PHSL2101 - PHSL2121 – PHSL2501 **Dr Richard Vickery**

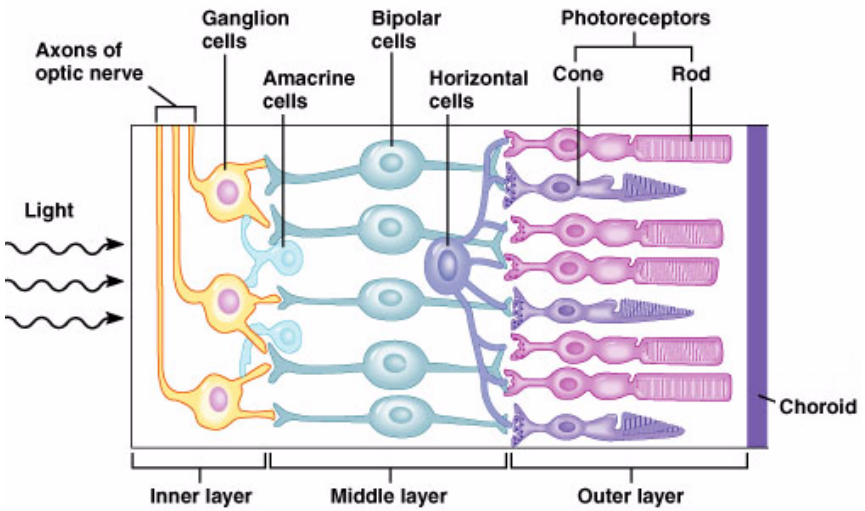
Neurophysiology 5 – Vision and motor units

Objectives

- Describe the transduction of light at the rods and cones.
- Explain the basis of colour vision, and of anomalous trichromacy (red/green colour blindness).
- Describe the organization of a motor unit, and the control of contractile force in skeletal muscle.
- Describe a muscle spindle and its response to muscle stretch and contraction.

Photoreceptors

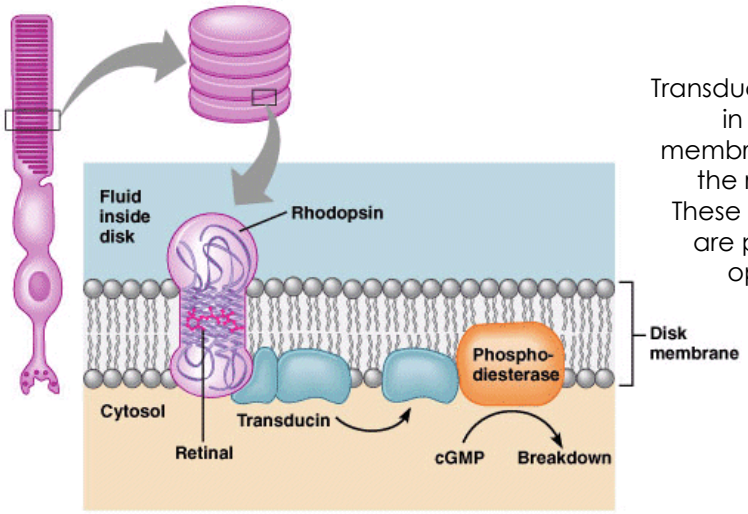
Retina uses several cell types to capture and process visual information



from Germann & Stanfield, Principles of Human Physiology

Photoreceptors

Transduction is a cascade beginning with opsin which then activates second messengers

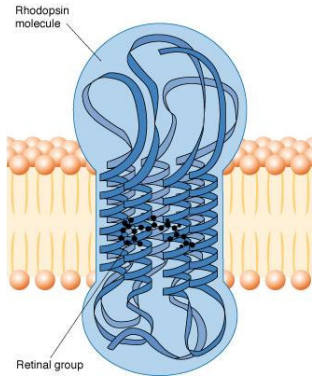


Transduction occurs in the stacked membrane discs of the rod or cone. These membranes are packed with opsin and the associated machinery.

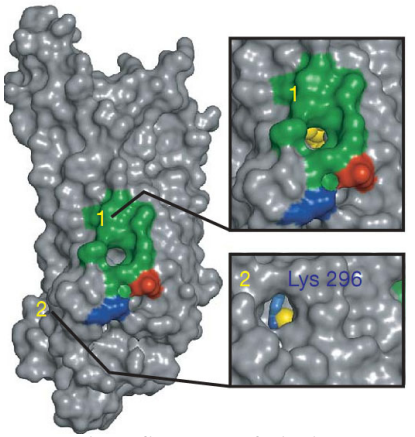
from Germann & Stanfield, Principles of Human Physiology

Photoreceptors

Opsins are membrane-spanning proteins that bind retinal



The rods and three types of cones have different opsin molecules. This alters the photon wavelength they can best capture.

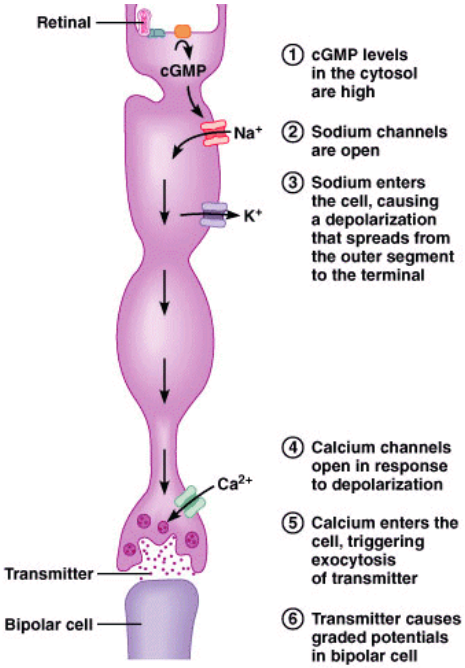


Retinal (in yellow) sits in a pocket inside the opsin molecule. Capturing a photon makes it change shape and exit the opsin molecule.

from Park et al. (2008), Nature 454: 183

Photoreceptors

In the dark, transmitter is released

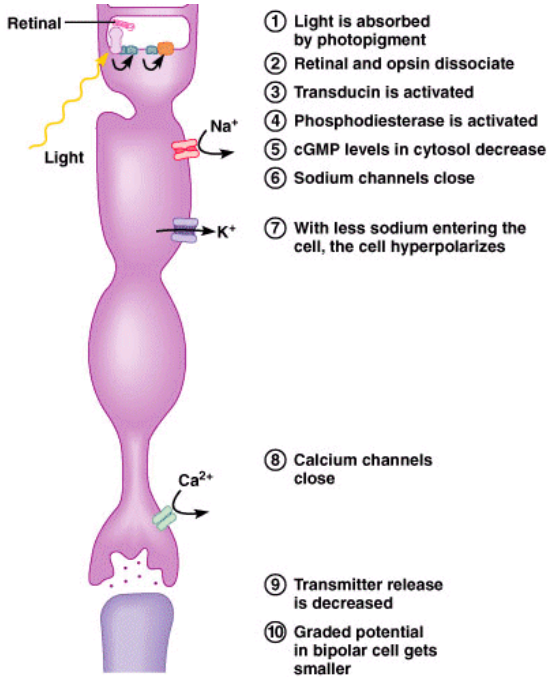


The sodium channel is gated by cGMP. It remains open in the dark because the concentration of cGMP is high.

from Germann & Stanfield, Principles of Human Physiology

Photoreceptors

Light reduces transmitter release

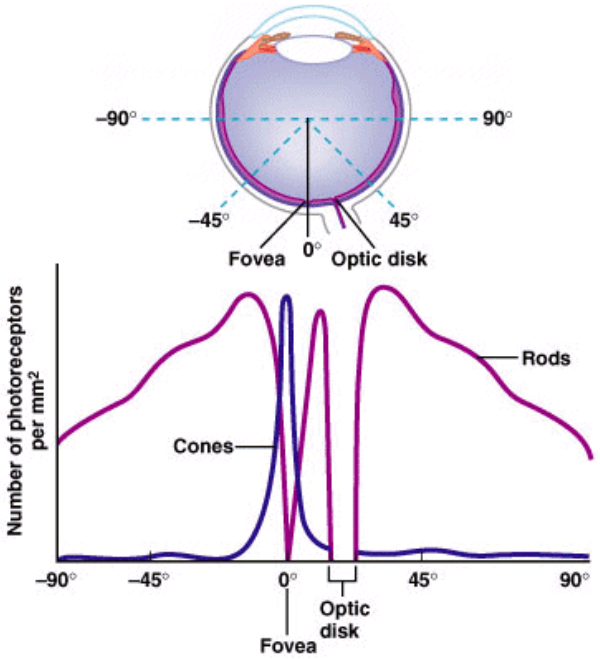


One photon activates one opsin which activates many transducins, each activating many phosphodiesterases, each using up many many molecules of cGMP and so affecting a large number of cGMP-gated channels in the photreceptor.

from Germann & Stanfield, Principles of Human Physiology

Photoreceptors

Distribution of photoreceptors



from Germann & Stanfield, Principles of Human Physiology

Photoreceptors

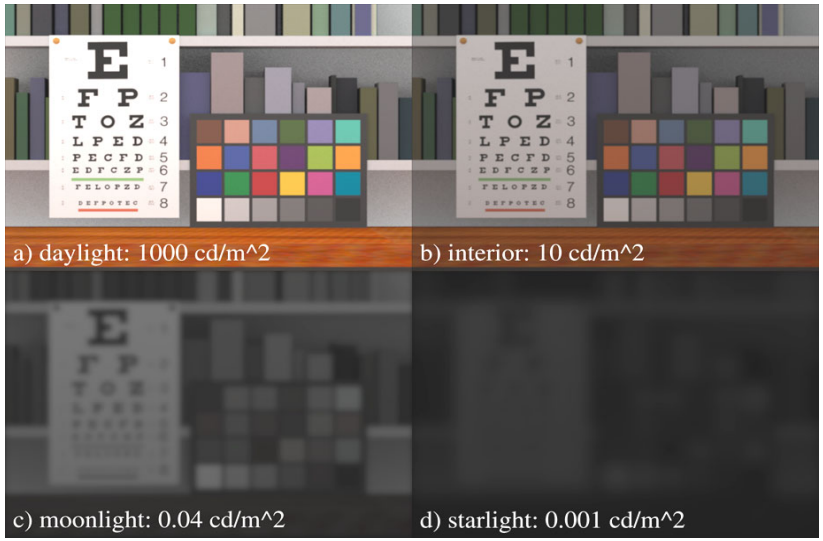
Eye movements help build a sharp image

Original image

How image would appear without eye movements, due to the varying receptor density on retina.
We use short-term memory to hold a stitched together hi-res colour image of the world around us.

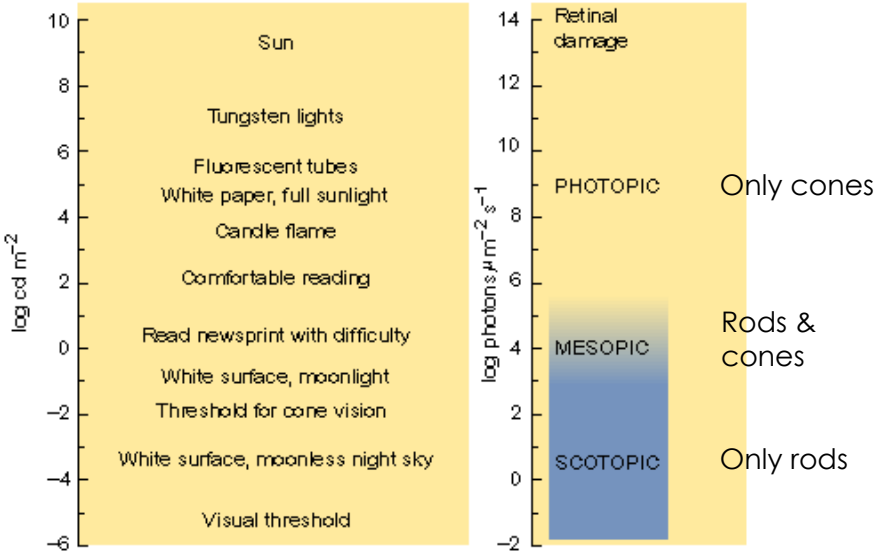
Photoreceptors

The different properties of rods and cones affects our vision at various levels of lighting



Photoreceptors

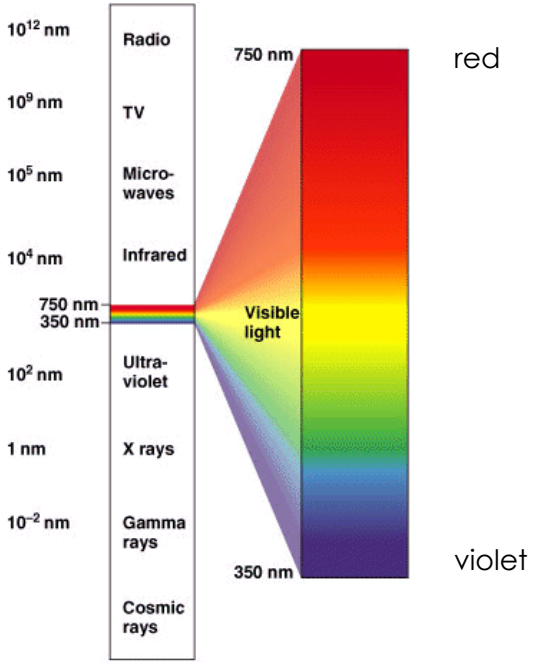
Rods and cones have different light sensitivity



from Pocock & Richards, Human Physiology

Colour vision

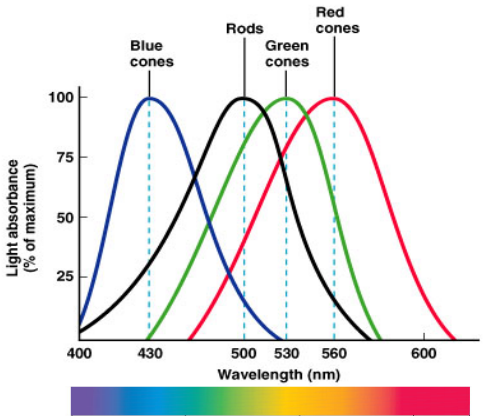
Spectral colours relate to wavelength



from Germann & Stanfield, Principles of Human Physiology

Colour vision

Each photoreceptor type preferentially absorbs particular wavelengths of light



Blue = S cone
Green = M cone
Red = L cone

S, M, L refers to Short, Medium and Long wavelength, because M and L cones both prefer shades of orange.

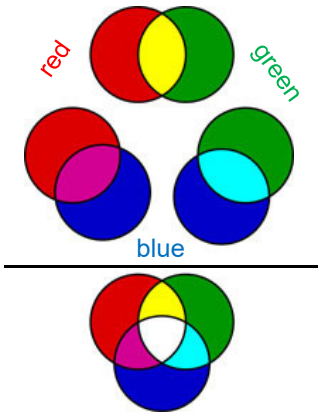
Each rod or cone can absorb photons of different wavelength, although each has a preferred wavelength. The bell-shaped absorbance curve makes colour ambiguous at night when we use only rods; but by day we use the ratio of activity in the three cones to determine colour.

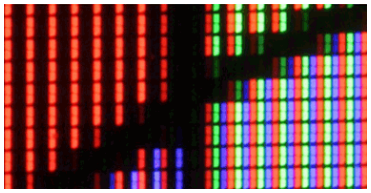
from Pocock & Richards, Human Physiology

Colour vision

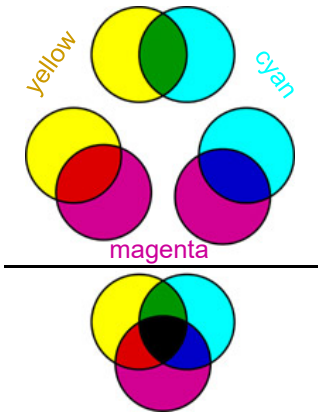
Producing colours

Additive colour, as on a TV





Subtractive colour, as on paper



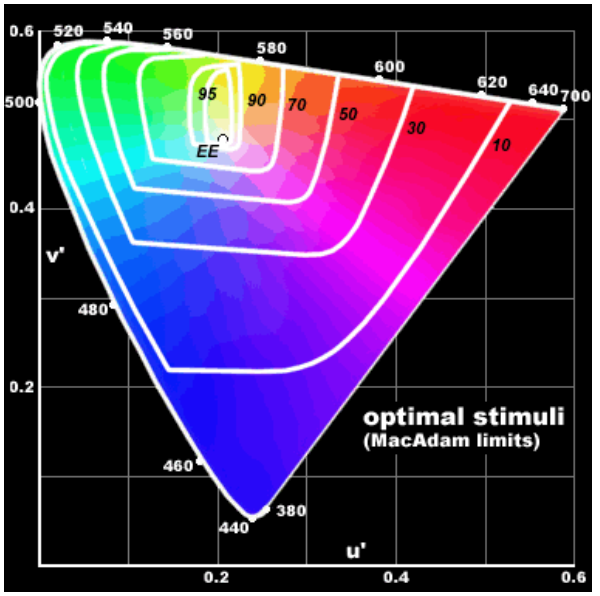
Subtractive colour processes combine to make black.

Additive colour processes combine to make white.

From www.joyousworld.com/qabalah/color/ and www.animations.physics.unsw.edu.au/jw/light/color-mixing.htm

Colour vision

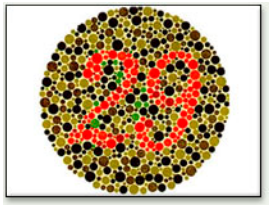
The right mix of three colours will replicate the perception any spectral colour



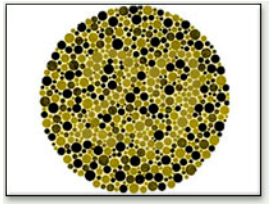
from Perales, Mora, Viqueira, de Fez, Gilabert & Martinez-Verdu (2005) in http://www.handprint.com/HP/WCL/wcolor.html

Colour vision

Simulated perception with different forms of colour blindness

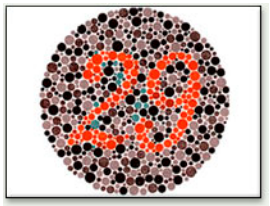


normal vision



protanopia (lacking red cones)

deuteranopia (lacking green cones)



tritanopia (lacking blue cones)

Colour vision

Anomalous trichromacy is the most common form of red-green colour blindness

- In anomalous trichromacy both red and green cones are present, but the peak absorbance of one of the opsins has been shifted closer to the other.
- The red and green opsins are evolutionarily recent (found in primates but not carnivores), closely related, and are both found on the X chromosome. Males are therefore more likely to have the condition (incidence ~6%) than females (incidence ~0.5%) because they only have one copy of each of these opsins.
- In anomalous trichromacy, reds and greens seem more similar than to normal viewers, as do purples and greys. Most colours, especially in context, are still distinguishable.
- Protanopia and Deuteranopia (absence of the cone type) account for another ~2% of colour blind males, and ~0.1% colour blind females.

Organization of motor units

MOTOR SYSTEM

"To move is all mankind can do and for such, the sole executant is muscle, whether in whispering a syllable or felling a forest."

(Sherrington, 1947)

Organization of motor units

Control of contraction

Motor Unit.

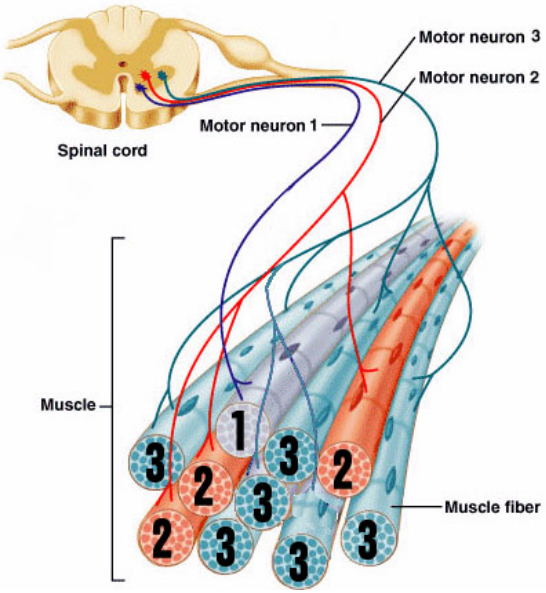
- Is a motor neuron and the entire group of muscle fibres innervated by the branches of its axon.
- Always one motor neuron, but multiple muscle fibres.
- Each muscle fibre belongs to only one motor unit.
- The smallest functional unit of the motor system.
- Vary in size from three muscle fibres, to over one thousand muscle fibres

Contractile force is regulated by:

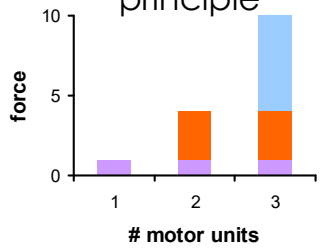
- frequency of action potentials in a motor unit (rate code)
- number of motor units activated (population code)

Organization of motor units

A motor neuron innervates multiple muscle fibres



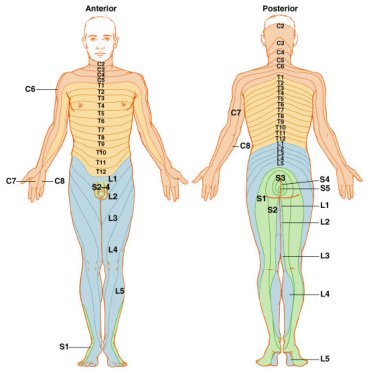
Small motor units are recruited first: the "size principle"



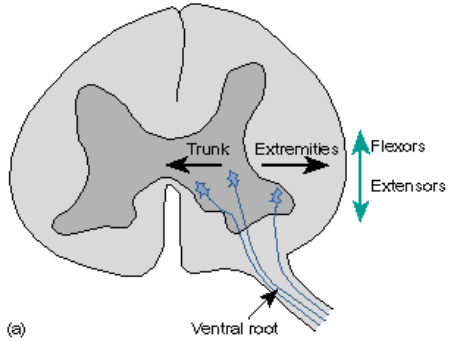
from Germann & Stanfield, Principles of Human Physiology

Organization of motor units

Topographic organization of motor neurons in ventral horn



Dermatomes are evidence of topographic organization along the spinal cord.
(from Neurophysiology lecture 1)

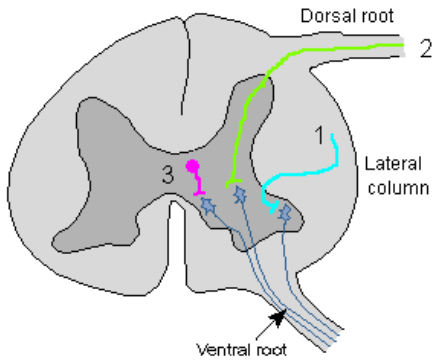


Within a level of spinal cord, there is a mapping of motor neurons based on distance from trunk, and on function.

from Pocock & Richards, Human Physiology

Organization of motor units

The 3 classes of input to lower (spinal) motor neurons



The only efferent connection to skeletal muscle is these lower motor neurons, which are therefore also called *the final common pathway*

1. upper (cortical) motor neurons
2. spindle afferents
3. spinal interneurons

modified from Pocock & Richards, Human Physiology

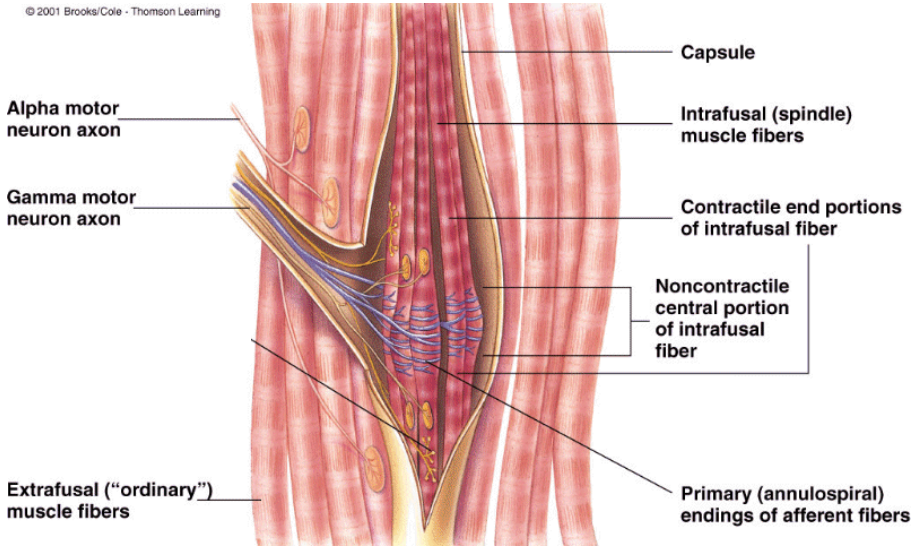
Organization of motor units

Organization of motor units

- Much as in the sensory system, the motor system uses topographic organization.
- The peripheral connection is not to a sheet of receptors, but to muscle fibres. Motor neurons innervating muscle fibres in the same muscle will be neighbours in the spinal cord. The neurons in higher centres such as motor cortex controlling the activity of these spinal motor neurons will also be neighbours.
- The benefit of the size principle of recruitment is that it allows the largest range of forces to be expressed by the muscle.
- Most motor neurons are controlled by indirect inputs from higher motor centres that arrive via spinal inter-neurons. There is some direct cortical control, particularly for our fingers. The muscle spindle has a direct connection to the motor neuron allowing fast reflex action.

Muscle spindle afferents

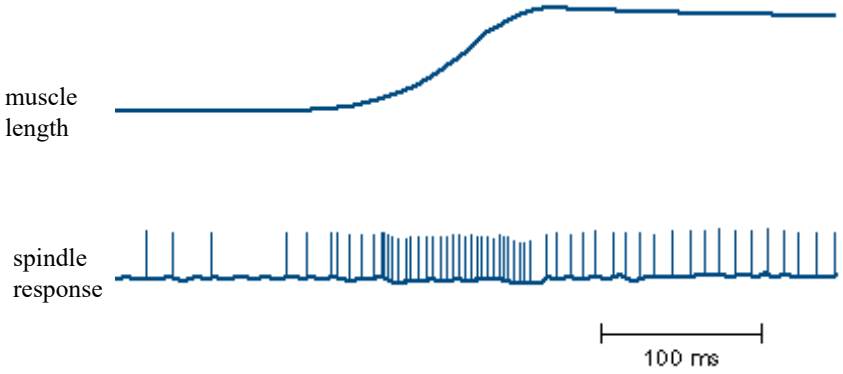
Muscle spindle afferents and gamma motor neurons



from Sherwood, Human Physiology

Muscle spindle afferents

Muscle spindle response to stretch

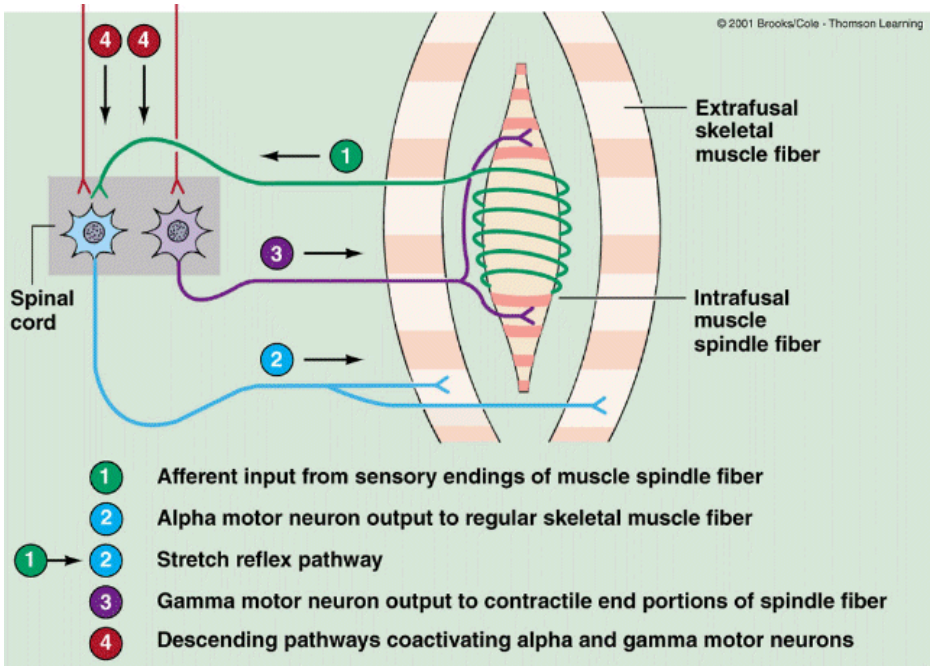


- **phasic component:** frequency of action potentials indicates the rate of stretch
- **tonic component:** frequency of action potentials indicates muscle length

from Pocock & Richards, Human Physiology

Muscle spindle afferents

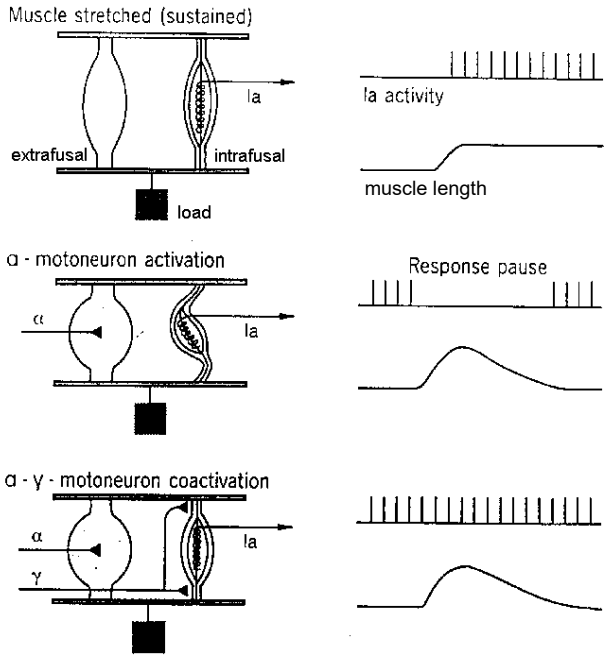
Alpha and gamma pathways



from Sherwood, Human Physiology

Muscle spindle afferents

Alpha - gamma co-activation



Muscle spindle afferents

Muscle spindle afferents

- These afferents are found in all muscles.
- One major role is to report the length of the muscle back to the body.
- They can also report the rate at which a muscle is lengthening.
- They make a direct synapse on the alpha motor neuron that makes the muscle they innervate contract. This allows rapid reflex reaction to changes in the activity of the spindle afferent.
- To ensure that the reflex control works efficiently at all muscle lengths, the gamma motor neurons can adjust the tension of the intrafusal muscle fibres so that the muscle spindles stay within their operating range regardless of whether the main muscle is contracted or extended.