Effect of Feedback Type and Training on Voluntary Control of Single Motor Units

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Control Of Motor Units

- Control over an individual motor unit’s (MU) activation and firing rate has been demonstrated by Basmajian (1963) with needle EMG
- Humans naturally control force, not MUs
- Learning MU control is possible with feedback
Questions?

• Can a subject control a single MUs activation and firing rate when provided with feedback from surface EMG signals?

• How do the feedback methods compare?
Apparatus
Feedback

- Linear double differential (LDD) Feedback signal
MU Feedback GUI
MU Control Tests

C1: Activate and isolate a single MU for 60s

C2: Activate and deactivate that MU every 5s for 60s
MU Control Tests

C3: Maintain the MU’s firing rate at 8 pulses per second (pps) for 60s

C4: Modulate the firing rate of the MU between 8 and 12pps every 5s for 60s
Feedback Tests

- Maintain a firing rate of 8 pps for 20s (i.e. C3)
  - F1: All feedback
  - F2: Only audio
  - F3: Only firing rate speedometer
  - F4: Only raw EMG signals
  - F5: No feedback
Training

• Two 15 minute training sessions
• All feedback provided
• Subjects verbally instructed on single MU control techniques
  • encouraged when performance is good
  • discouraged when performance is bad
• Encouraged to practice the four MU control tests
sEMG Signal Decomposition

- Firing patterns of identifiable MUs used to extract MU templates
Controlled MU

LDD sEMG Amplitude (uV)

Time (ms)

window comparator
Evaluation of MU activation control

- Firing pattern used to extract control signal
Evaluation of MU activation control

- Performance Indicator (PI) = mean squared error (MSE) between target (red) and control (blue) signals
  - \[ \text{PIa} = \text{mean}(S_{\text{Target}} - S_{\text{Control}})^2 \]
Evaluation of MU firing rate control

- Instantaneous firing rate (IFR) used to evaluate performance
- accuracy: IFR mean
  \[ P_{fr1} = ((\text{mean}(\text{IFR}) - S_{\text{Target}})/S_{\text{Target}})^2 \]
- precision: IFR variance
  \[ P_{fr2} = \text{var}(\text{IFR})/S_{\text{Target}} \]
Results

- Contraction levels: $0.6 \pm 0.75 \% \text{MVC}$
- Always below 2.5 \%MVC
- Initially subjects struggled to isolate a single MU
- Improvement with training
  - reduced MSE
  - increased accuracy: mean closer to target
  - increased precision: decreased variance
Training Improvements

No training

15 min training

30 min training

Training = 0 min  MSE = 0.33926

Training = 15 min  MSE = 0.18796

Training = 30 min  MSE = 0.12612

Time (s)
Training Improvements

No training

15 min training

30 min training

Training = 0 min  Mean: 11.4579  Variance: 13.422

Training = 15 min  Mean: 9.9935  Variance: 1.9156

Training = 30 min  Mean: 9.8548  Variance: 1.4397
Results

- Preferred feedback
  - MU peak audio beeps
  - Firing rate speedometer
- Subjects found raw sEMG feedback to be confusing
- Further statistical analysis needed to prove significance
Conclusion

- Individuals show the ability to learn control over activation and firing rate of a single MU from **surface** EMG feedback.
- The simplest forms of feedback seem to be the most useful forms of feedback for subjects inexperienced in EMG.

Direct audio and visual indication of MU features seems to provide the best feedback.
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MU Template Extraction

- Feedback EMG signal (μV)
- 1st averaging window
- Firing patterns of identified MUs
- Windows of 30ms centered at each MU firing
- 20ms
MU Template Extraction

- Moving window averaging
- Motor unit template
- Averaged windows

20ms
Testing Protocol

- Sixteen healthy volunteers
  - age: 24 ± 2.37 years (mean ± S.D)
  - height: 1.77 ± 0.09 m
  - weight: 67.9 ± 11.8 kg
- Isometric contractions of abductor pollicis brevis (APB) muscle
- Below 2.5% MVC
Apparatus

- Load cell
- 15 channel electrode grid
  - 1 mm silver electrodes
  - 2.5 mm inter-electrode distance (IED)
- Single Differential (SD) sEMG
- Multichannel EMG amplifier (EMG-16, OT Bioelettronica)
Feedback

• **Visual feedback**
  – Raw EMG signals (Single Differential)
  – Feedback Signal (Double Differential)
  – Window comparator
  – Firing rate speedometer

• **Audio feedback**
  – High tone beep when a peak is detected
  – Low tone beep when peak is above comparator window