Muscle Receptors and Motor Control
Muscle and Joint Receptors

Alpha motor neurons to extrafusal striated muscle end plates

Gamma motor neurons to intrafusal striated muscle end plates

Ia (Aα) fibers from annulospiral endings (proprioception)

II (Aβ) fibers from flower spray endings (proprioception); from paciniform corpuscles (pressure) and pacinian corpuscles (pressure)

III (Aδ) fibers from free nerve endings and from some specialized endings (pain and some pressure)

IV (unmyelinated) fibers from free nerve endings (pain)

Ib (Aα) fibers from Golgi tendon organs (proprioception)

Aα fibers from Golgi-type endings

Aβ fibers from paciniform corpuscles and Ruffini terminals

Aδ and C fibers from free nerve endings
## Innervation of the Soleus Muscle of the Cat

### AFFERENT

<table>
<thead>
<tr>
<th>#</th>
<th>Fiber type</th>
<th>Target</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>Ia fibers</td>
<td>50 spindle primary endings</td>
</tr>
<tr>
<td>40</td>
<td>Ib fibers</td>
<td>45 Golgi tendon organs</td>
</tr>
<tr>
<td>50</td>
<td>II fibers</td>
<td>50 spindle secondary endings</td>
</tr>
<tr>
<td>[200-400]</td>
<td>IV fibers</td>
<td>pain, vasculature]</td>
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</tbody>
</table>

### EFFERENT

| 150  | alpha motor neurons | 25,000 extrafusal muscle fibers   |
| 100  | gamma motor neurons | 300 intrafusal fibers in 50 spindles |
The GTO is “in series” with the muscle. It can be activated by contraction of the muscle or by pulling on the tendon.
Effect of Contraction of a Single Motor Unit

The GTO (Ib) provides a signal related to muscle force.
Muscles used for fine control (e.g. muscles of hand and neck) have relatively more spindles (#/gram) than other muscles.

Soleus  Lat. Gastrocnemius
The spindle is situated ‘in parallel’ with the extrafusal fibers. Stretching the muscle stretches the spindle.
Muscle fibers, unlike neurons, have more than one nucleus – they are **multinucleated**.
Ia fibers
Primary
“annulospiral” endings

Type II fibers
Secondary ("flower spray") endings
Gamma motor neuron

Equatorial zone

Contractile pole

Annulospiral ending

Ia fiber
The Ia axon is sensitive to muscle **stretch** (length)
Muscle spindle afferents provide signals related to *muscle length* (static aspect) and *rate-of-change of length* (dynamic aspect).
Dynamic vs static transduction properties appear to depend on the physical characteristics of the intrafusal muscle fibers rather than the nerve terminals.
Intrafusal fibers do not generate action potentials. Their contraction is modulated by temporal summation of end-plate potentials.

Gamma motor neuron activity is said to “bias” the spindle, i.e. make it more sensitive or more active at a given length.

Intrafusal fibers do not generate action potentials. Their contraction is modulated by temporal summation of end-plate potentials.
Static and Dynamic Gamma Motor Neurons

- Afferent Axons
  - Ia
  - Ii

- Dynamic Bag-1 fiber
- Static Bag-2 fiber
- Nuclear Chain Fiber

- Dynamic gamma
- Static gamma

- Annulo-spiral ending
- Secondary ending
Note: To interpret the Ia input in terms of muscle length, the CNS must take account of the gamma activity or *gamma bias*. It must use some kind of *efference copy* for this.
Medial reticular formation

Static bias

Stimulation of site A

Lateral reticular formation

Dynamic bias

Stimulation of site B
Muscle length (stretched)
Ia output
Muscle length

Ia output
Coactivation of alphas and gammas allows the spindle to adjust its length to the changing length of the muscle.
Alpha and Gamma Lower Motor Neurons

Skeletal muscle fibers (extrafusal)

Neuromuscular junctions on extrafusal skeletal muscle fibers

Muscle spindle

Nuclear bag fiber

Nuclear chain fiber

Lamina afferent nerve fibers

Trail and plate endings on contractile elements (intrafusal fibers) of muscle spindles

Lamina afferent synapse on α-LMN

α-LMN

γ-LMN

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Myotatic Reflex and Reciprocal Innervation (Inhibition)

Note that the gamma motor neurons are not targets of the Ia input.
Myotatic Reflex and Automatic Load Management

A. Initial Equilibrium

B. New Load

C. New Equilibrium
The myotatic reflex as a regulator of muscle length

With respect to muscle length, the Ia feedback is negative because an increase in spindle output results in a decrease in muscle length.

The myotatic reflex contributes to the stiffness of the muscle, i.e. its resistance to lengthening.

Increasing the sensitivity of the spindle by gamma bias would increase the ‘stiffness’ of the reflex.
Spasticity: Hypertonia, Hyperreflexia
The Myotatic Reflexes are Hyperexcitable
Hyperreflexia of Leg and Arm

Spasticity can result from abnormally high gamma activity.

Because this has its effect via the Ia afferents, spasticity goes away if the dorsal roots are cut.