Motor Neurons

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Systems Neuroscience Course 2012
NYU
Why should we study motor neurons?
(only ~0.0003 % of all neurons, ~300,000)

1. Know their function
   • to contract muscle (generate tension, shorten)

2. MNs are the “final common path”
   • Bottleneck (333,333:1)

3. Accessibility
   • Large size, so easy to record
   • Easy to identify
   • Muscles are targets, so use them as surrogate (MUAP)

4. Historical
   • Sherrington (defined basic concepts of synapse, inhibition, excitation, reflex loops, recruitment)
   • Eccles (among first vertebrate CNS intracellular recordings) measurement of synaptic delay, mechanism of synaptic inhibition in the CNS.
What are motor neurons?

How do you know whether you are recording a MTN?
How Are Motor Neurons Organized in the Spinal Cord?

1. Columnar Nuclei (Pools)
2. Overall topography
Motor neurons and muscles

Motor neuron A1

Motor nucleus A

Motor nucleus B

Muscle A

Muscle B

MN pool-2
Topography of motor neuron pools
Types of motor neurons innervating skeletal muscle

1. alpha motor neurons
2. gamma motor neurons
3. beta motor neurons
Innervation/Function of MN types

1. alpha motor neurons
   extrafusal muscle fibers, motor

2. gamma motor neurons
   intrafusal muscle fibers, sensory-related

3. beta motor neurons
   extrafusal and intrafusal muscle, both sensory and motor?
Historical/ Early Observations

Red vs white muscles
Slow vs fast contraction

S-fibers (human muscle)
33% triceps
40% brachioradialis
80% adductor pollicis
88% soleus (100% cat)
The Motor Unit

Spinal (lower) motoneuron + Muscle fibers = Motor unit

(Muscle unit)
Muscle unit classification-1

[Graphs showing muscle unit classification with labels for fast and slow, fast fatigable, and fast fatigue-resistant categories.]
Muscle Fiber Contractile Properties

Tension

Fast FF
75%

F(int)
45%

FR
5%

25%

Slow
25%

Fatigue resistance

Fiber diameter

Twitch contraction time
Table 2.2 Classification of motor units and their muscle fibres

<table>
<thead>
<tr>
<th>Physiological motor unit type</th>
<th>Slow</th>
<th>Fast</th>
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<tbody>
<tr>
<td>Traditional simple classification</td>
<td>S</td>
<td>FR, Fint/FF</td>
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<tr>
<td>‘Burke-classification’</td>
<td>S</td>
<td>FR, Fint/FF</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cytochemical fibre type</th>
<th>Ia</th>
<th>Ila (Ild, Ilbm)</th>
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<tbody>
<tr>
<td>mATPase histochemistry</td>
<td>I</td>
<td>Ila</td>
</tr>
<tr>
<td>MHC isoform</td>
<td>I</td>
<td>Ila</td>
</tr>
<tr>
<td>mATPase/MHC &amp; metabol enz</td>
<td>SO</td>
<td>FOG, FG</td>
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<table>
<thead>
<tr>
<th>Physiological characteristics</th>
<th>+</th>
<th>++</th>
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<tbody>
<tr>
<td>Force-sag*</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Isometric twitch speed*</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Fatigue index (%)*</td>
<td>&gt;75</td>
<td>&gt;75, 25–75/0–25</td>
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<tr>
<td>Maximum tetanic force</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Recruitment hierarchy</td>
<td>1</td>
<td>2, 3</td>
</tr>
<tr>
<td>Amount of daily activity</td>
<td>+++</td>
<td>++</td>
</tr>
</tbody>
</table>

Simplified summary of major terminologies and characteristics of motor unit types in mammalian limb muscles.

Abbreviations: mATPase, myofibrillar ATPase; MHC, myosin heavy chain; metabol. enz., activity of metabolic enzymes (oxidative, glycolytic).

* Properties used for physiological classification.
Motor neuron properties correlate with motor unit properties

Slow M.U.s as compared to Fast M.U.s have
smaller motor neuron axon
smaller motor neuron (body plus dendrites)
more oxidative enzymes, mitochondria
distinct electrical properties

S → FR → FF
Motor neuron electrophysiology

Eccles et al 1958
AHP of MN sets minimum firing rate and is matched to twitch time of muscle fibers.
Control of Force

- Recruitment gradation (number of motor units activated)
- Rate gradation (firing rate changes of active units)
- Size principle
Motor unit recruitment

Figure 15.8  Motor units recorded transcutaneously in a muscle of the human hand as the amount of voluntary force produced is progressively increased. Motor units (represented by the lines between the dots) are initially recruited at a low frequency of firing (8 Hz); the rate of firing for each unit increases as the subject generates more and more force. (After Monster and Chan, 1977.)
Fig. 26-3. Stretch-evoked responses of five alpha motoneurons recorded from filament of first sacral ventral root during stretch, A and B, and release, C and D, of triceps surae muscle. Small numerals above action potentials indicate rank of units according to size. (From Henneman et al.29)
Size Principle

Recruitment order

No. of units small many few large
Axon diameter small large few many
No. of terminals small large few many
Tetanic tension small large few many
Speed of contraction slow or fast fast little or none rapid
Fatigue little or none little or none scanty
Metabolism aerobic anaerobic
Myoglobin plentiful scanty
Glycogen little much
Mitochondria high density very low density
Capillaries rich supply few or none
Muscle fibers small, red large, pale

Fig. 24-20. Histogram illustrating numeric distribution of motor unit properties according to their sizes (i.e., maximal tetanic tensions). Characteristics correlated with motor unit size are shown for the two ends of the histogram. An approximately continuous gradation between these limits is assumed.
Large vs Small to same stim
Why are small MNs more excitable?

- Higher input resistance ($R_{in}$)
  - Less membrane area
  - Higher membrane resistivity
- Smaller $V_{thresh}$ / and intrinsic properties
- Rheobase lower

So if other factors equal, small MNs activated first
When does the size principle apply?