

# Motor Neurons

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Systems Neuroscience Course 2012  
NYU

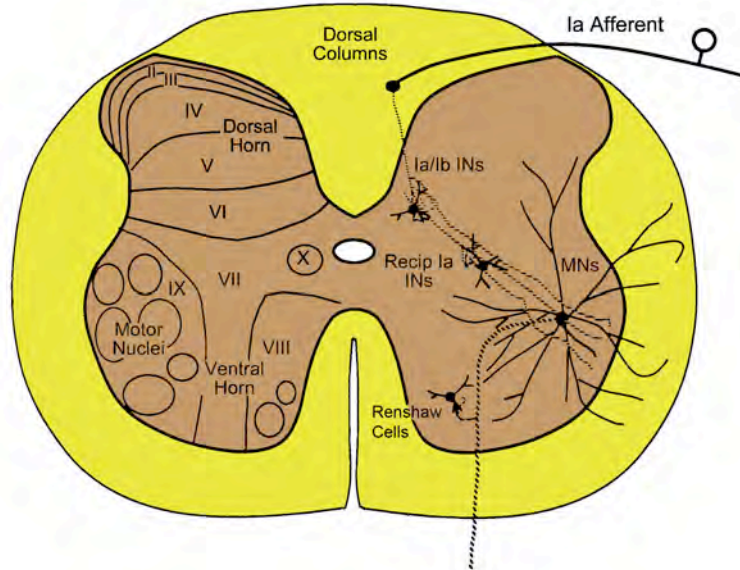
# Why should we study motor neurons?

(only ~0.0003 % of all neurons, ~300,000)

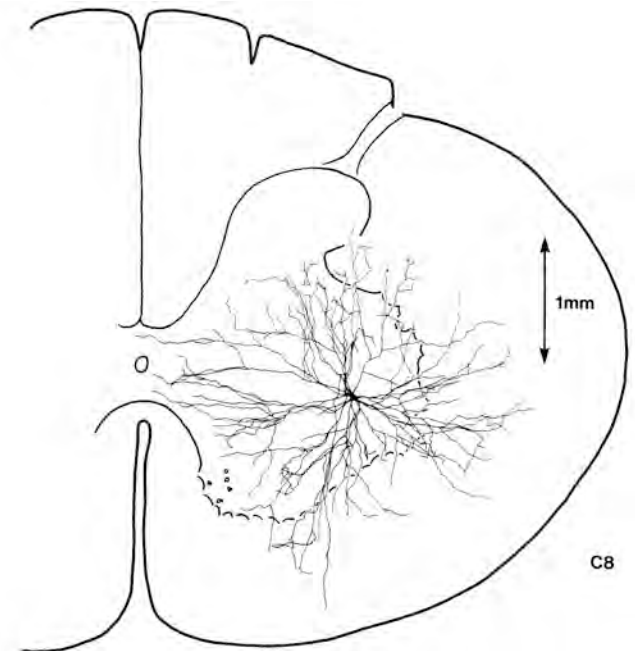
1. Know their function
  - to contract muscle (generate tension, shorten)
2. MNs are the “final common path”
  - Bottleneck (333,333:1)
3. Accessibility
  - Large size, so easy to record
  - Easy to identify
  - Muscles are targets, so use them as surrogate (MUAP)
4. Historical
  - Sherrington (defined 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?



Burke, Syn Org Brain

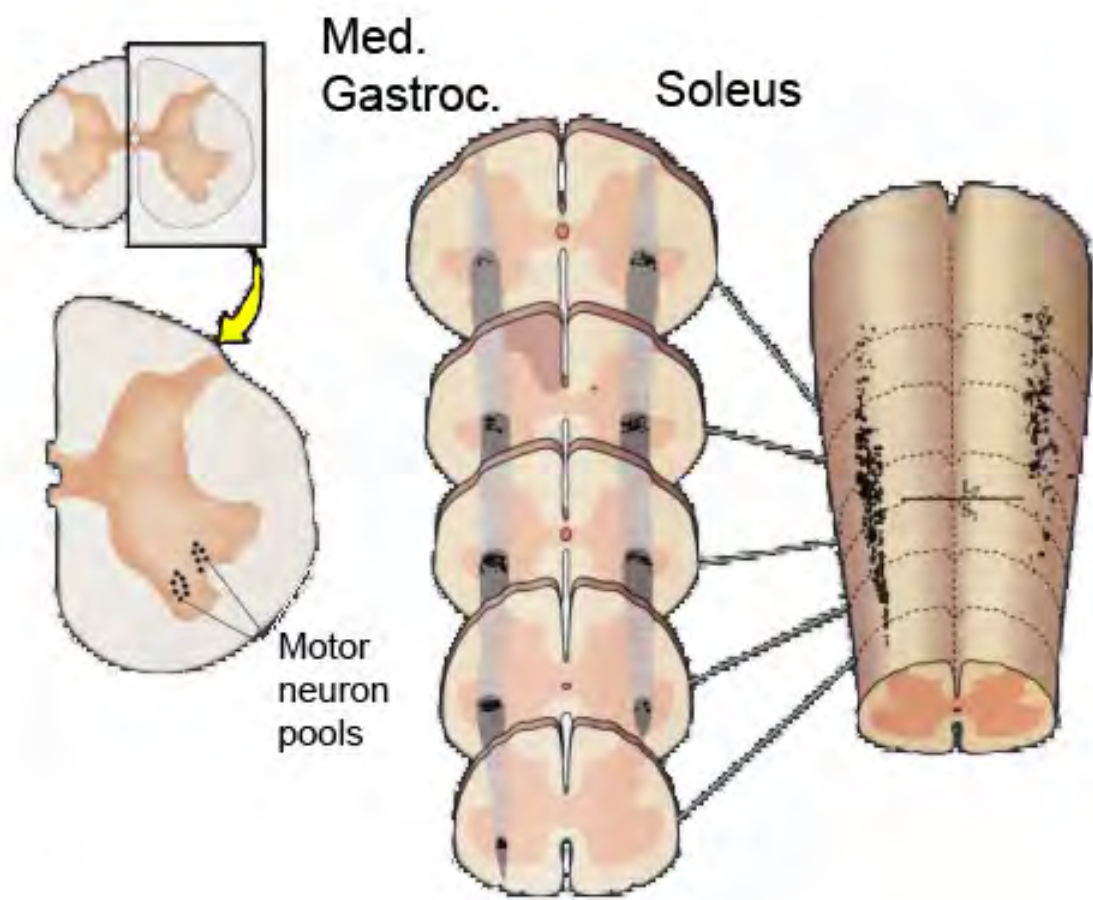


Porter and Lemon

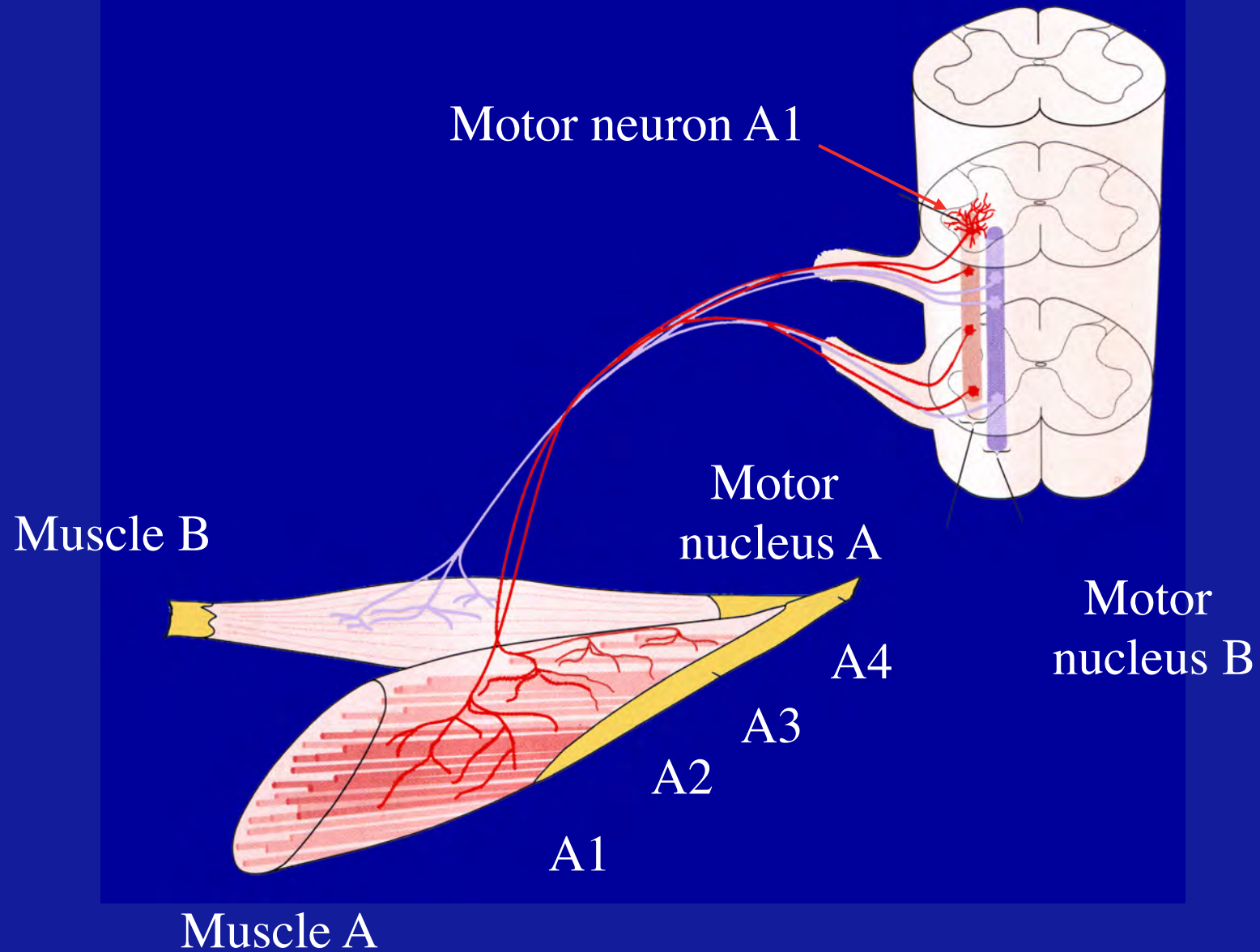
How do you know whether you are recording a MTN?

# How Are Motor Neurons Organized in the Spinal Cord?

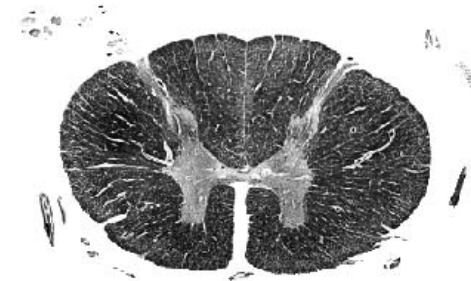
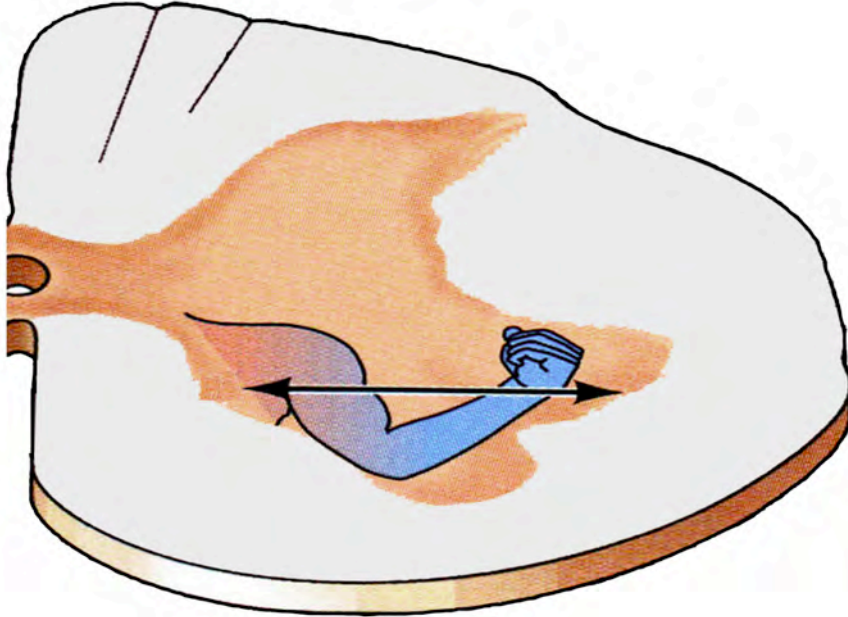
1. Columnar Nuclei (Pools)
2. Overall topography



# Motor neurons and muscles



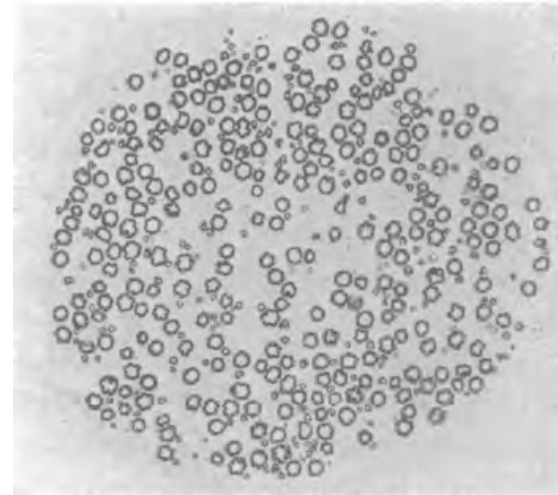
# Topography of motor neuron pools





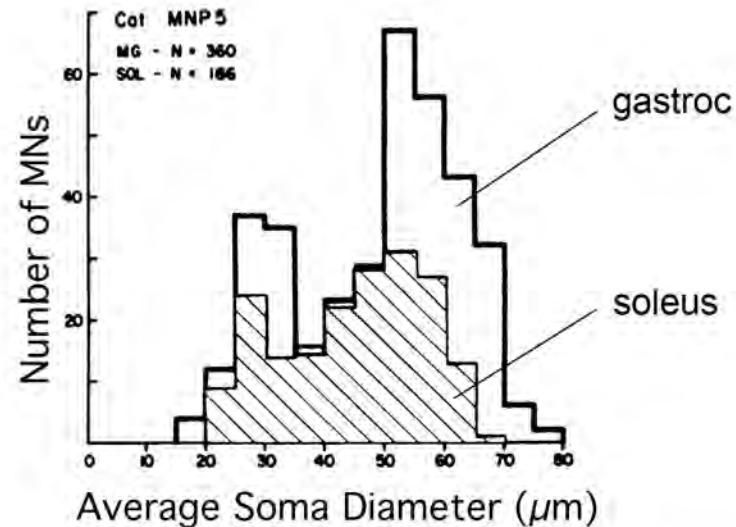
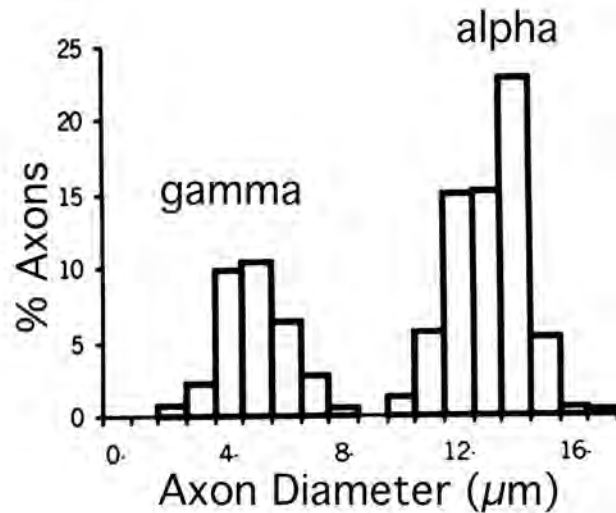
# Types of motor neurons innervating skeletal muscle

1. alpha motor neurons
2. gamma motor neurons
3. beta motor neurons



Motor axons in nerve to gastroc muscle

Eccles Sherrington 1930



Kernell (Eccles Sherrington 1930)



# Innervation/Function of MN types

1. alpha motor neurons

extrafusal muscle fibers, motor

2. gamma motor neurons

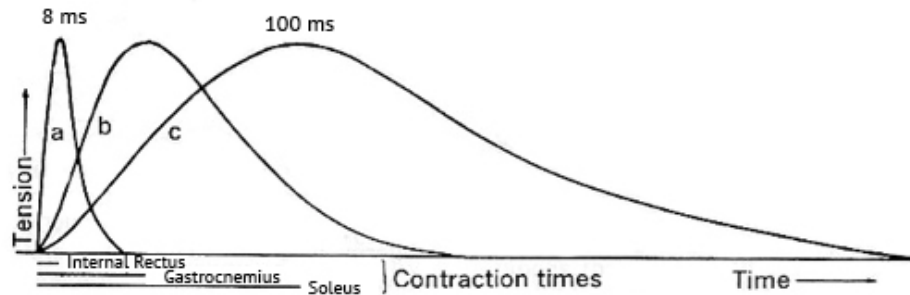
intrafusal muscle fibers, sensory-related

3. beta motor neurons

extrafusal and intrafusal muscle, both  
sensory and motor?

# Historical/ Early Observations

Red vs white muscles  
Slow vs fast contraction



**Fig. 24-7.** Twitch contractions of three cat muscles, arranged to show the great differences in their speeds. Curve *a* represents internal rectus, curve *b* represents gastrocnemius, and curve *c* represents soleus. (From Cooper and Eccles.<sup>15</sup>)

S-fibers (human muscle)

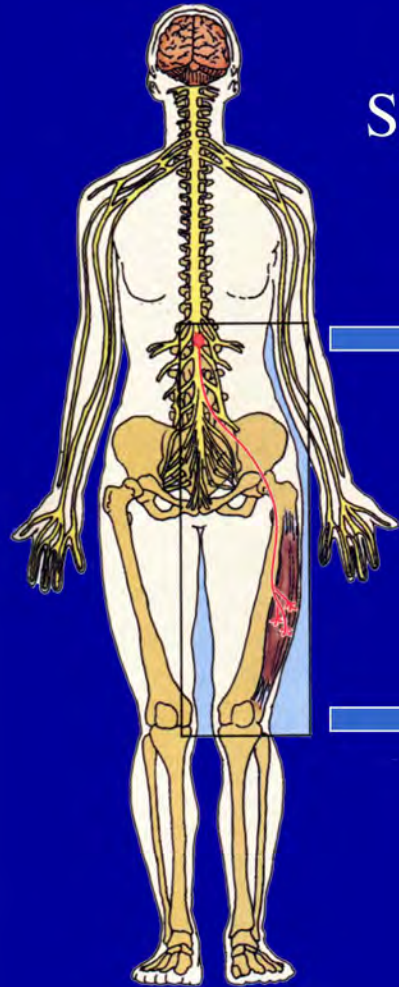
33%triceps

40%brachioradialis

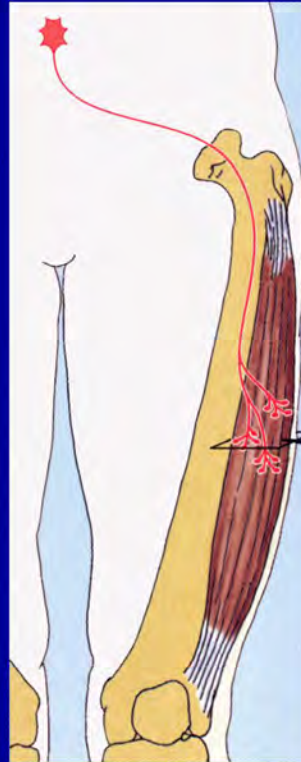
80%adductor pollicis

88%soleus (100%cat)

# The Motor Unit



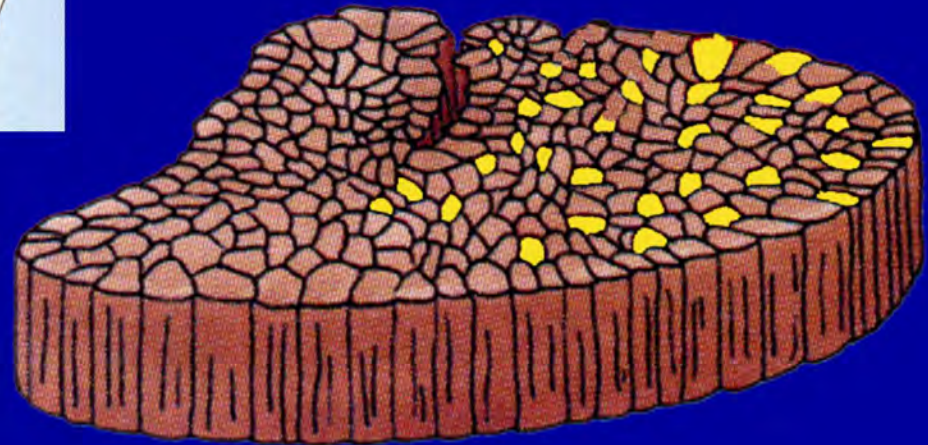
Spinal (lower) motoneuron



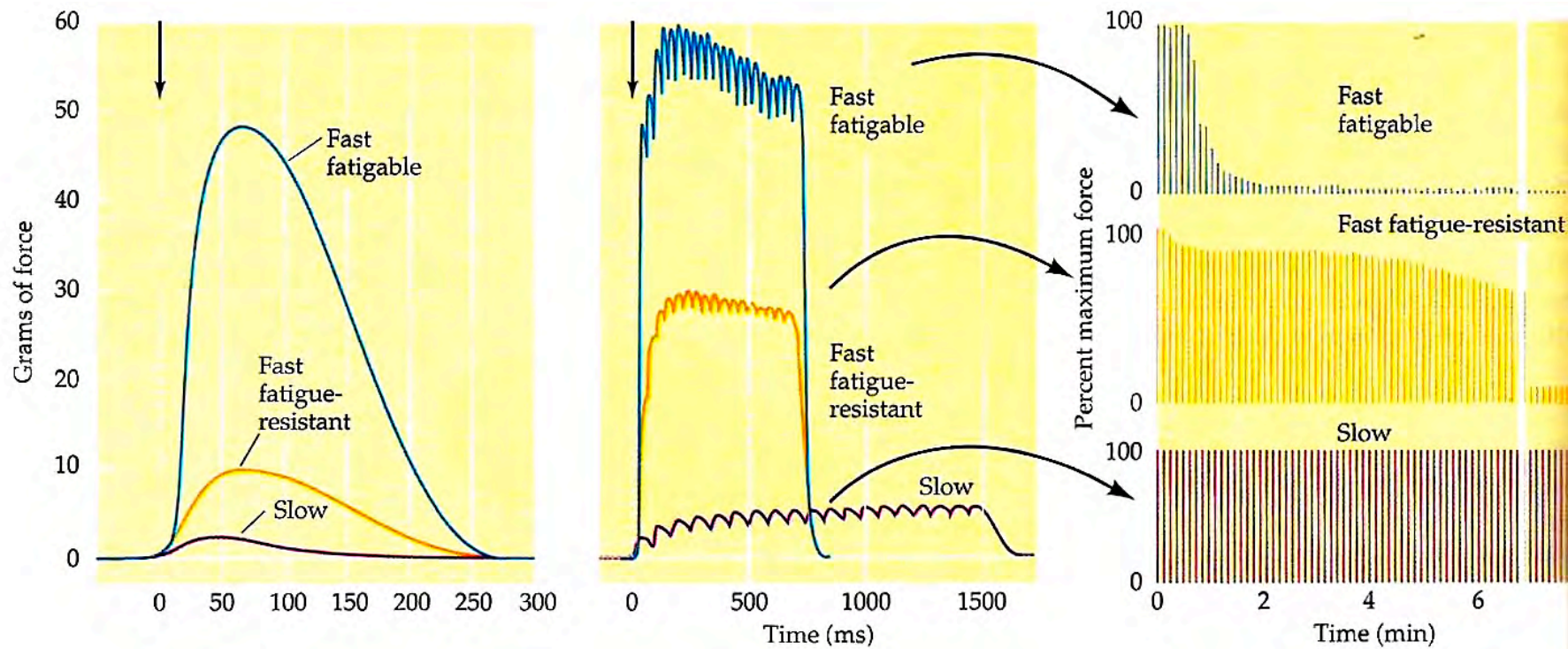
+ Muscle fibers

= Motor unit

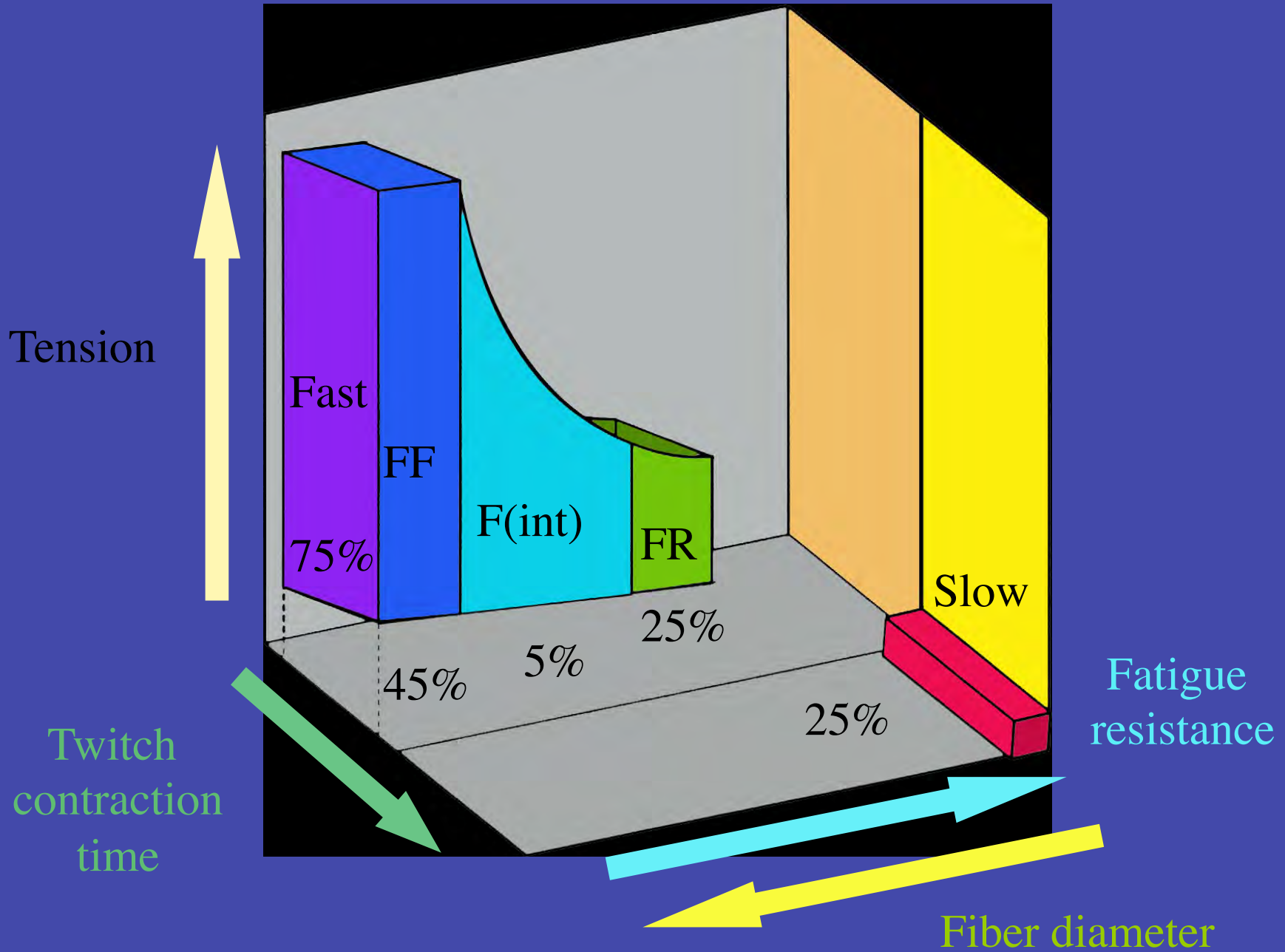
(Muscle unit)



# Muscle unit classification-1



# Muscle Fiber Contractile Properties





# Muscle unit classification-2

**Table 2.2** Classification of motor units and their muscle fibres

## Physiological motor unit type

Traditional simple classification	Slow	Fast	
'Burke-classification'	S	FR	Fint/FF
<b>Cytochemical fibre type</b>			
mATPase histochemistry	I	Ila	Ilb (Ilbd, Ilbm)
MHC isoform	I	Ila	Ilx (= Ild), Ilb
mATPase/MHC & metabol. enz.	SO	FOG	FG
<b>Physiological characteristics</b>			
Force-sag*	0	+	+
Isometric twitch speed*	+	++	++
Fatigue index (%)*	>75	>75	25-75/0-25
Maximum tetanic force	+	++	+++
Recruitment hierarchy	1	2	3
Amount of daily activity	+++	++	+

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)

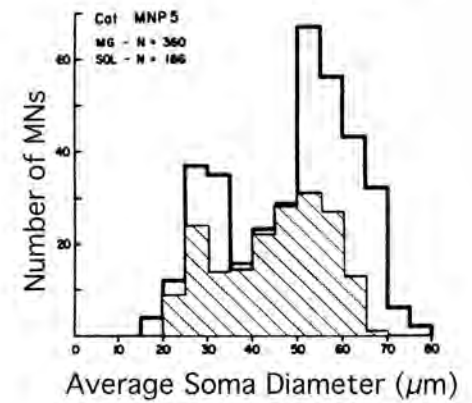
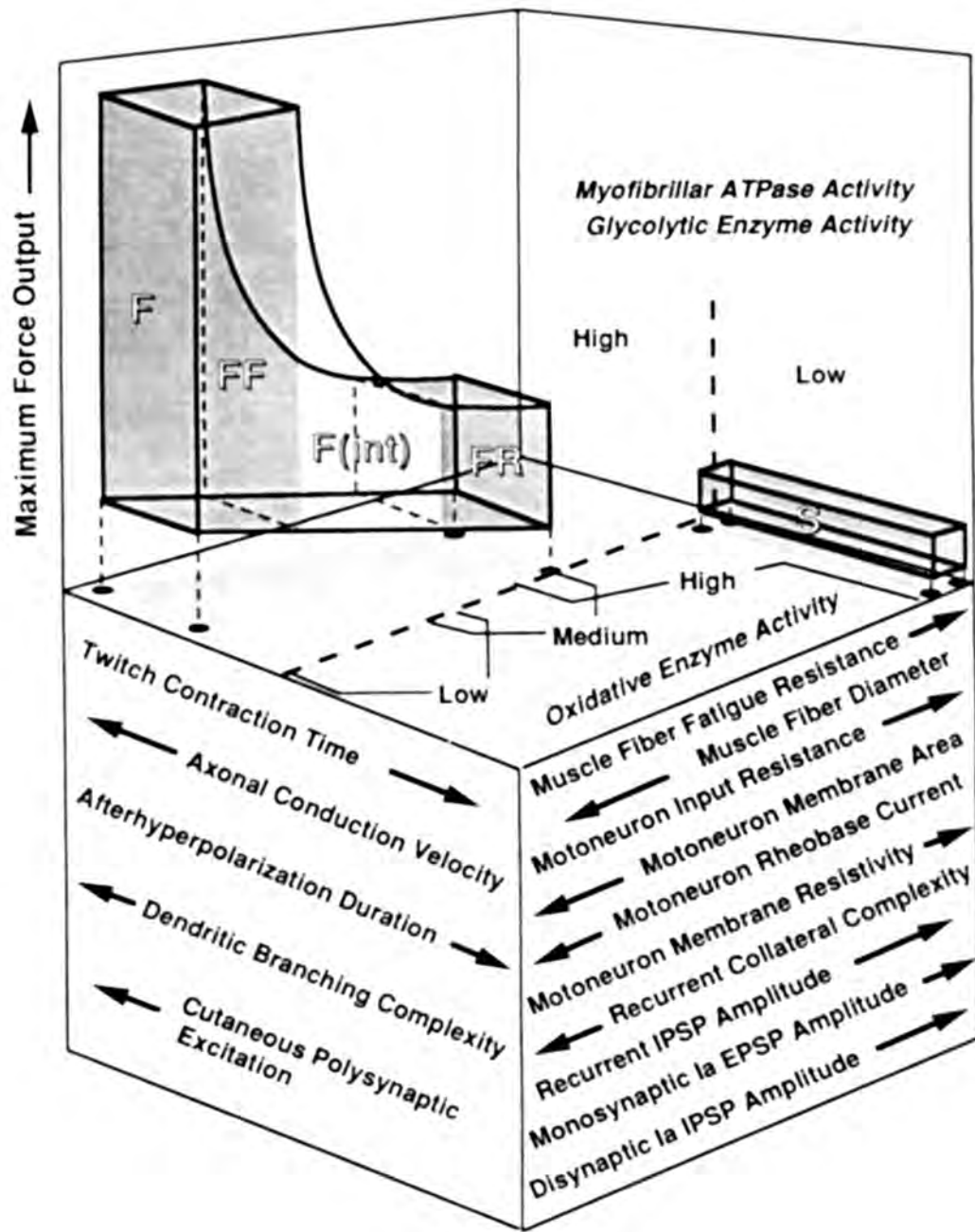
\* Properties used for physiological classification.

# Motor neuron properties correlate with motor unit properties

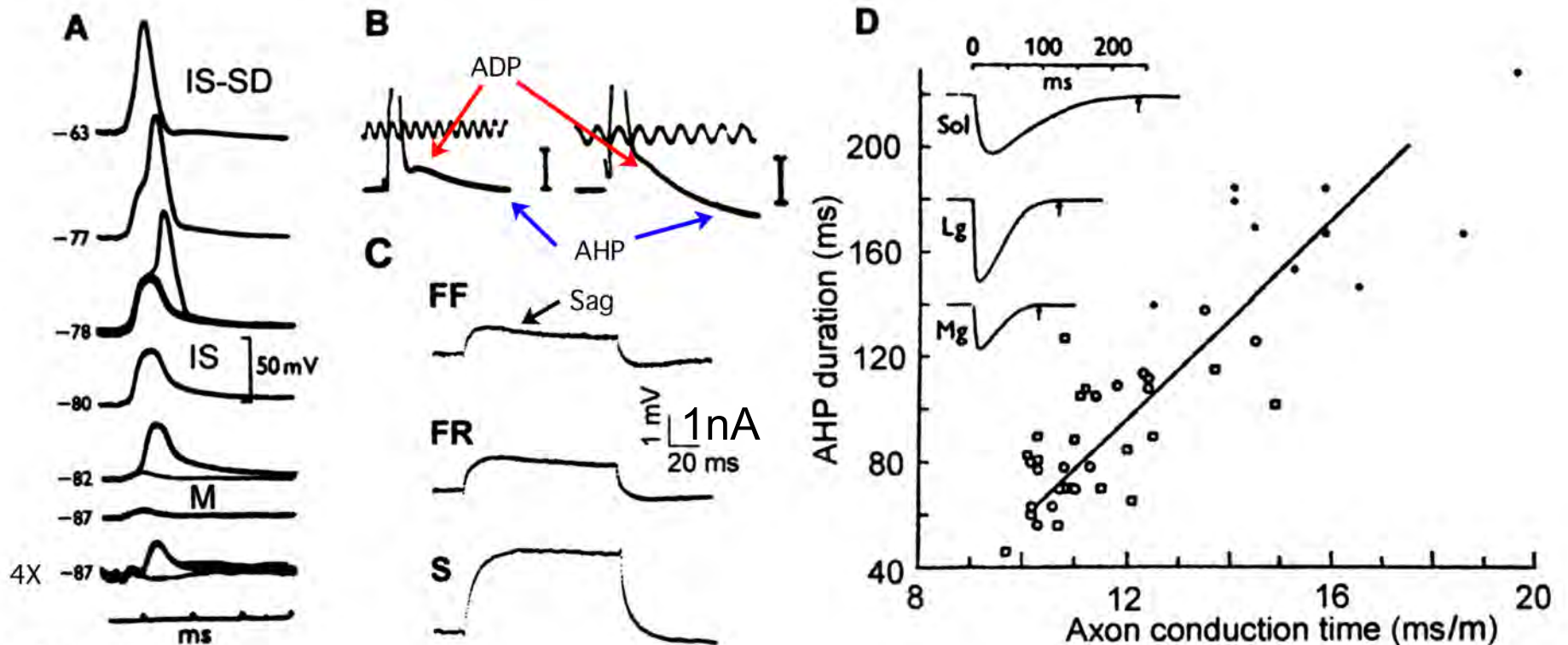
Slow M.U.s as compared to Fast M.U.s have  
smaller motor neuron axon  
smaller motor neuron (body plus dendrites)  
more oxidative enzymes, mitochondria  
distinct electrical properties

S → FR → FF



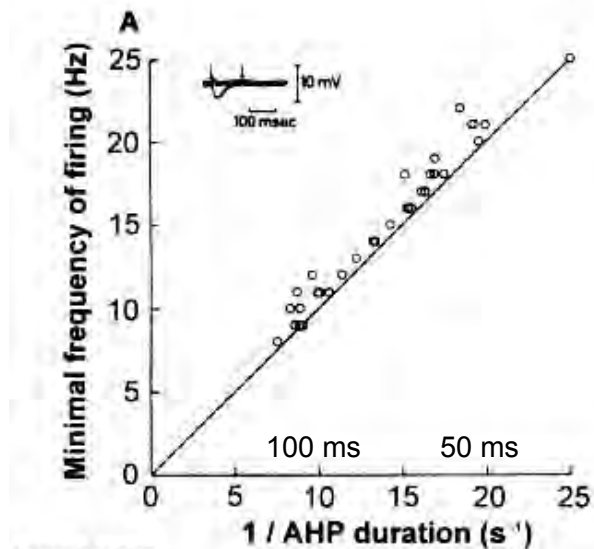
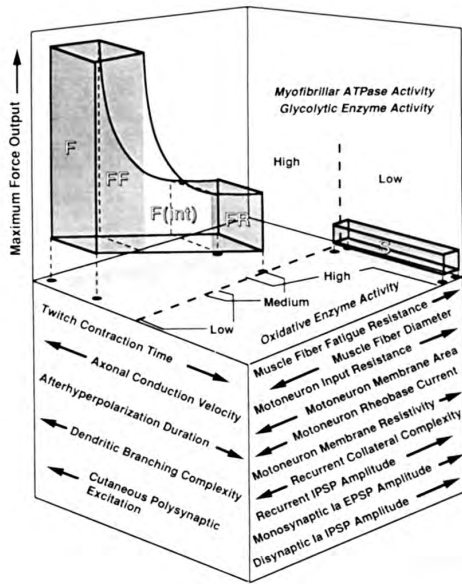


# Motor neuron electrophysiology

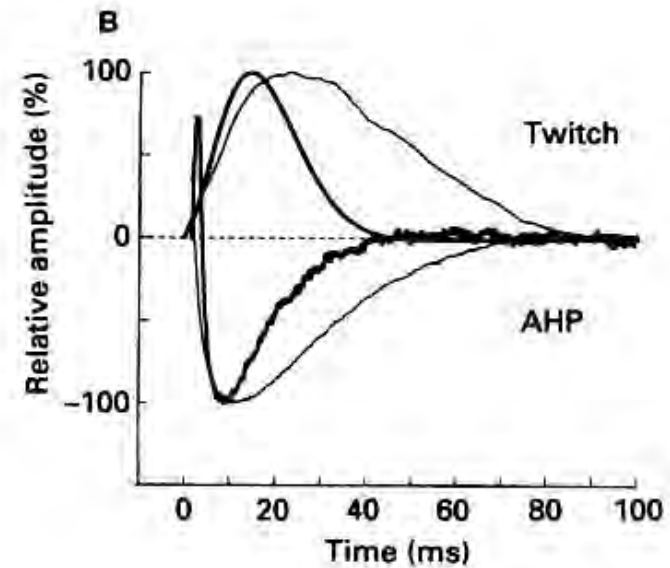


Eccles et al 1958

# AHP of MN sets minimum firing rate and is matched to twitch time of muscle fibers

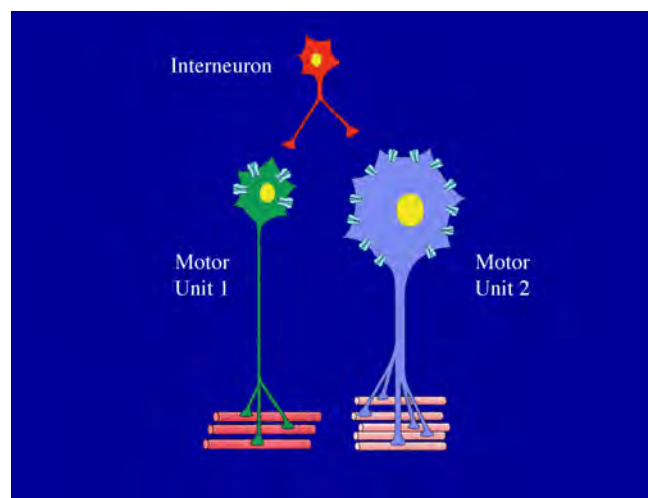


Krenell 2006

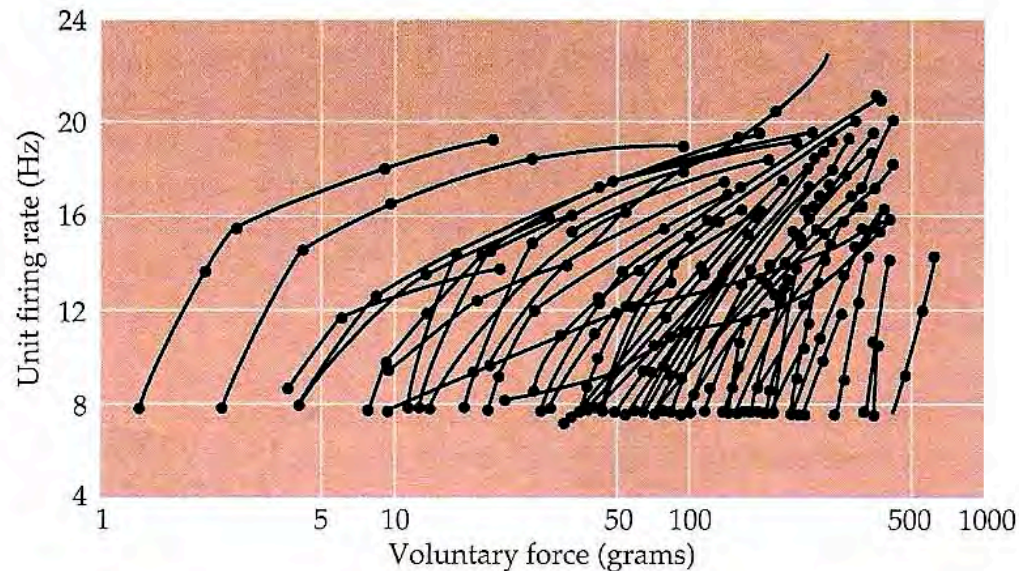


# Control of Force

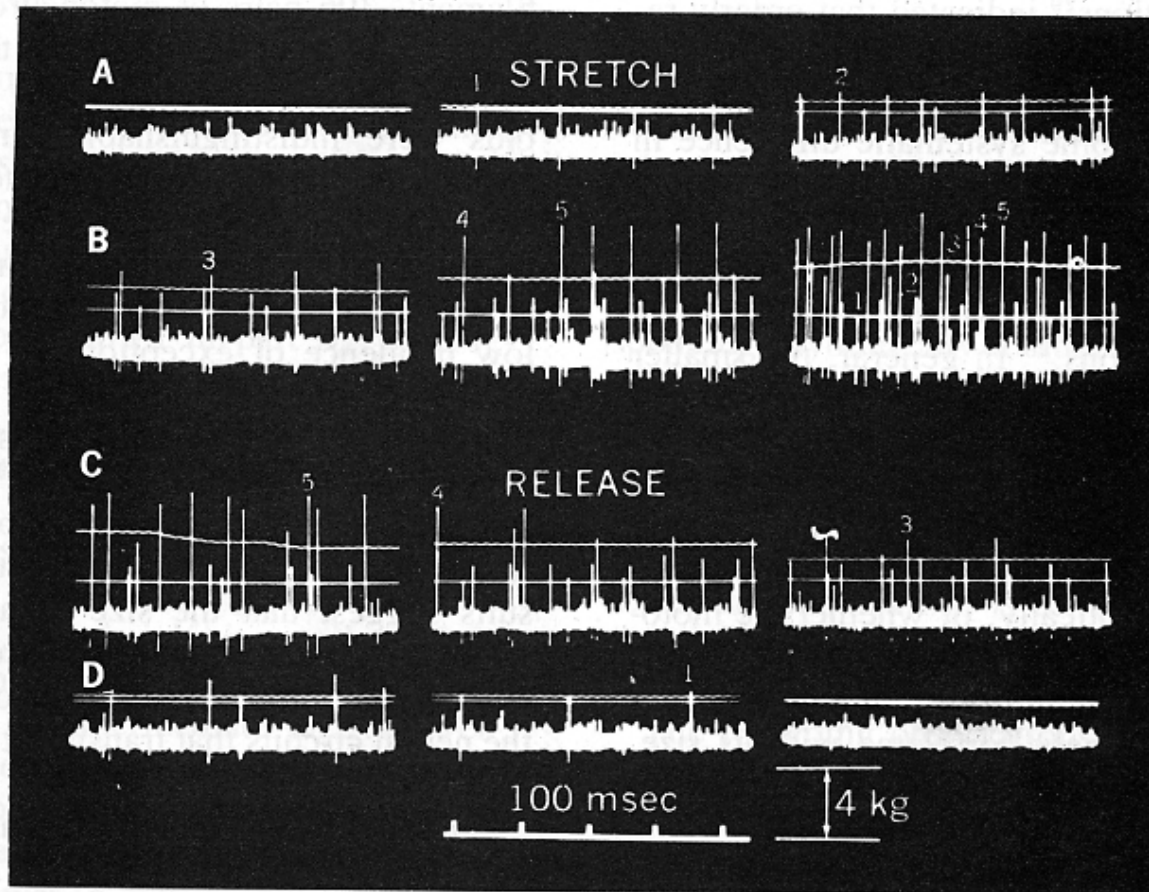
- Recruitment gradation (number of motor units activated)
- Rate gradation (firing rate changes of active units)
- Size principle



# Motor unit recruitment

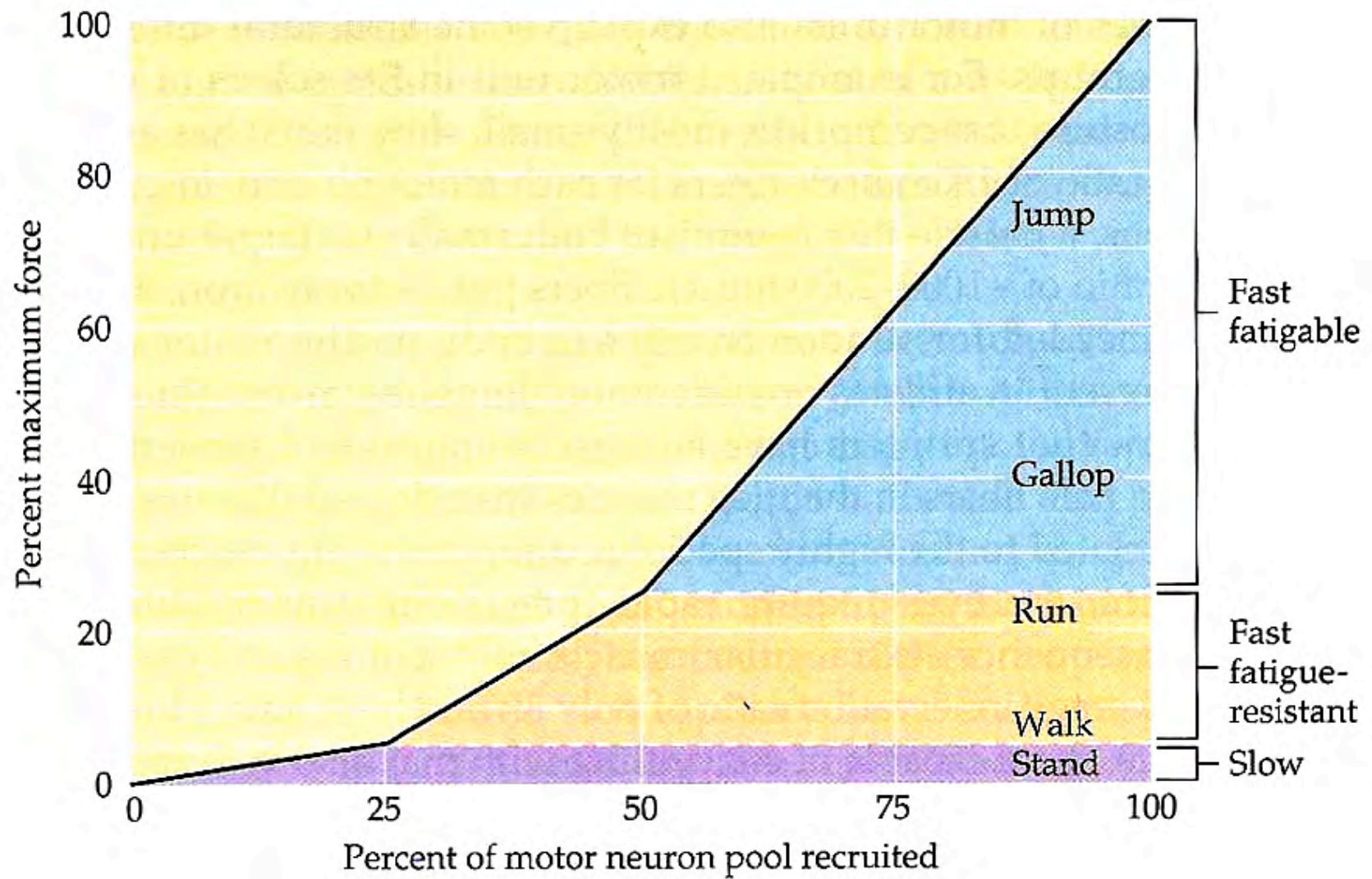


**Figure 15.8** Motor units recorded transcutaneously in a muscle of the human hand as the amount of voluntary force produced is progressively increased. Motor units (represented by the lines between the dots) are initially recruited at a low frequency of firing (8 Hz); the rate of firing for each unit increases as the subject generates more and more force. (After Monster and Chan, 1977.)



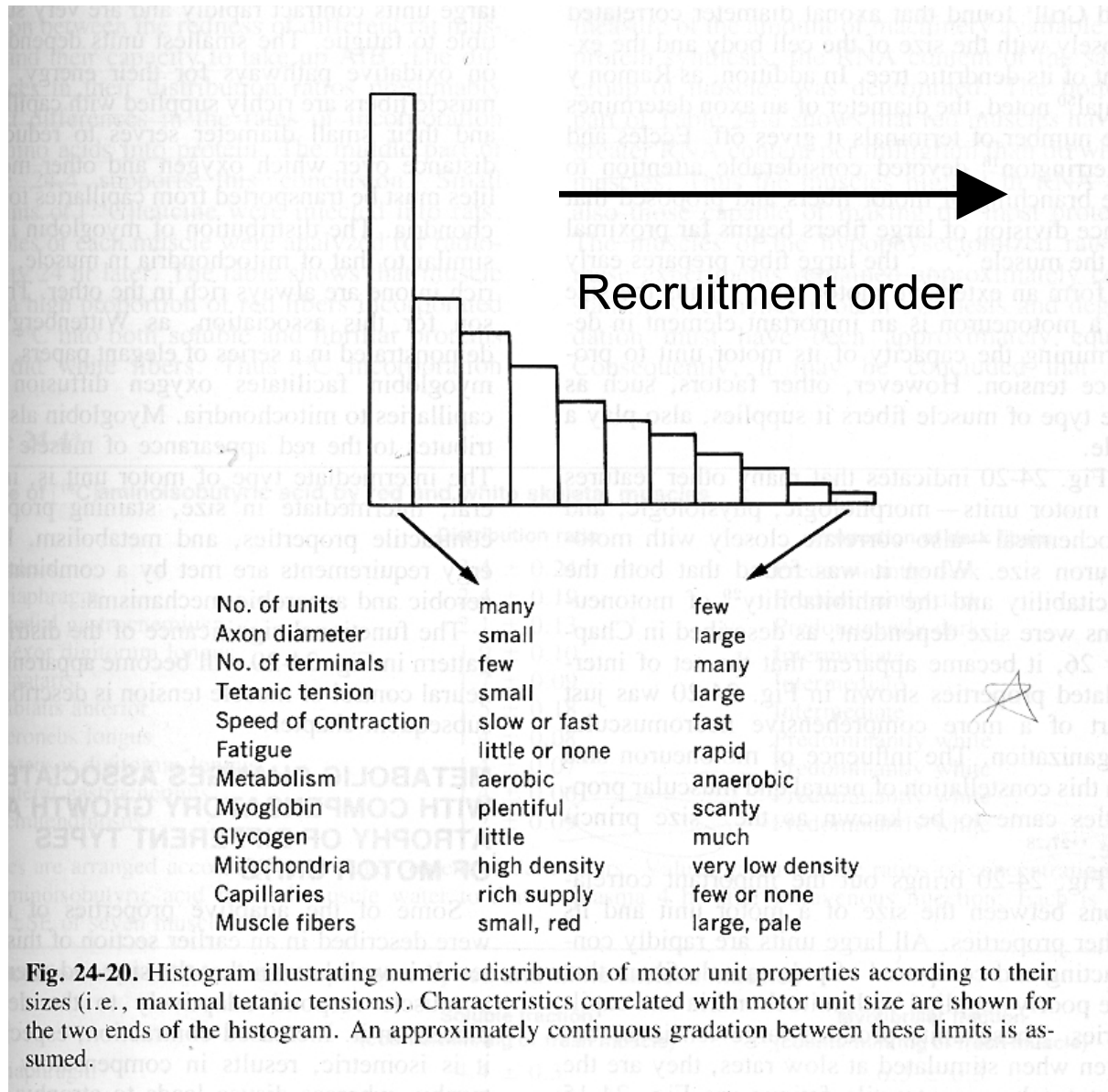
**Fig. 26-3.** Stretch-evoked responses of five alpha motoneurons recorded from filament of first sacral ventral root during stretch, **A** and **B**, and release, **C** and **D**, of triceps surae muscle. Small numerals above action potentials indicate rank of units according to size. (From Henneman et al.<sup>29</sup>)




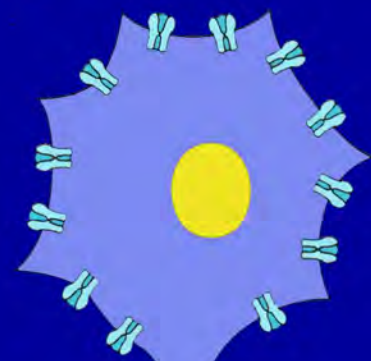




# Size Principle



Interneuron  
Stim. 

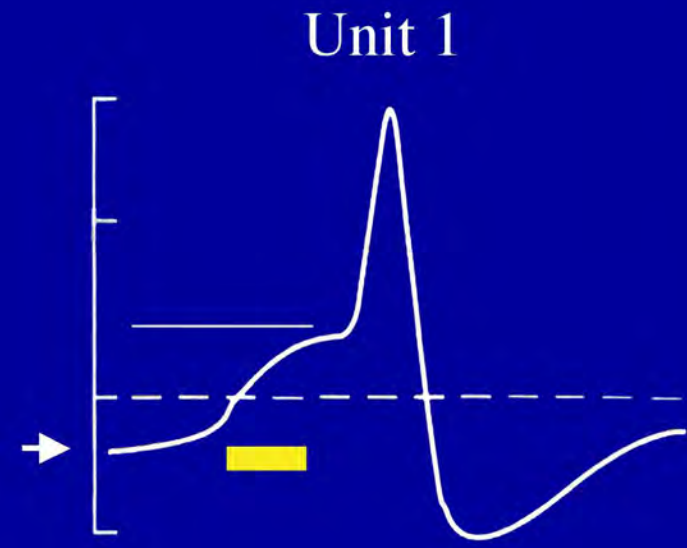


Motor  
Unit 1

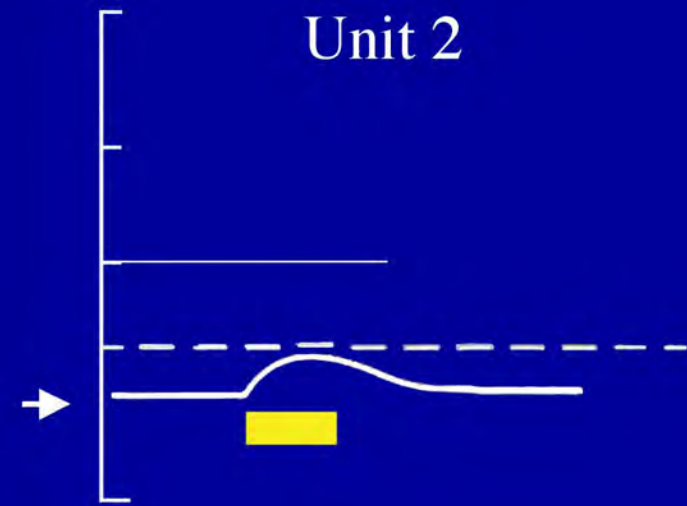
Motor  
Unit 2



RP →



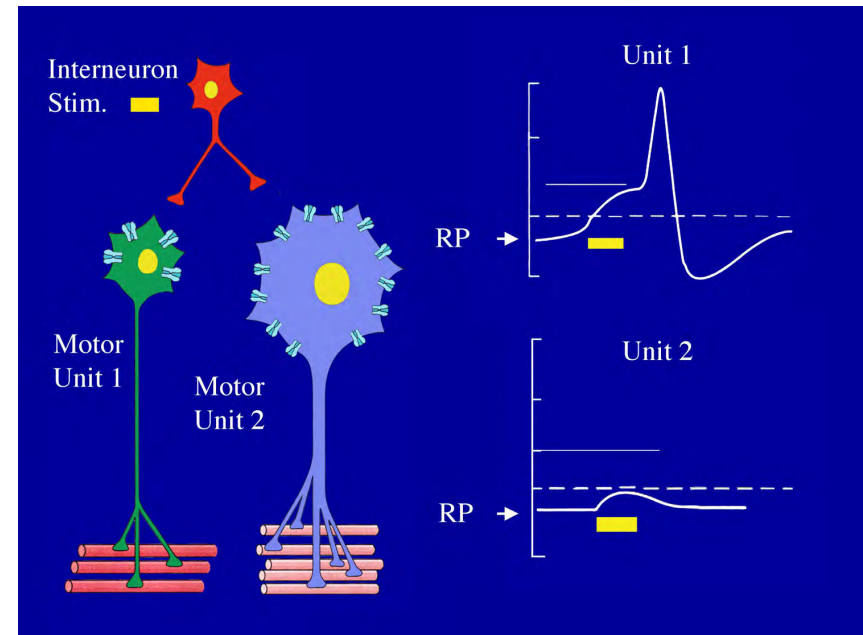
RP →



# 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?

