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

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Acknowledgments

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• Support

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

Motor neurons

Synapse

Ventral horn

Muscle fibers

MU firings

Twitch

Tetanic Force

Click here to animate
The amplitude of the sEMG signal is proportional to the force produced by the muscle.

Activation Timing

Time (s)
Decomposition of the sEMG Signal

Surface Electrode

Raw sEMG Signal

DECOMPOSITION

Individual Motor Unit Action Potential Trains (MUAPTs)

α-Motoneurons
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
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
**Characteristics**

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

The sEMG Precision Decomposition System
-- Block Diagram

1. Acquisition & Data Management System
2. Decomposition Algorithms (AI-IPUS)
3. Editor
4. Data Processor
5. Output
6. Display (Subject)
7. Decomposition Algorithms
8. Display (Operator)
9. Decompression
10. Raw EMG
11. Other Sensors
Play Film

– Large (58 MB)
– Small (2 MB)
Detection Technique

-50% MVC; FDI

Surface EMG Sensor

PROCESSING UNIT IN SENSOR

sEMG Signals

V_1

V_2

V_3

V_4

500uV

100 mS
4 channels of EMG Signal
Motor Unit Action Potentials (MUAPs)
A more complex segment
Superpositions

MU #: 5

CH 1

CH 2

CH 3

CH 4

BAR PLOT

MU #11
MU #10
MU #9
MU #8
MU #7
MU #6
MU #5
## Superpositions

<table>
<thead>
<tr>
<th>MU #:</th>
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### BAR PLOT

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Superpositions

MU #: 5 6 7 8 9 10

CH 1

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CH 3

CH 4

BAR PLOT

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**BAR PLOT**

- MU #11
- MU #10
- MU #9
- MU #8
- MU #7
- MU #6
- MU #5
sEMG Decomposition Sample
– FDI 80% MVC

Entire Raw Waveform

Contraction Signal

MU #

Residue
sEMG Decomposition Sample
– FDI 80% MVC

Entire Raw Waveform

Contraction Signal

MU 1    MU 2    MU 3    MU 4    MU 5    MU 6    MU 7    MU 8

MU 9    MU 10   MU 11   MU 12   MU 13   MU 14   MU 15   MU 16

MU 17   MU 18   MU 19   MU 20   MU 21   MU 22
• **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
**Calculation of firing rate**

![Graph showing mean firing rate over time](image)

- **Axes:**
  - Y-axis: Mean Firing Rate (pps)
  - X-axis: Time (s)

- **Graph Details:**
  - The graph illustrates the change in mean firing rate over time, with significant peaks at certain intervals.

- **Legend:**
  - Red line represents one set of data.
  - Green line represents another set of data.

- **Observation:**
  - The peak at time 4 seconds is notably higher than others, indicating a significant event or stimulus.
Accuracy is critical!!

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
Cross-Correlation of Firing rates

![Graph showing cross-correlation of firing rates with time and force percentage.](image-url)
Common Drive

Cross-Correlation of Firing rates

Mean Firing Rate (pps)

Time (s)

Force (%MVC)

Cross Correlation

Time Lag (s)
Cross-Correlation of Firing rates

![Graph showing cross-correlation of firing rates with time and force.]
Common Drive
Cross-Correlation of Firing rates

![Graph showing cross-correlation of firing rates](image)

- Mean Firing Rate (pps)
- Time (s)
- Force (%MVC)
- Time Lag (s)
- Cross Correlation

Legend:
- MU13
- MU10
- MU15
Common Drive
Cross-Correlation of Firing rates

Time (s)

Mean Firing Rate (pps)

0 5 10 15 20 25 30 35 40

Force (%MVC)

0 5 10 15 20 25 30 35 40

Time Lag (s)

Cross Correlation

0 0.5 1 1.5

MU13
MU10
MU15
MU18
MU18
Between Synergists


Between Antagonists

Onion Skin

Inverse relationship between recruitment threshold and firing rate
Onion Skin

Inverse relationship between recruitment threshold and firing rate

- Mean Firing Rate (pps)
  - Force (%MVC)
  - Time (s)
- Average Firing Rate (pps)
- Recruitment Threshold (%MVC)

Graph showing the inverse relationship between recruitment threshold and firing rate, with curves depicting mean firing rate over time and force (%MVC) against recruitment threshold.
Onion Skin

Inverse relationship between recruitment threshold and firing rate

\[ y = -0.15x + 22 \]
Inverse relation between Recruitment threshold and Firing Rate

**Tibialis Anterior**

- 20% MVC
- 50% MVC
- 100% MVC

**50% MVC**

- FDI
- VL

Average Firing Rate (pps) vs Recruitment Threshold (%MVC)
Vastus Lateralis, 20 % MVC

- $Y = -0.52x + 44.0 \text{ pps}$
- $Y = -0.29x + 29.6 \text{ pps}$
- $Y = -0.17x + 24.4 \text{ pps}$
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
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
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?
Thank You!