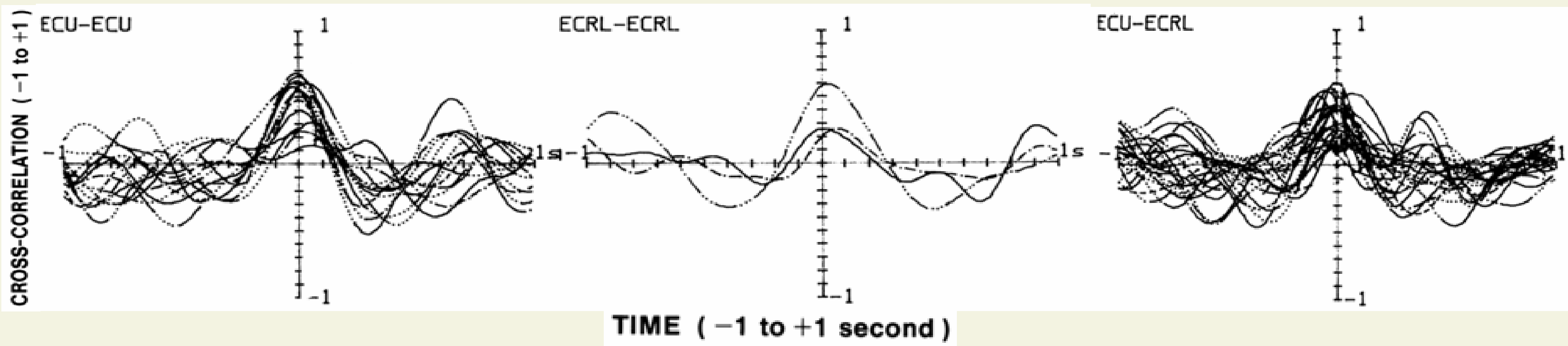
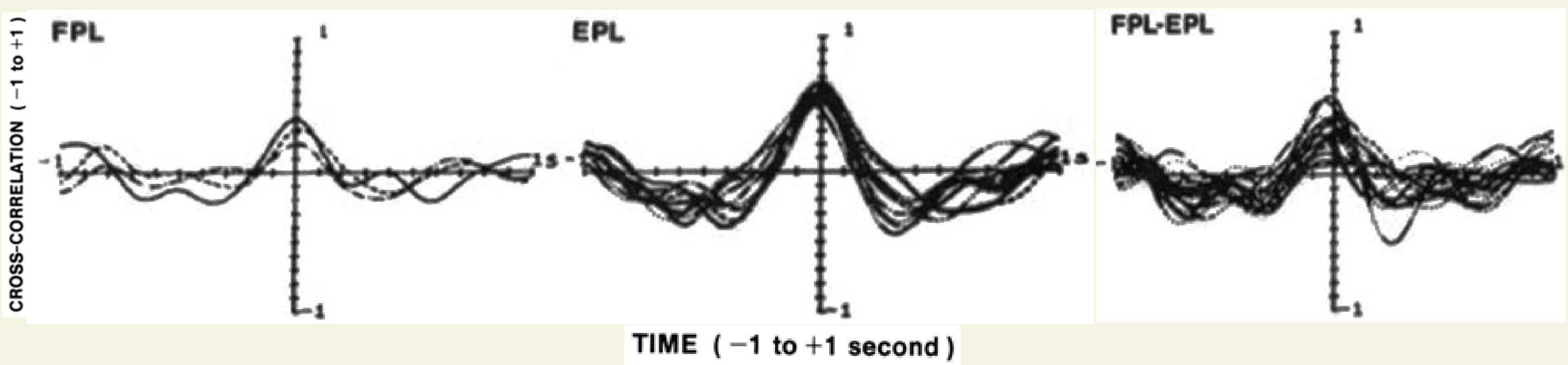
Between Synergists



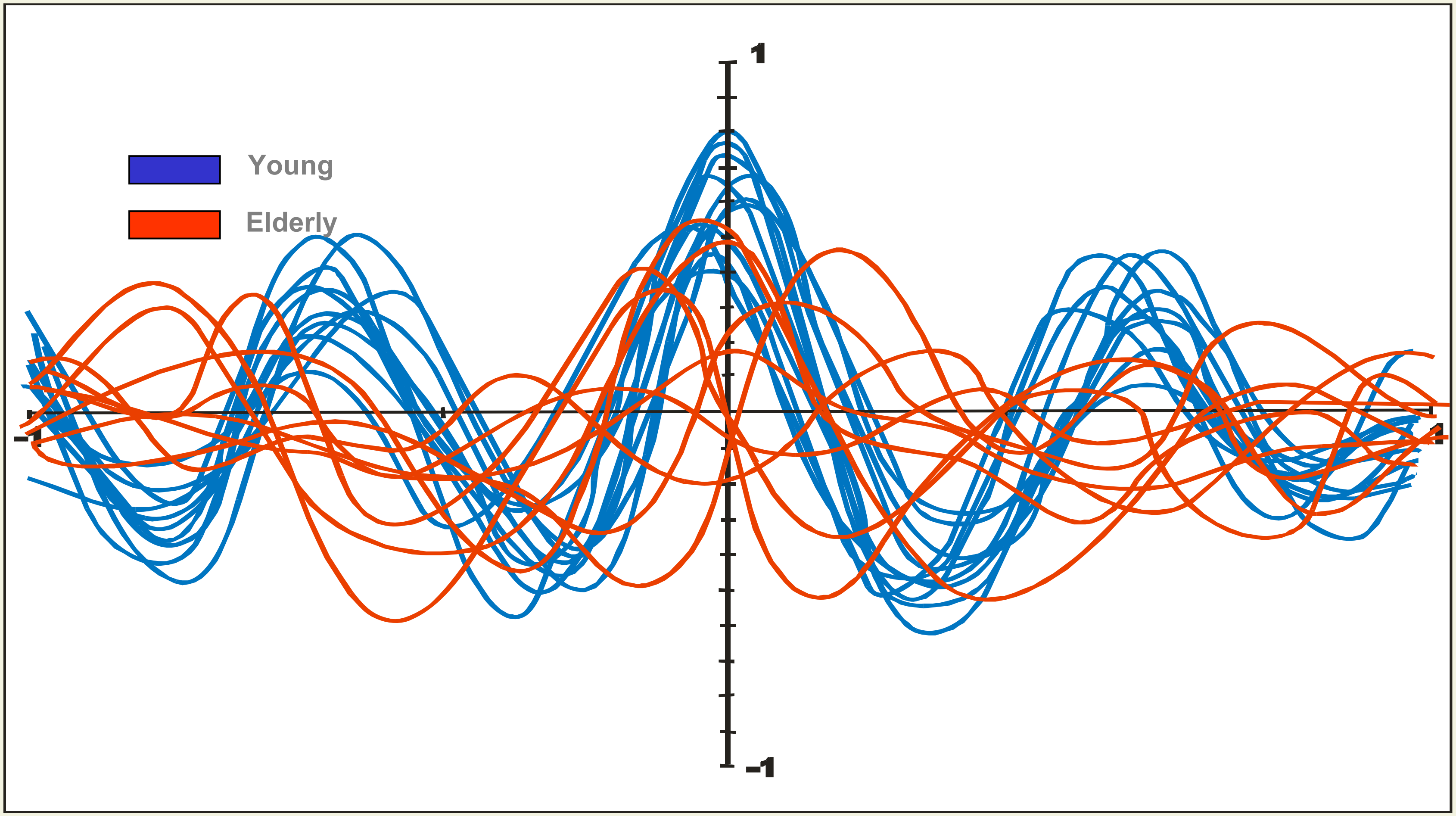
De Luca CJ and Erim Z. *J Neurophysiol* 87: 2200-1858, 2002.

Between Antagonists



De Luca CJ and Mambrito B. *J Neurophysiol* 58: 525-542, 1987.

Common Drive & Aging
Tibialis Anterior



Z. Erim, M.F. Beg, D.T. Burke and C.J. De Luca, "Effects of Aging on Motor Unit Control Properties", J. NeuroPhysio. 22, 2081-2091

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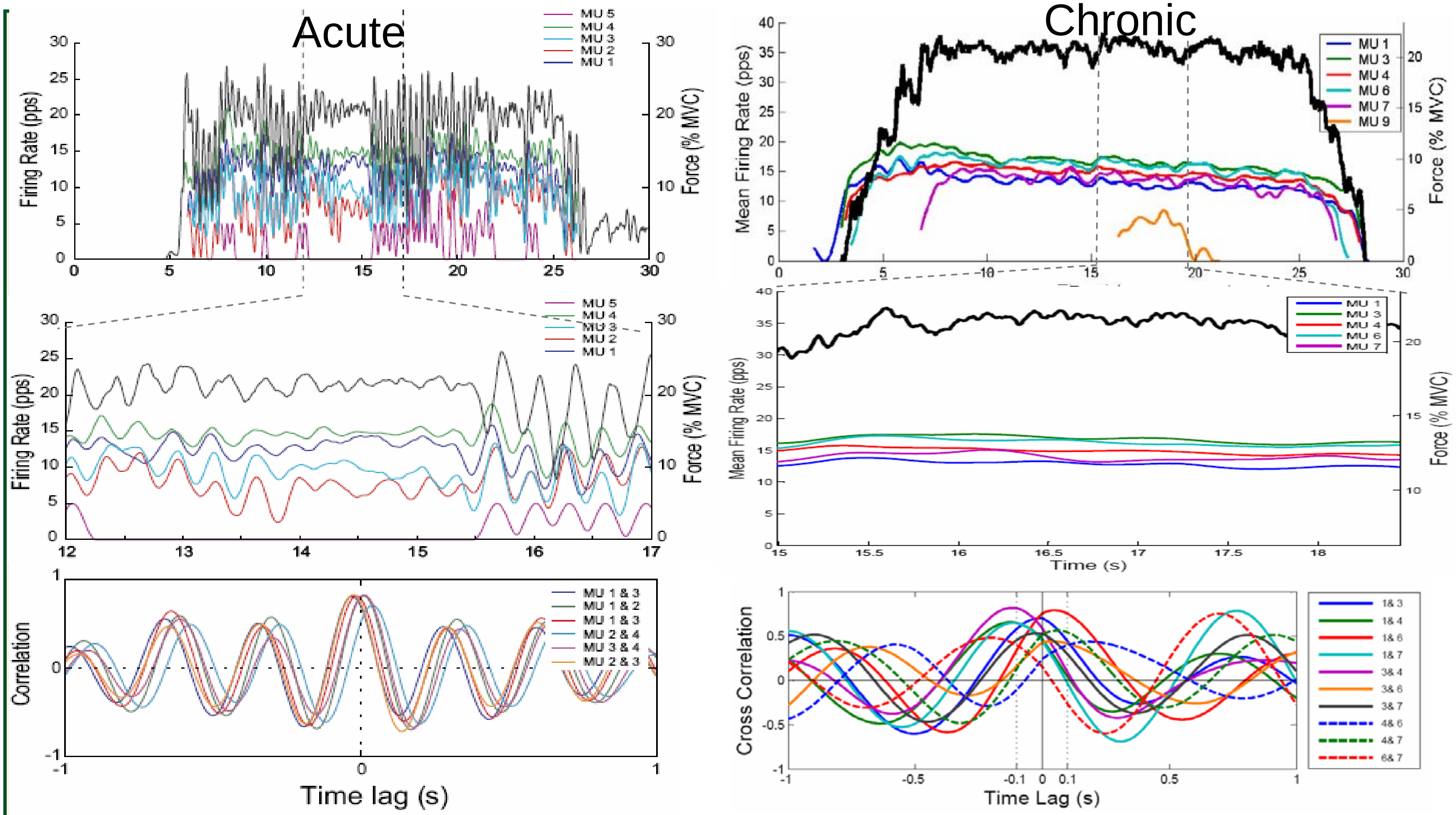
Cerebellar Stroke



Sauvage C, Manto M, Adam A, Roark R, Jissendi P, and De Luca CJ. Ordered motor unit firing behavior in acute cerebellar stroke. *Journal of Neurophysiology*, 96: 2769-2774, 2006

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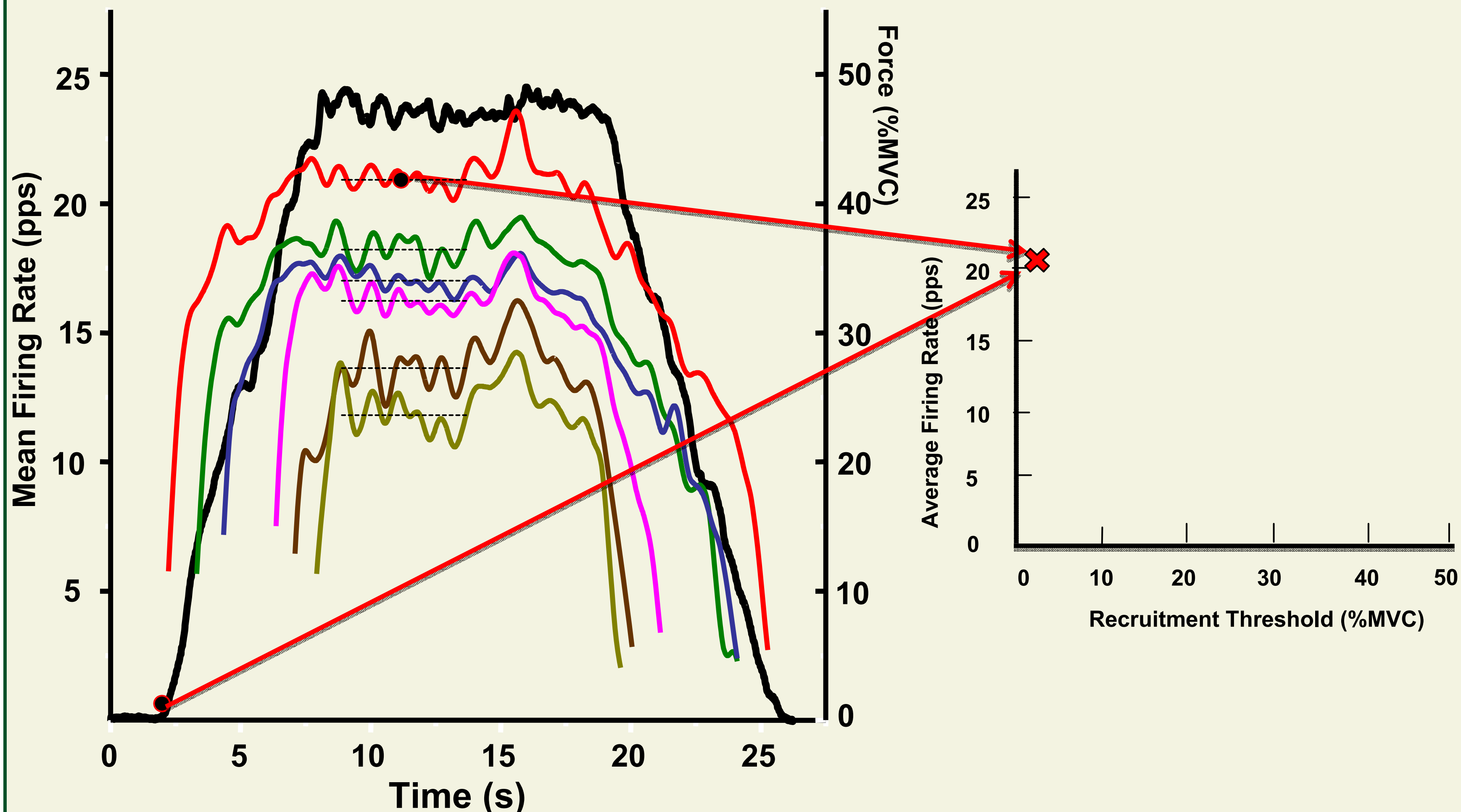
Onion Skin

Inverse relationship between recruitment threshold and firing rate



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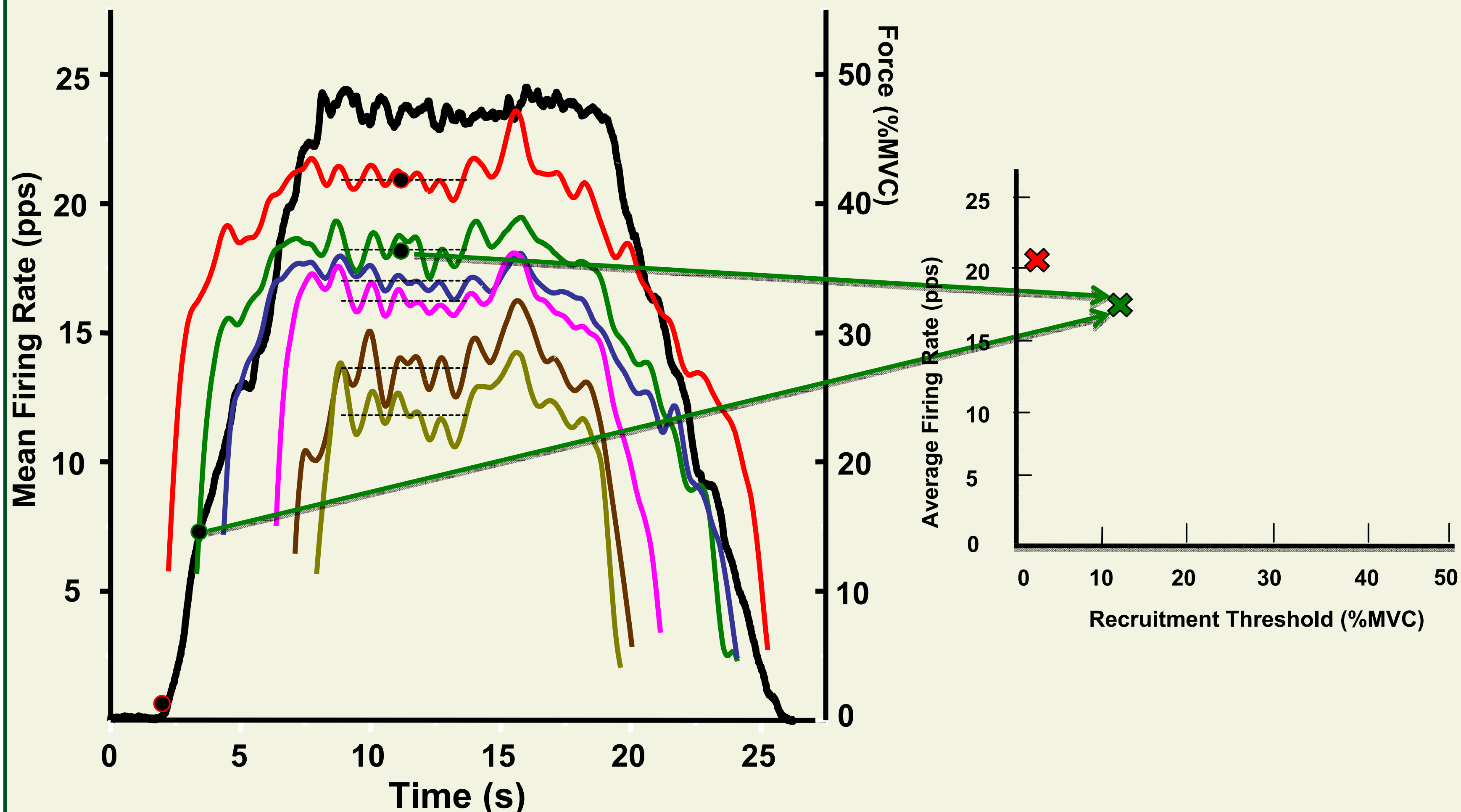
Onion Skin

Inverse relationship between recruitment threshold and firing rate



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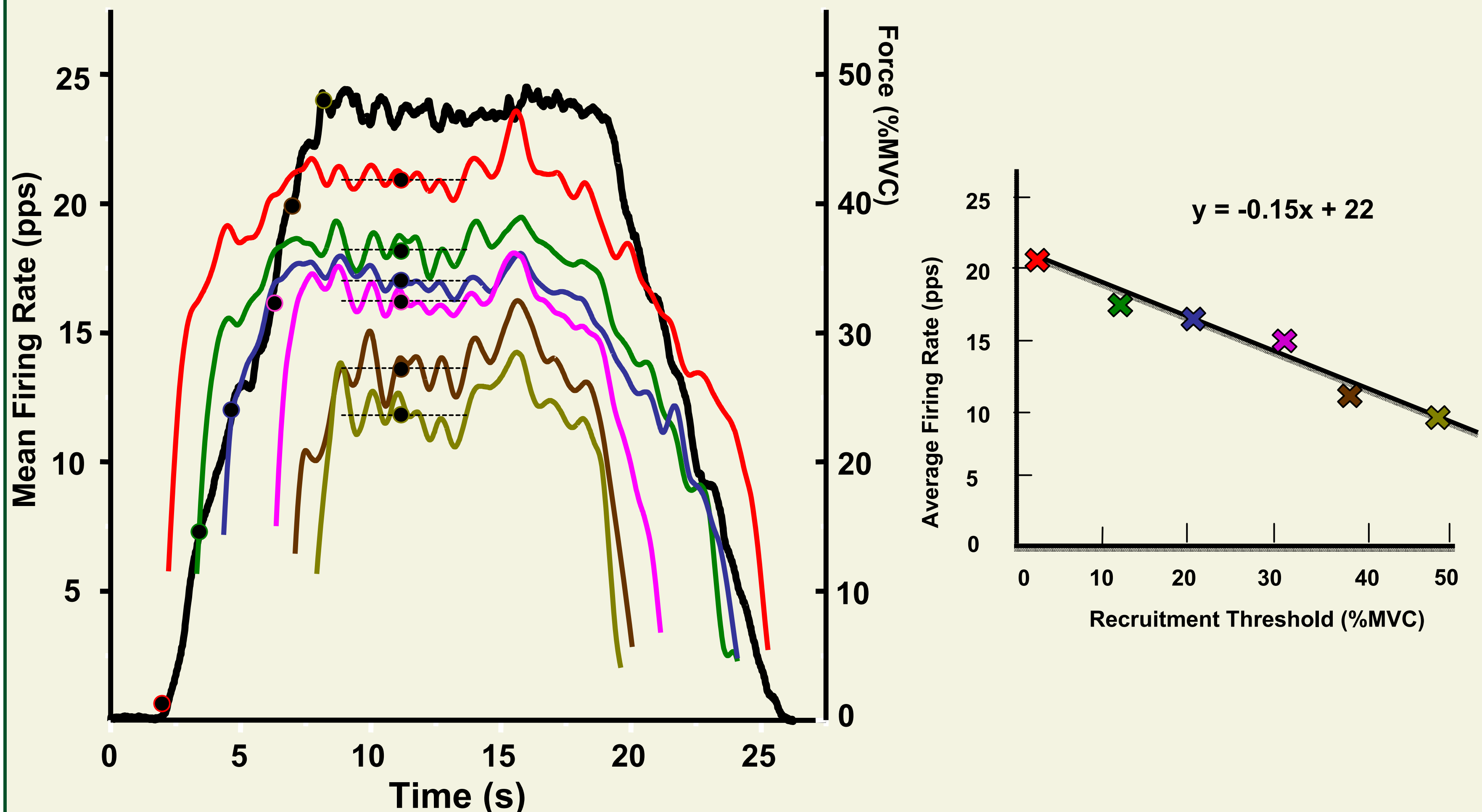
Onion Skin

Inverse relationship between recruitment threshold and firing rate



05/12/08

Onion skin across Force and Muscles

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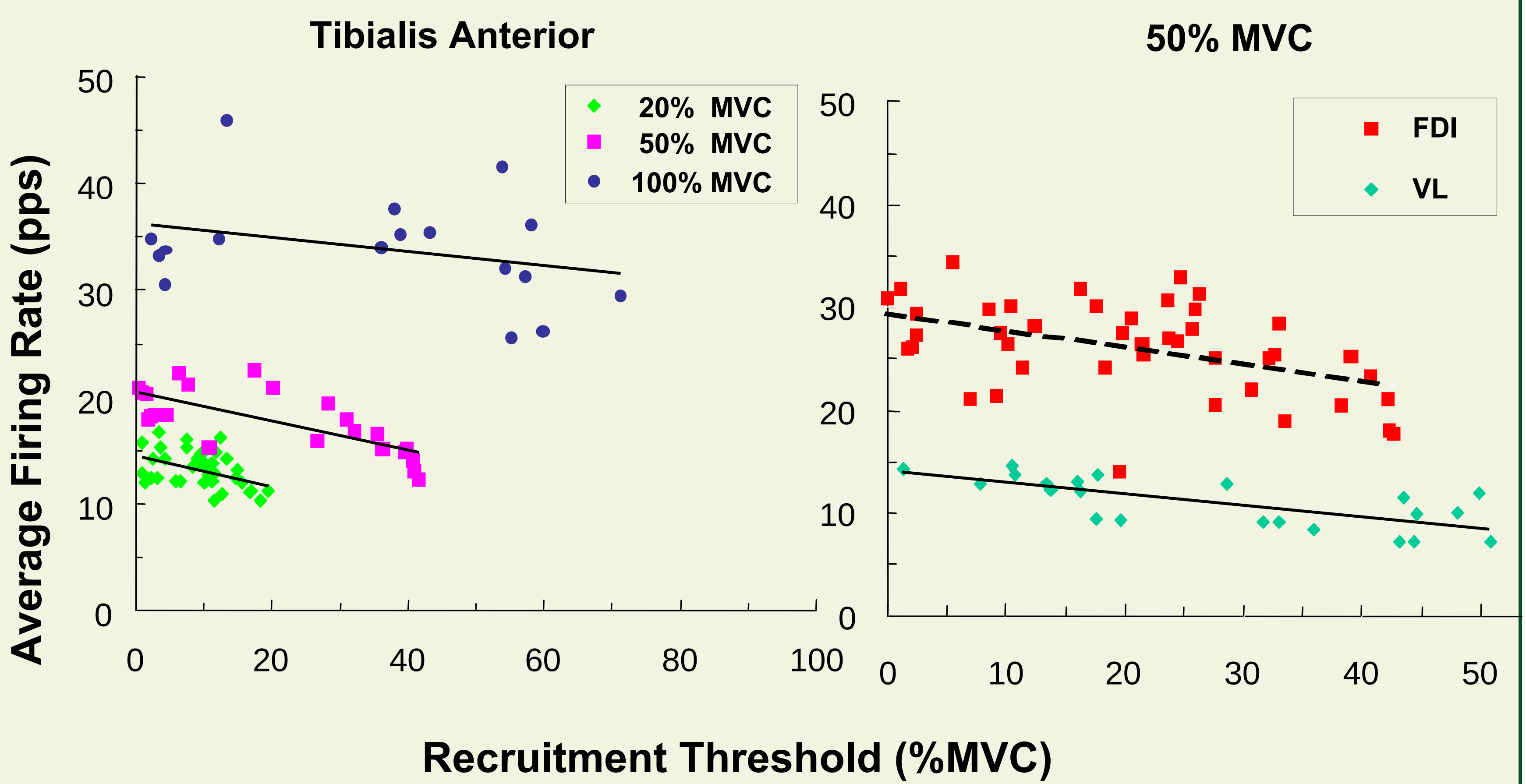
Inverse relation between Recruitment threshold and Firing Rate



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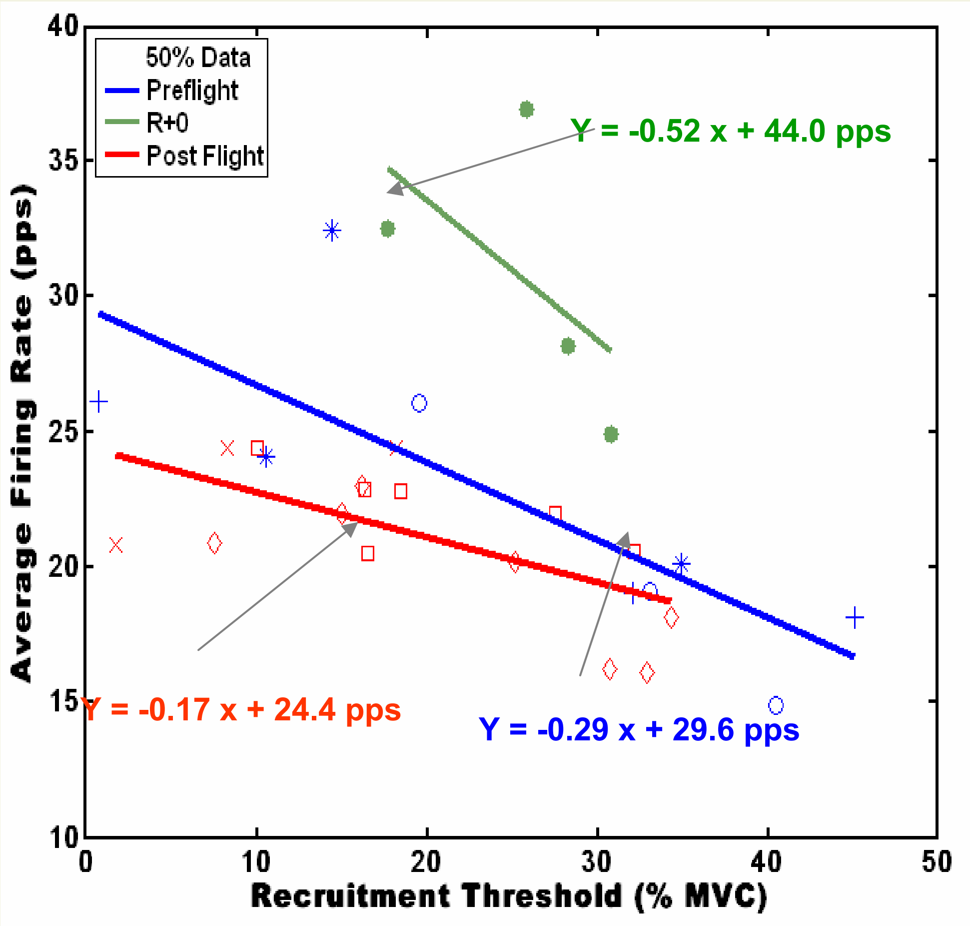
Microgravity

Vastus Lateralis, 20 % MVC



Exercise Physiology and Sports

- 1 Measure time delay between MU firing and the force output
  - Cross-correlation of firing rates and force
- 2 Neural Modifications of MU firing rates and recruitment
  - Behavior of Low threshold MU vs. high-threshold MU
  - During fatigue
  - Skilled performance
  - Elite performance
  - Injuries

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Applications -- 2

Motor Control

- **Motor Unit control strategies**
  - During Isometric contractions
  - During Anisometric contractions
  - During eccentric contractions

- **Muscle control strategies**
  - Synergist contractions
  - Antagonist contractions
  - Eccentric contraction

- **Influence of feedback on the control of motor units**
  - Spindle
  - Renshaw system (recurrent inhibition)
  - Golgi Tendon Organs (non-reciprocal inhibition)
  - Mechanoreceptors

- **Influences of altered environments on motor unit control**
  - Microgravity environment

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Applications -- 3

Clinical

- Influence of brain lesions on the control of motor units
  - Objective assessment of the impact of the lesion
    (How many muscles are affected?)
- Monitoring slow progressions of neural alterations
  - Age related factors
  - Mild long-term exposures to toxins
- Monitoring the progression of treatment
  - Testing new medications
  - Progression towards normalcy
- Pre-clinical diagnosis of motor disorders?
  - ALS ?

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Thank You!

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