TEMA 36. Organización funcional y transmisión de información en el sistema nervioso

1. Componentes celulares del sistema nervioso.
    - Neuronas.
        - Neuronas de proyección; interneuronas.
        - Diferencias en propiedades electrofisiológicas.
    - Células gliales.
        - Astrocitos; oligodendrocitos; microglía.

2. Organización anatómica del sistema nervioso.
    - Sistema nervioso central (SNC).
        - Compartimentos o divisiones del SNC.
    - Sistema nervioso periférico (SNP).
    - Sistema nervioso autónomo (SNA).
        - División simpática.
        - División parasimpática.

3. Organización funcional del sistema nervioso.
    - Diagrama básico de la relación estímulo sensorial-integración-respuesta.
    - Circuitos neurales.
    - Relaciones funcionales entre las divisiones del sistema nervioso.

4. Principios de organización de los sistemas funcionales del SN.

5. Neurotransmisión.
    - Transmisión sináptica.
        - Sinapsis eléctricas.
            - Uniones "gap". Paso de iones y moléculas pequeñas.
        - Sinapsis químicas.
            - Vesículas sinápticas.
            - Fusión a membrana dependiente de Ca^{2+}.
            - Exocitosis y reciclamiento de vesículas.

6. Neurotransmisores.
        - NT de pequeño tamaño molecular.
            - Acetilcolina.
            - Aminas biógenas.
                - Catecolaminas.
                    - Dopamina.
                    - Noradrenalina / Norepinefrina.
                    - Adrenalina / Epinefrina.
                - Serotonina.
                - Histamina.
            - Aminoácidos.
            - Purinas.
        - Neuropéptidos.
            - Péptidos gastrointestinales.
            - Péptidos opiáceos.
                - Endorfinas.
                - Encefalinas.
                - Dinorfinas.
            - Péptidos hipofisarios.
            - Péptidos hipotalámicos.
            - Otros neuropéptidos.
        - NT no convencionales.

7. Co-transmisión de NT. Liberación diferencial de NT.

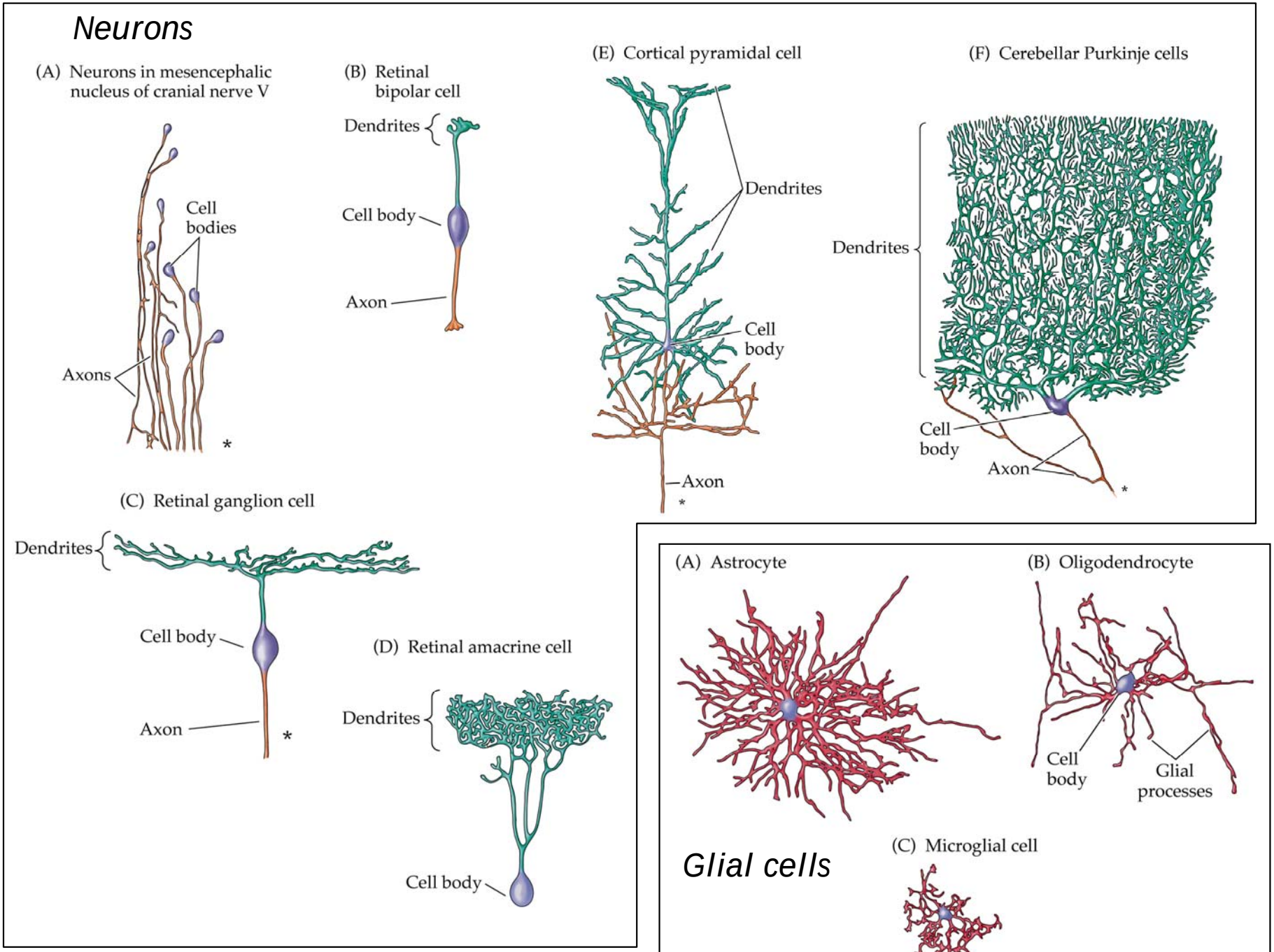
8. Síntesis, empaquetamiento, liberación y eliminación de NT.
   - Acetilcolina.
   - Glutamato.
   - GABA y glicina.
   - Aminas biógenas.

9. Receptores de NT.
   - Ionotropos.
   - Metabotropos.

10. Distribución de neuronas y proyecciones liberadoras de NT específicos en el cerebro.

Cellular components of the mammalian nervous system

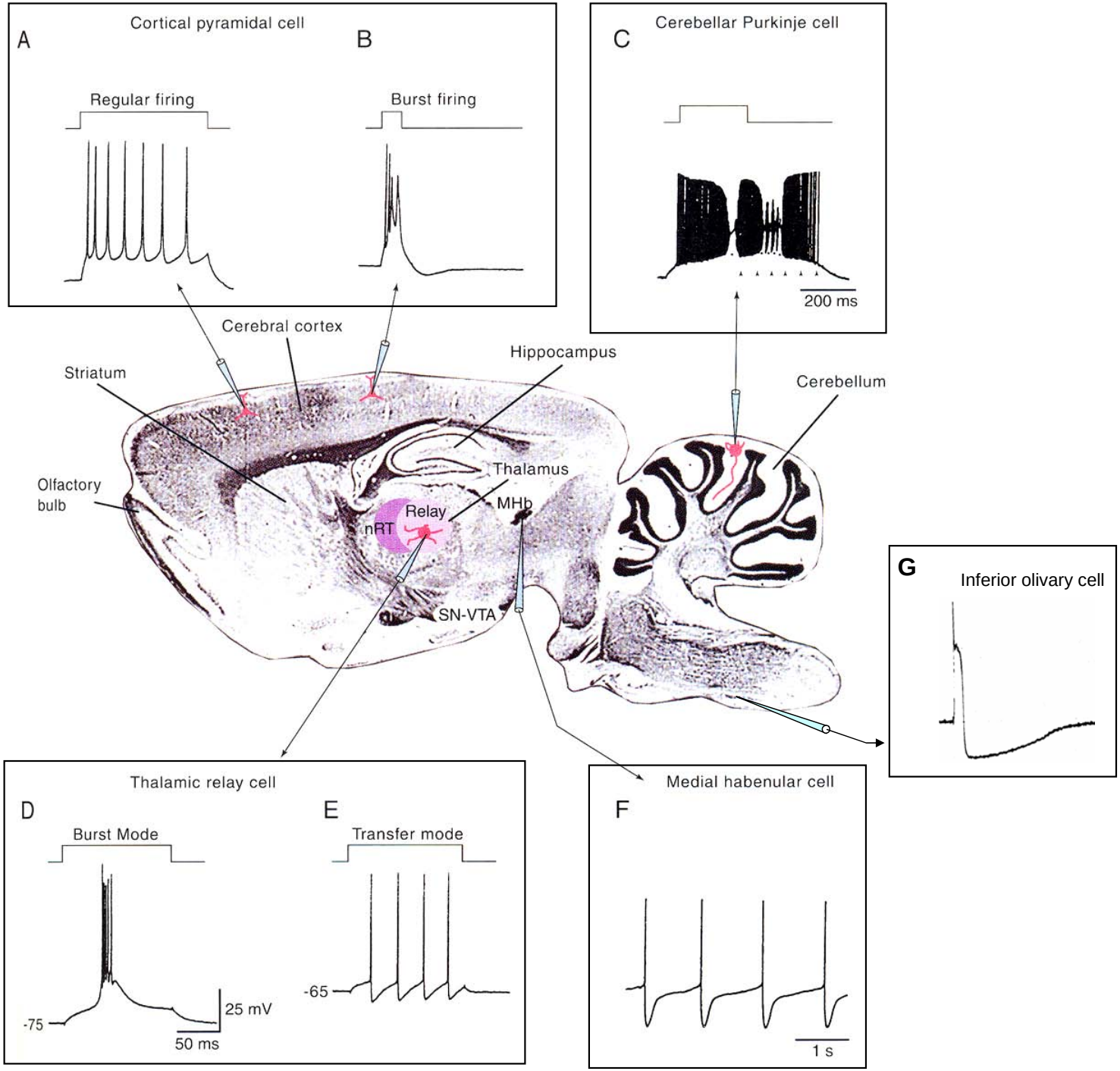
Neurons



Glial cells

Figures: Purves 2004

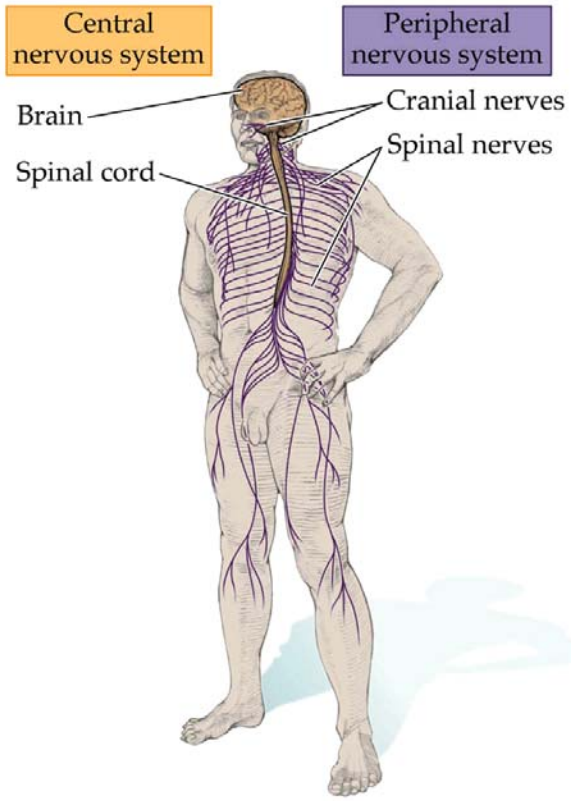
Neurons show different excitability properties



Figures: Zigmond 1999

Functional organization of the nervous system

Anatomical organization

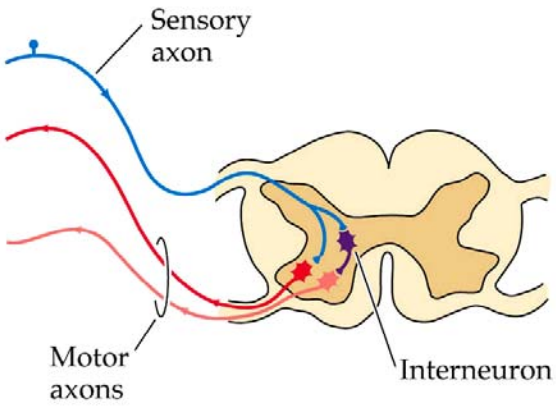


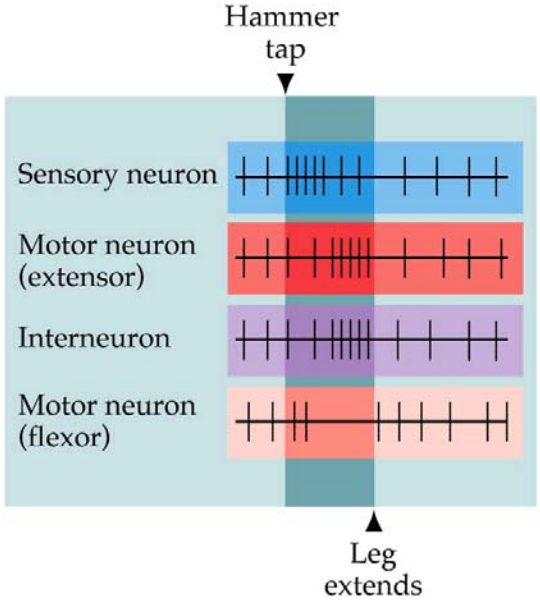
Central Nervous System (CNS)
- Brain
- Spinal Cord

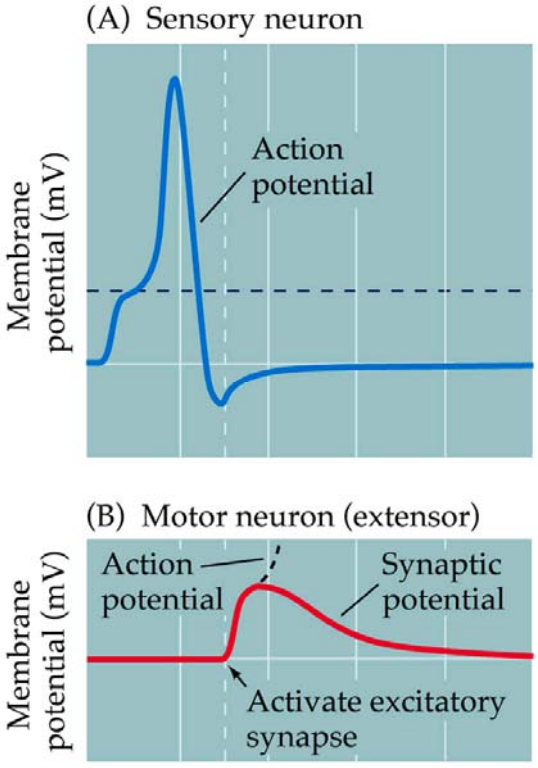
Peripheral Nervous System (PNS)

Autonomic Nervous System (ANS)
- Sympathetic division
- Parasympathetic division

Neural circuits

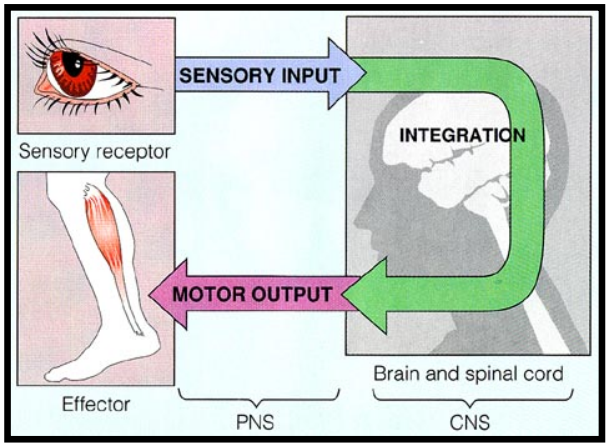






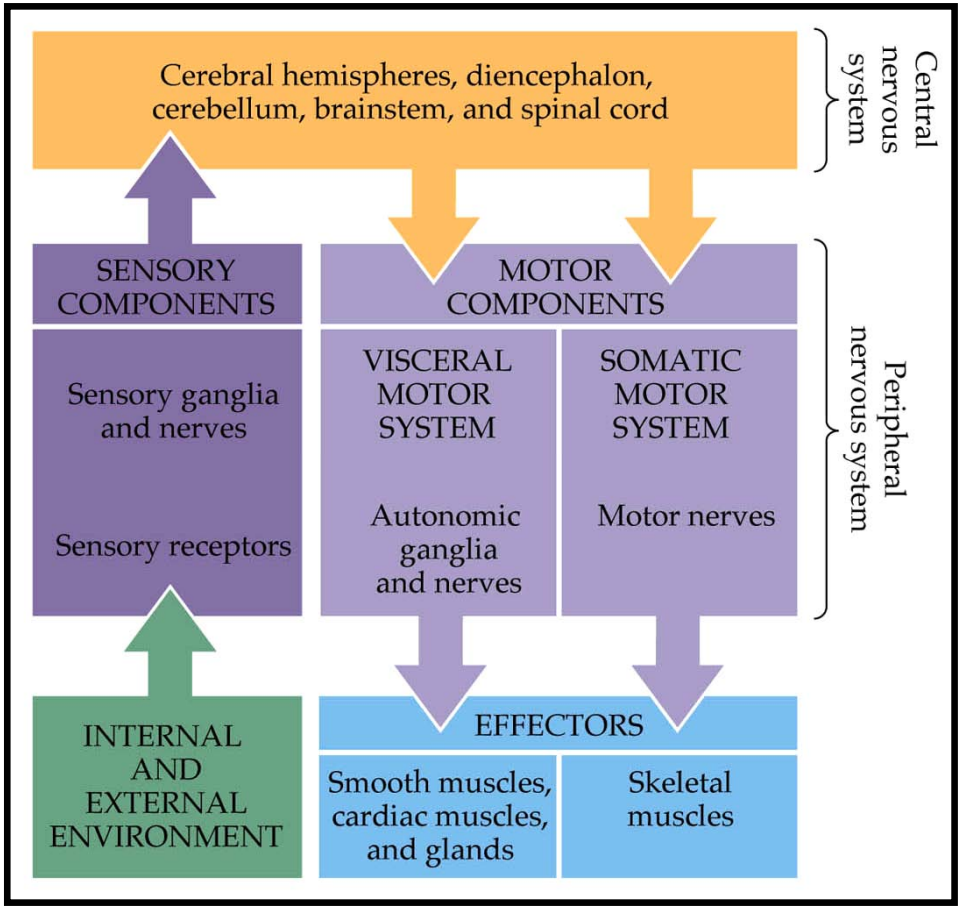
Figures: Purves 2004

Functional organization of the nervous system



Five principles govern the organization of the major functional systems

Functional relationships among the major components of the nervous system



1 Each functional system involves several brain regions that perform different information processing.

2 Axon pathways link the components of a functional system.

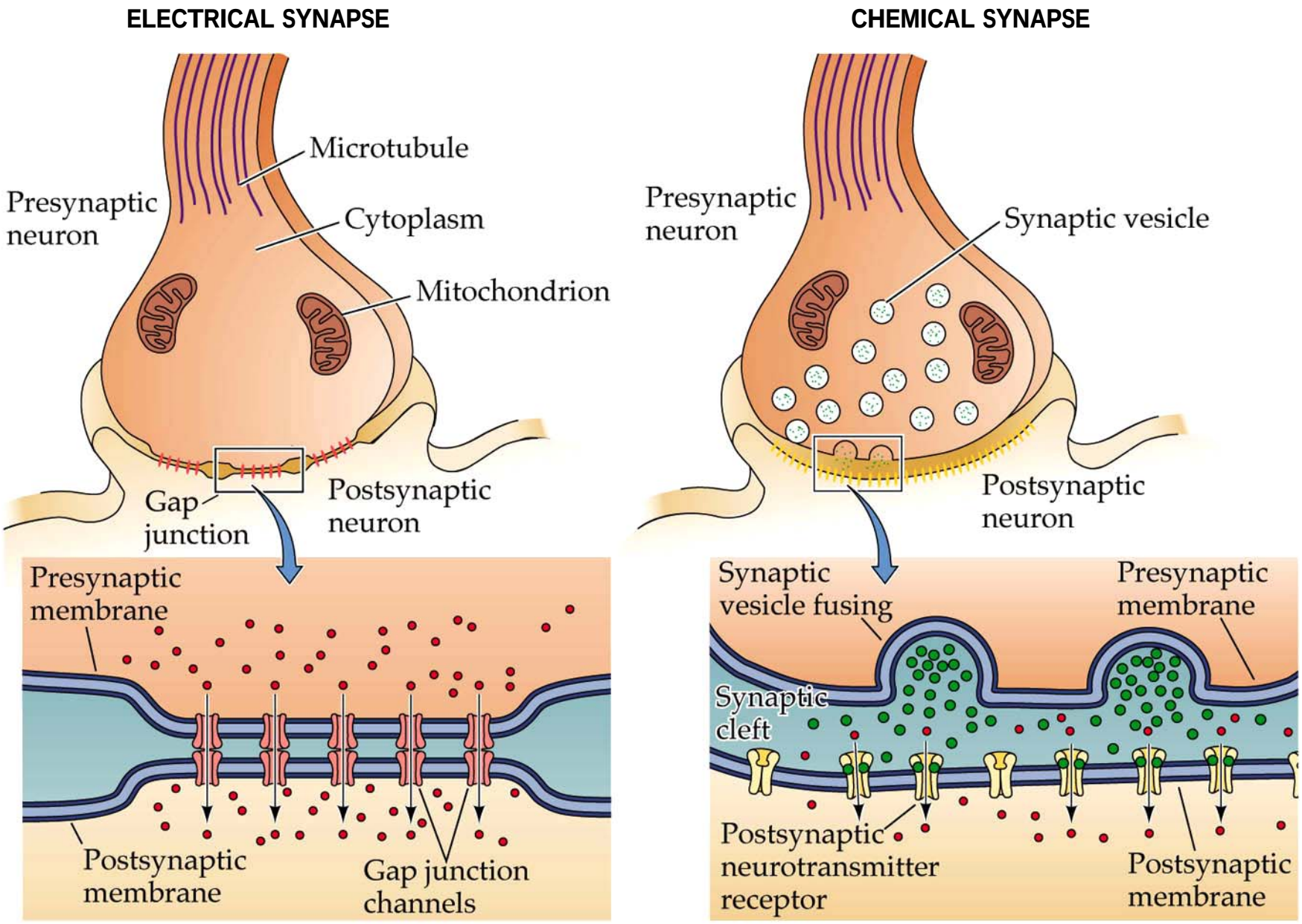
3 Axonal projections occur in an orderly fashion, and create topographical maps.

4 Functional systems are organized in a hierarchical way.

5 Functional systems on one side of the nervous system control the contralateral side of the body.

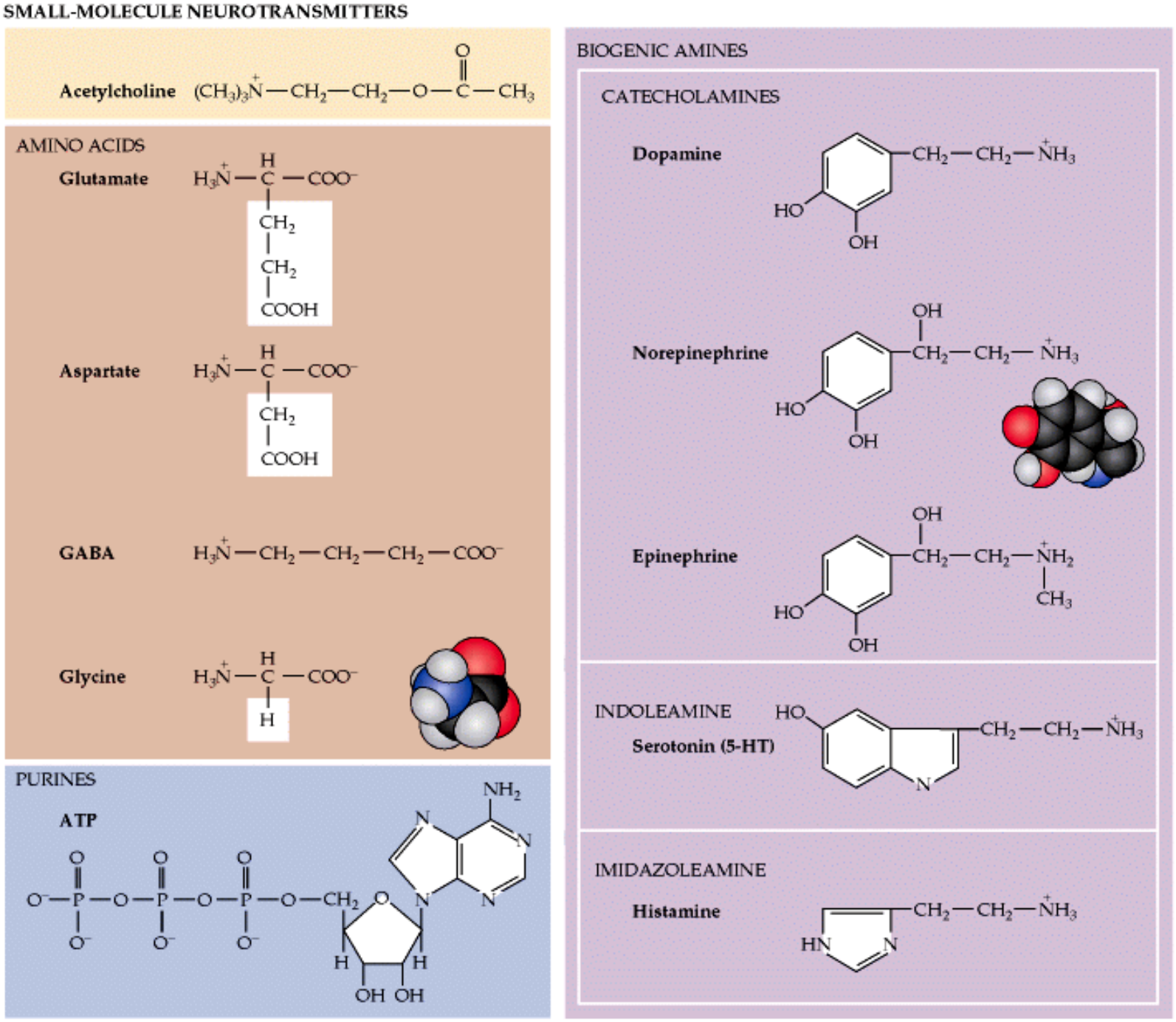
Figures: Purves 2004

Synaptic transmission



Figures: Purves 2004

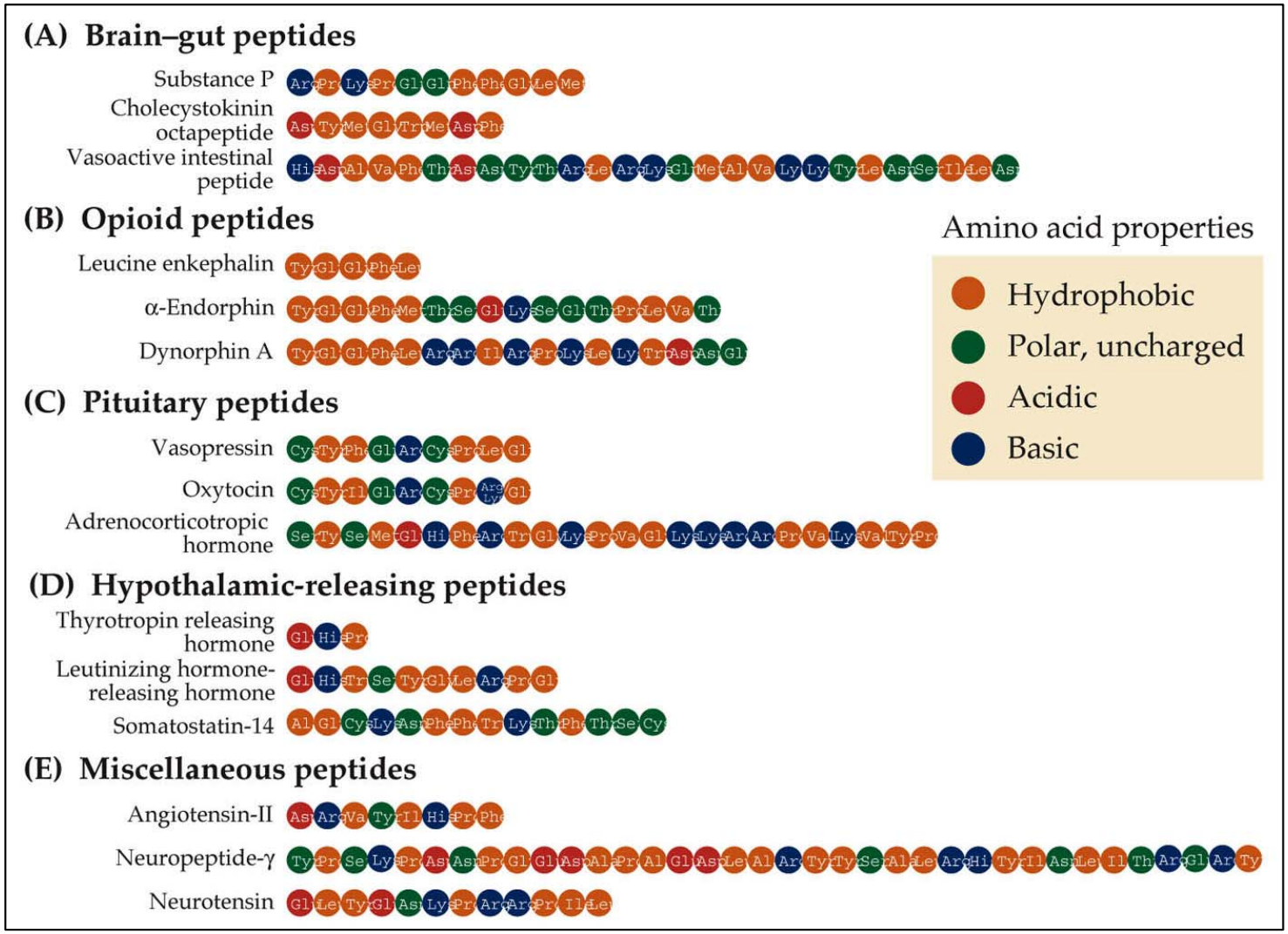
Neurotransmitter (NT) categories



Figures: Purves 2004

Neurotransmitter (NT) categories

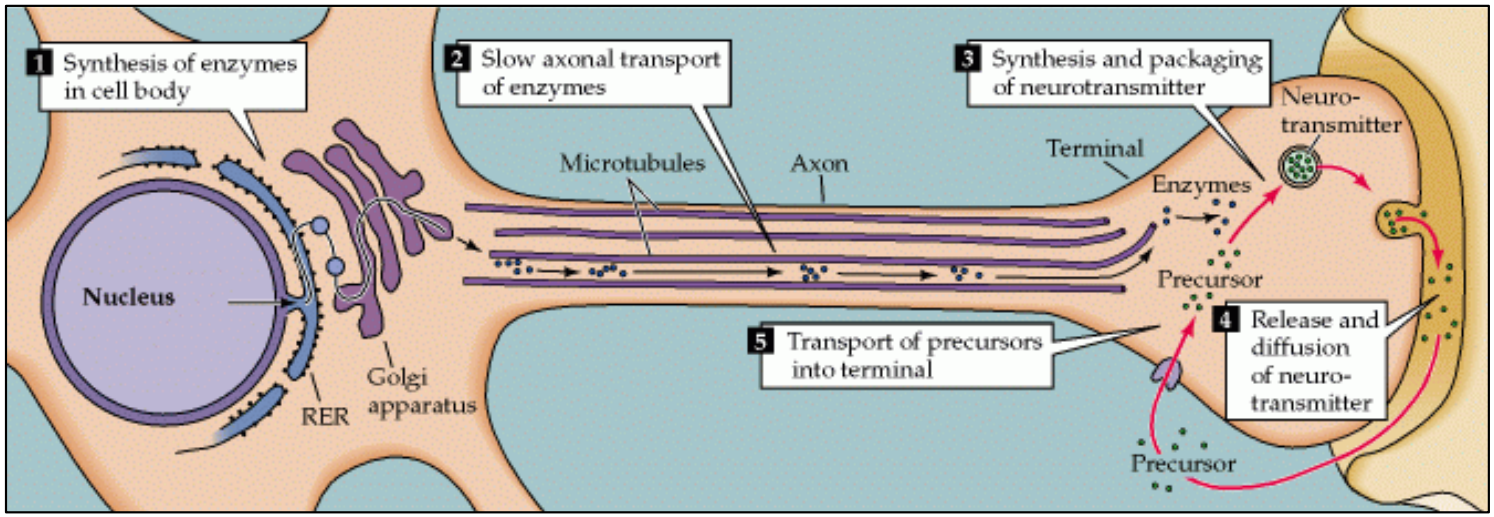
Neuropeptides vary in length, but usually contain between 3 and 36 amino acids



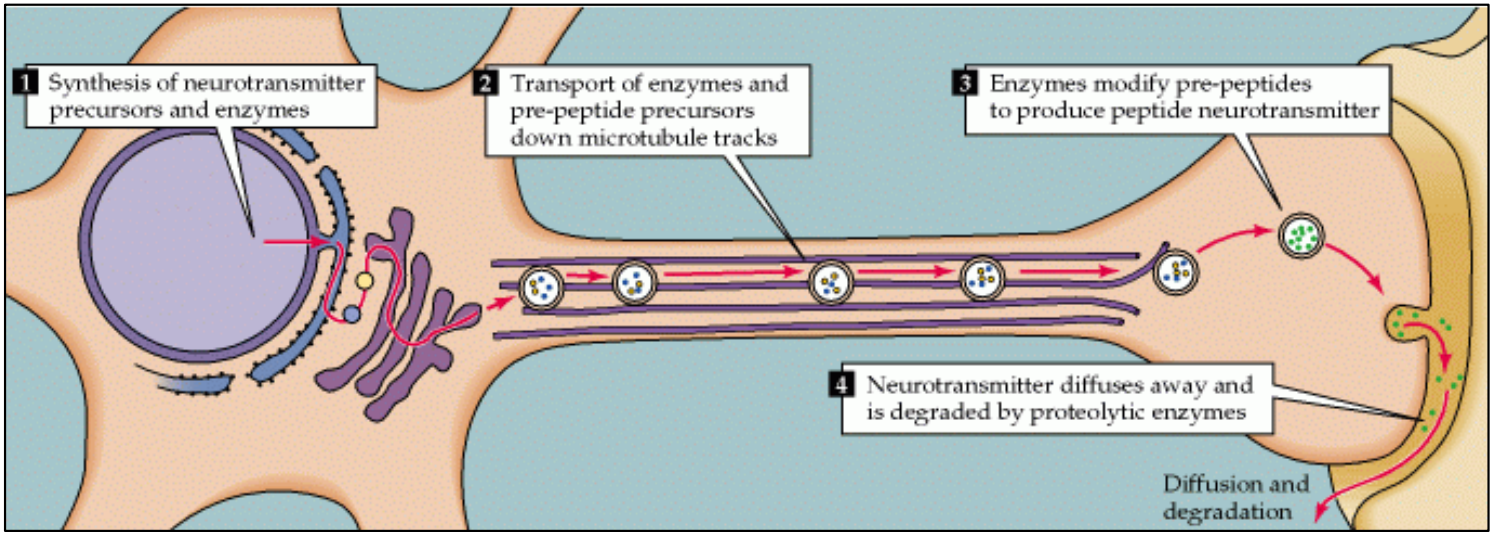
Figures: Purves 2004

Synthesis, packaging, secretion and removal of NT

Small-molecule NT



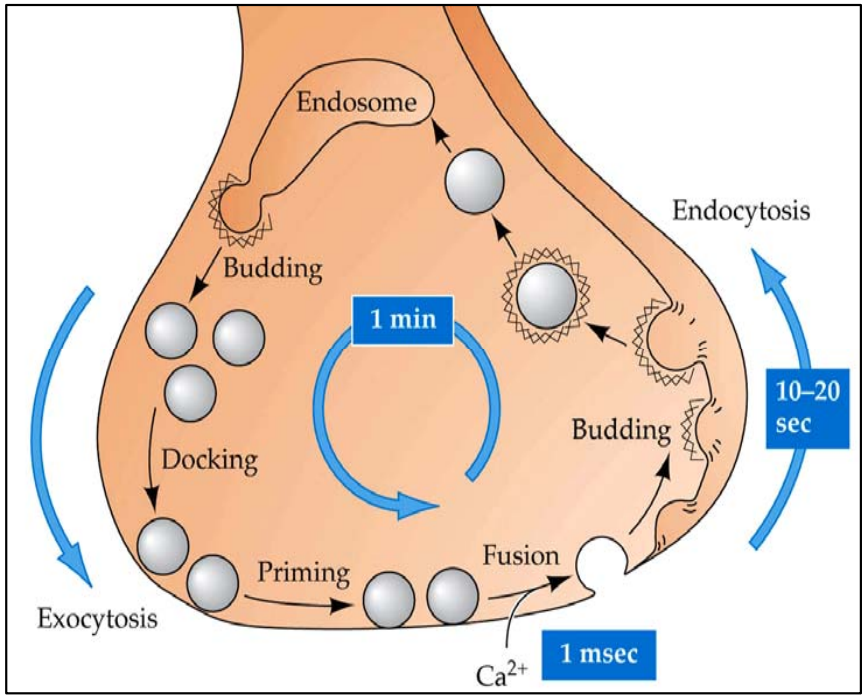
Peptide NT



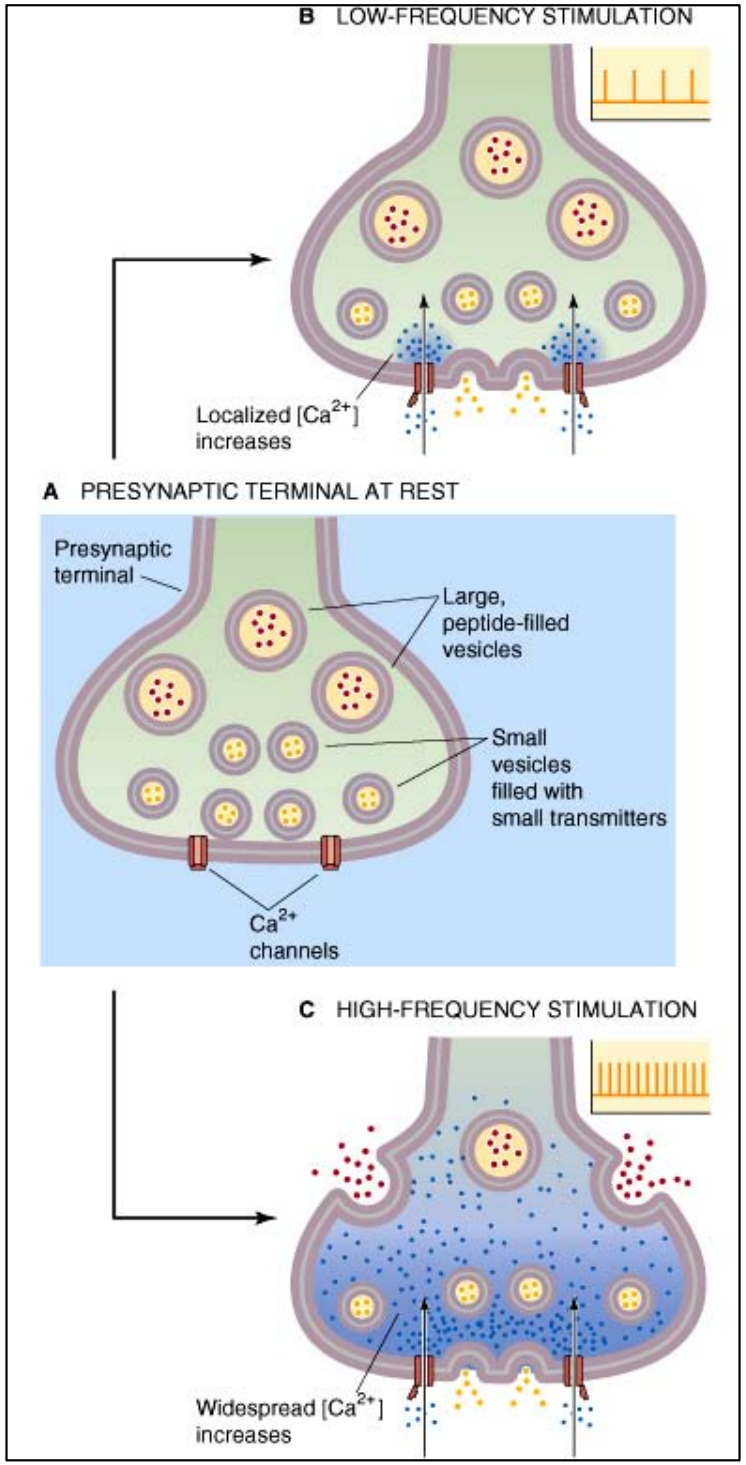
Figures: Purves 2004

Neurotransmission

Local recycling of synaptic vesicles in presynaptic terminals



Several NT can be co-released by a given neuron

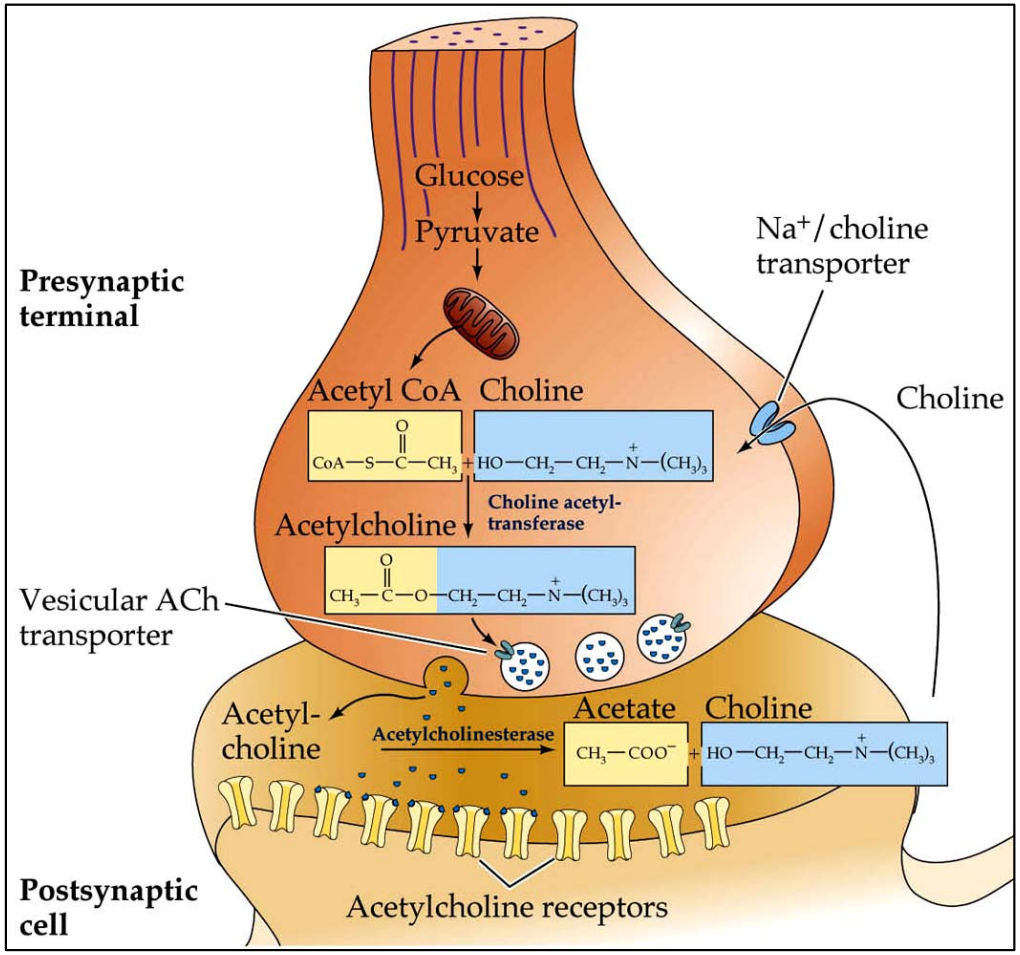


Figures: Purves 2004; Boron & Boulpapep 2005

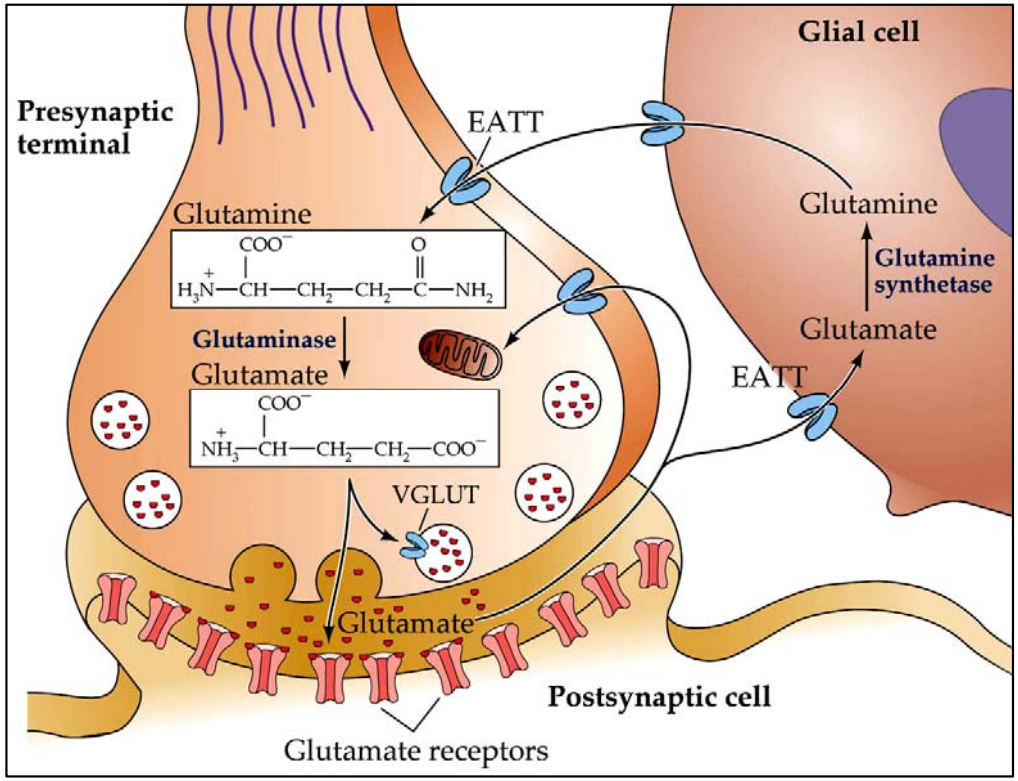
Neurotransmission

Synthesis and removal of NT

Acetylcholine



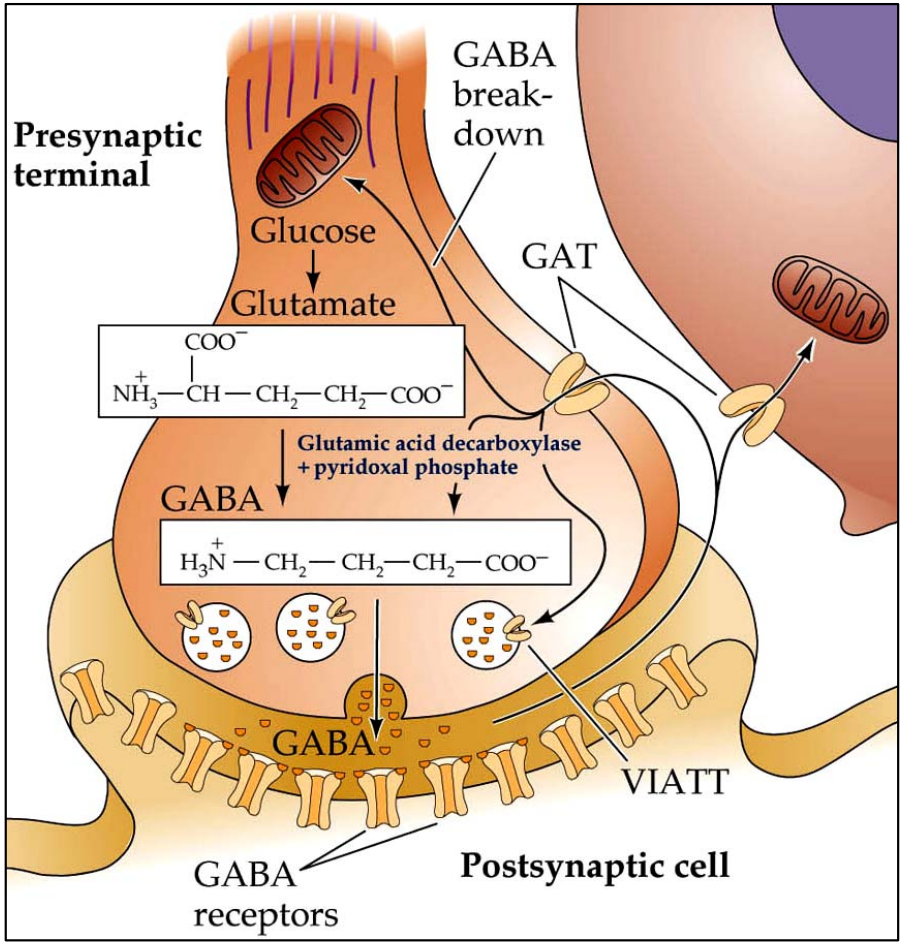
Glutamate



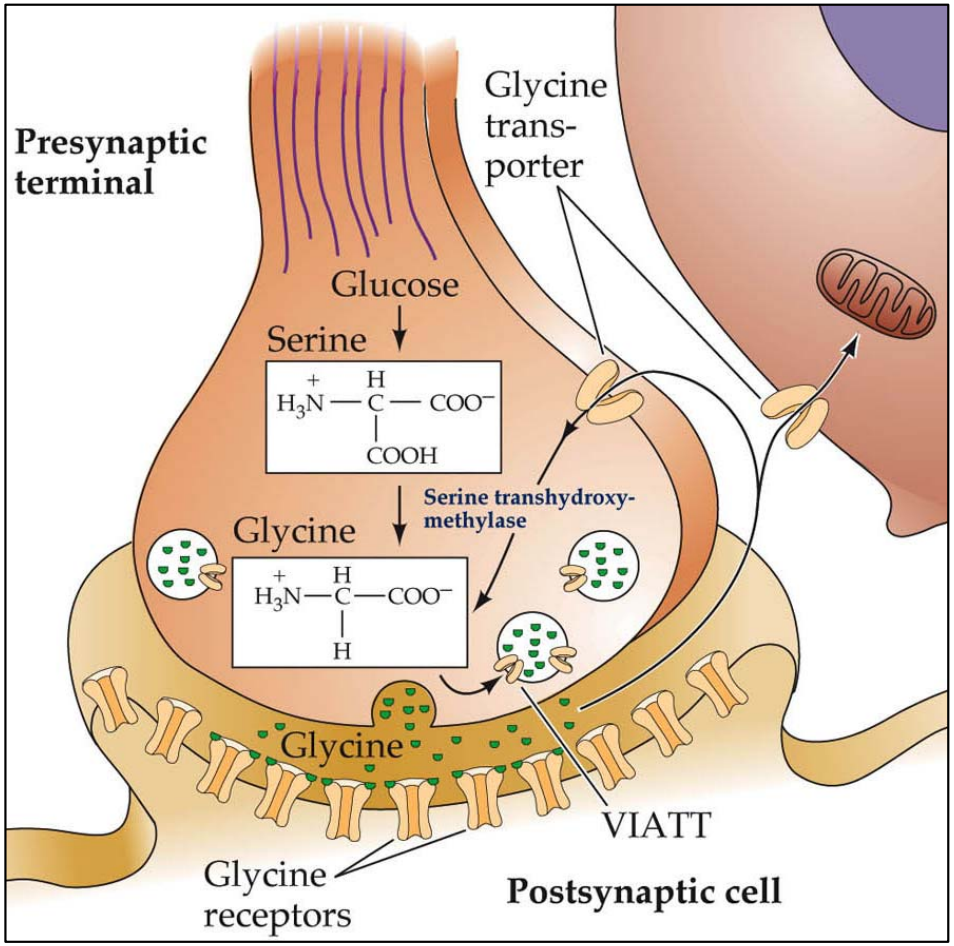
Figures: Purves 2004

Synthesis and removal of NT

GABA



Glycine

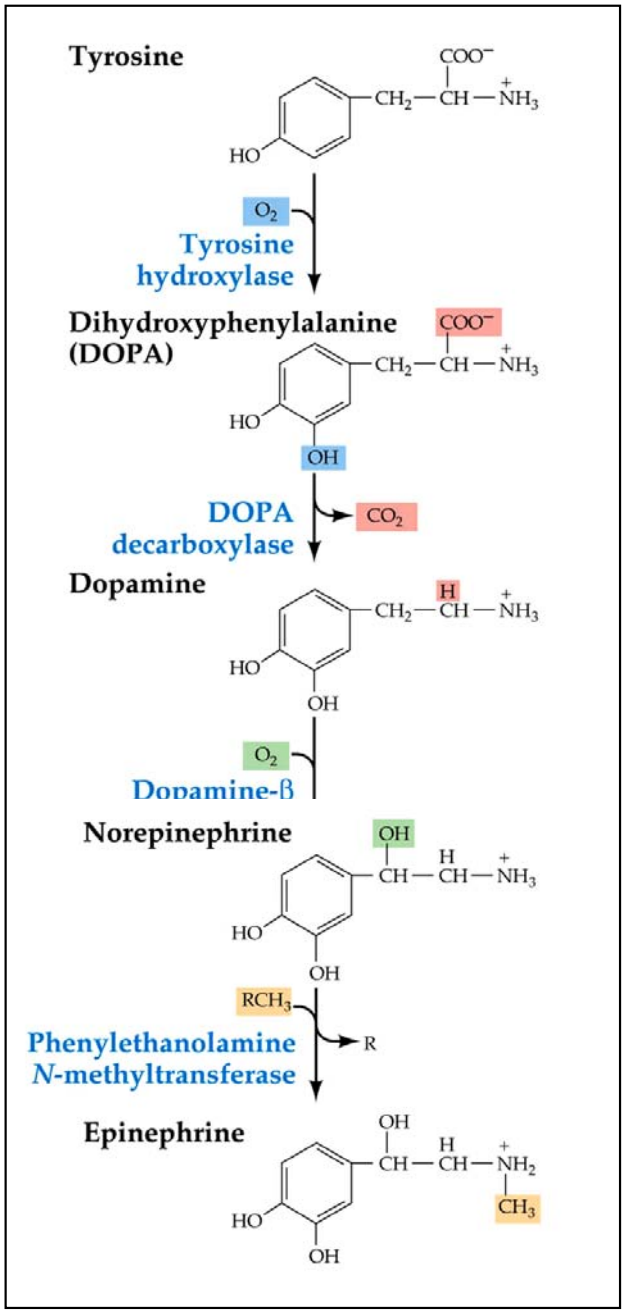


Figures: Purves 2004

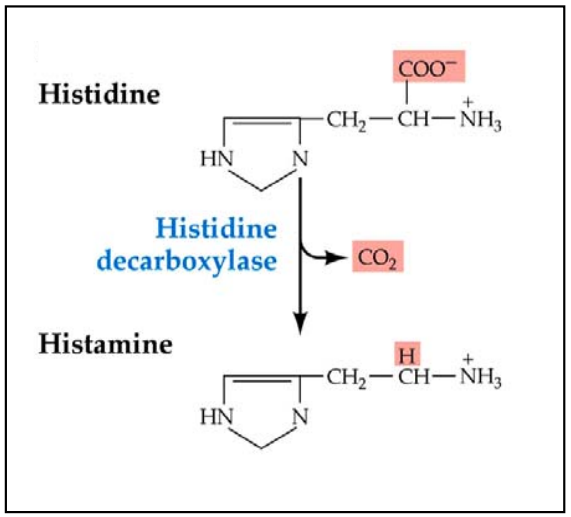
Neurotransmission

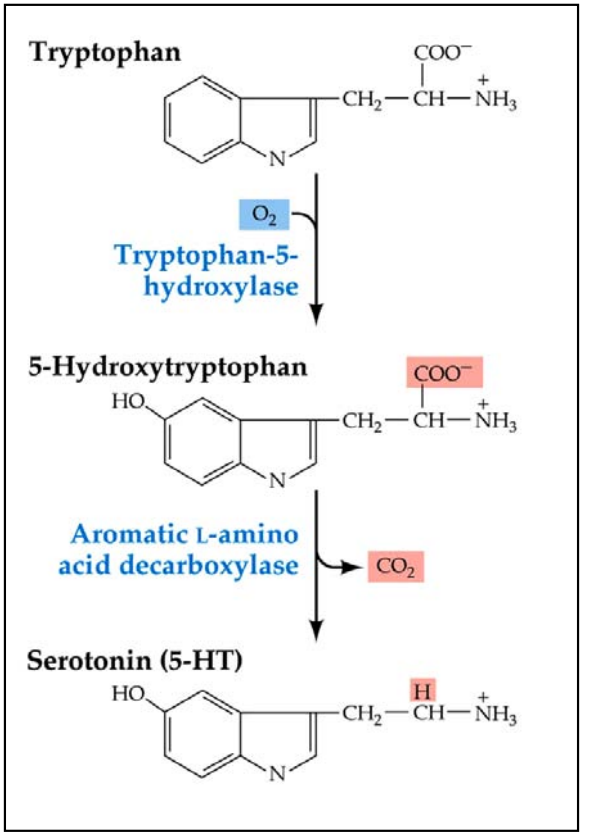
Synthesis and removal of NT

Biogenic amines



Catecholamines (*dopamine, noradrenaline, adrenaline*)
Serotonin
Histamine





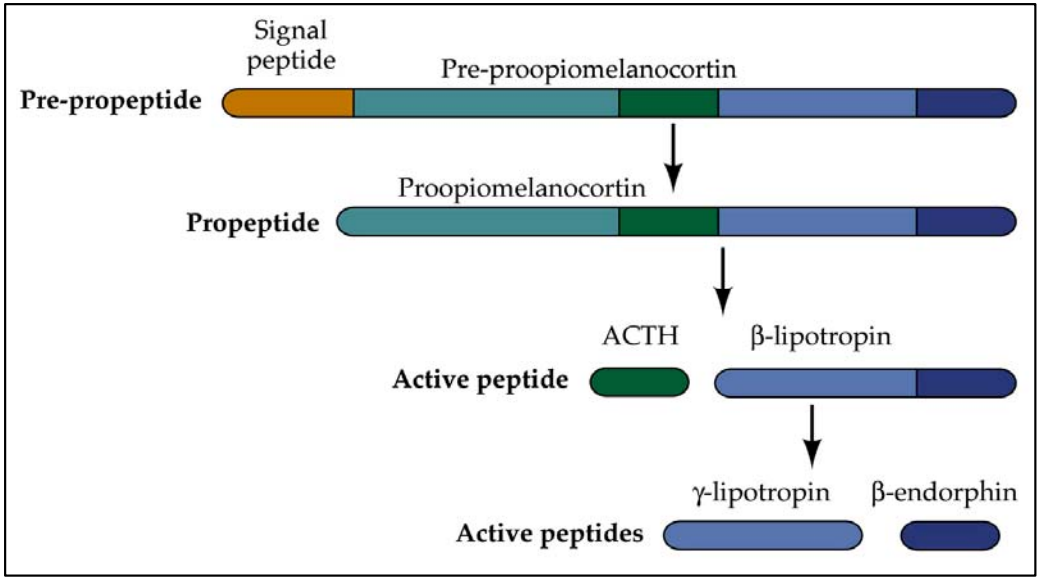
Removal: degradation by
MAO/COMT (catecholamines)
MAO (5-HT)
MAO/HMT (Histamine)

Figures: Purves 2004

Neurotransmission

Synthesis and removal of NT

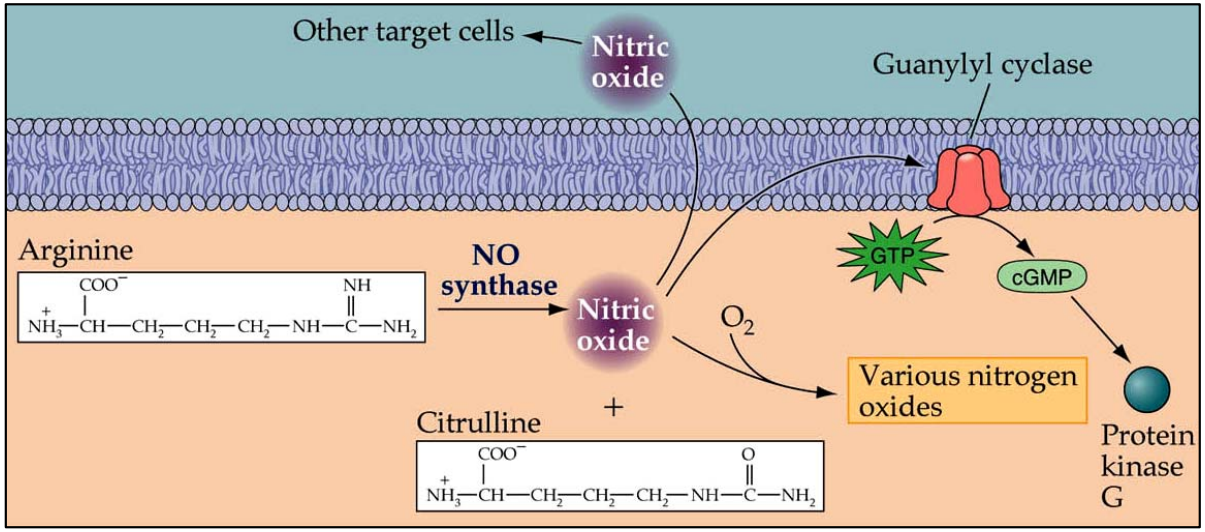
Peptide neurotransmitters



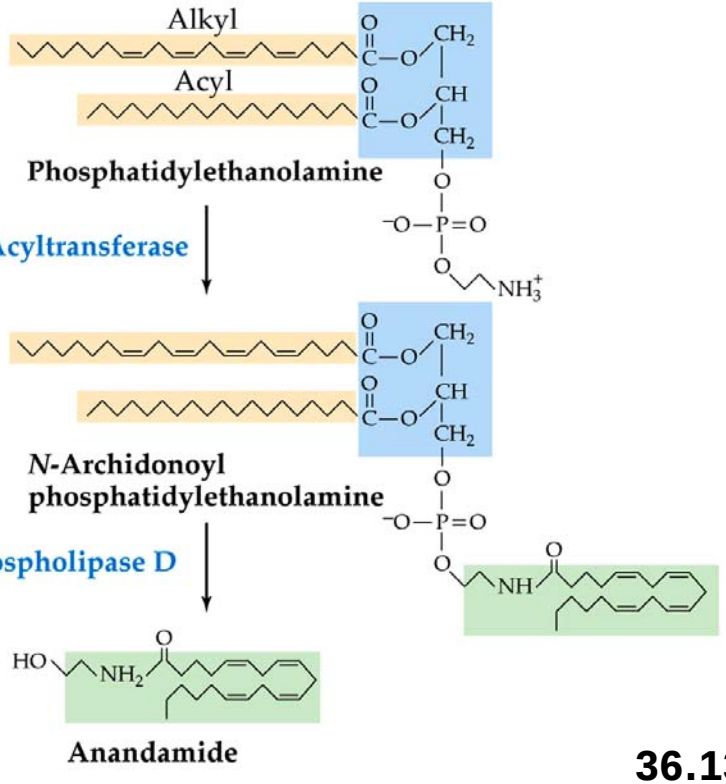
Removal: degradation by proteases

Unconventional neurotransmitters

Nitric oxide



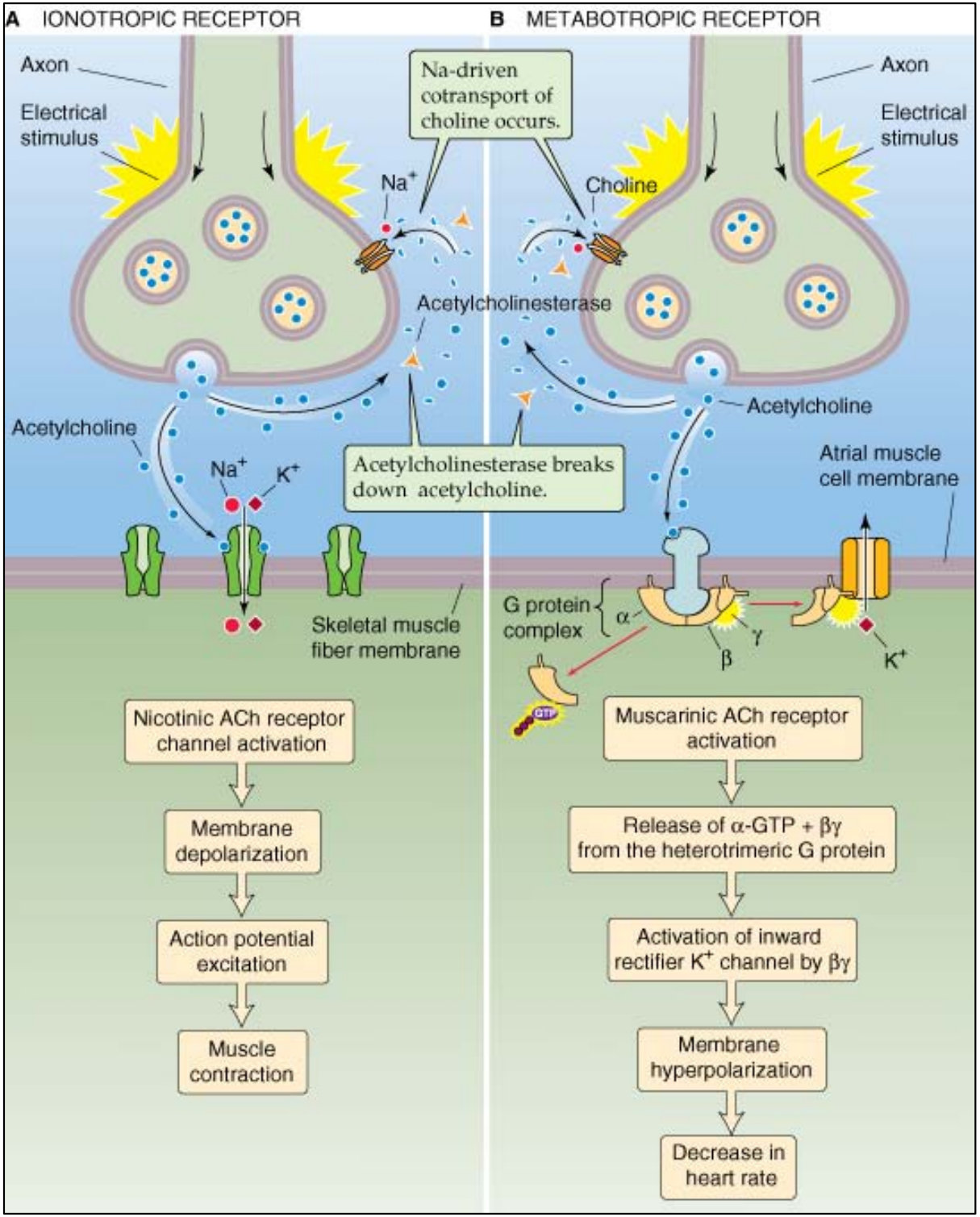
Endocannabionoids



Figures: Purves 2004

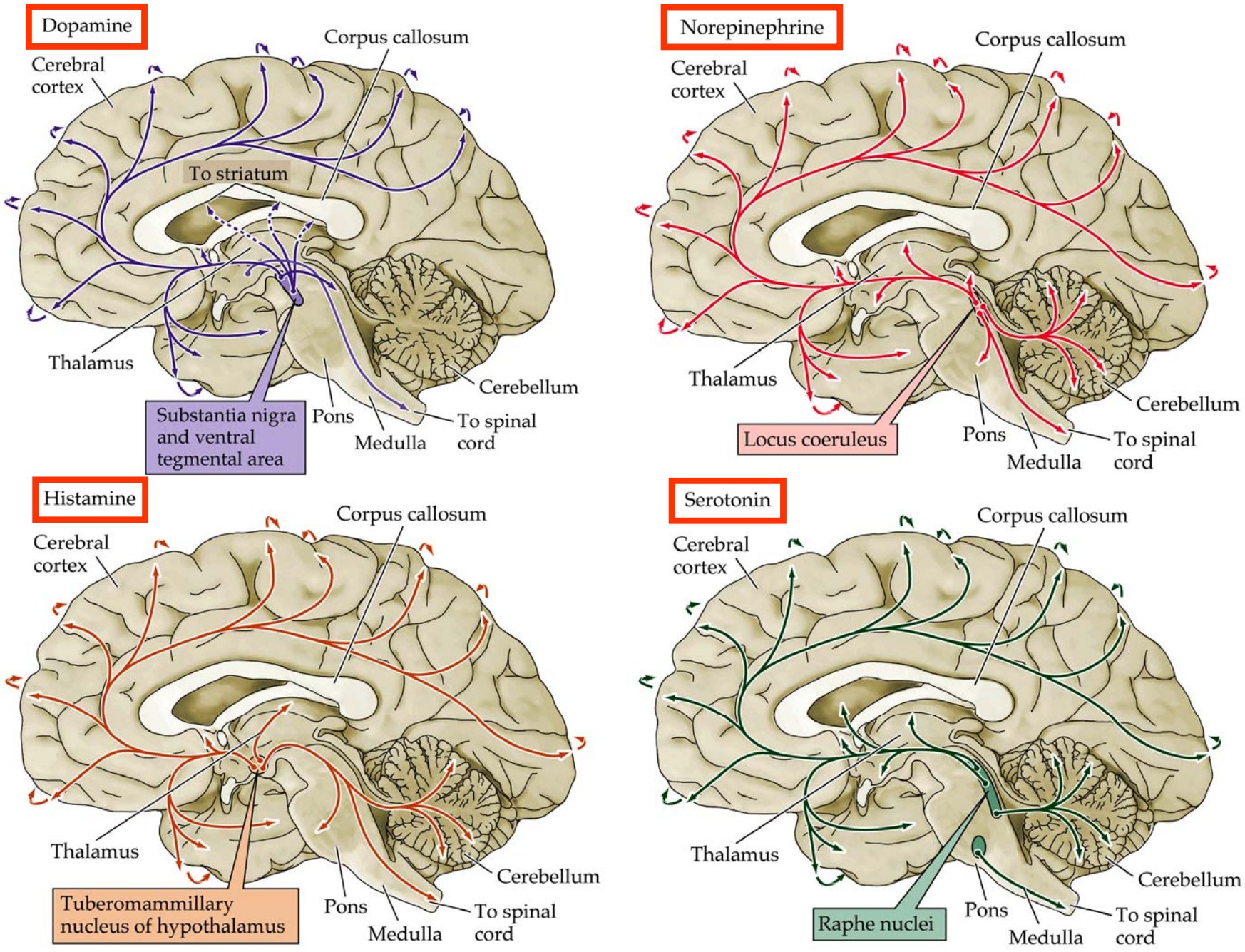
Neurotransmission

Receptors for NT



Figures: Boron & Boulpapep 2005

Distribution of neurons and projections containing biogenic amines as NT



Figures: Purves 2004

TEMA 37. Fluidos intracraneales y barreras sangre-sistema nervioso

1. Relaciones entre los compartimentos de fluidos intracraneales.

2. El líquido cefalorraquídeo (LCR).
   Sistema ventricular del cerebro humano.

3. Dinámica de distribución del LCR.
   Secreción en plexos coroideos.
      Morfología funcional de los plexos coroideos.
      Mecanismos de formación.
      Cuantía de producción.
   Circulación del LCR.
   Drenaje del LCR.
      Granulaciones aracnoideas.

4. Volumen y presión del LCR.
   Medición y valores normales.

5. Composición del LCR.
   Electrólitos, osmolalidad, pH, PCO_2, proteínas, glucosa...

6. Funciones generales del LCR.
   Determinación del medio interno neuronal.
   Función mecánica.
   Comunicación química.

7. Barreras sangre-LCR-SNC.
   Barrera sangre-LCR.
      Plexos coroideos.
   Barrera hemato-encefálica (BHE).
      Uniones adherentes en endotelio vascular cerebral.
      Transporte y selectividad a través de la barrera hemato-encefálica.
   Barrera metabólica: sistemas enzimáticos específicos de la BHE.
   Áreas de exclusión de la BHE.
      Órganos circunventriculares.

8. Metabolismo cerebral.
   Consumo de O_2 y producción de CO_2.
   Consumo de glucosa.
      Aporte de glucosa al sistema nervioso.
      Hipoglucemia.

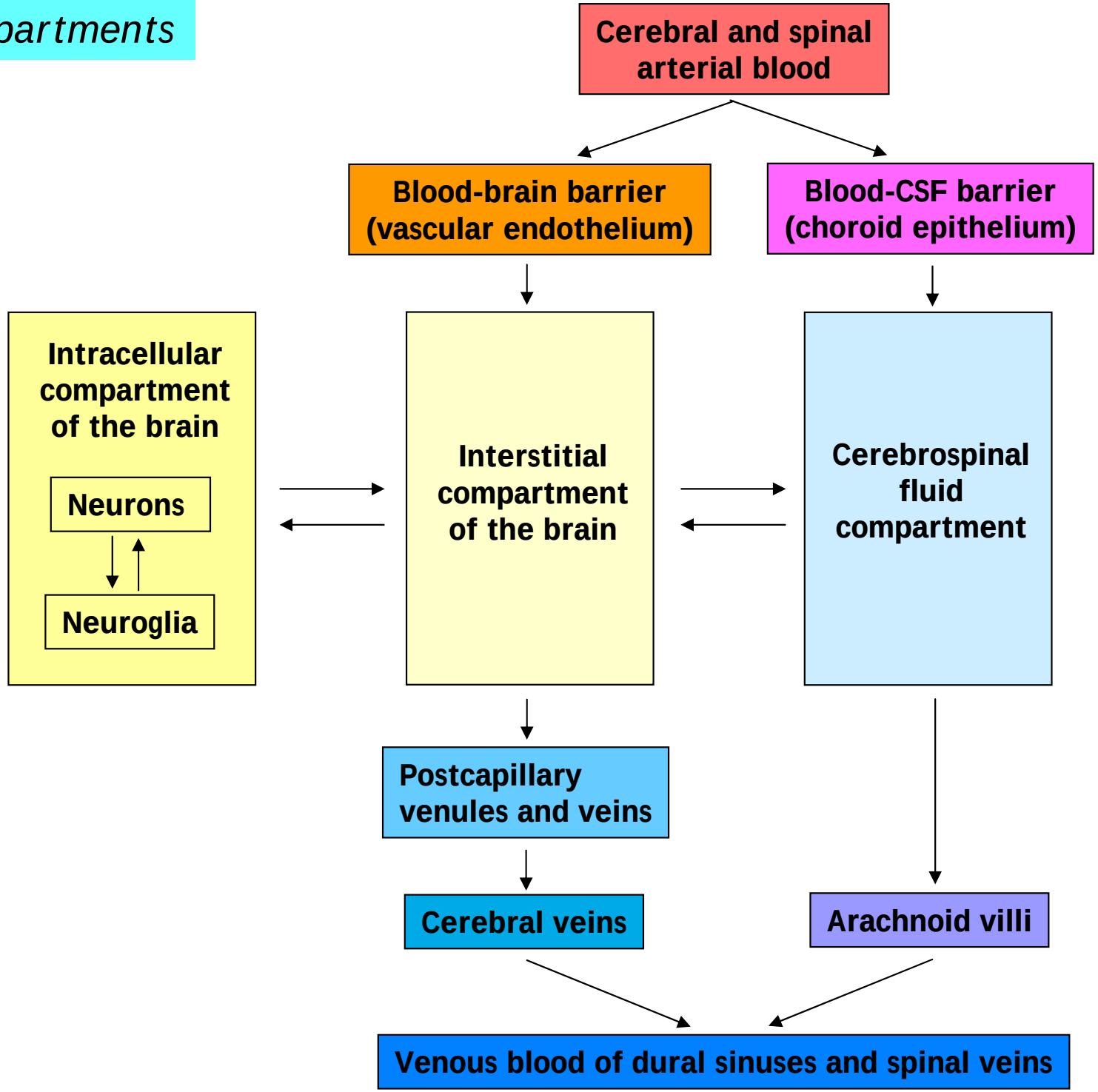
9. Papel de los astrocitos en el metabolismo neuronal. Astrocitos como sensores de la actividad neuronal.
      Regulación por glutamato del metabolismo astrocitario.
         Glucolisis y glucogenolisis.
      Regulación de la concentración extracelular de K^+.
      Metabolismo del nitrógeno.
         Conversión glutamato-glutamina.

10. Flujo sanguíneo cerebral (FSC).
    - FSC total y regional.
        - Valores normales del FSC.
        - Variaciones en distintas circunstancias fisiológicas.
            - Reposo, ejercicio, actividad mental, etc.
    - Variabilidad.
        - Interés en clínica, neurobiología y neurociencia cognitiva.
    - Medición del FSC total y regional.
    - Técnicas de neuroimagen para variaciones regionales del FSC.
        - TEP, RMF.

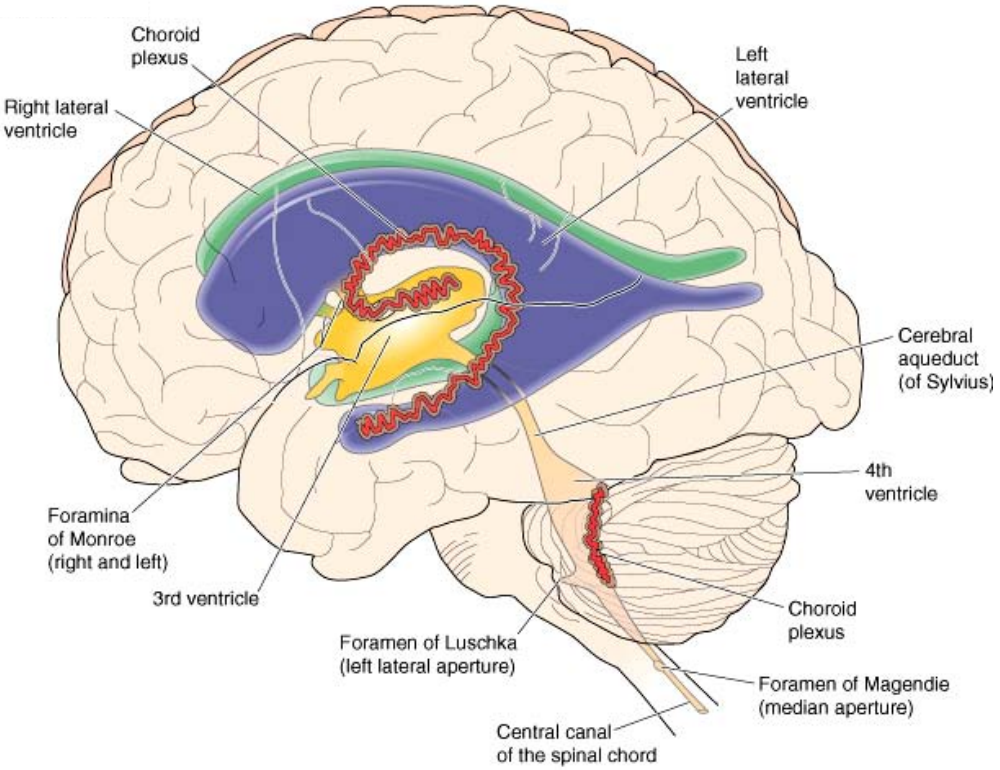
11. Regulación de la circulación cerebral.
    - Factores que condicionan el FSC.
        - Presiones arterial y venosa.
        - Presión intracraneal.
        - Vasodilatación y vasoconstricción locales.
    - Implicaciones de los cambios de la presión intracraneal en el FSC.

    - Autorregulación en la circulación cerebral.
        - Acoplamiento entre metabolismo y flujo sanguíneo.
            - PCO_2, PO_2, $[H^+]$, $[K^+]$, adenosina.
    - Factores endoteliales.
        - NO, prostaciclina, endotelinas.
    - Factores hormonales y humorales generales.

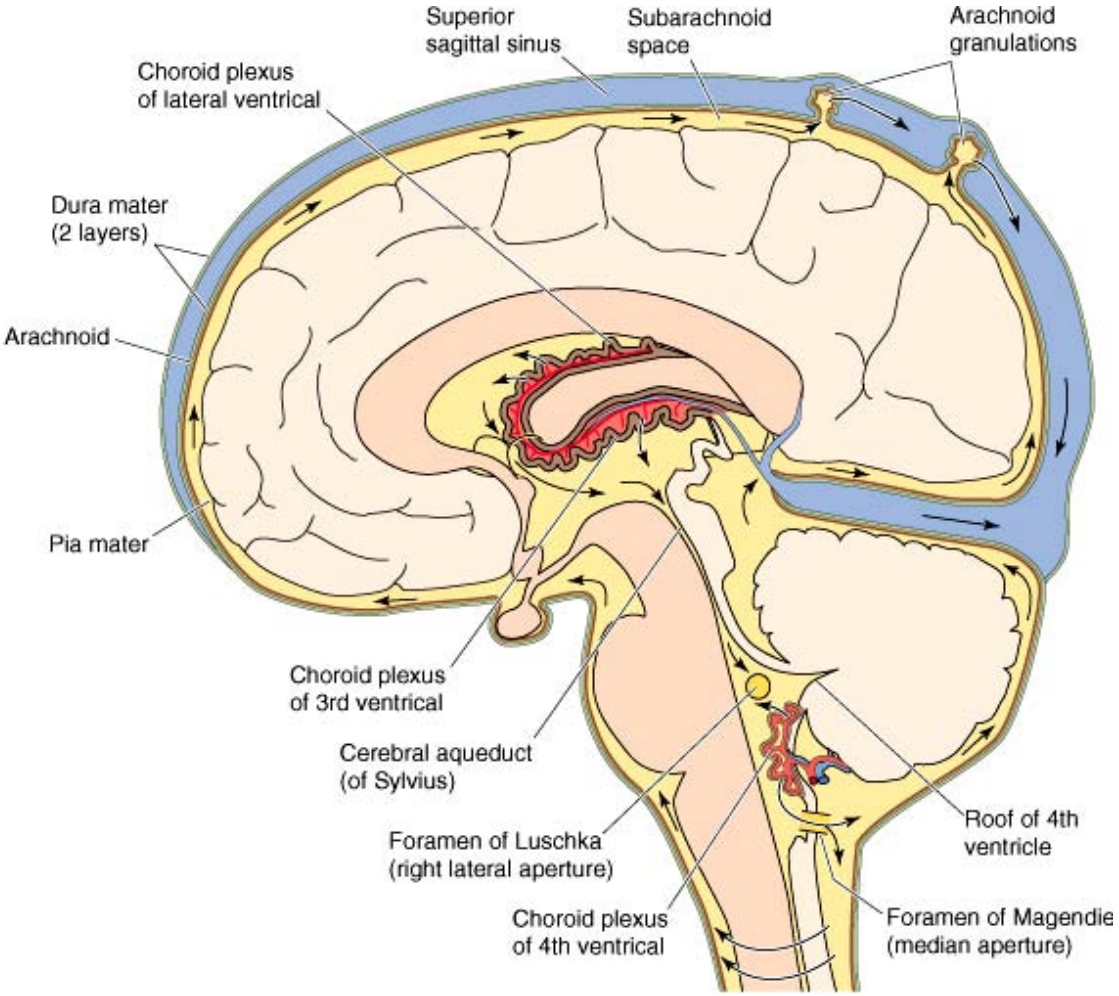
Relationships between brain fluid compartments

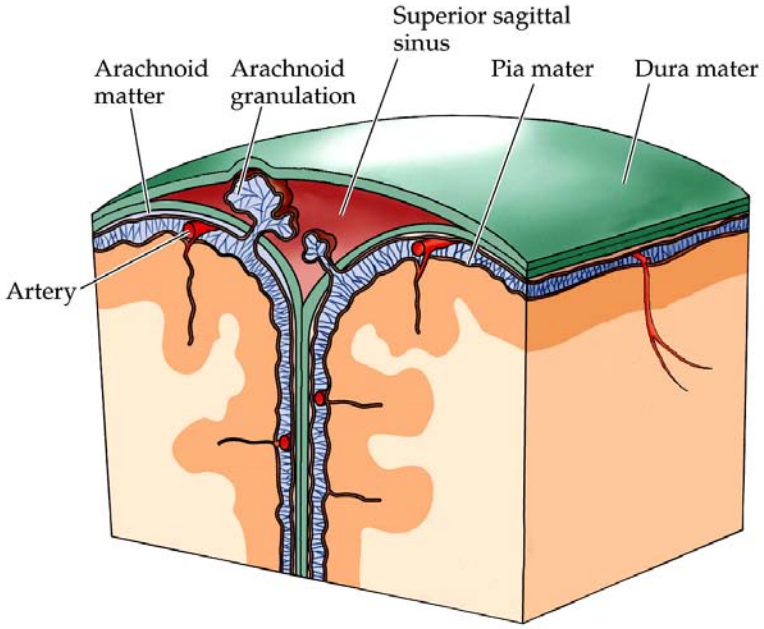


Ventricular system of the human brain



Distribution of the cerebrospinal fluid (CSF)

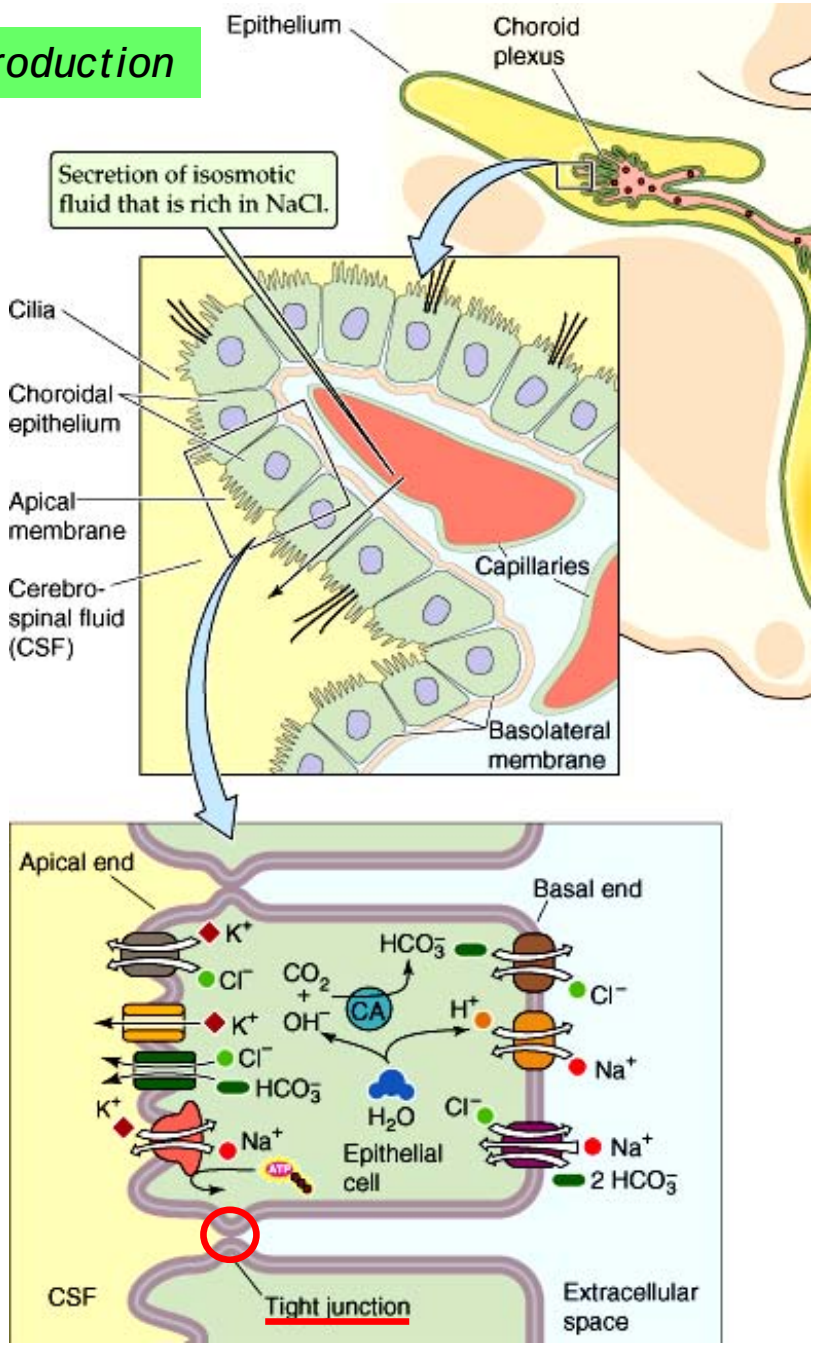




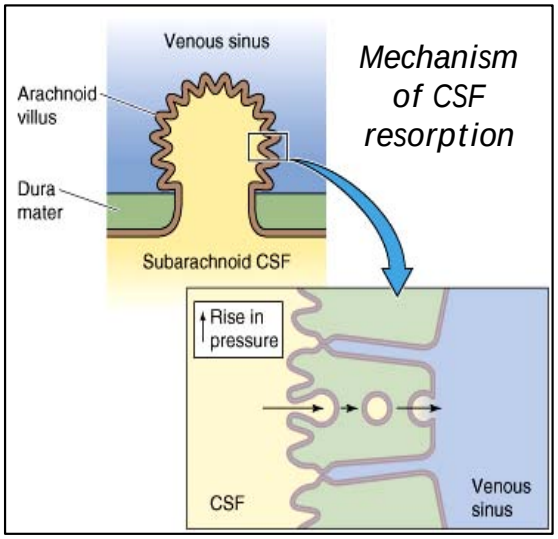
Figures: Purves 2004; Boron & Boulpapep 2005

Morphofunctional characteristics of the choroid plexus: The blood-CSF barrier

CSF production



CSF resorption

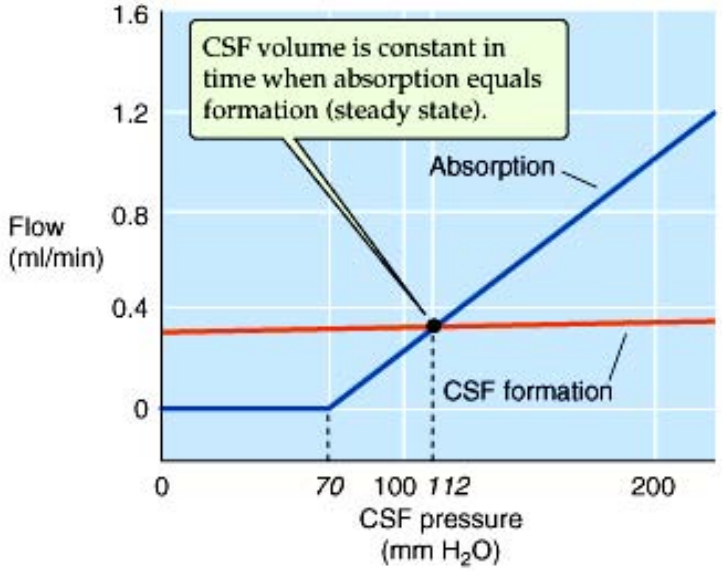


Volume and pressure of the CSF

Normal volume of CSF: 150 ml

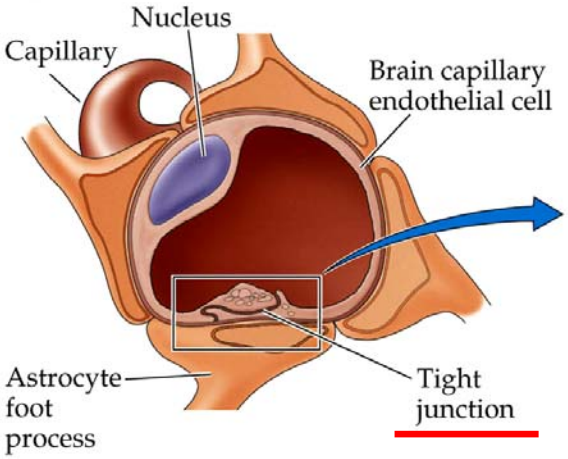
Normal production of CSF: 550 ml/day

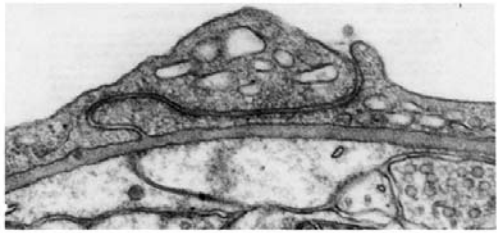
Normal pressure: 70-180 mm CSF

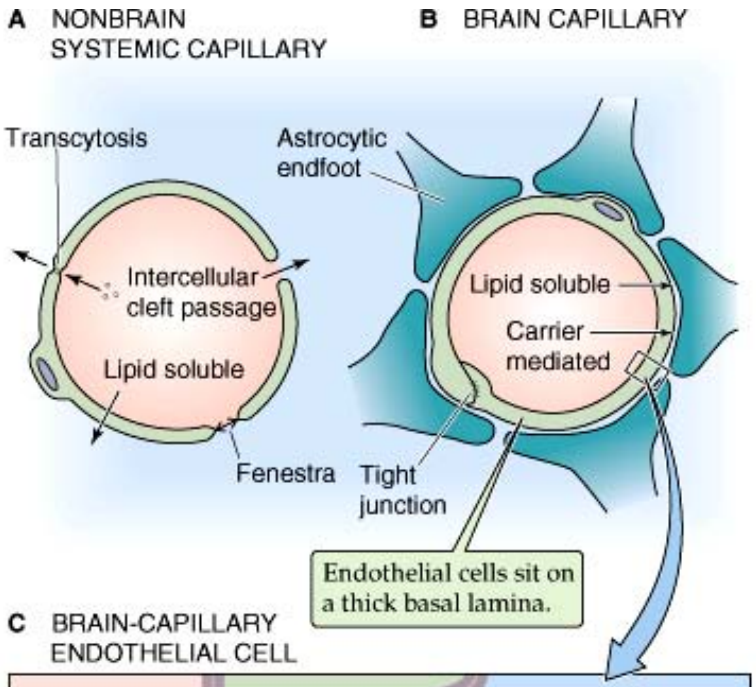


Figures: Boron & Boulpapep 2005

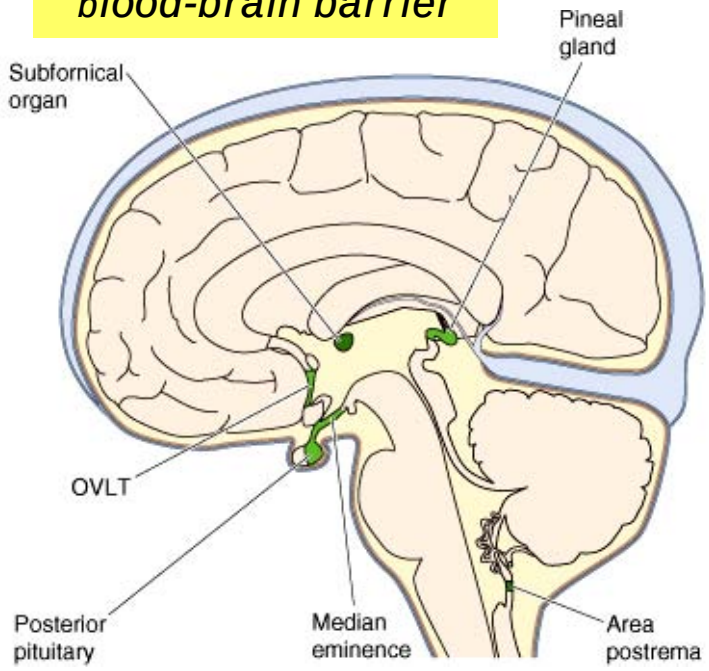
The blood-brain barrier



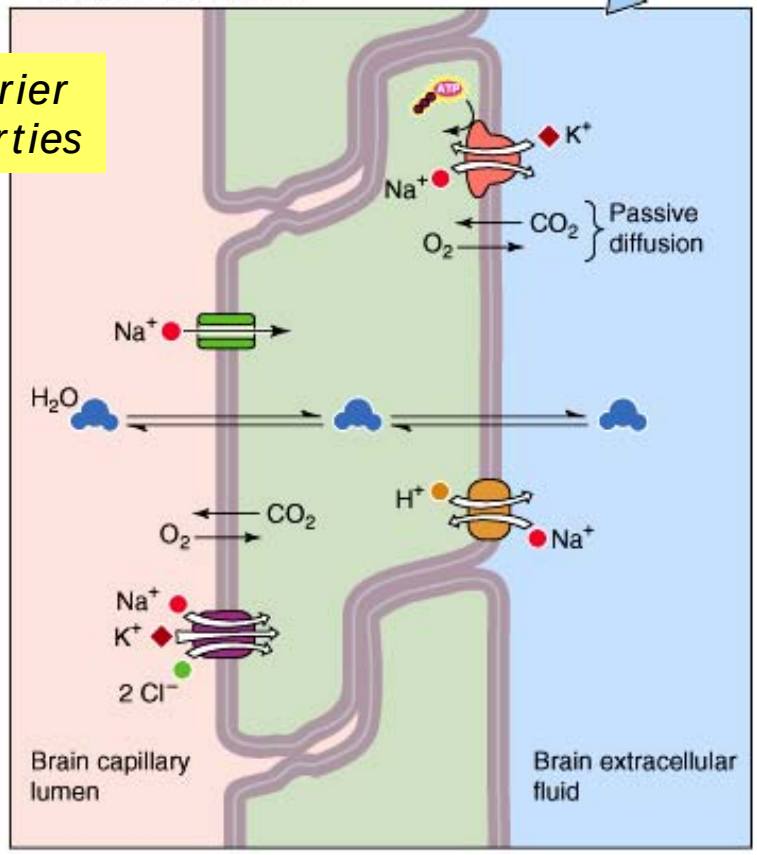




Brain regions without blood-brain barrier



Blood-brain barrier transport properties

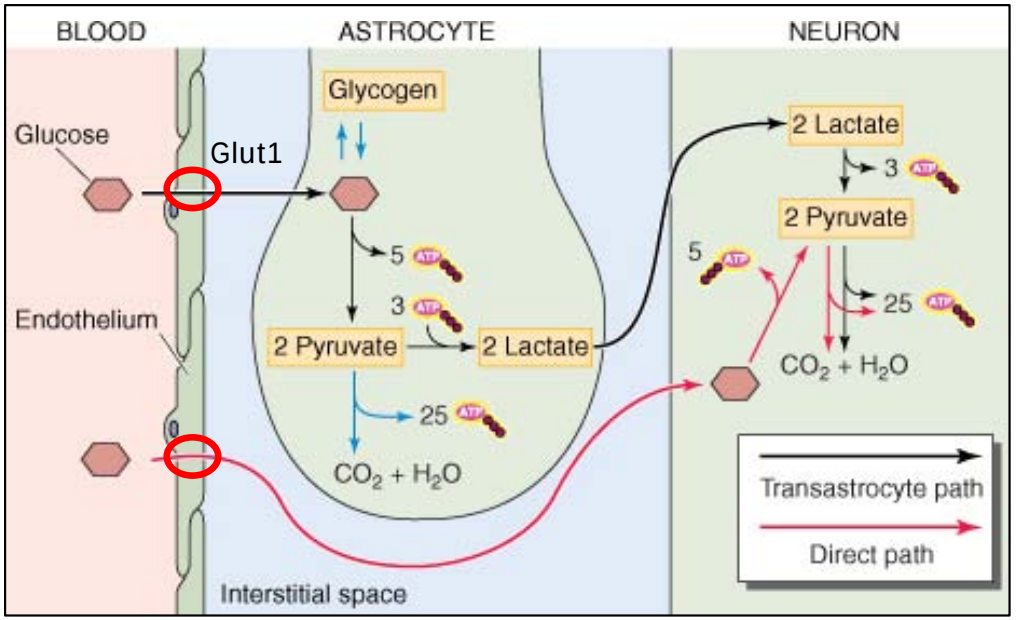


Figures: Purves 2004; Boron & Boulpapep 2005

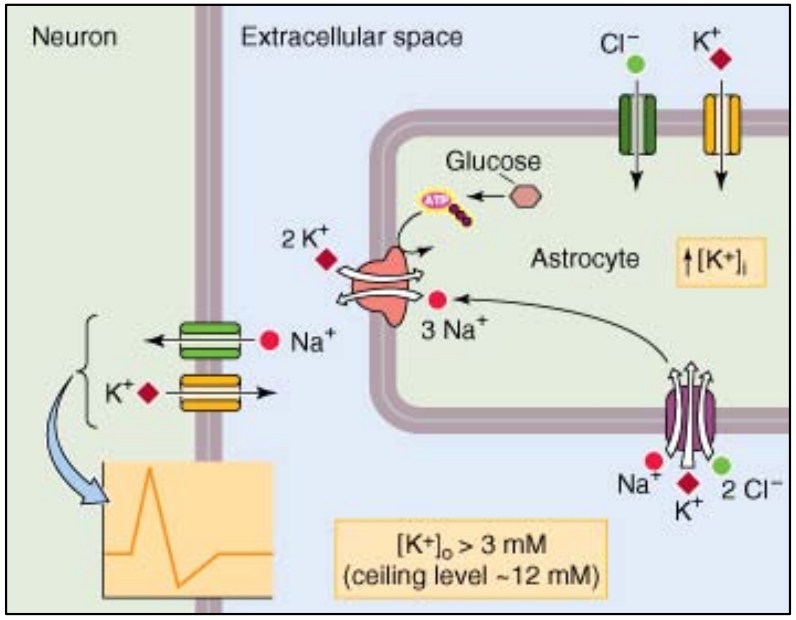
Brain Metabolism

Astrocytes role in neuronal metabolism

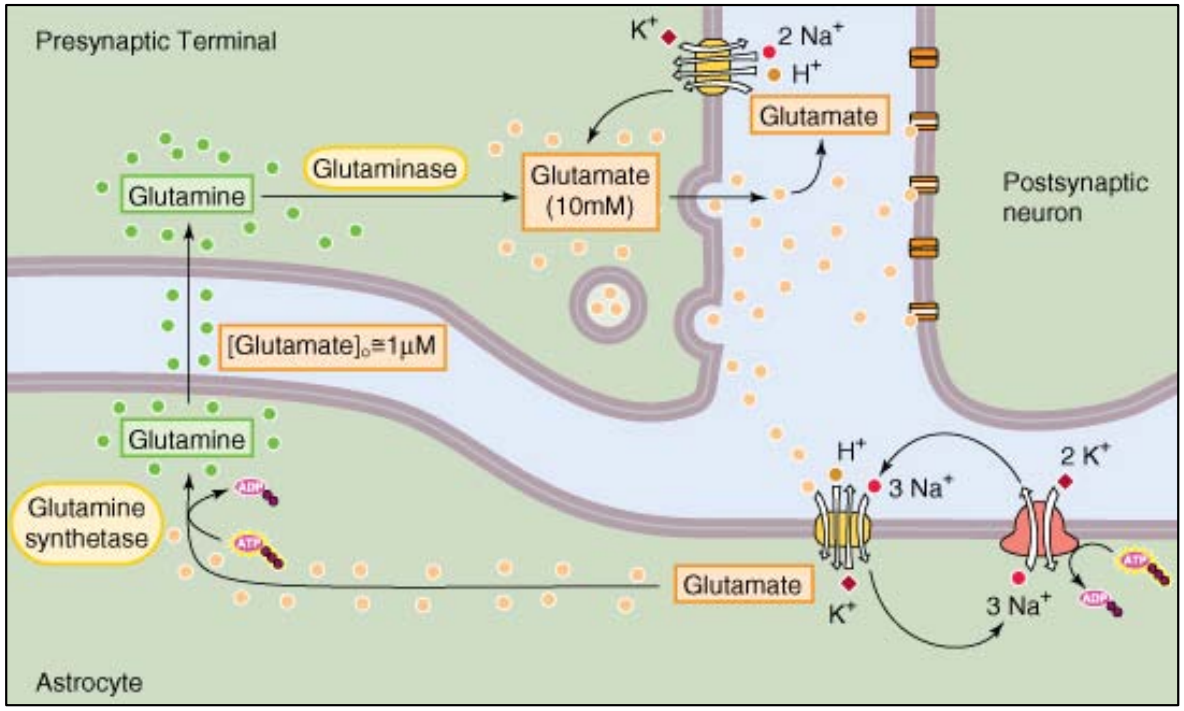
Glucose



K^+

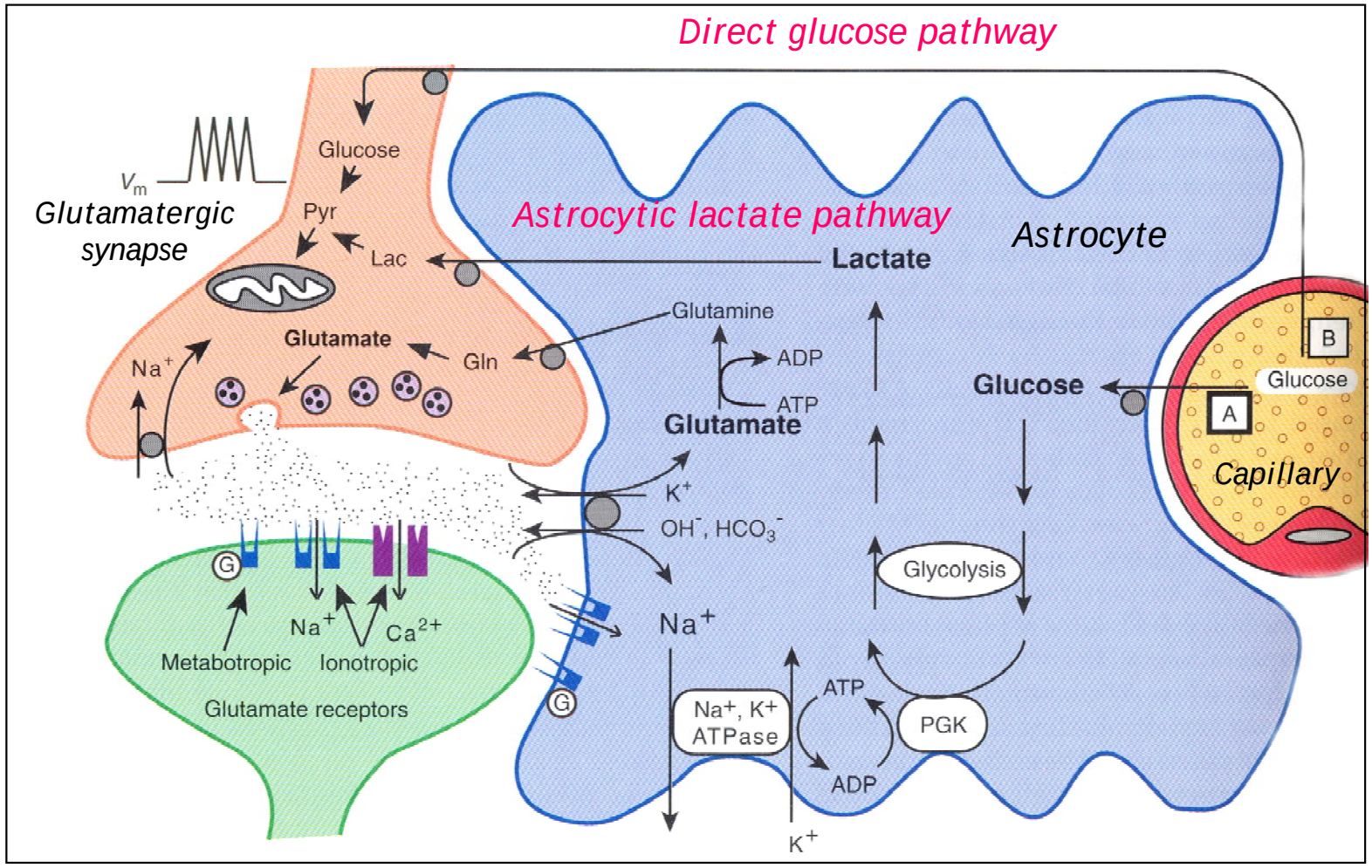


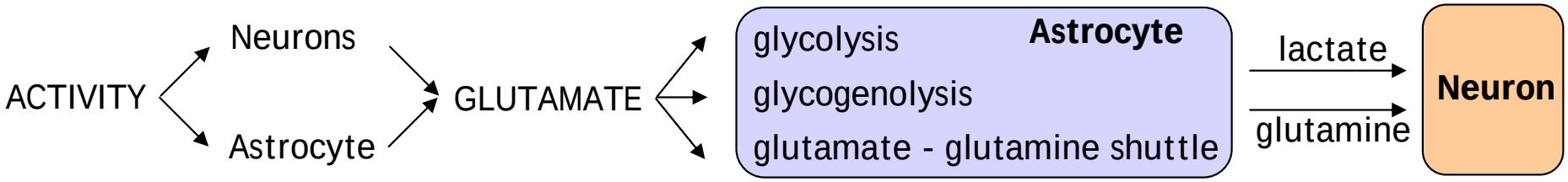
Glutamate-glutamine



Figures: Boron & Boulpapep 2005

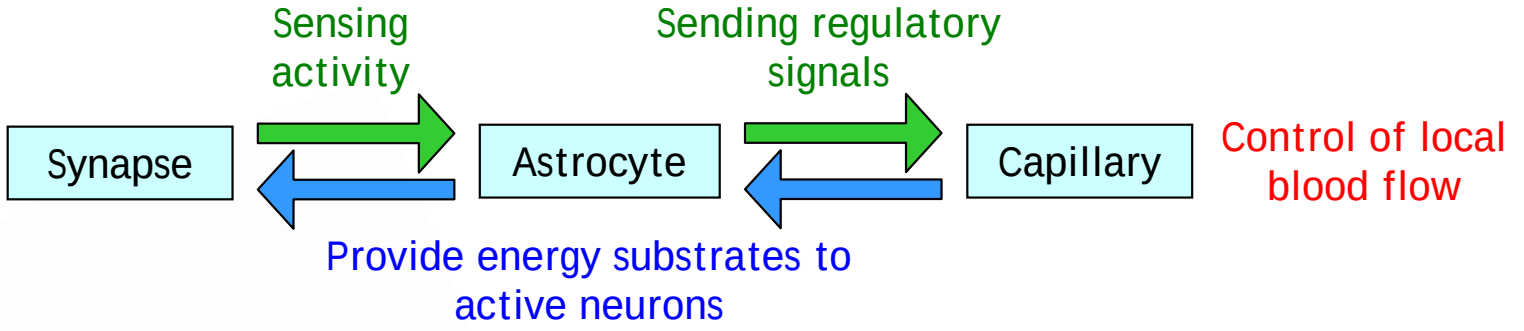
Astrocytes shuttle lactate and glutamine to neurons in an activity-dependent way

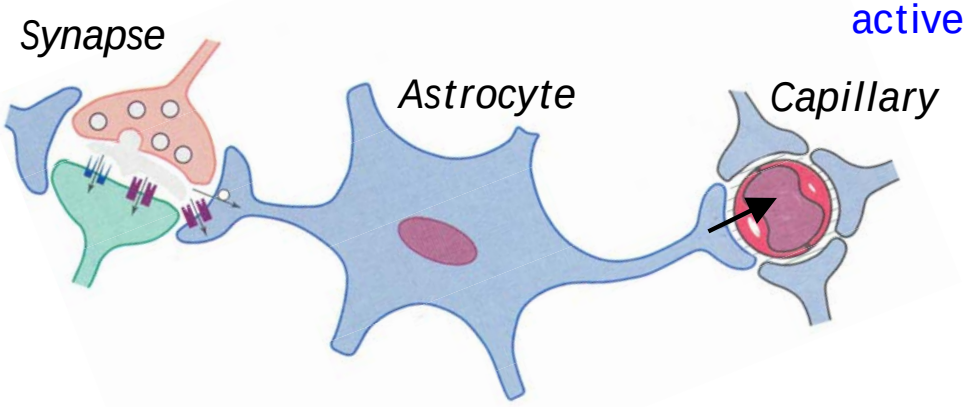




Figures: Zigmond 1999

Brain Metabolism

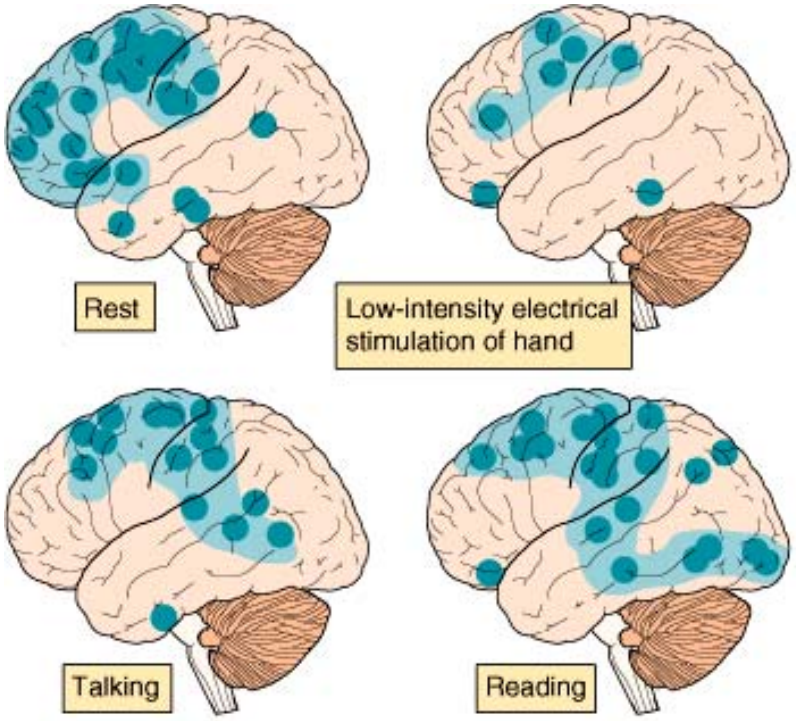




Regulation of brain blood flow

Brain blood flow
Total = 54 ml/min/100g of tissue
Regional:
Gray matter = 69 ml/min/100g of tissue
White matter = 28 ml/min/100g of tissue

Regional brain blood flow



Figures: Zigmond 1999; Boron & Boulpapep 2005

TEMA 38. FISIOLOGÍA DE LOS SISTEMAS SENSORIALES

1. Introducción.
   Los sistemas sensoriales.

2. Aspectos comunes de los sistemas sensoriales.
   Estímulo físico → Transducción por receptor → Percepción sensorial.

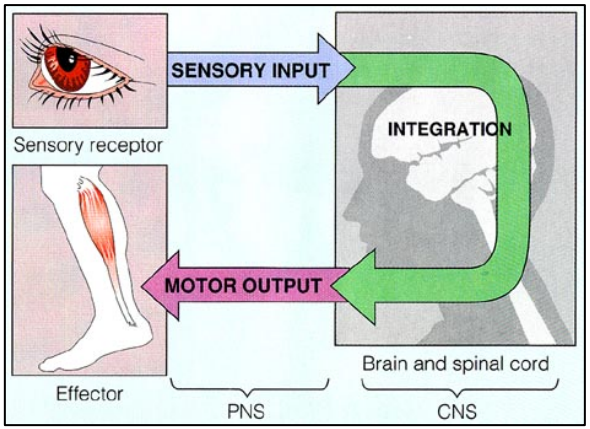
3. Atributos o propiedades del estímulo que extraen los sistemas sensoriales.
   Modalidad.
   Localización.
   Intensidad.
   Duración.

4. Sustrato morfológico en el procesamiento de la información sensorial.
   Receptores moleculares sensoriales.
   Receptores celulares.
      Primarios.
      Secundarios.
   Organización de las vías sensoriales.
      Procesamiento en serie en núcleos de relevo.
      Procesamiento en paralelo.
      Mapas sensoriales.

5. Mecanismos fisiológicos en el procesamiento de la información sensorial.
   Transducción del estímulo.
      Conversión de energía del estímulo en energía electroquímica en el receptor.
   Codificación de la información sensorial.
      Modalidad.
         Especificidad de receptor según características del estímulo.
            Submodalidades.
      Localización.
         Distribución espacial de receptores activados.
            Conceptos de campo receptor y unidad sensorial.
            Solapamiento de campos receptores.
         Mapas topográficos sensoriales.
      Intensidad.
         Código de frecuencia de potenciales de acción.
            Umbrales sensoriales.
         Código de población de receptores activados.
            Reclutamiento de unidades sensoriales.
      Duración.
         Adaptación de receptores sensoriales.
            Bases moleculares.
               Cambios en molécula receptora.
               Cambios en paso de amplificación.
               Cambios en canales iónicos y excitabilidad neural.

6. Mecanismos de discriminación espacial de estímulos.
   Inhibición lateral (retrógrada). Incremento del contraste entre estímulos.
   Otros tipos de inhibición: anterógrada y distal.

Sensory system physiology



Common aspects of sensory systems

Physical **stimulus** → Transduction into nerve impulses by **Sensory receptor**

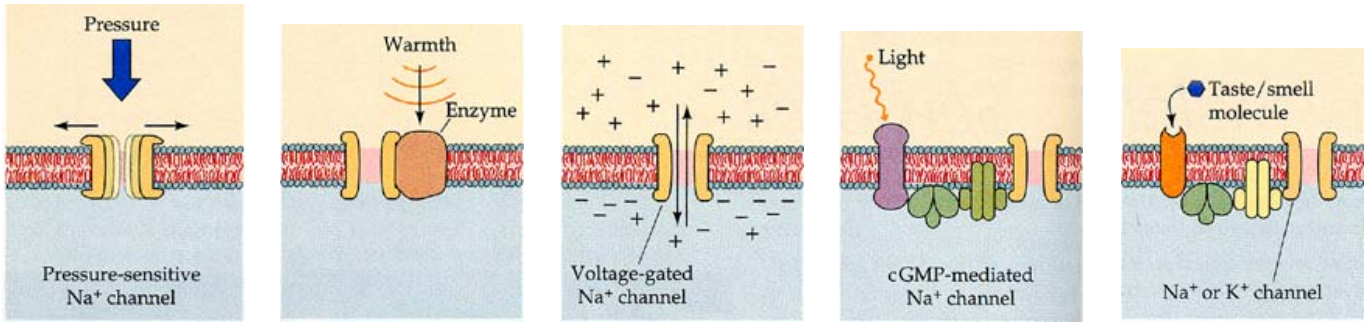
Stimulus attributes
- Modality
- Location
- Intensity
- Duration

Response to stimulus: **Perception** (conscious experience of sensation)

Morphological substrate: Molecular sensors

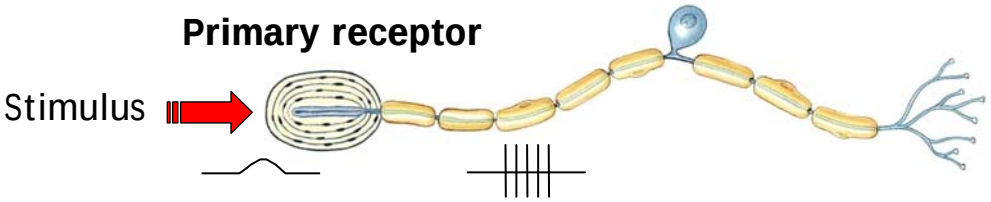
Each receptor molecule transduces a specific type of energy into electrical signals

Mechanosensor | Thermosensor | Electrosensor | Photosensor | Chemosensor

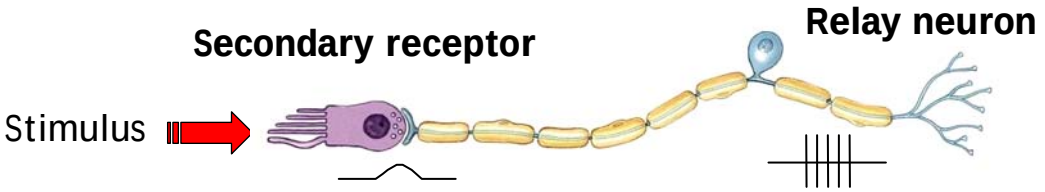


Figures: Purves 2004

Sensory receptor cell



Types of sensory receptor

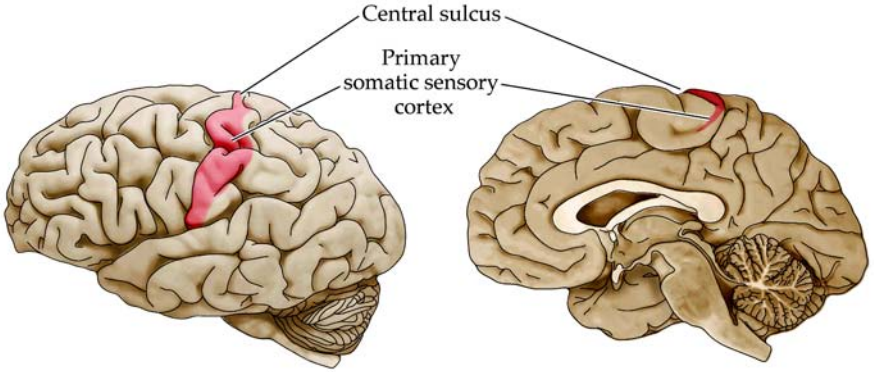


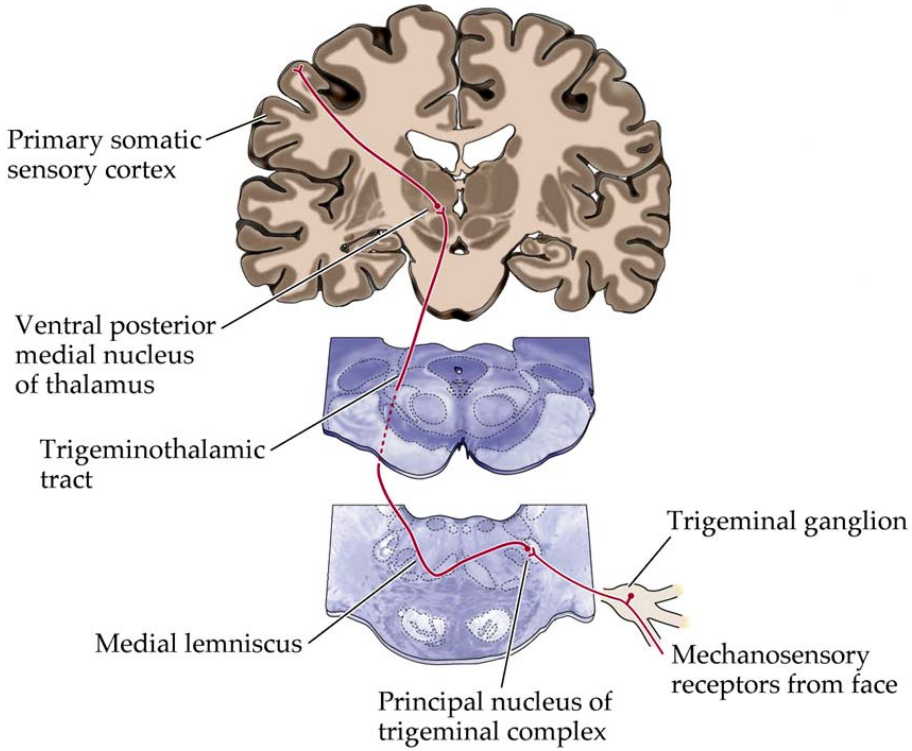
Organization of sensory pathways

1. Serial processing

2. Parallel processing

3. Sensory maps



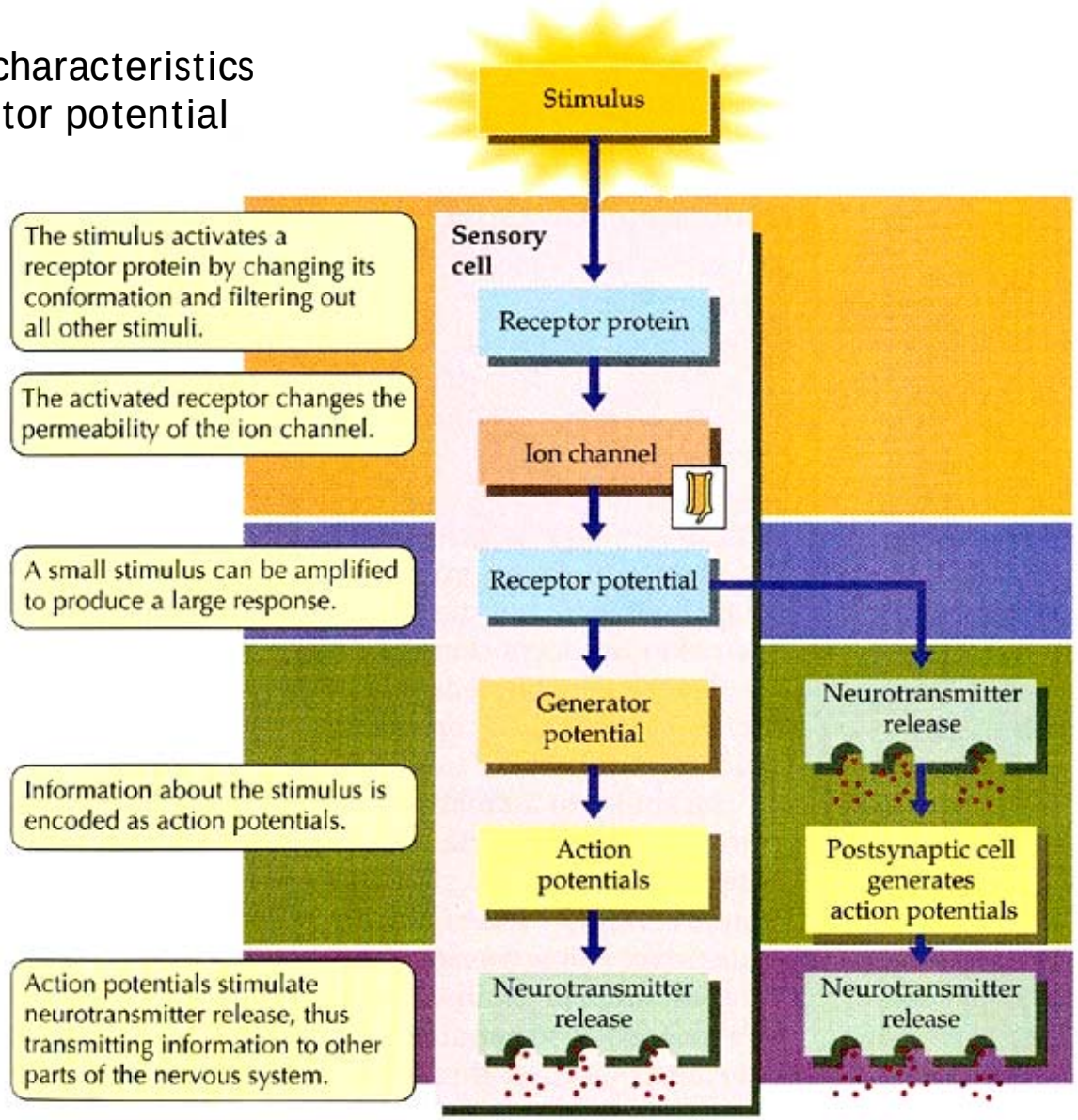


Figures: Purves 2004; Silverthorn 2007

Stimulus transduction

How does a sensory cell transduce stimulus energy into action potentials?

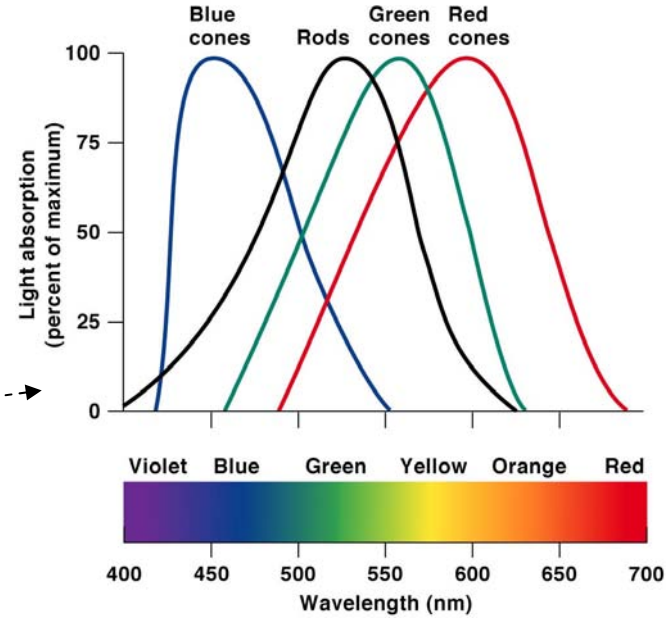
Concept and characteristics of the receptor potential



Modality

Type of energy. Specialized receptor are tuned to an 'adequate' stimulus.

TYPE OF RECEPTOR	EXAMPLES OF STIMULI
Chemoreceptors	Oxygen, pH, various organic molecules such as glucose
Mechanoreceptors	Pressure (baroreceptors), cell stretch (osmoreceptors), vibration, acceleration, sound
Photoreceptors	Photons of light
Thermoreceptors	Varying degrees of heat

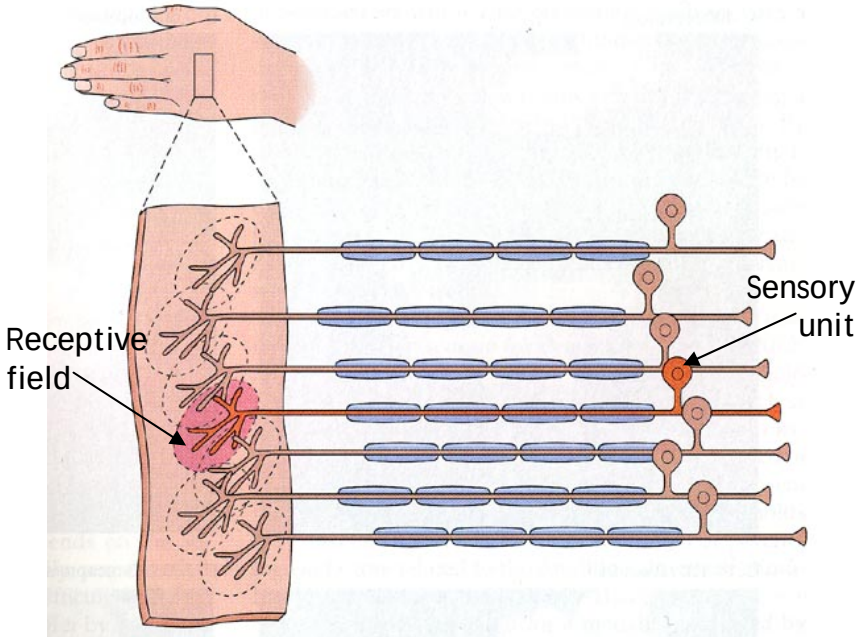


Each modality has **submodalities**

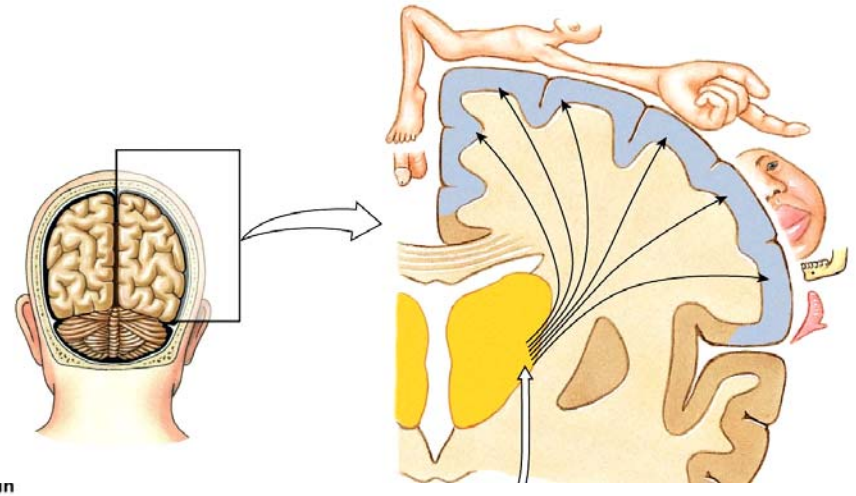
Figures: Silverthorn 2007

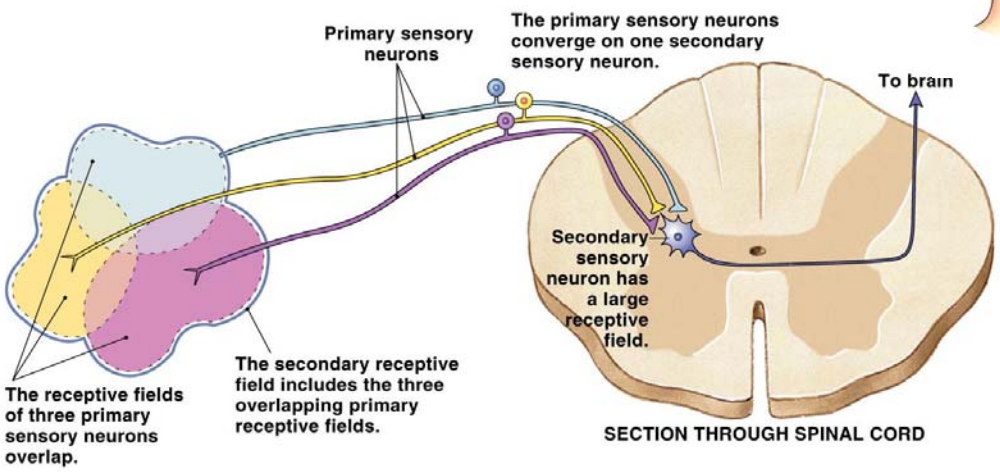
Location

Spatial distribution of activated receptors.
Concepts of receptive field and sensory unit.



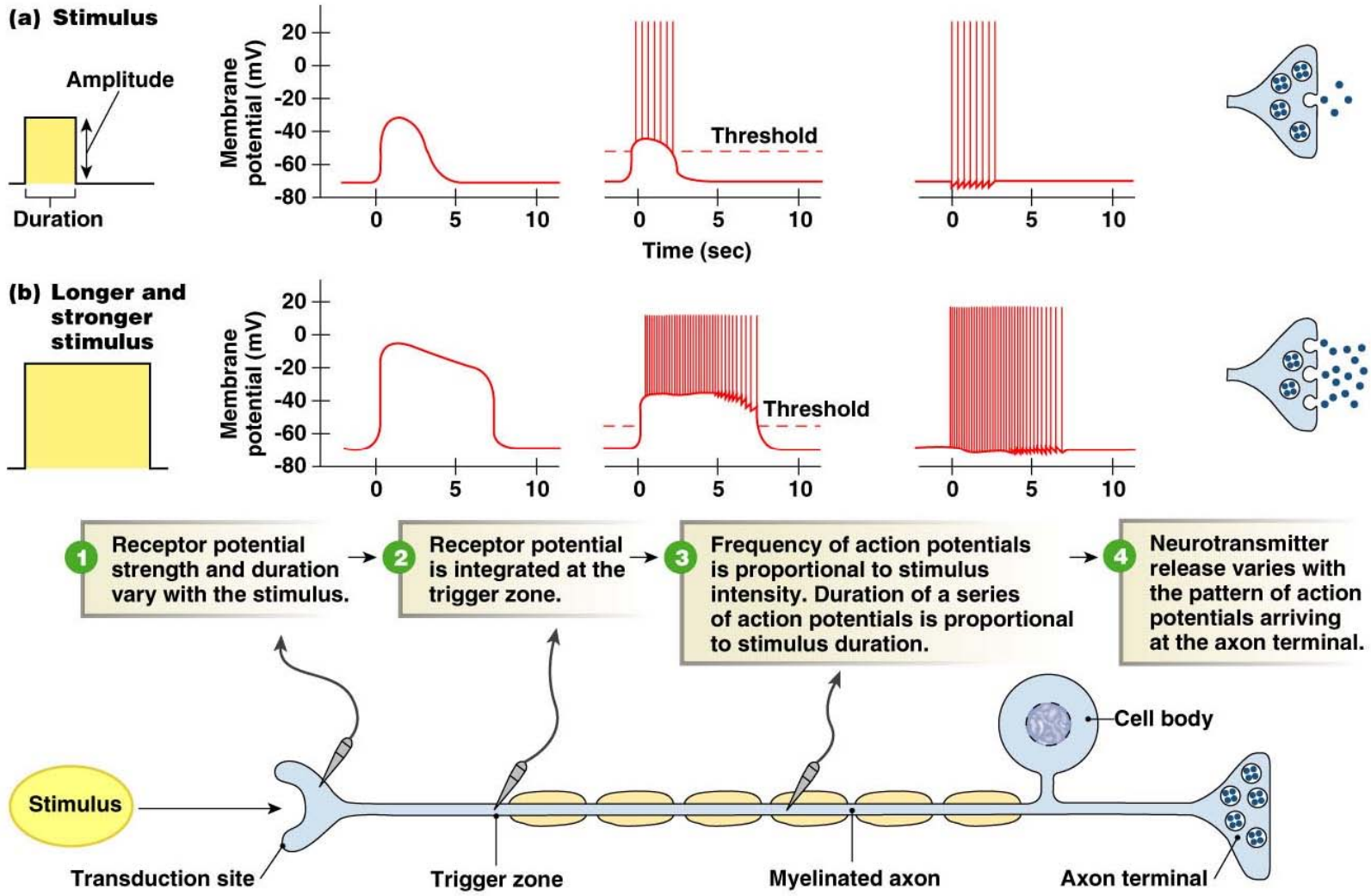
Receptor projections and their relay neurons organize in a topographic map.





Figures: Purves 2004; Silverthorn 2007

Intensity



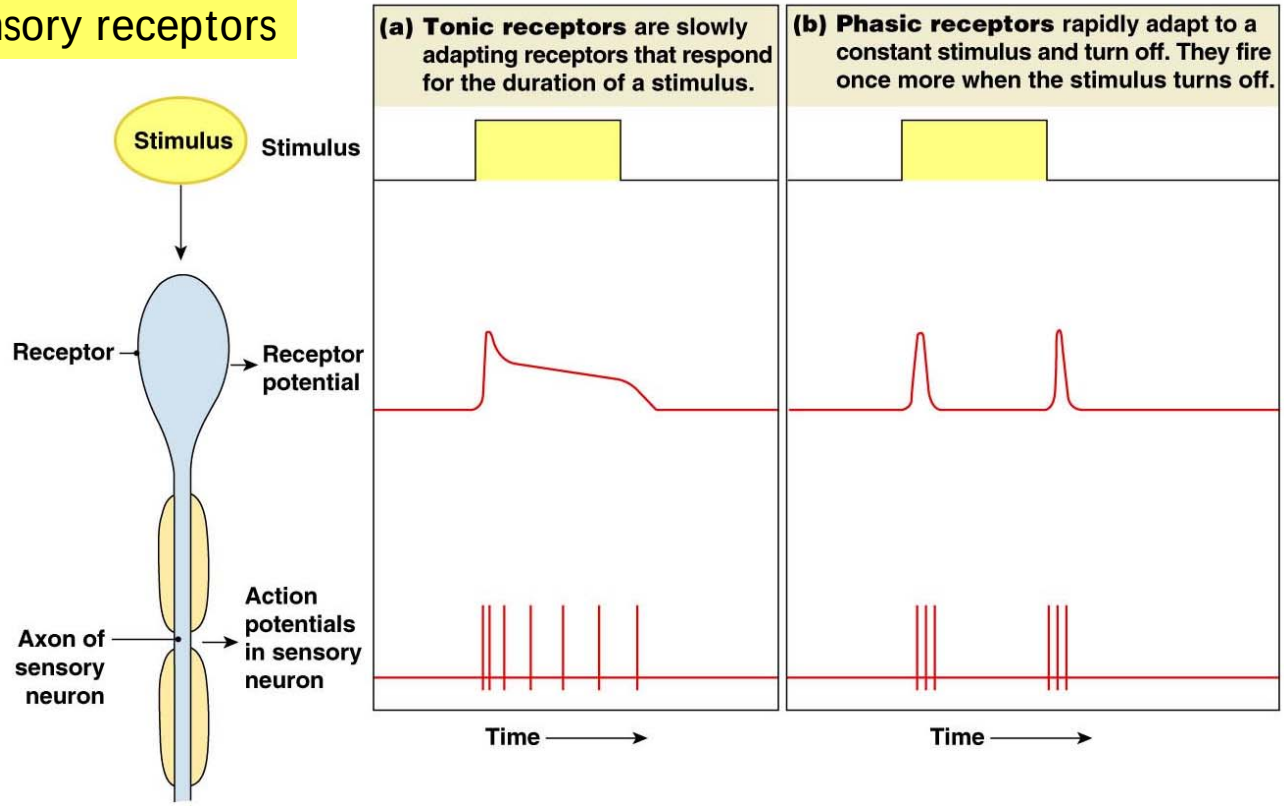
Sensory threshold

Firing frequency has an upper limit → Stimulus intensity is also encoded by the size of the responding receptor population → Recruitment of sensory units

Figures: Silverthorn 2007

Duration

Duration can be coded by the adaptation of sensory receptors



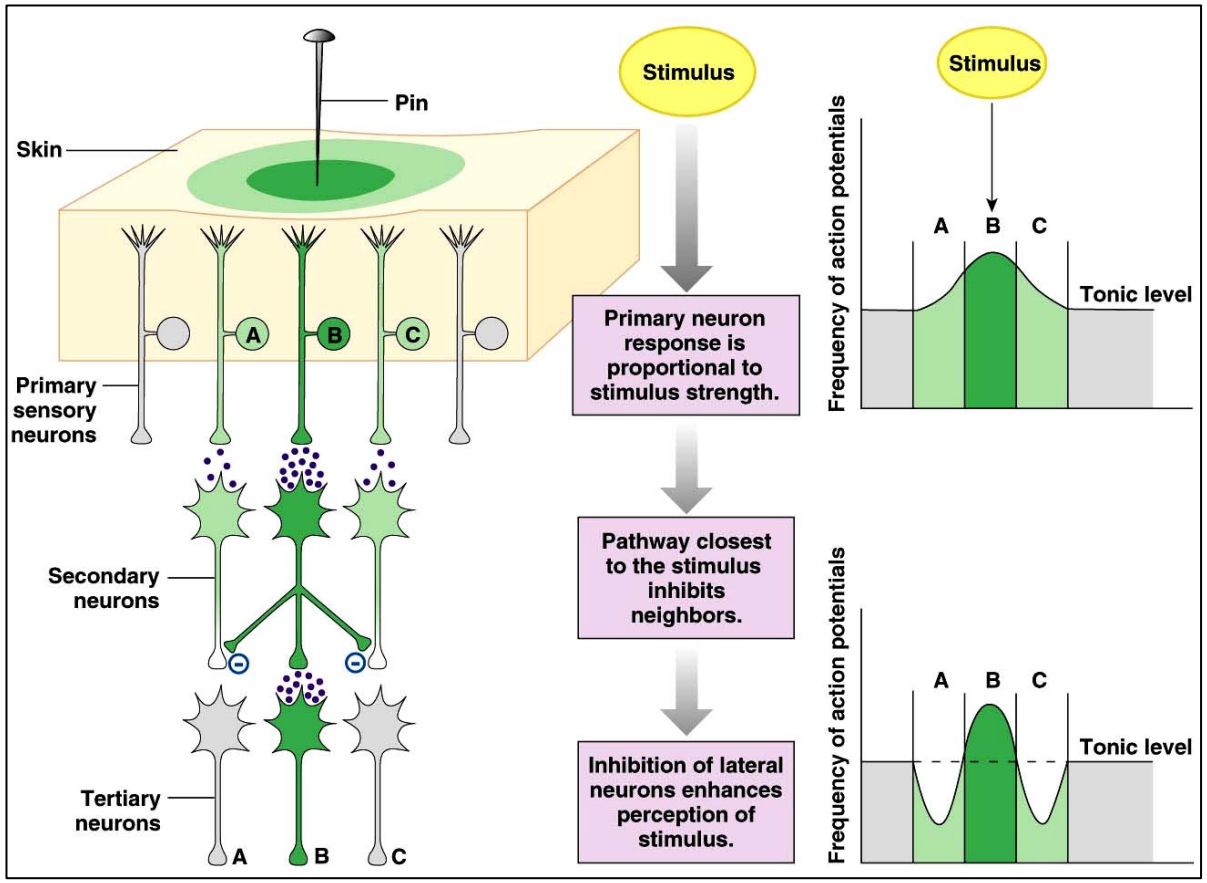
Concept and molecular basis of adaptation

1. Changes in receptor protein
2. Changes in amplification step
3. Changes in ionic channels and neural excitability

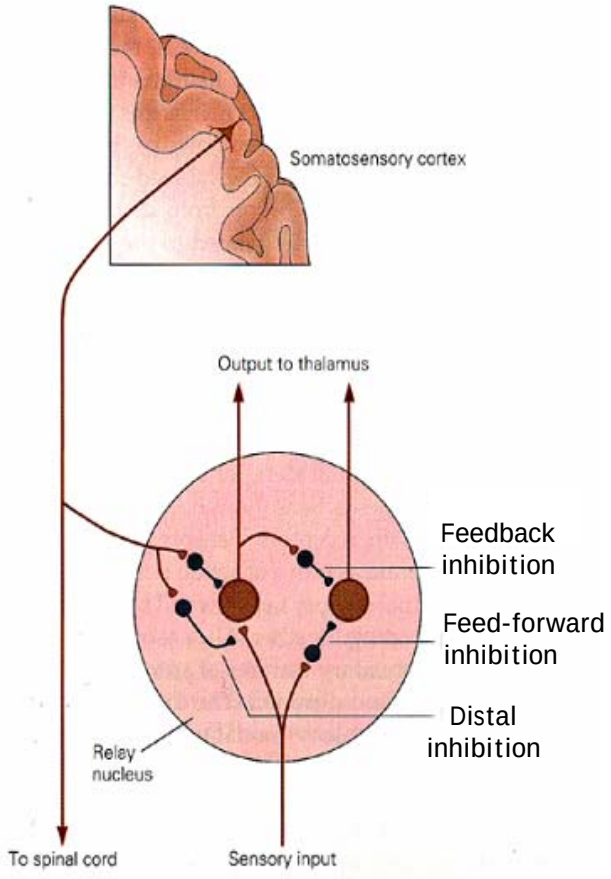
Figures: Silverthorn 2007

Inhibitory mechanisms in the relay neurons enhance contrast between stimuli

Lateral inhibition



Types of inhibitory mechanisms



Figures: Kandel 1999; Silverthorn 2007

TEMA 39. EL SISTEMA SOMATOSENSORIAL

1. Introducción.
   Sensibilidad somática y visceral. Somestesia.

2. Modalidades sensoriales somestésicas.
   Estímulos mecánicos.
      Sensibilidad táctil.
      Sensibilidad propioceptiva.
   Nocicepción (estímulos dolorosos).
   Termorrecepción.

3. Generalidades del sistema somatosensorial.
   Receptores sensoriales de la piel y receptores propioceptivos.
   Vías sensoriales. Sistemas somestésicos ascendentes.
      Sistema de los cordones posteriores.
      Sistema anterolateral o espinotalámico.
   Organización topográfica de receptores somatosensoriales en la piel.
   Córtex sensorial. Circunvolución postcentral.
      Organización somatotópica.

4. Detección de estímulos mecánicos.
   Especializaciones funcionales de receptores mecanosensoriales.
   Fibras nerviosas aferentes Aβ.
   Discriminación mecanosensorial.
      Técnicas de estudio e implicaciones funcionales.
   Plasticidad de la representación somatotópica cortical.

5. Termorrecepción.
   Receptores cutáneos para el frío y el calor.
      Papel en la termorregulación.
   Fibras nerviosas aferentes termorreceptivas.
      Fibras Aδ en receptores de frío.
      Fibras C en receptores de calor.
   Percepción termorreceptiva.
      Adaptación.

6. Nocicepción.
   Nociceptores.
      Especialización. Tipos.
         Mecánicos y térmicos.
         Polimodales.
         Viscerales o silentes.
   Tipos de dolor.
      Dolor rápido, inicial, primero, punzante.
         Fibras aferentes Aδ.
      Dolor lento, tardío, segundo, sordo.
         Fibras aferentes C.
   Agentes que activan o sensibilizan a los nociceptores.

7. Dolor cutáneo.
      Estimulación mecánica, térmica o química.

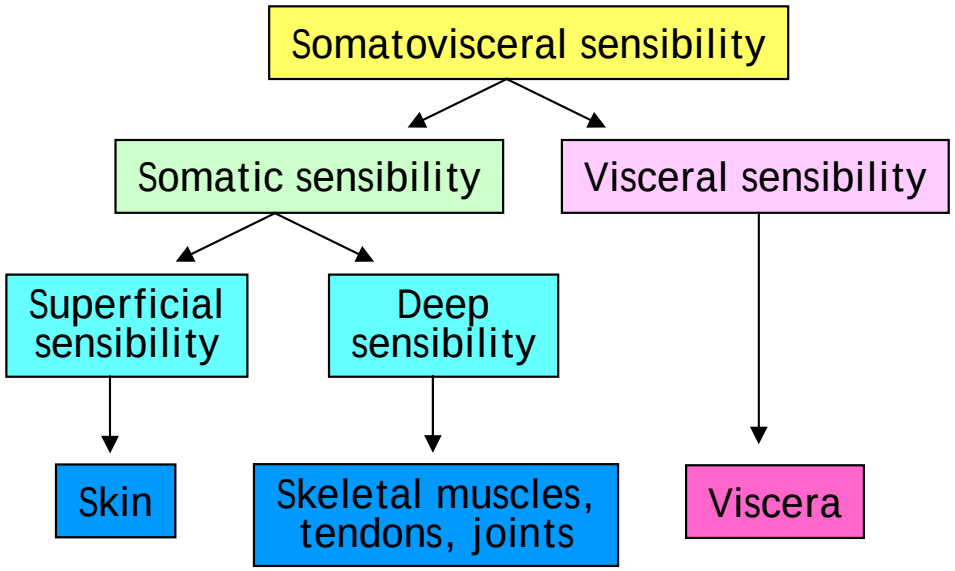
8. Dolor visceral.
    - Características generales del dolor visceral.
        - Localización; irradiación.
        - Síntomas asociados digestivos, autonómicos y musculares.
    - Papel general de la inervación aferente visceral.
        - Funciones de regulación.
            - Inervación preferentemente parasimpática.
        - Dolor visceral.
            - Inervación preferentemente simpática.
    - Dolor referido.
        - Dermatoma asociado.
        - Mecanismos.
            - Convergencia de información nociceptiva somática y visceral.

7. Modulación de la sensación dolorosa.
    - Sistema de control endógeno del dolor.
        - Vías nerviosas implicadas.
        - Péptidos opiáceos endógenos y sus receptores.
        - Integración medular de la información nociceptiva.

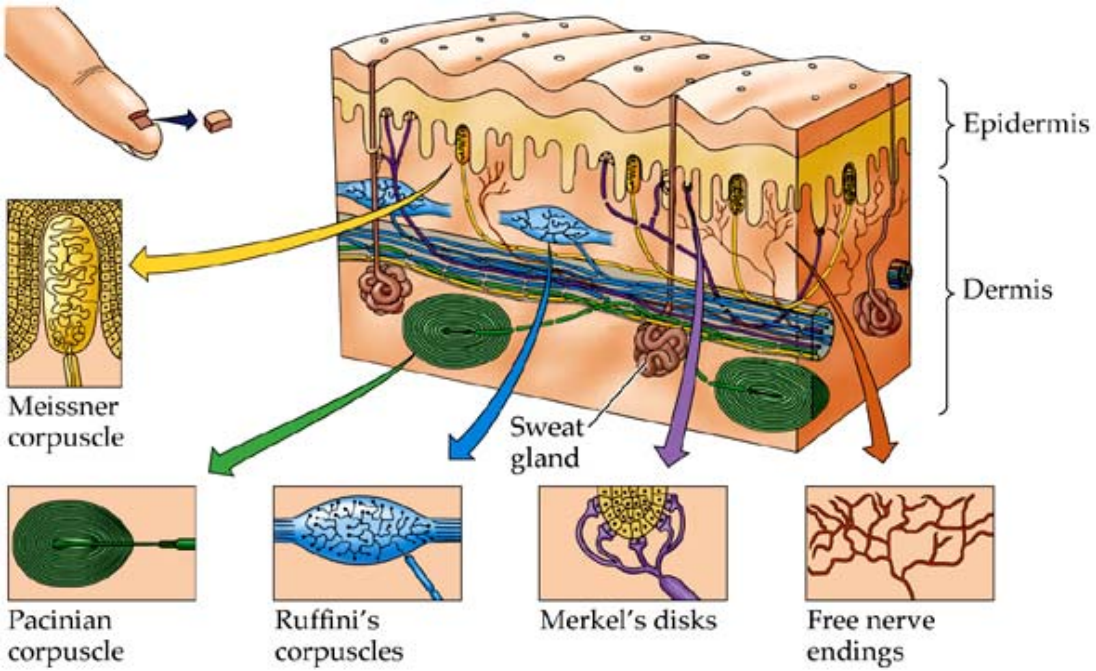
The somatic sensory system

Somatosensory system

- Detection of mechanical stimuli
- Detection of painful stimuli and temperature



Sensory receptors in the skin



Sensory modalities

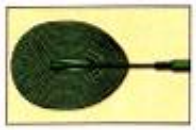
Touch

Proprioception

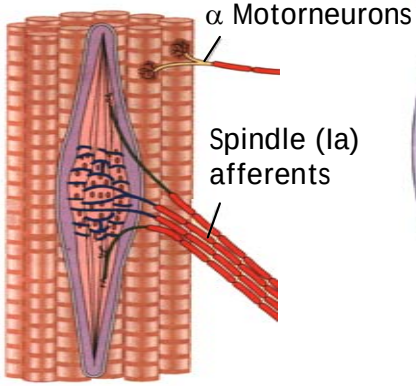
Nociception (pain)

Termoception

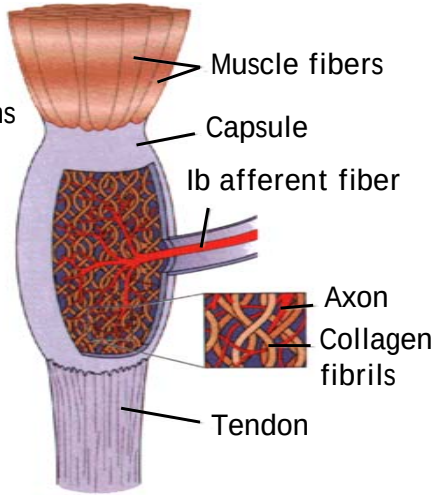
Proprioceptive receptors



Pacinian corpuscle in ligaments



Muscle spindle



Golgi tendon organ

Figures: Purves 2004

Properties of somatosensory receptors and fibers

The Major Classes of Somatic Sensory Receptors

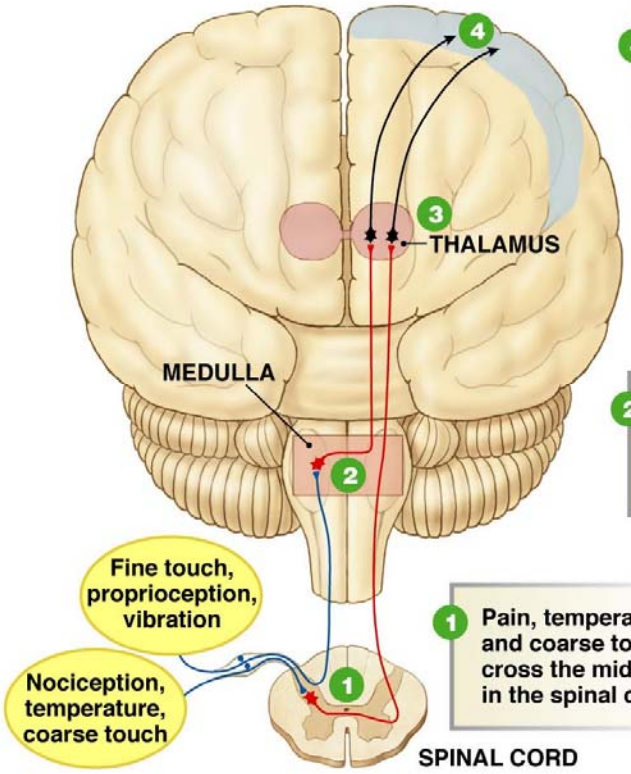
Receptor type	*Anatomical characteristics*	*Associated axons[a] (and diameters)*	*Axonal conduction velocities*	*Location*	*Function*	*Rate of adaptation*	*Threshold of activation*
Free nerve endings	Minimally specialized nerve endings	C, Aδ	2–20 m/s	All skin	Pain, temperature, crude touch	Slow	High
Meissner's corpuscles	Encapsulated; between dermal papillae	Aβ 6–12 μm		Principally glabrous skin	Touch, pressure	Rapid	Low
Pacinian corpuscles	Encapsulated; onionlike covering	Aβ 6–12 μm		Subcutaneous tissue, interosseous membranes, viscera	Deep pressure, vibration	Rapid	Low
Merkel's disks	Encapsulated; associated with peptide-releasing cells	Aβ		All skin, hair follicles	Touch, pressure	Slow	Low
Ruffini's corpuscles	Encapsulated; oriented along stretch lines	Aβ 6–12 μm		All skin	Stretching of skin	Slow	Low
Muscle spindles	Highly specialized (see Figure 8.5 and Chapter 15)	Ia and II		Muscles	Muscle length	Both slow and rapid	Low
Golgi tendon organs	Highly specialized (see Chapter 15)	Ib		Tendons	Muscle tension	Slow	Low
Joint receptors	Minimally specialized	—		Joints	Joint position	Rapid	Low

TABLE 10-5 Classes of Somatosensory Nerve Fibers

FIBER TYPE	FIBER CHARACTERISTICS	SPEED OF CONDUCTION	ASSOCIATED WITH
Aβ (beta)	Large, myelinated	30–70 m/sec	Mechanical stimuli
Aδ (delta)	Small, myelinated	12–30 m/sec	Cold, fast pain, mechanical stimuli
C	Small, unmyelinated	0.5–2 m/sec	Slow pain, heat, cold, mechanical stimuli

Figures: Purves 2004; Silverthorn 2007

Organization of the somatosensory system



4 Sensations are perceived in the primary somatic sensory cortex.

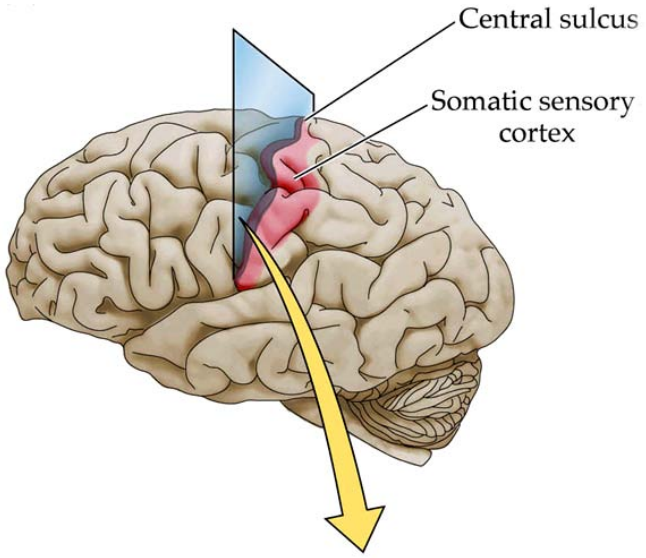
3 Sensory pathways synapse in the thalamus.

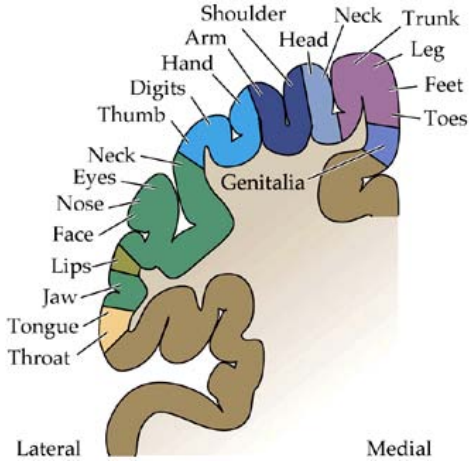
2 Fine touch, vibration, and proprioception pathways cross the midline in the medulla.

1 Pain, temperature, and coarse touch cross the midline in the spinal cord.

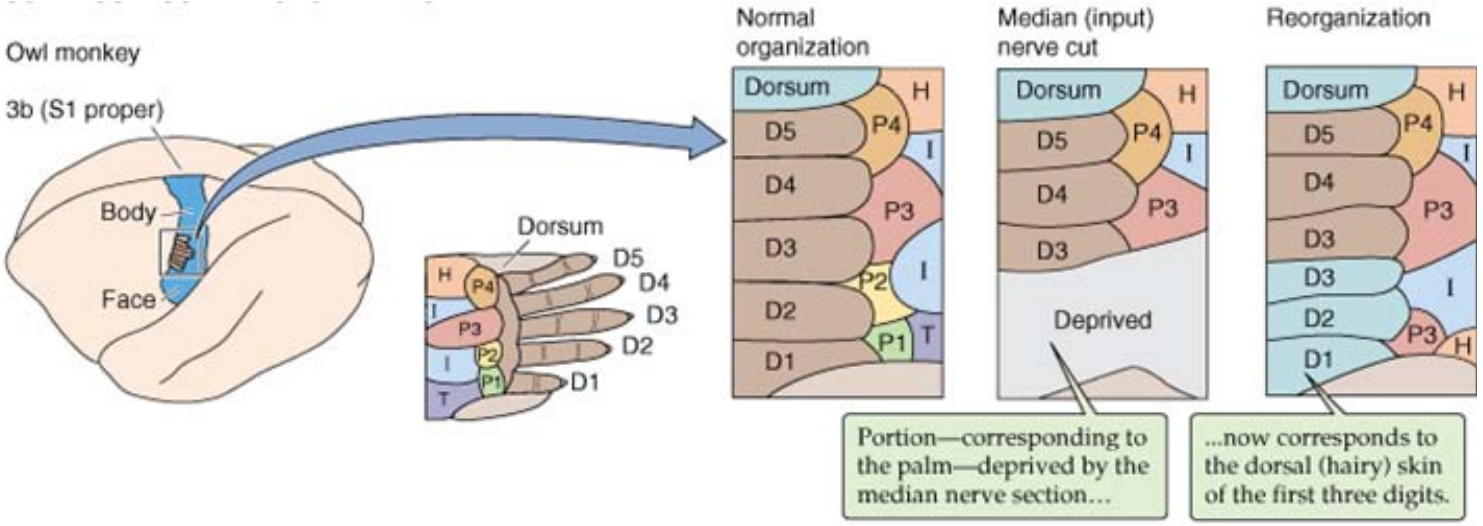
KEY
- Primary sensory neuron
- Secondary sensory neuron
- Tertiary neuron

Somatotopic organization





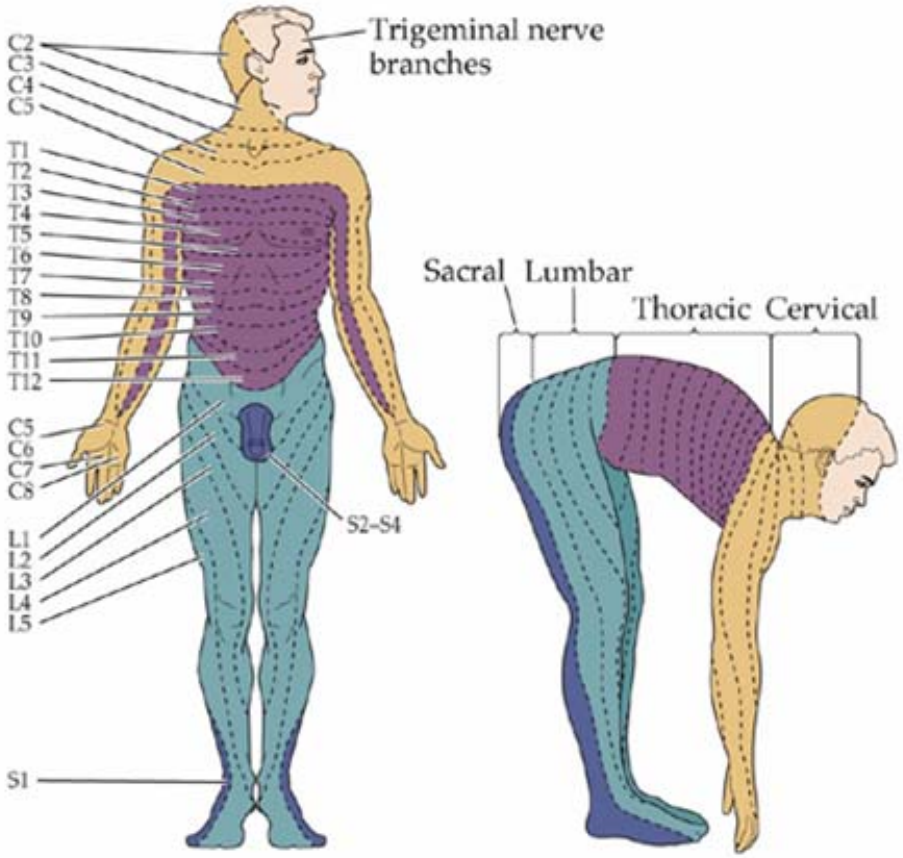
Plasticity in cortical organization



Figures: Purves 2004; Boron & Boulpapep 2005; Silverthorn 2007

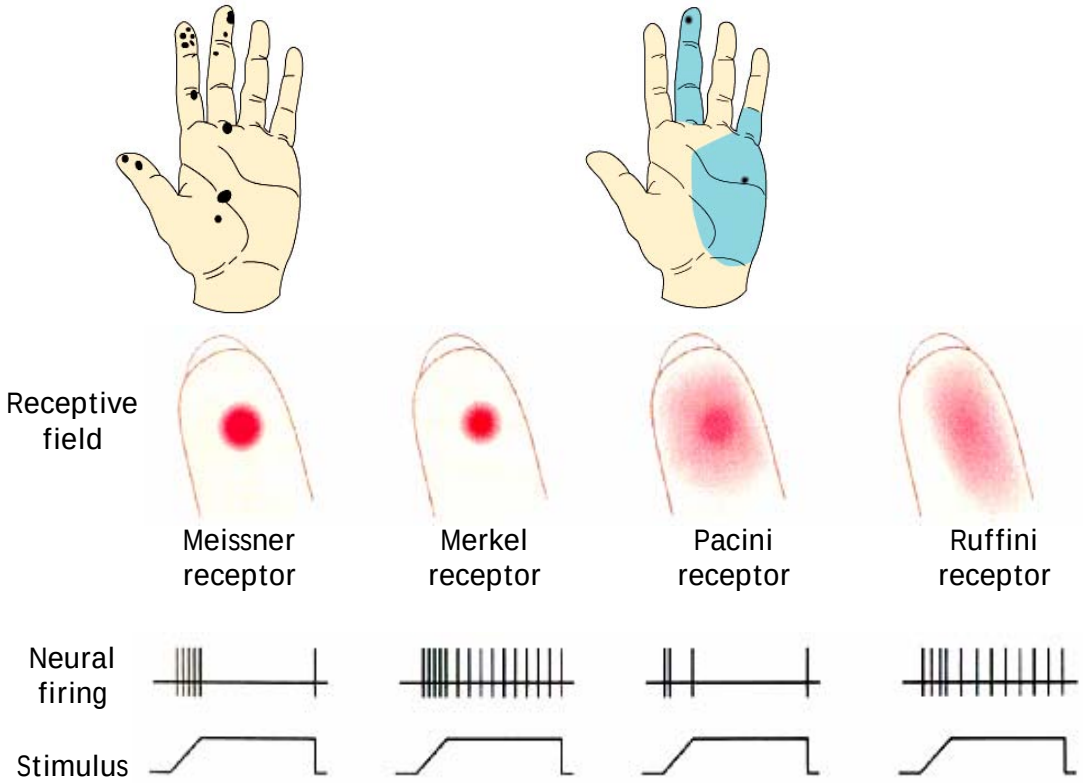
Topographic arrangement of somatosensory receptors in the skin

Dermatomal map



Detection of mechanical stimuli

Functional specializations of mechanosensory receptors

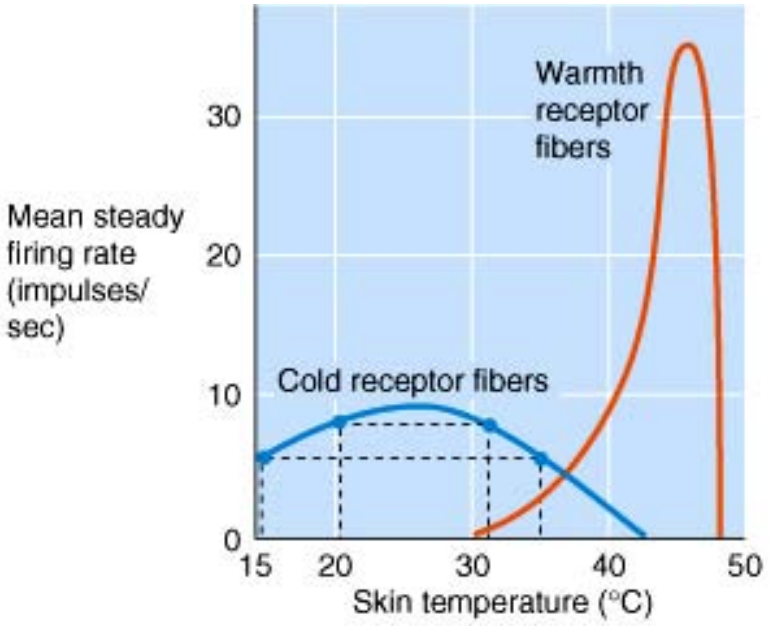


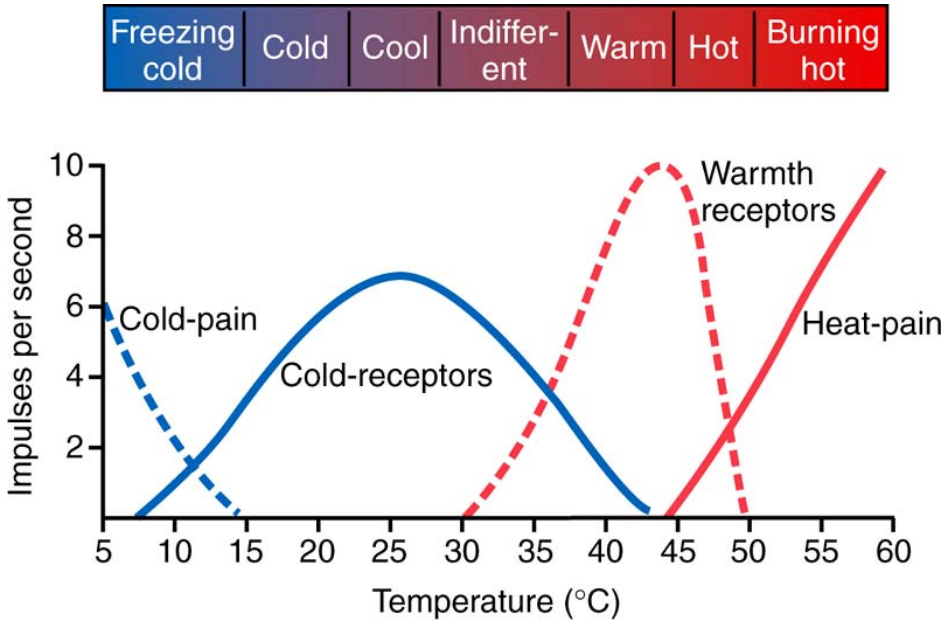
Figures: Kandel, 1999; Purves 2004; Boron & Boulpapep 2005

Thermoreceptors and nociceptors

Receptors for temperature (thermoreceptors) and pain (nociceptors) are specialized sensory receptors

Types of thermal receptors





Based on the axon characteristics:

Cold receptors: Fibers Aδ

Warmth receptors: Fibers C

Types of nociceptors

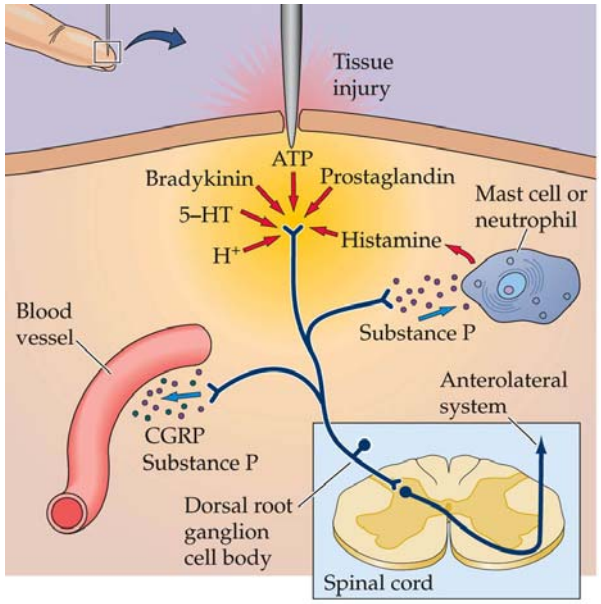
1. Mechanical nociceptors } *Aδ Fibers*
2. Thermal nociceptors } *Aδ Fibers*
3. Polymodal nociceptors *C Fibers*

Different types of axon fiber determines types of pain:

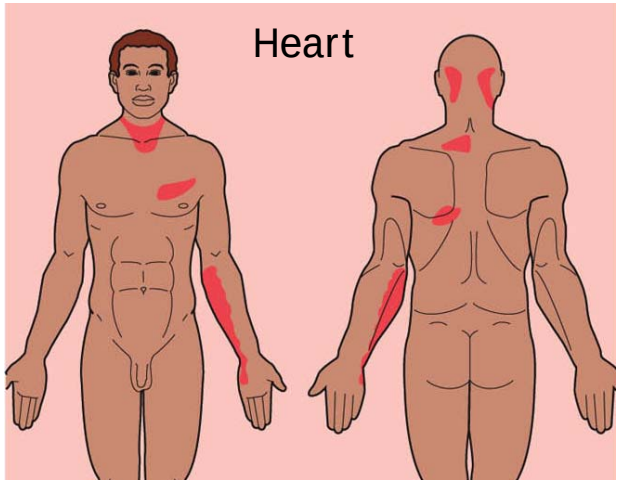
- Sharp, first pain (Aδ)
- Slow, burning pain (C)

Figures: Boron & Boulpapep 2005

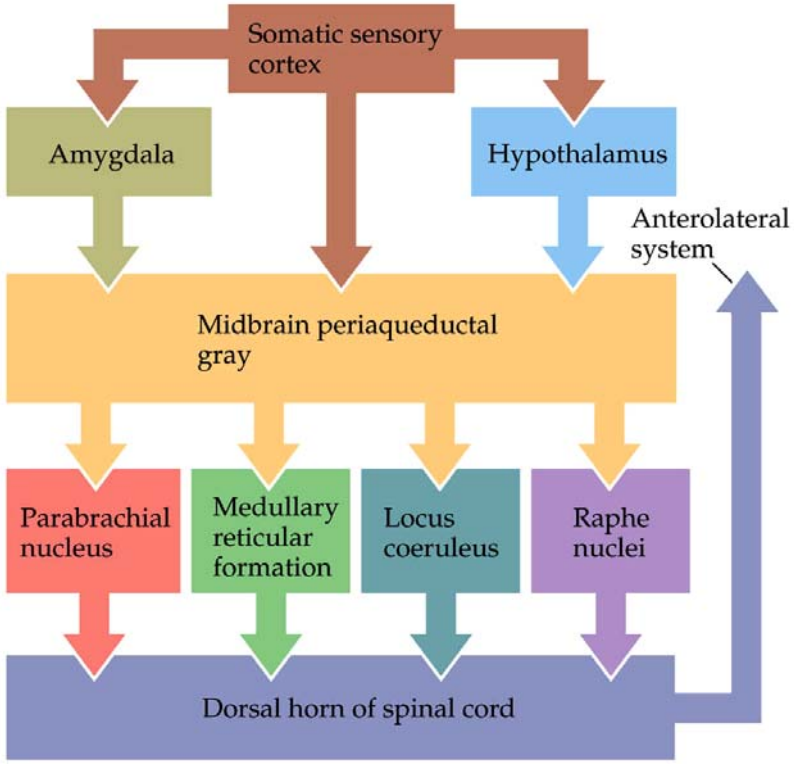
Agents that sensitize and activate nociceptors

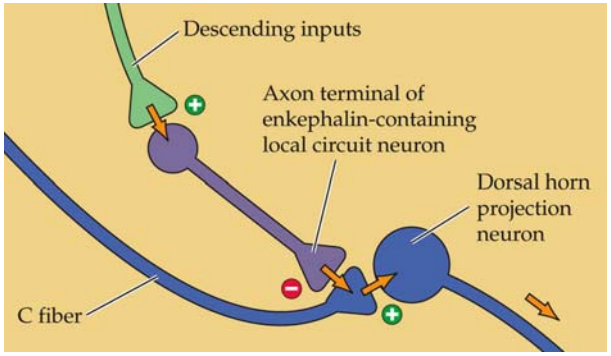


Referred visceral pain



Endogenous pain control system





Opioid receptors

κ, μ, and δ receptors

Endogenous opioid peptides

- Leucine-enkephalin
- Methionine-enkephalin
- β-endorphin
- Dynorphin
- α-neoendorphin

Figures: Purves 2004

TEMA 40. QUIMIORRECEPCIÓN

1. Recepción de estímulos químicos.
    - Características comunes. Funciones generales.
        - Estímulos químicos del medio externo.
            - Olfacción (sustancias en el aire), gustación (sustancias ingeridas),
            - Quimiorrecepción trigeminal (exposición facial a sustancias irritantes).
        - Estímulos químicos del medio interno.
            - Sustancias en vísceras o en sangre.

Olfato

2. Estímulos olfativos: odorantes.
    - Propiedades generales.
        - Tipos (volátiles, hidrosolubles o liposolubles).
        - Mezclas complejas $\Rightarrow$ Olor único.
        - Diferencia en umbrales.
    - Modalidades sensoriales: Dificultad para su determinación.
    - Sensibilidad del sistema de olfacción. Discriminación ($\approx 10^4$ olores percibidos).

3. Morfología funcional.
    - Fosas nasales.
    - Epitelio olfatorio.
        - Células receptoras, células de soporte.
        - Mantenimiento del epitelio olfativo.
            - Regeneración neuronal, implicaciones clínicas.
    - Bulbo olfatorio.

4. Transducción de la señal olfativa.
    - Transducción químico-eléctrica. Potencial de receptor.
    - Receptores de membrana y cascada de señalización intracelular. Amplificación.

5. Codificación de la información olfativa.
    - En las neuronas receptoras.
        - Variabilidad y expresión diferencial de los receptores de membrana.
            - Relaciones receptor molecular $\Leftrightarrow$ receptor celular.
            - Propiedades combinatorias.
    - Mapa de olores en el bulbo olfatorio (glomérulos).
    - Codificación espacial y temporal: Husmeo; adaptación.

6. Procesamiento central de la información olfativa.
    - Discriminación consciente de olores: Córtex orbitofrontal.
        - Vía directa: Receptor $\rightarrow$ bulbo olfatorio $\rightarrow$ cortex piriforme.
        - Vía a través del tálamo.
    - Aspectos emotivos de la sensación olfativa.
        - Proyecciones límbicas: Amígdala, hipotálamo, hipocampo.
    - Peculiaridades de la organización en el sistema olfatorio.

7. Respuestas fisiológicas y comportamentales a odorantes.

Gusto

8. Estímulos gustativos: sabores.
    - Propiedades generales.
        - Tipos (hidrosolubles o liposolubles).
            - Mezclas complejas ⇒ Sabor único.
            - Diferencia en umbrales.
    - Modalidades sensoriales: Dificultad de clasificación.
        - Dulce, salado, ácido, amargo, umami.

9. Morfología funcional.
    - Papilas gustativas.
    - Botones o corpúsculos gustativos.
        - Células receptoras. Regeneración.
        - Fibras nerviosas aferentes.

10. Transducción químico-eléctrica de la señal gustativa.
    - Bases moleculares según modalidad.
        - Canales iónicos: salado, ácido, umami.
        - Receptores de membrana: dulce, amargo, umami.

11. Codificación de la información gustativa.
    - Variabilidad y expresión diferencial de los receptores de membrana.
        - Relaciones receptor molecular ⇔ receptor celular.
        - Propiedades combinatorias.
    - Codificación temporal (adaptación).

12. Procesamiento central de la información gustativa.
    - Vías periféricas y centrales.
    - Conexión con el sistema nervioso autónomo.

13. Sensación de sabor.
    - Combinación de entradas gustatorias, olfatorias y somatosensoriales.
    - Respuestas fisiológicas y comportamentales a los sabores.

Quimiorrecepción Trigeminal

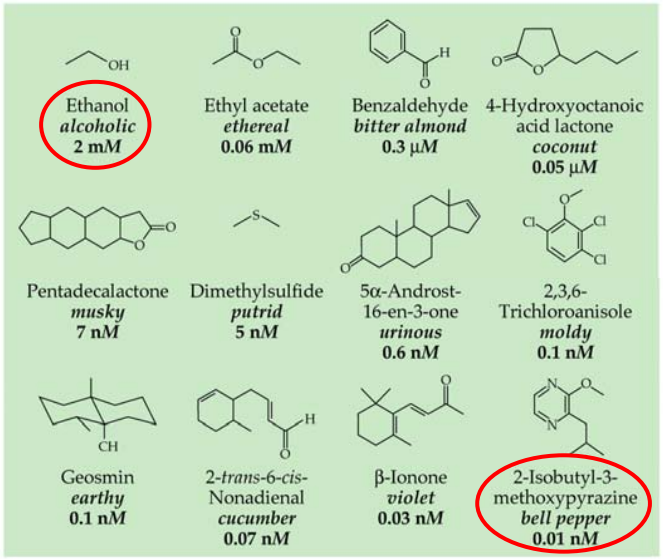
14. Estímulos.
    - Sustancias irritantes.

15. Morfología funcional.
    - Ramas del nervio trigémino.
    - Receptores nociceptivos polimodales.

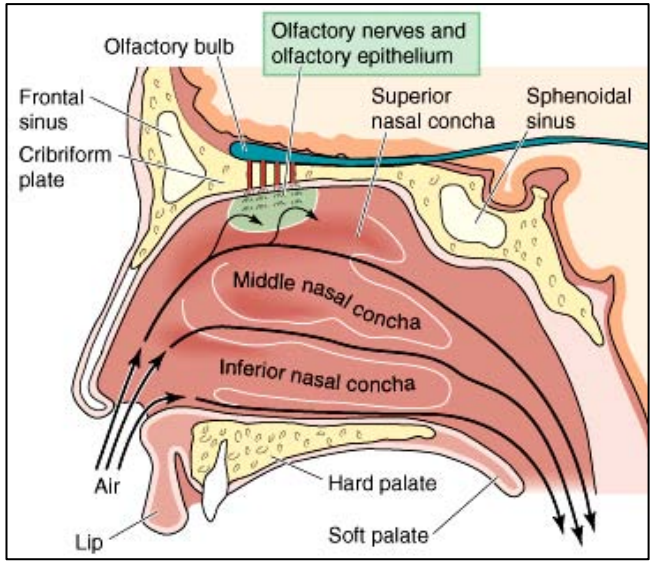
16. Repuestas comportamentales a estímulos irritantes.

Olfaction

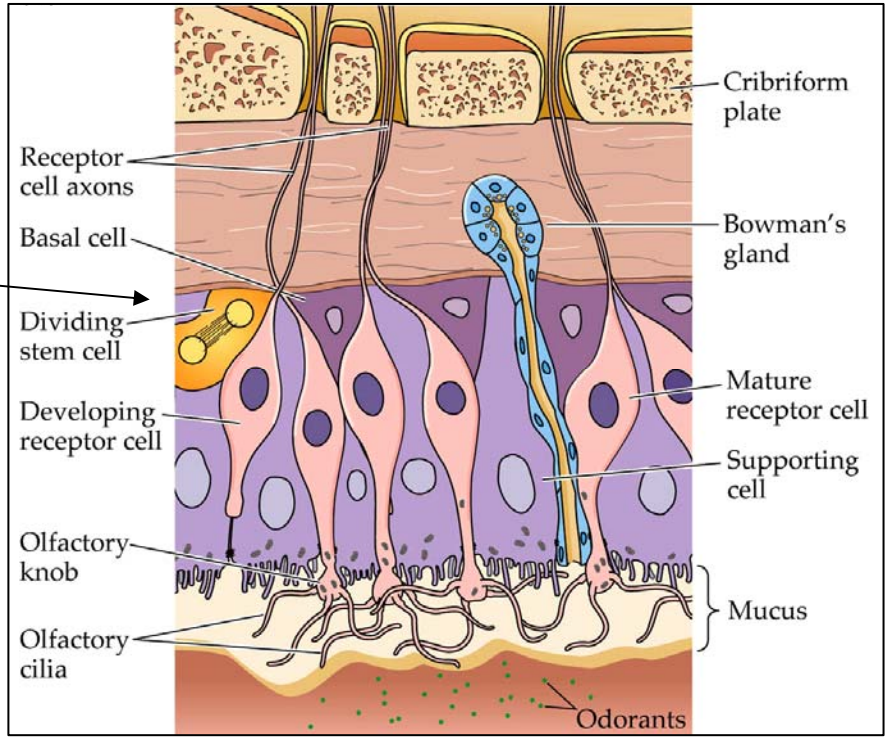
Odorants

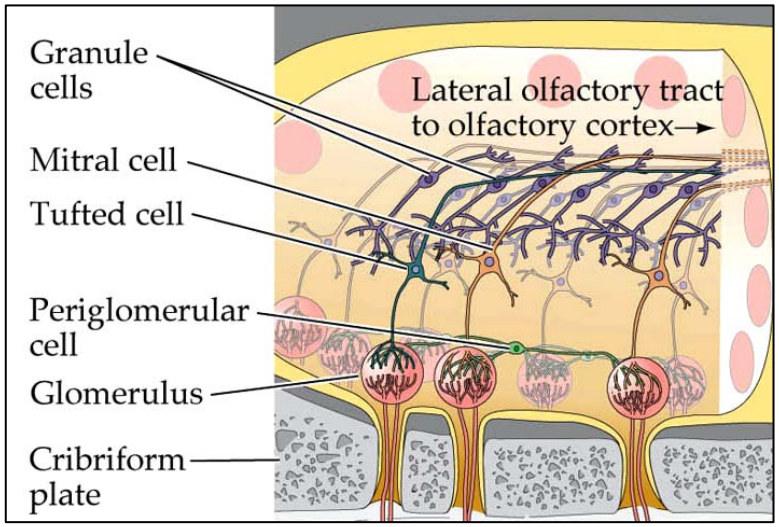


Functional morphology



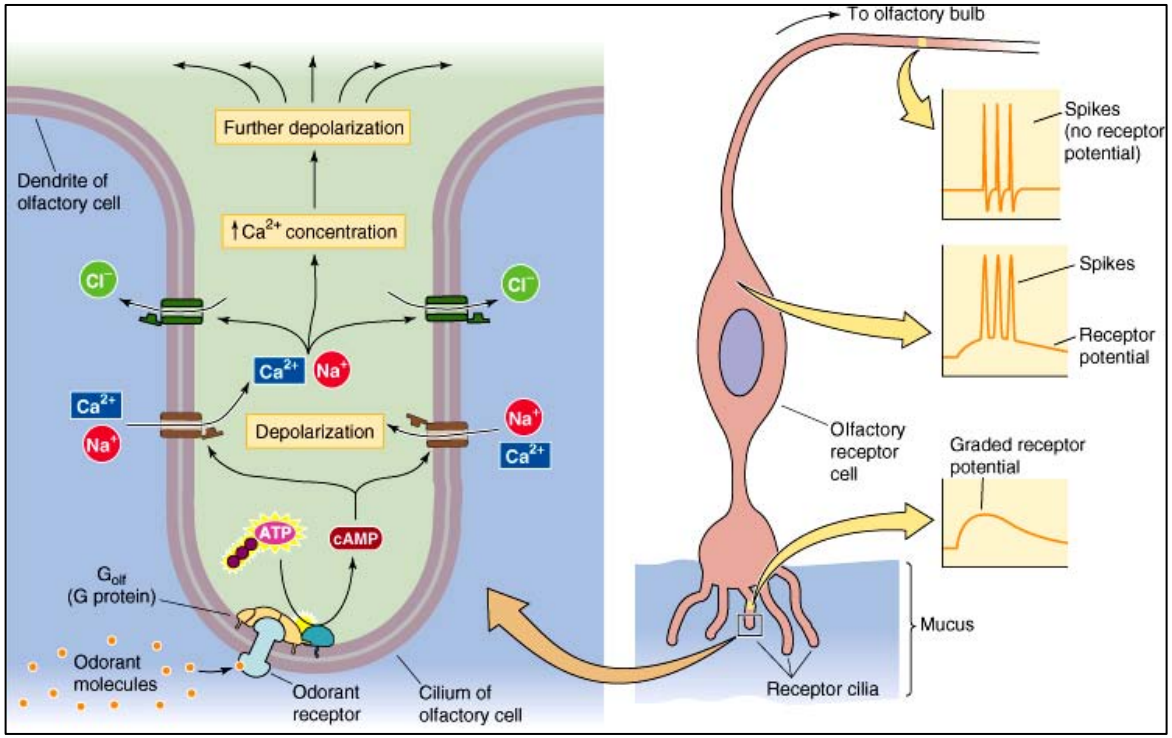
Regeneration: average life span 1-2 months





Figures: Purves 2004; Boron & Boulpapep 2005

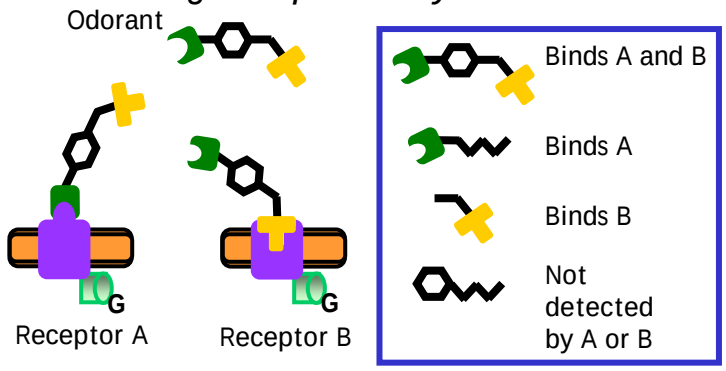
Olfactory transduction

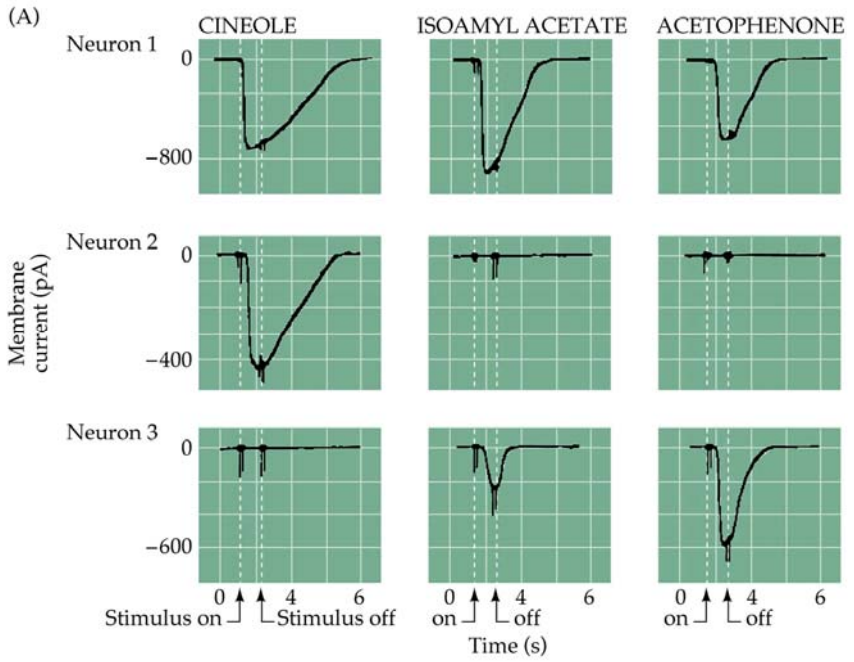


Coding the olfactory stimulus

1 olfactory receptor cell ⇔ ≈1 odorant receptor

Ligand specificity

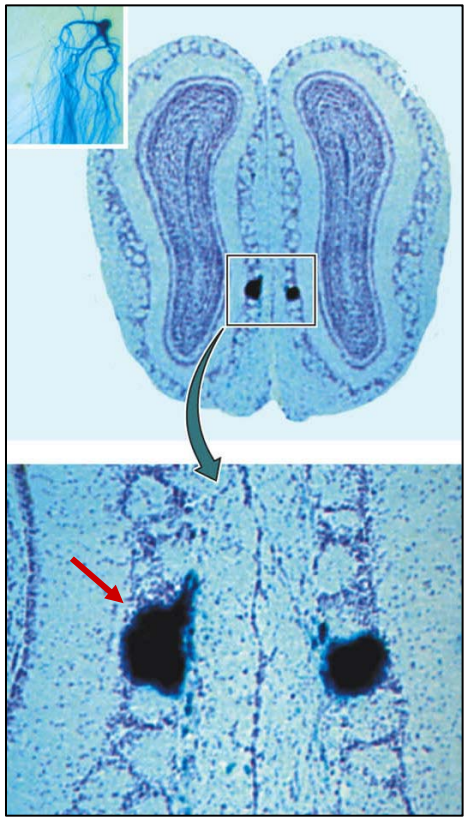


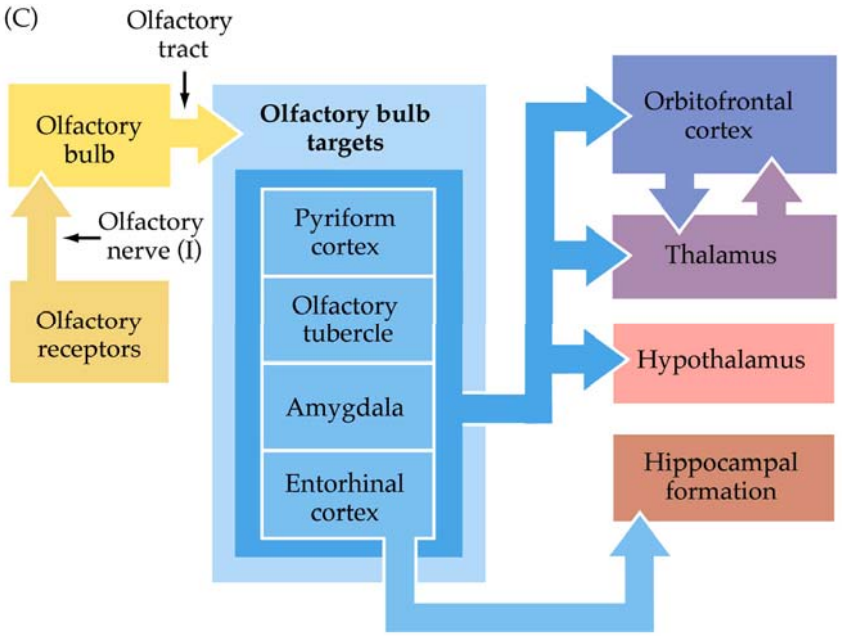


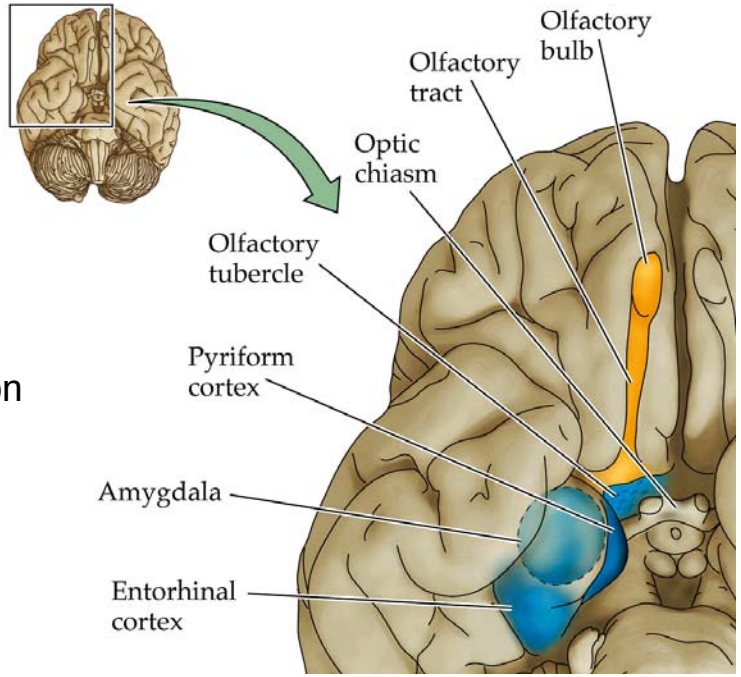
Figures: Purves 2004; Boron & Boulpapep 2005

Central processing of olfactory information

Olfactory bulb spatial map







Properties:

1) Direct pathway to cortex
(Phylogenetically *old functional system*)

2) Pathway to cortex through thalamus

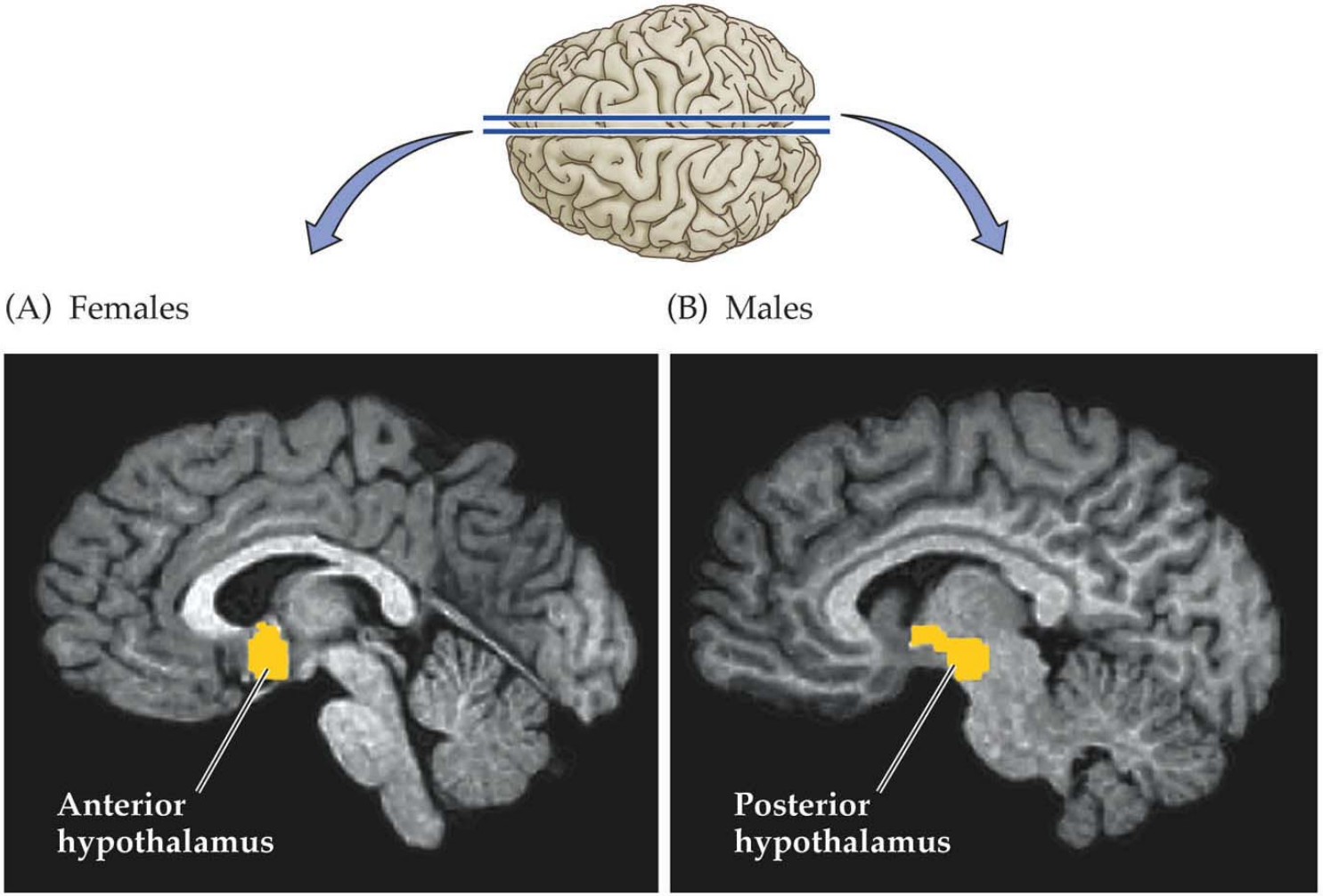
} Conscious discrimination of odors

3) Limbic projections → Emotive aspects

4) Hippocampus → Memory aspects

Figures: Purves 2004

Activation in hypothalamus after exposure to an estrogen- or androgen-containing odor mix.



Figures: Purves 2004

Taste system

Tastants

Salt → Electrolite balance (NaCl, 10 mM)

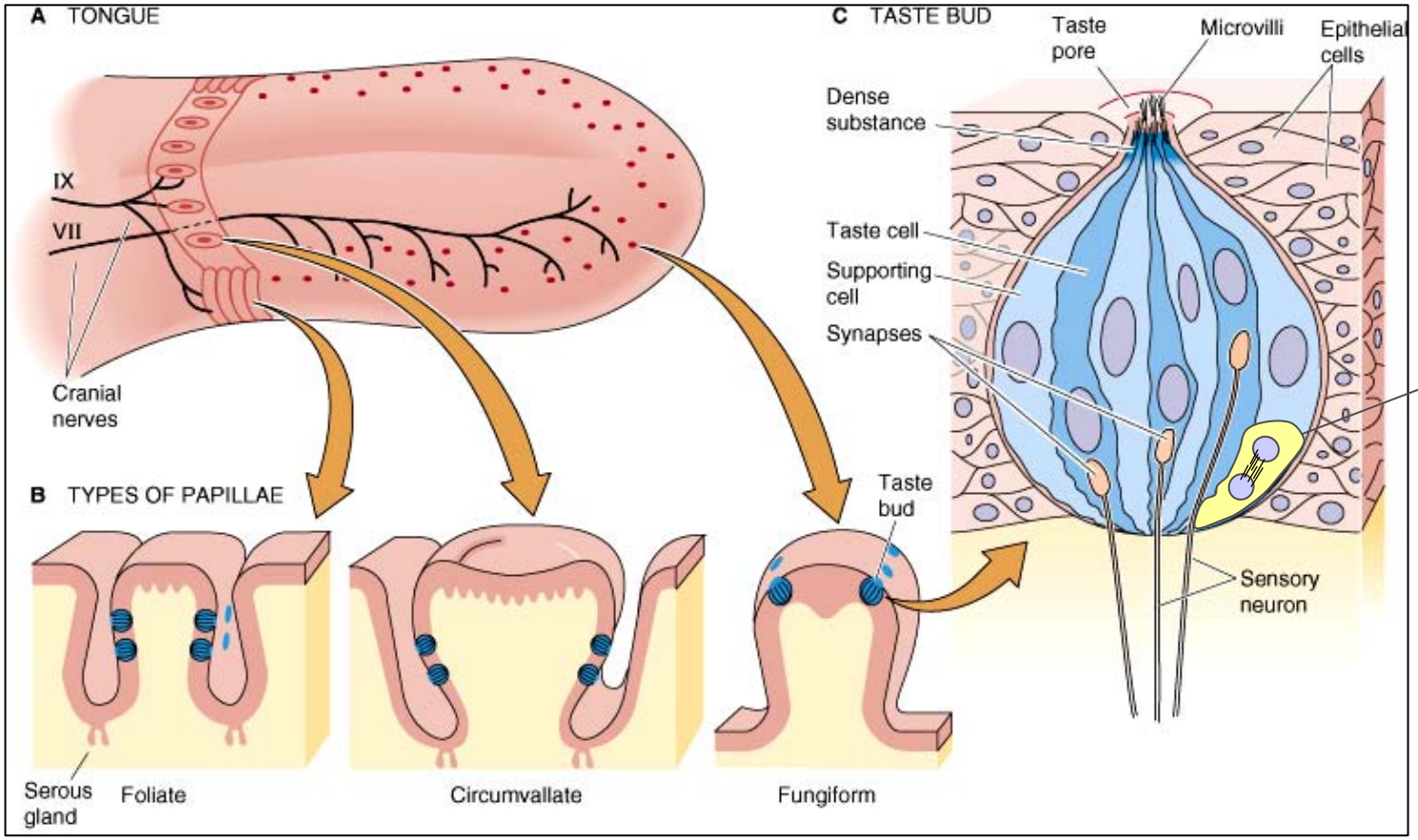
Acids → Food palatability (Citric acid, 2 mM)

Sugars → Energy (Sucrose, 20 mM)

Glutamate → Protein synthesis

Bitter tasting molecules → Poison signaling
Alkaloids (Strychnine, 0.0001 mM)

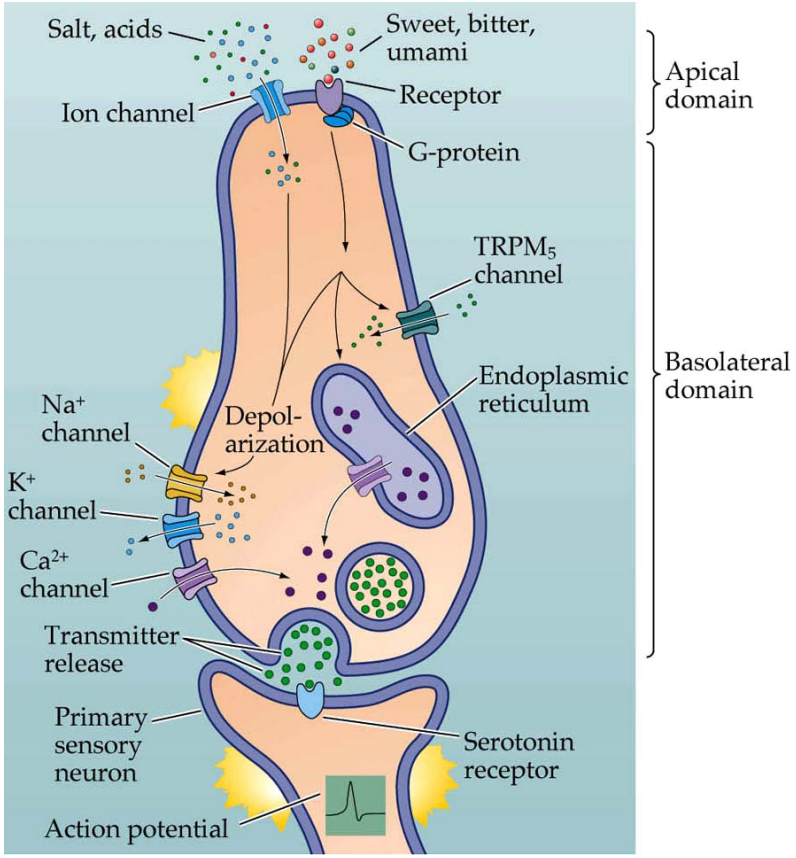
Functional morphology

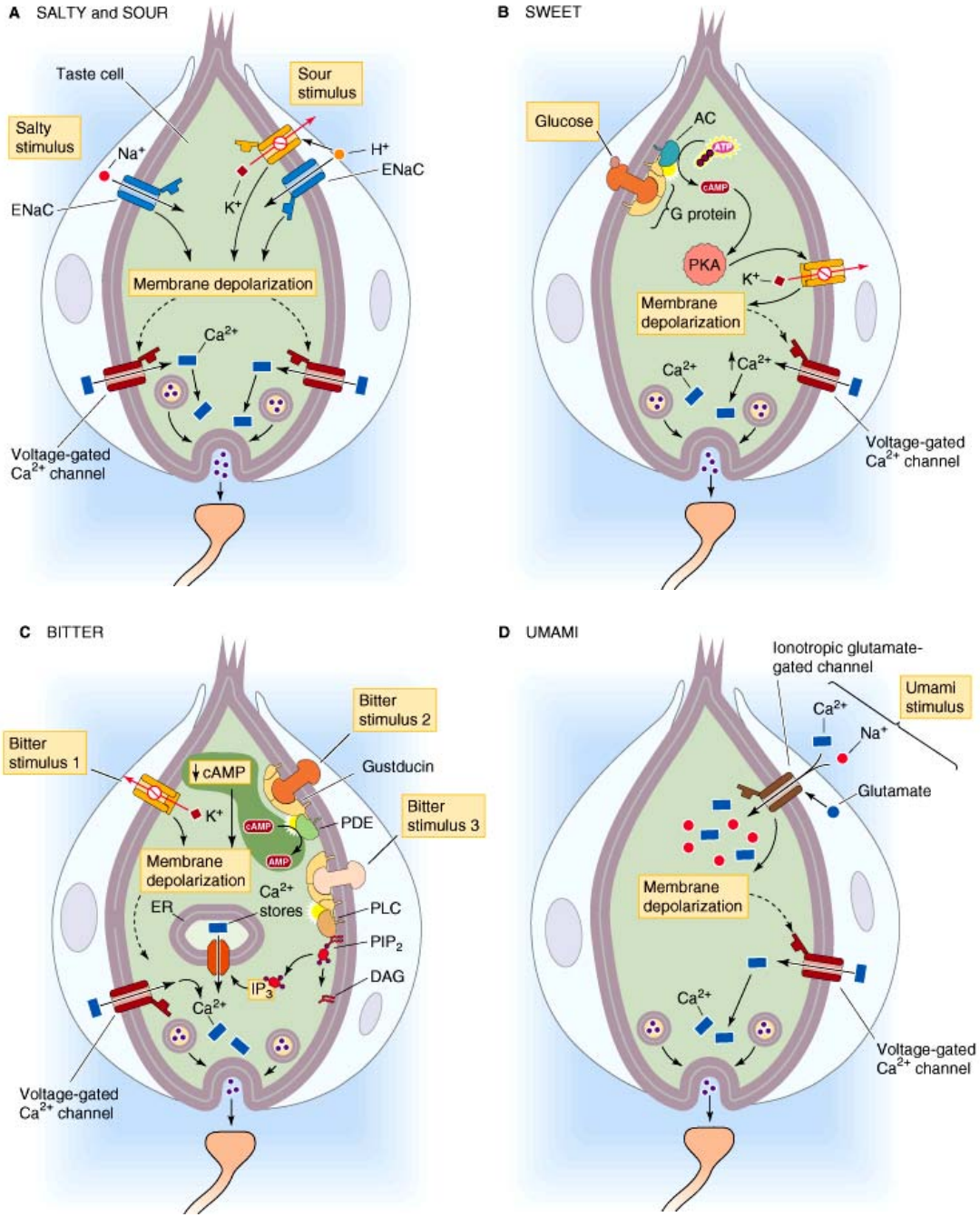


Regeneration: average life span 10 days

Figures: Purves 2004; Boron & Boulpapep 2005

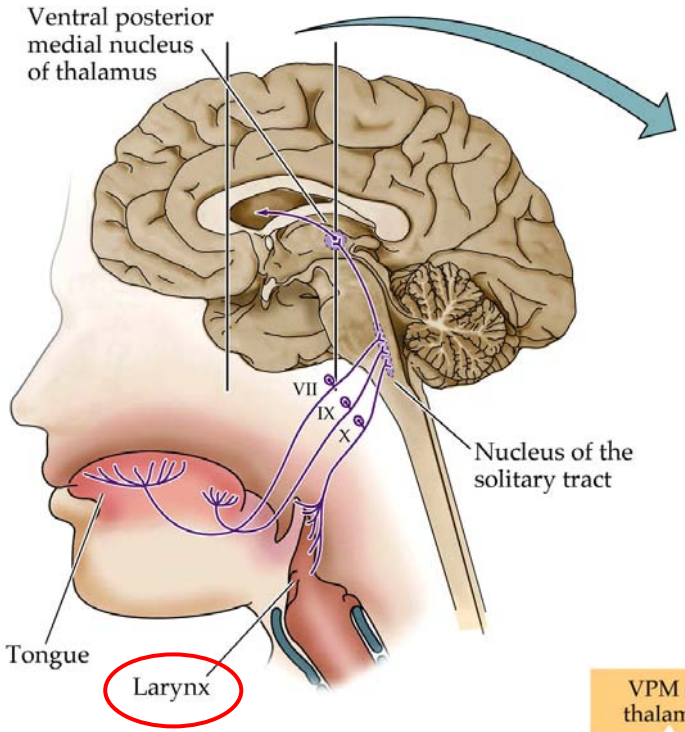
Taste transduction

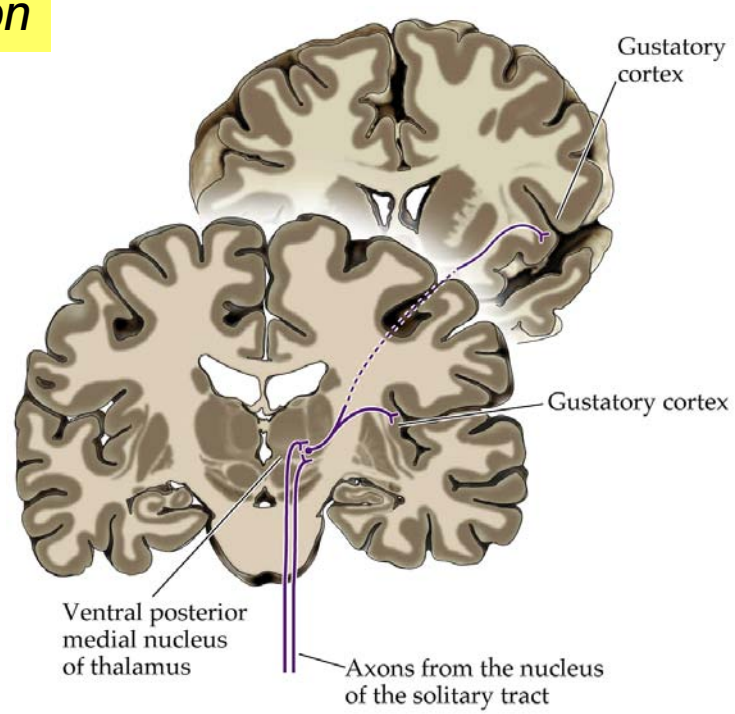


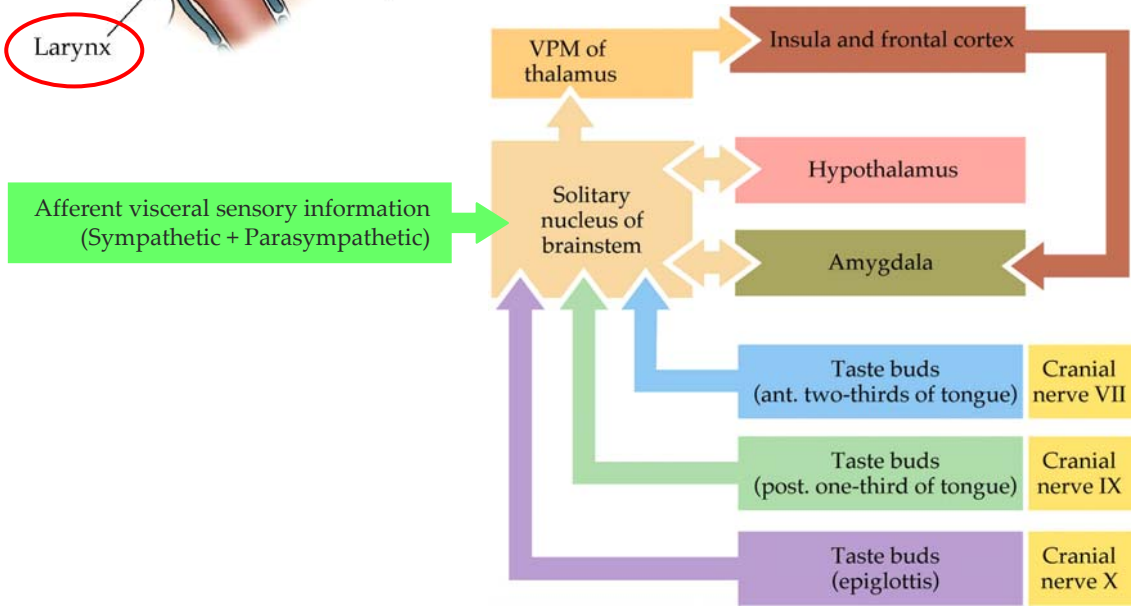


Figures: Purves 2004; Boron & Boulpapep 2005

Central processing of gustatory information

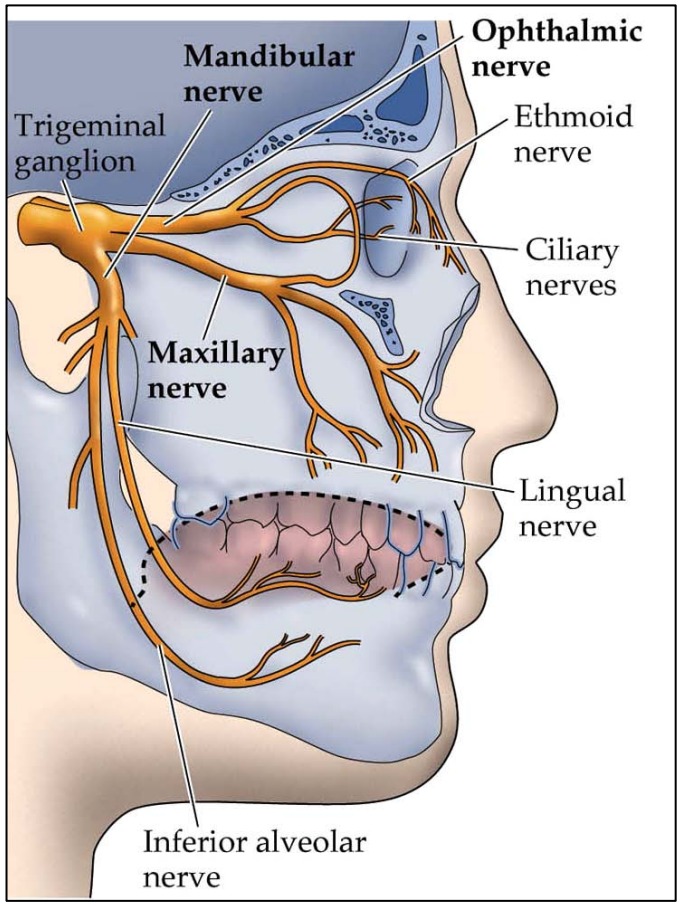






Figures: Purves 2004

Trigeminal chemoreception

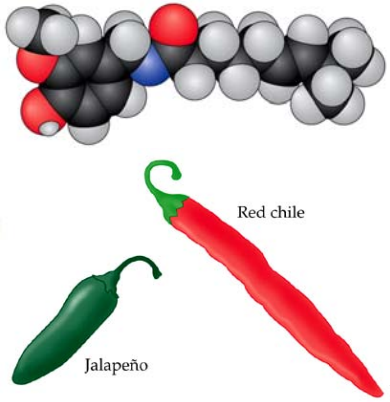


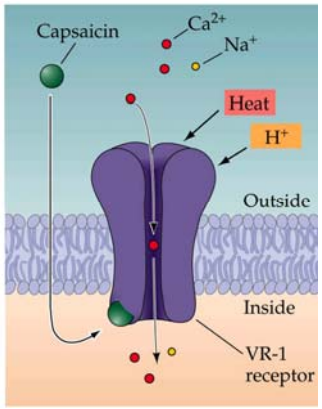
Properties:

1) Mediated by **polymodal nociceptive neurons**

2) Activated by **irritants**:

air pollutants (sulfur dioxide)
ammonia (smelling salts)
ethanol (liquors)
acetic acid (vinegar)
carbon dioxide (in soft drinks)
capsaicin





3) **Higher thresholds** than gustatory or olfactory receptors

- NaCl 0.1 M → salty taste
- NaCl 1 M → irritant

4) **Function**: Triggers protective reactions.

Figures: Purves 2004

TEMA 41. AUDICIÓN Y EQUILIBRIO

Sistema auditivo

1. Estímulo auditivo
    - Propiedades del sonido.
        - Amplitud, frecuencia, Timbre.
    - Espectro de sonidos audibles.
    - Audiometría.
        - Audición óptima: frecuencias de 3kHz.

2. Estructura funcional del oído.
    - Oído externo.
        - Amplificación de la señal.
    - Oído medio.
        - Ajuste de impedancias acústicas.
    - Oído interno.
        - Estructura de la cóclea.
            - Cámaras o escalas: Vestibular, timpánica y media.
            - Membranas: Tectorial y basilar.
                - Mapa topográfico de frecuencias: tonotopia.
        - Estructura del órgano de Corti.
            - Células ciliadas: Tipos, localización, inervación.
                - Células ciliadas internas:
                    - Receptores sensoriales.
                - Células ciliadas externas:
                    - Electromotilidad→"amplificador coclear"

3. Propiedades de resonancia mecánica de la membrana basilar.
    - Mecanismo de discriminación de frecuencias basado en posición.
        - Tonotopia.

4. Mecanismo de transducción en las células ciliadas.
    - Transducción mecano-eléctrica.
        - Especializaciones iónicas de la endolinfa y perilinfa.
    - Mecanismo de discriminación de frecuencias basado en respuesta eléctrica de células ciliadas.
        - Código de frecuencias en tiempo real ($\leq$ 3 kHz).

5. Procesamiento central de la información auditiva.
    - Organización en paralelo.
    - Organización tonotópica.
    - Integración de la información de los dos oídos.
        - Localización del sonido.
            - Diferencias temporales interaurales. Detector de coincidencia en la oliva superior medial.

Sistema vestibular

6. Estímulo vestibular:
    "Navegación" vestibular.

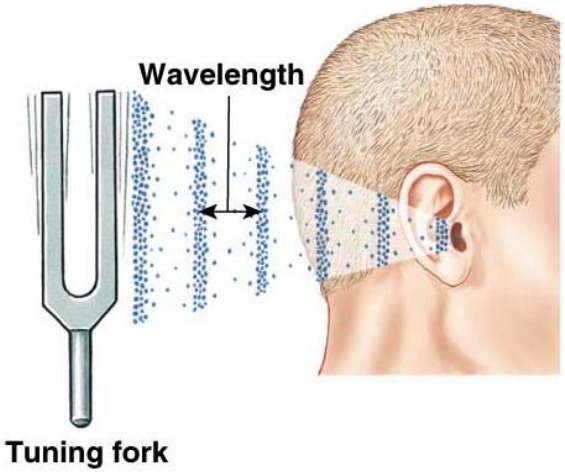
7. Estructura funcional.
    Órganos otolíticos: Utrículo, sáculo.
        Organización de las células ciliadas vestibulares: polarización, otolitos.
            Respuesta estática (posición de la cabeza).
            Respuesta a aceleración lineal (movimiento lineal).
    Canales semicirculares.
        Cúpula y ampula.
            Respuesta a la aceleración angular (movimientos circulares).

8. Codificación de la información vestibular.
    Transducción en las células ciliadas vestibulares.
    Respuesta eléctrica de las neuronas aferentes.

9. Procesamiento central de la información vestibular.
    Reflejos vestibulares.

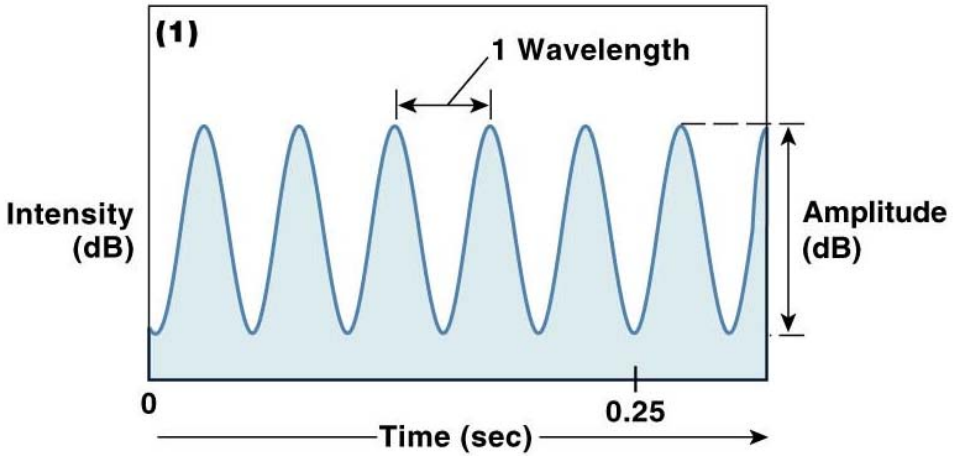
Auditory system

Auditory stimulus: Properties of the sound

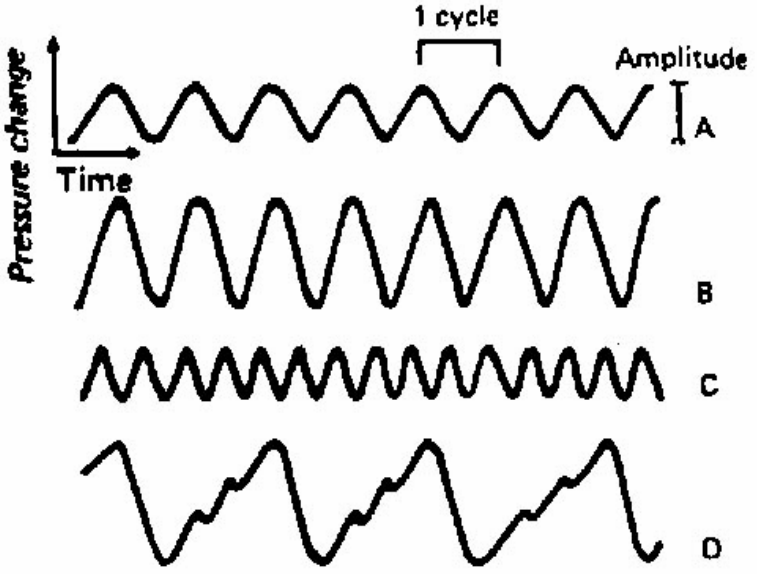


Frequency → cycles per second = Hertz

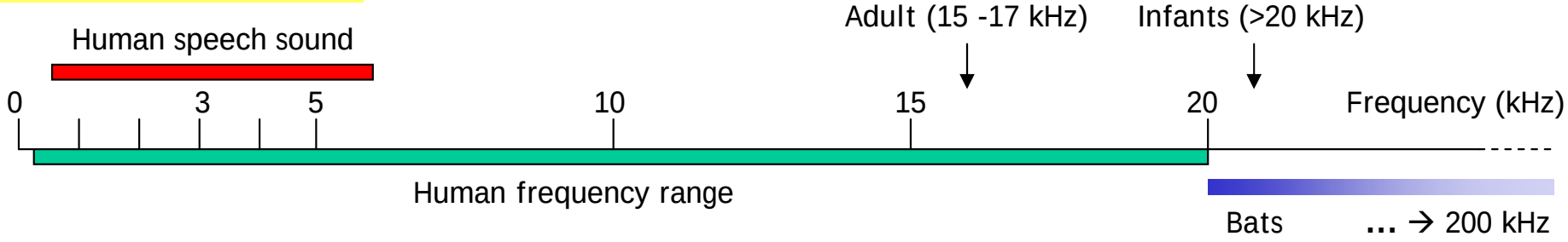
Amplitude → decibels. Number of dB = 20 • log (P/P_0)



Complex sound waves: *Timbre*

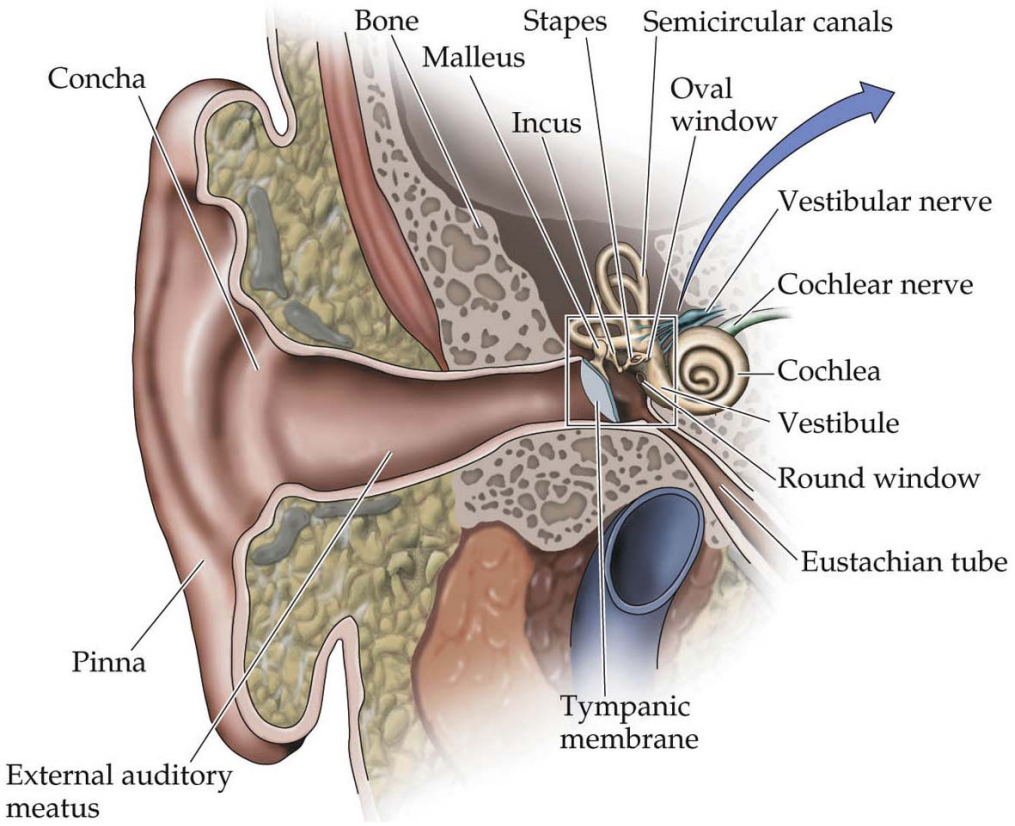


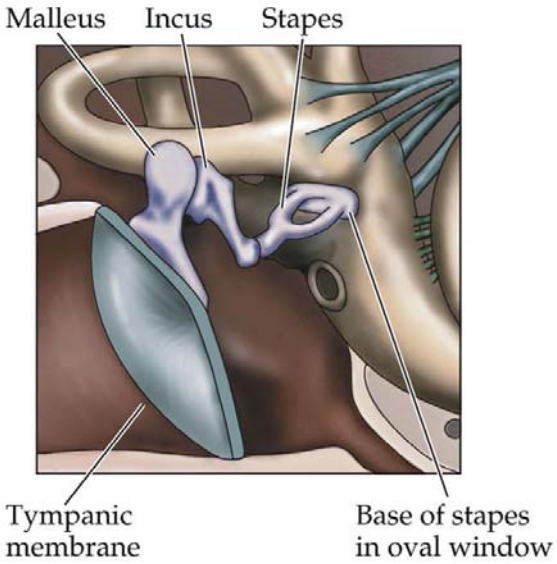
Frequency spectrum



Figures: Purves 2004; Boron & Boulpapep 2005, Silverthorn 2007

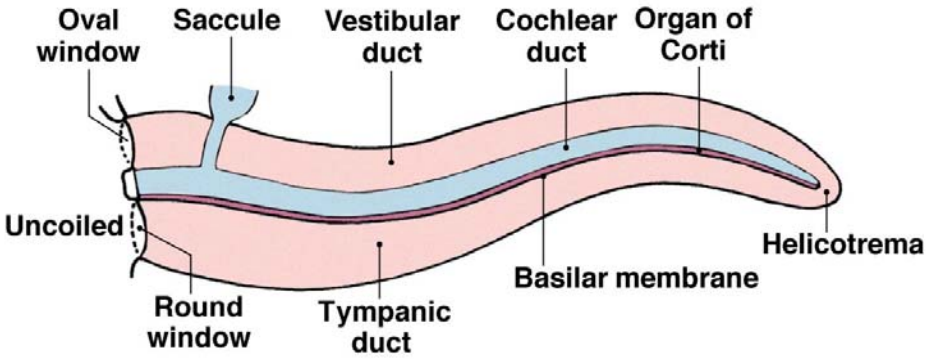
Functional morphology. Outer and middle ear

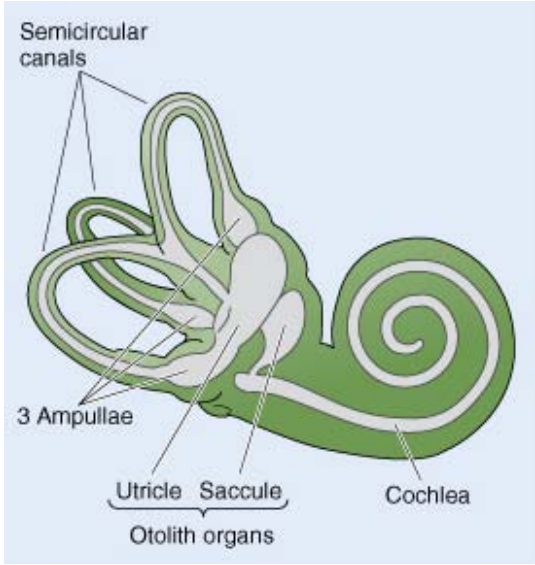




Impedance adjustment

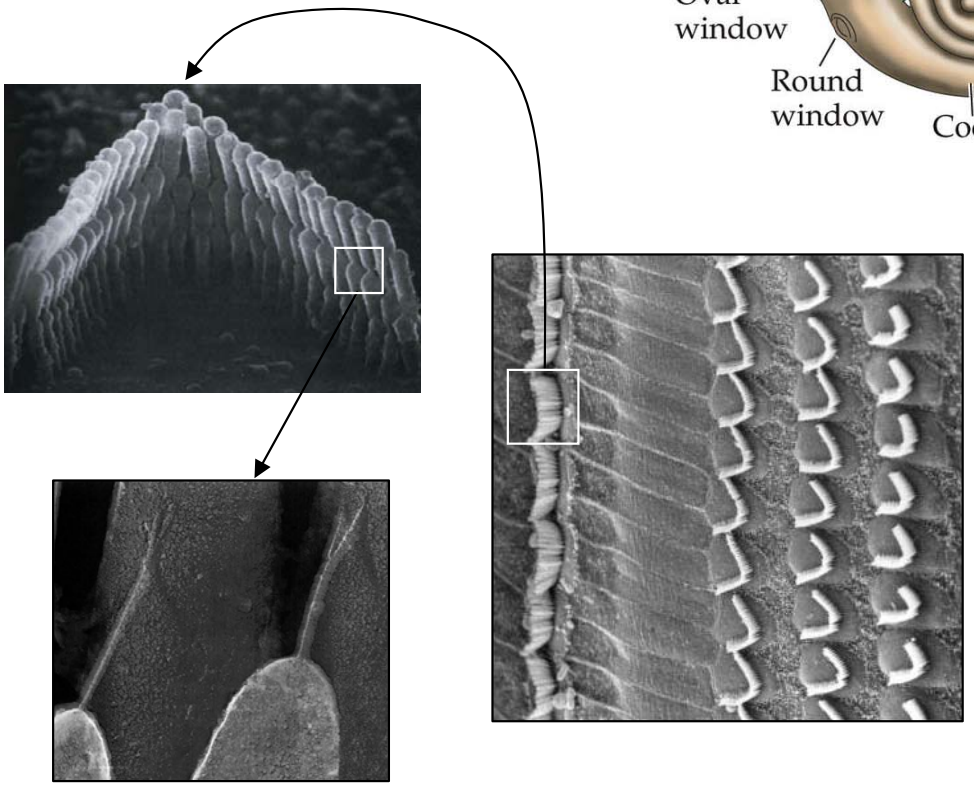
Faithful transmission of sound energy across the air-fluid boundary

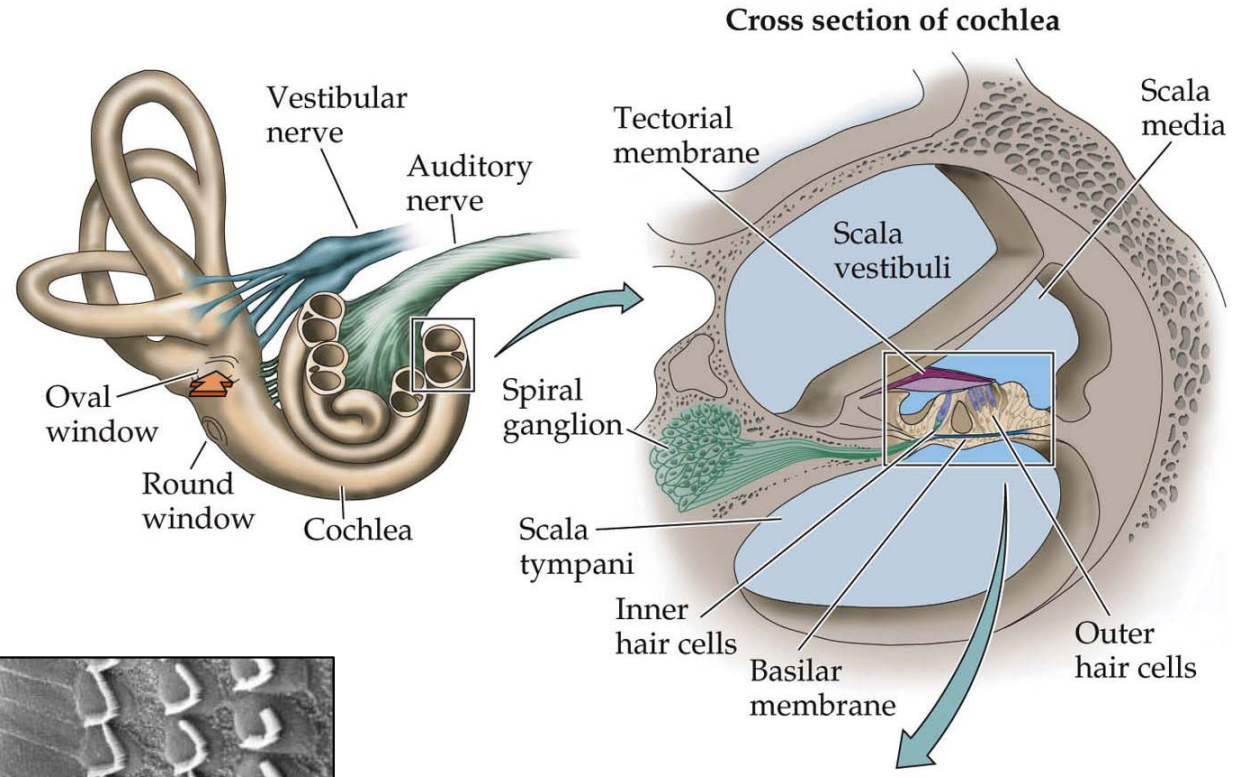


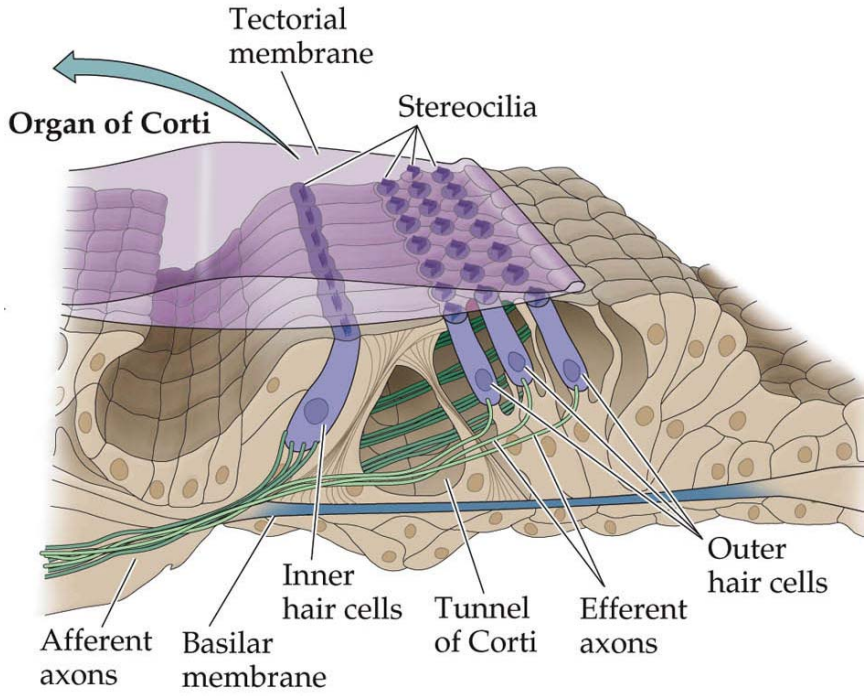


Figures: Purves 2004; Boron & Boulpapep 2005, Silverthorn 2007

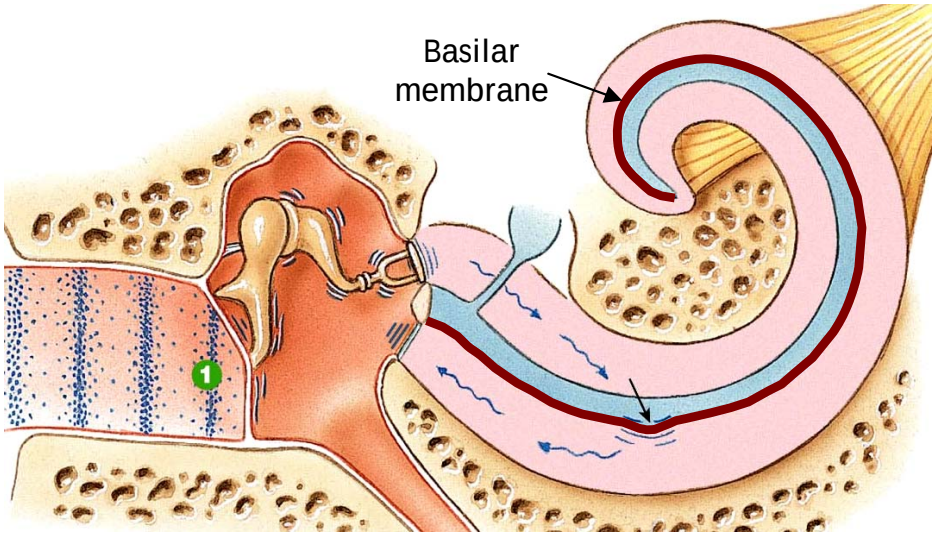
Functional structure. Inner ear

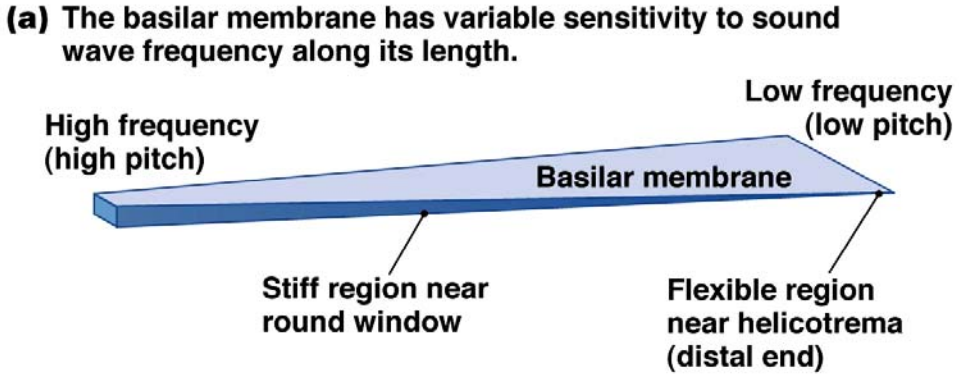




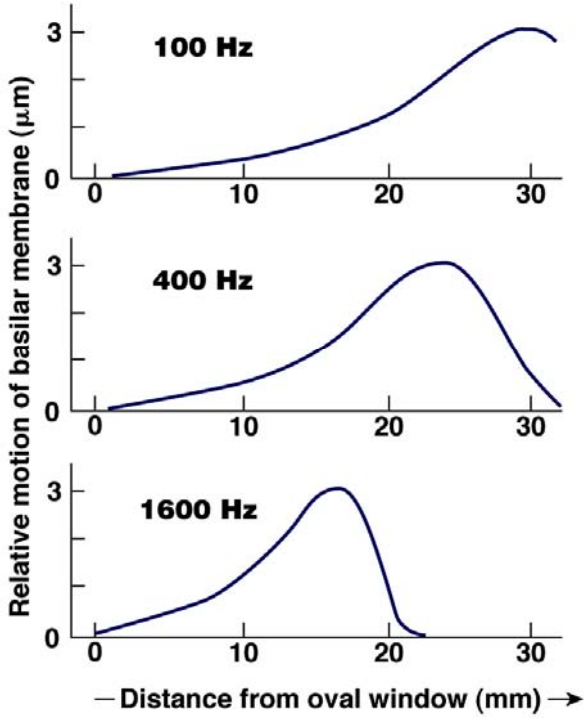


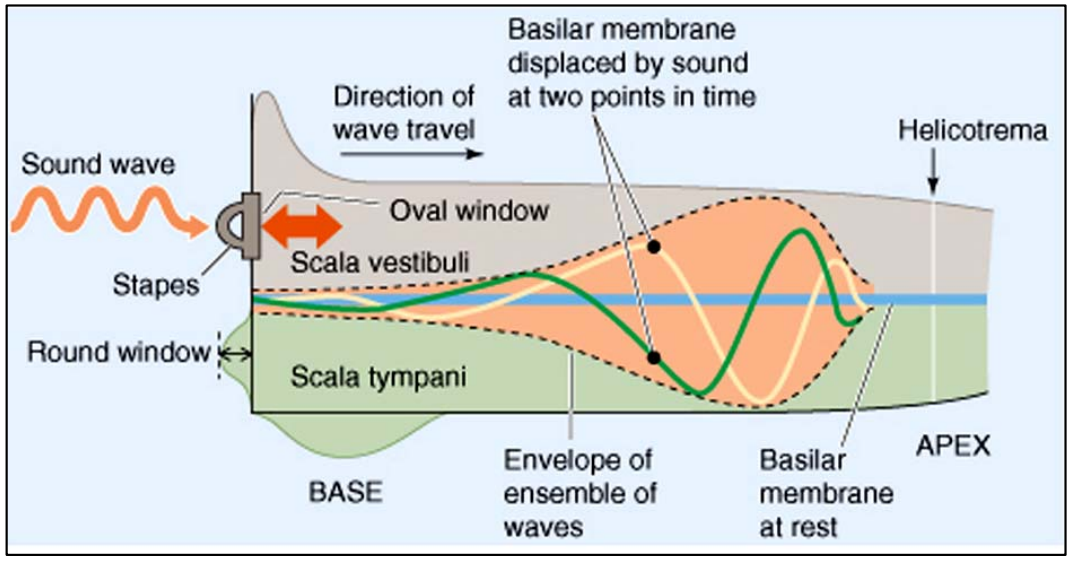
Figures: Purves 2004; Boron & Boulpapep 2005





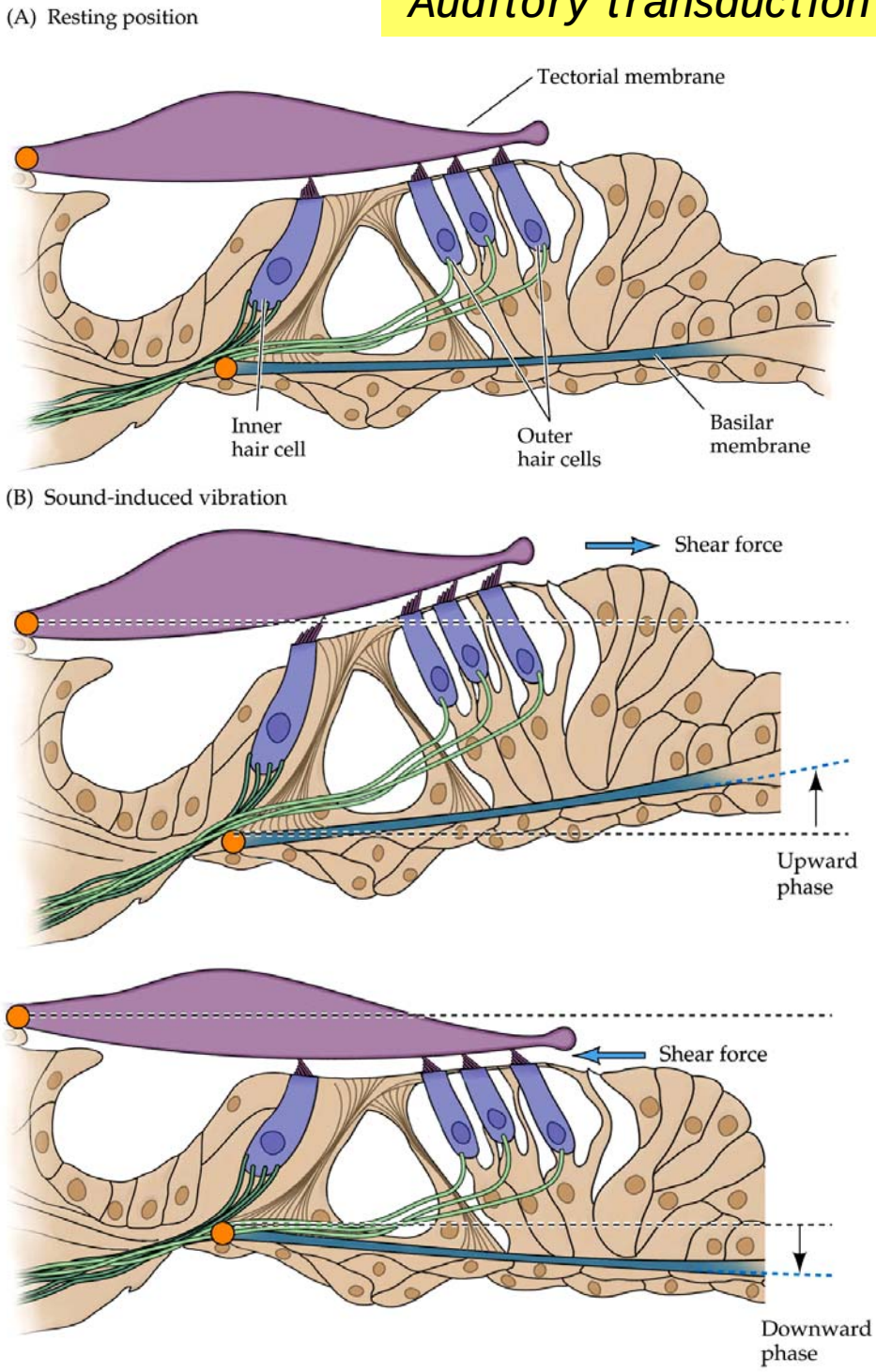
(b) The frequency of sound waves determines the displacement of the basilar membrane. The location of active hair cells creates a code that the brain translates as information about the pitch of sound.

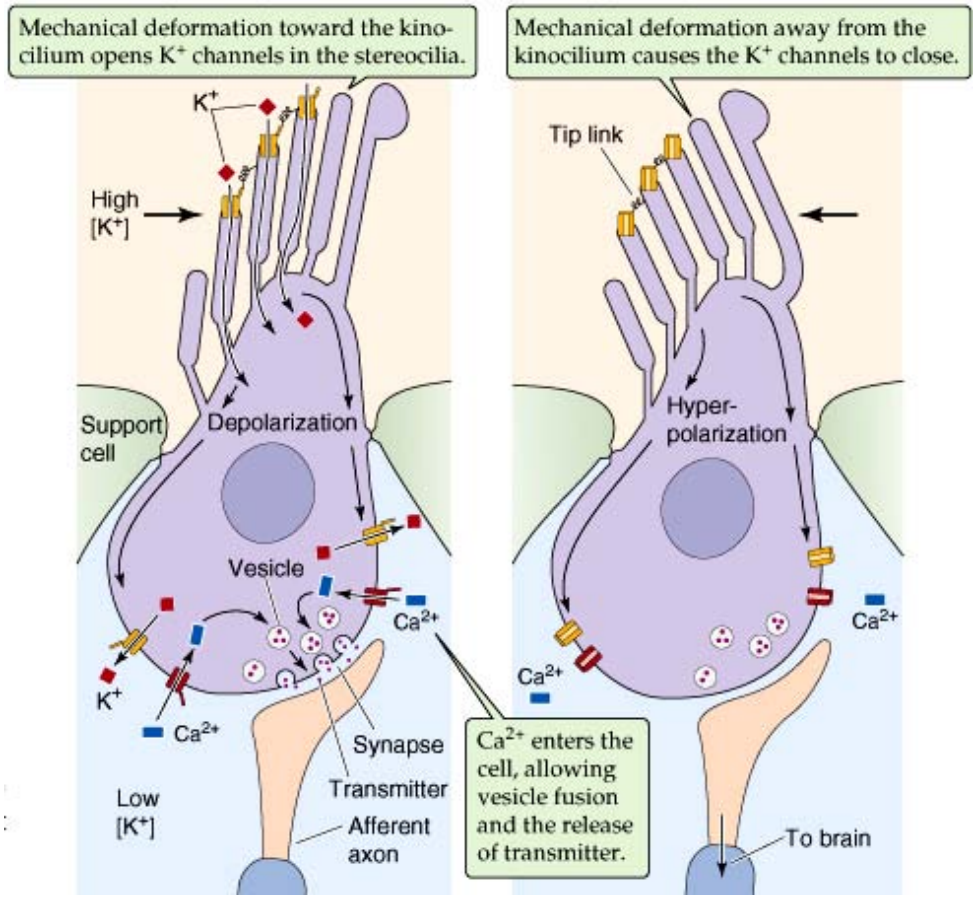


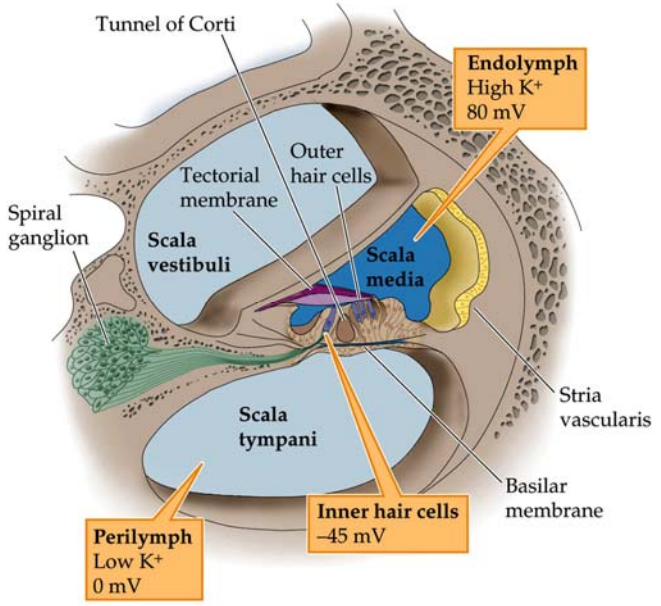


Figures: Boron & Boulpapep 2005, Silverthorn 2007

Auditory transduction

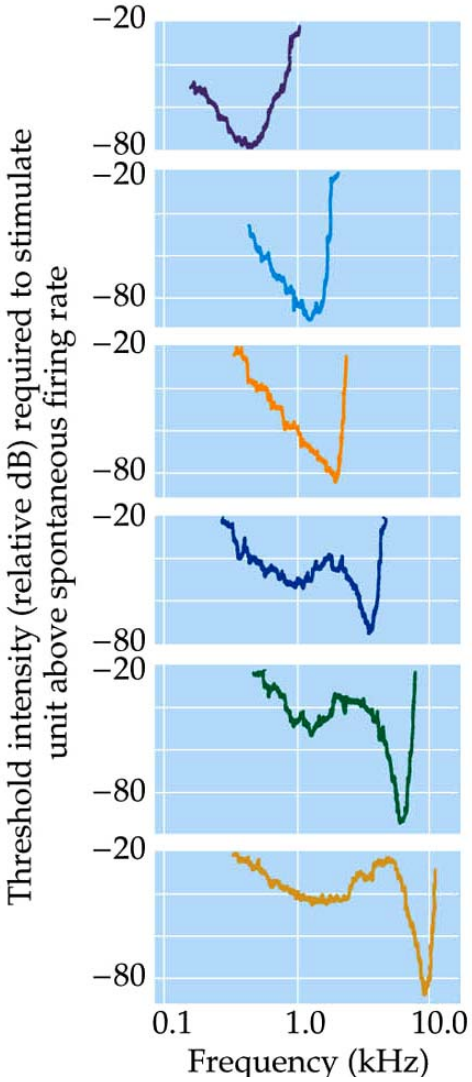


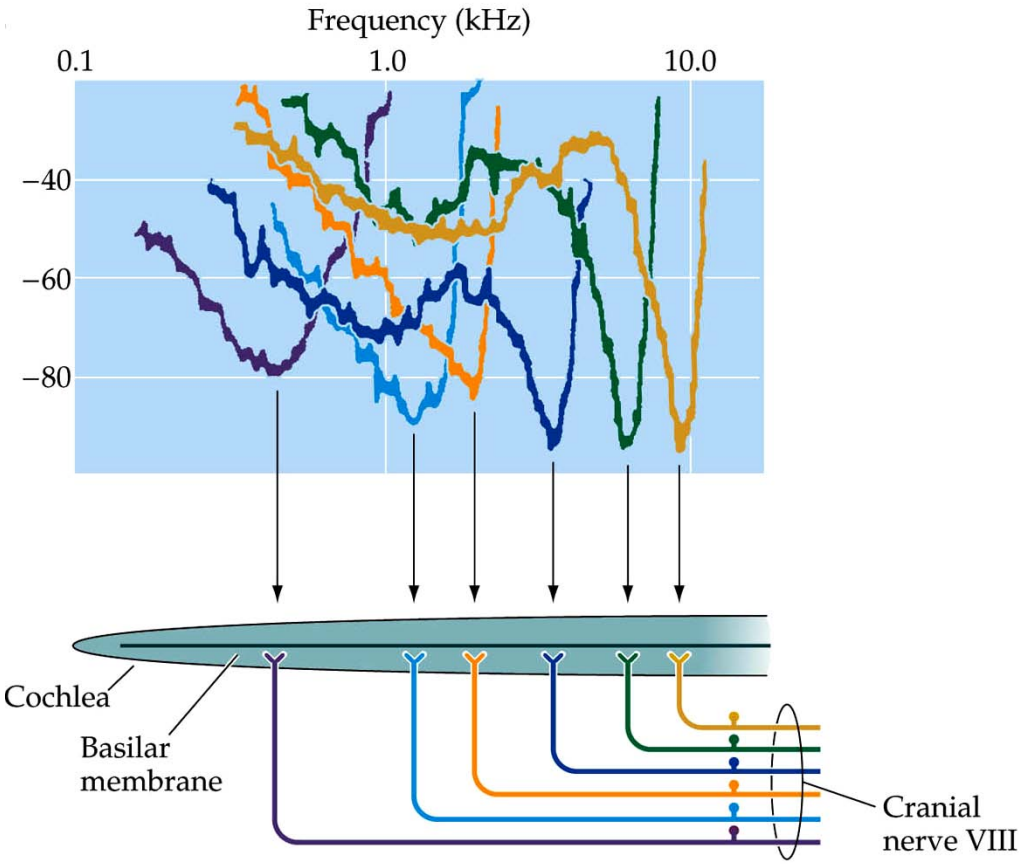




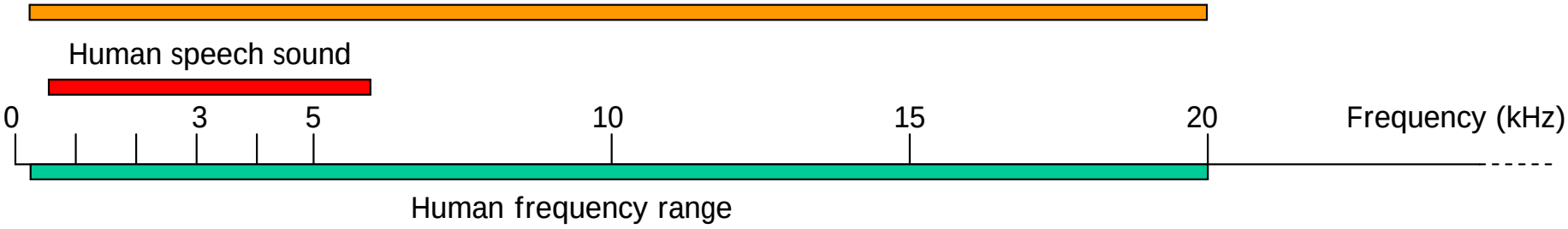
Figures: Purves 2004; Boron & Boulpapep 2005

Frequency discrimination



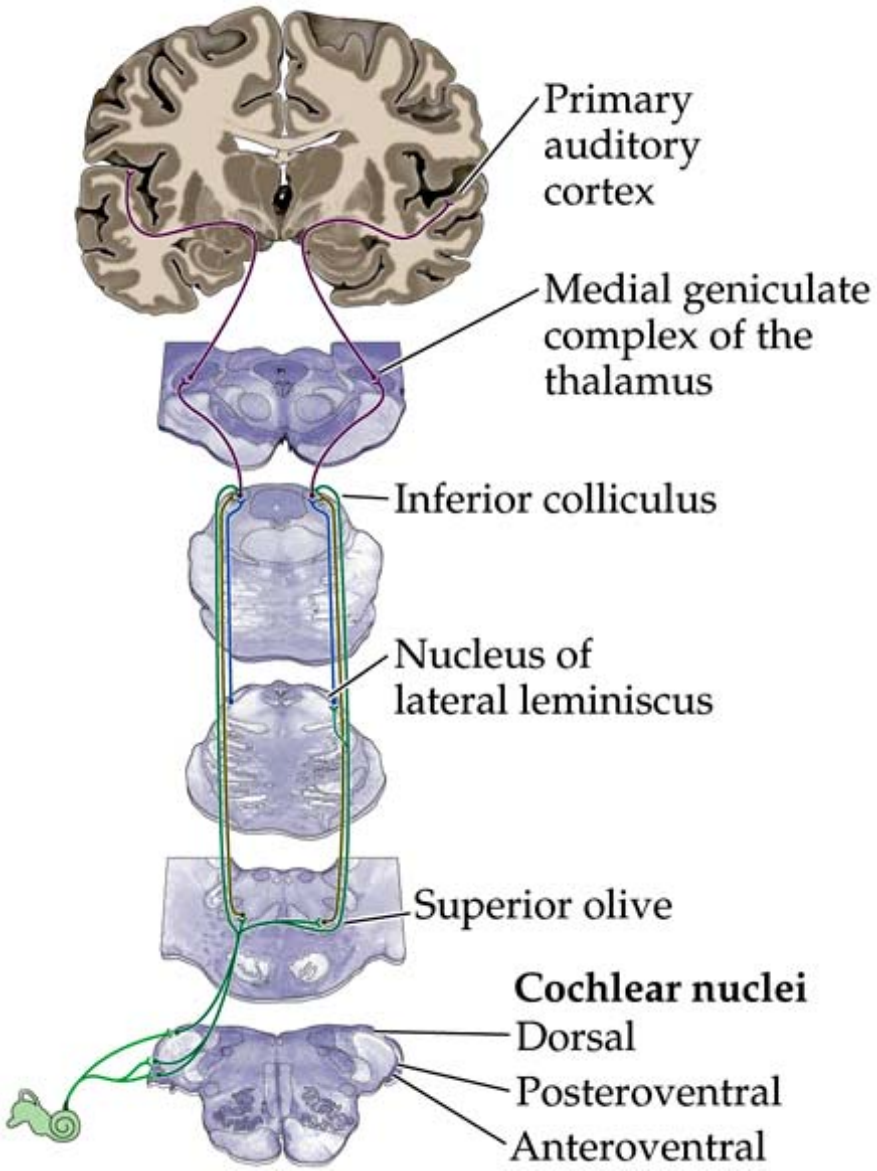


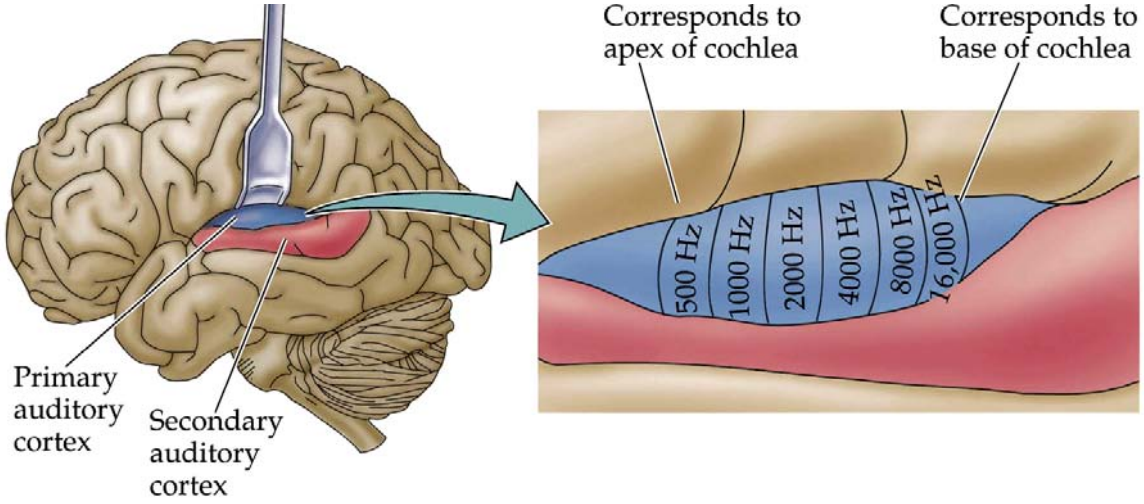
Tonotopical organization → frequency code



Figures: Purves 2004

Central processing of auditory information





1) Several **parallel pathways**

2) Each ear → Both sides of the system → **Divergence**

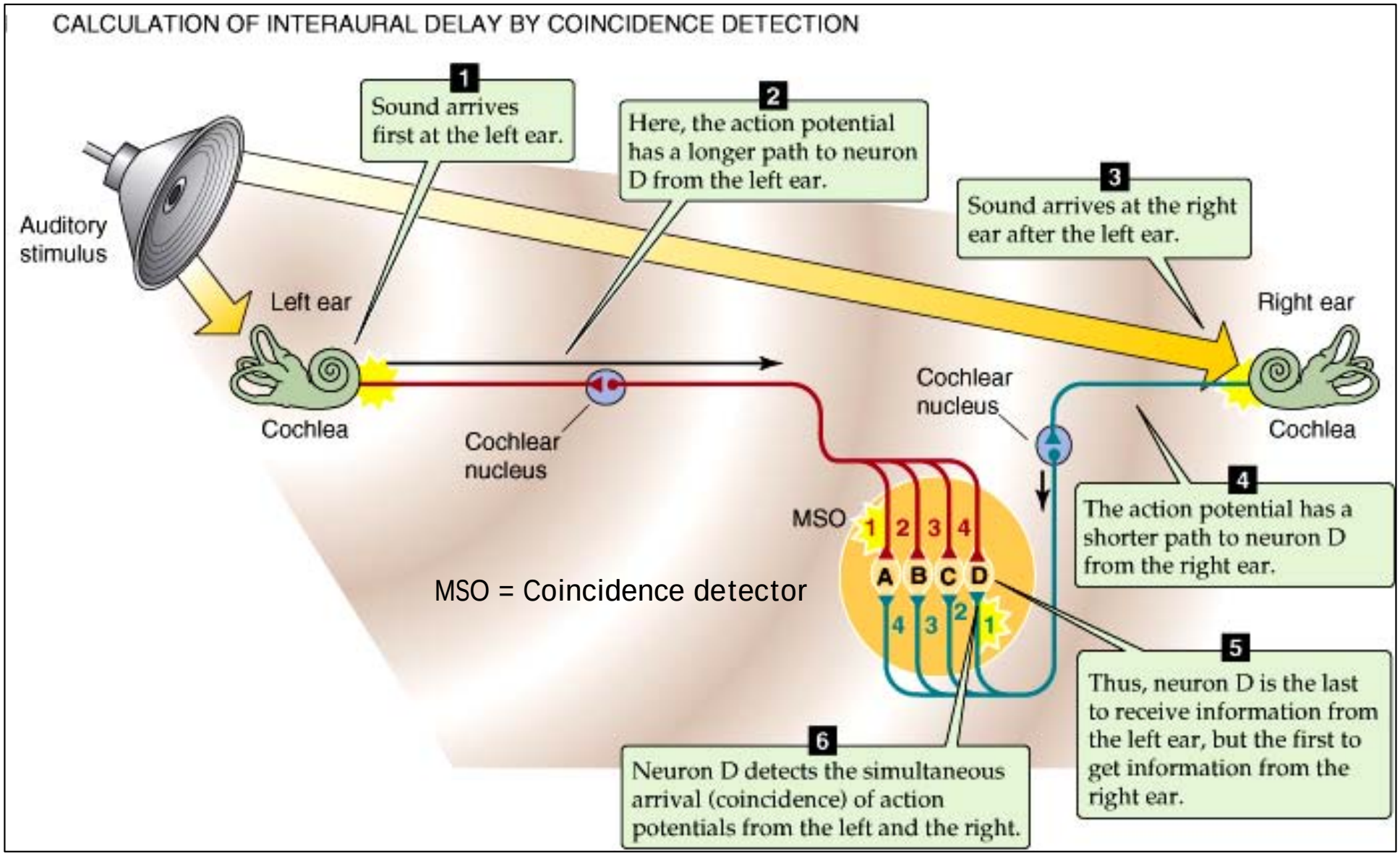
3) Preserved topographic map of frequencies
From the cochlear nucleus to auditory cortex → **Tonotopy**

4) Both ears → One side of the system → **Convergence**

Figures: Purves 2004; Boron & Boulpapep 2005

Central processing of auditory information

Best understood function of brainstem nuclei: Sound localization.



Figures: Boron & Boulpapep 2005

Vestibular system

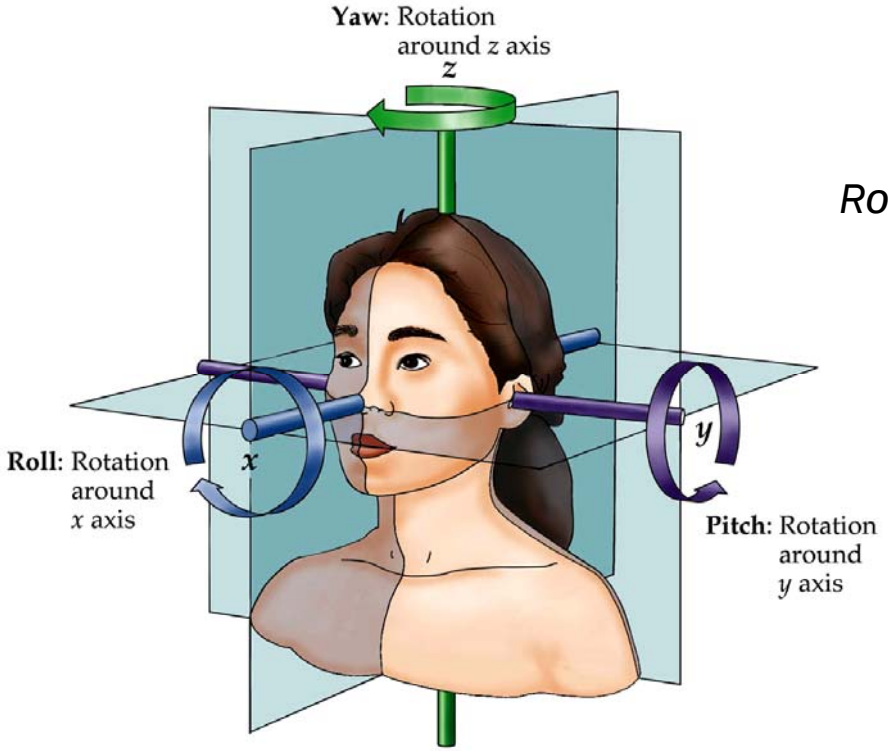
Vestibular stimulus: Head position and motion

Movement along the axes
→ Linear acceleration

Head position
→ Static

↓

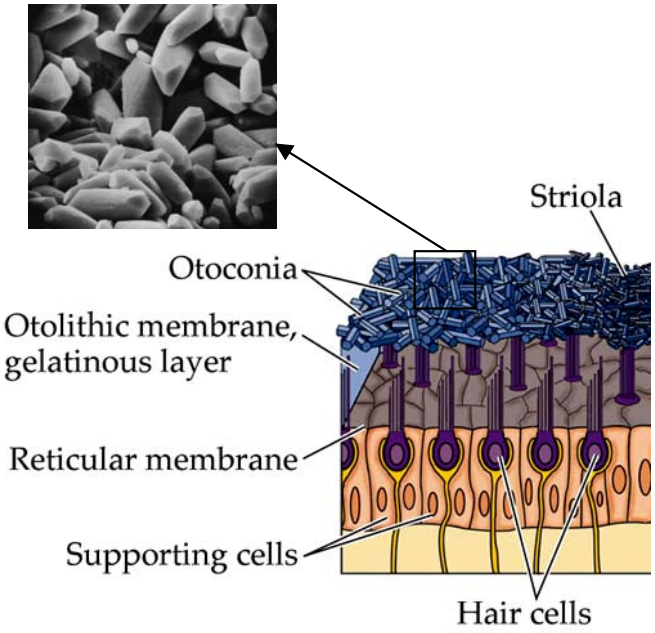
Utricle
Saccule

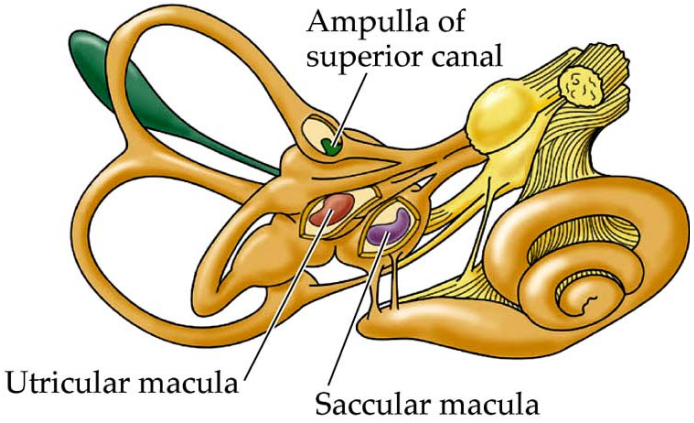


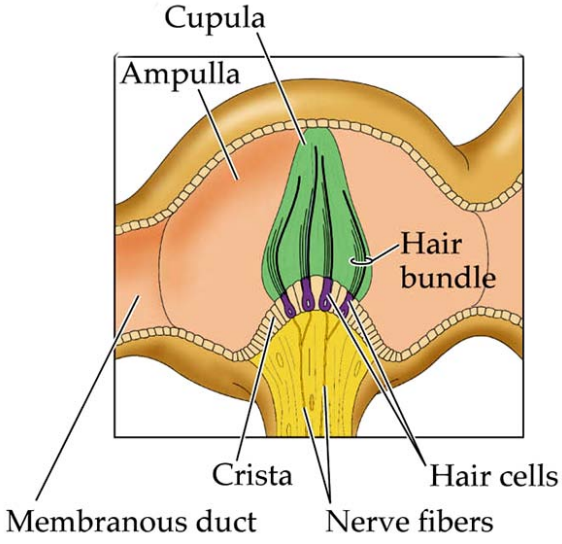
Rotation relative to the axes
→ Angular acceleration

↓

Semicircular canals

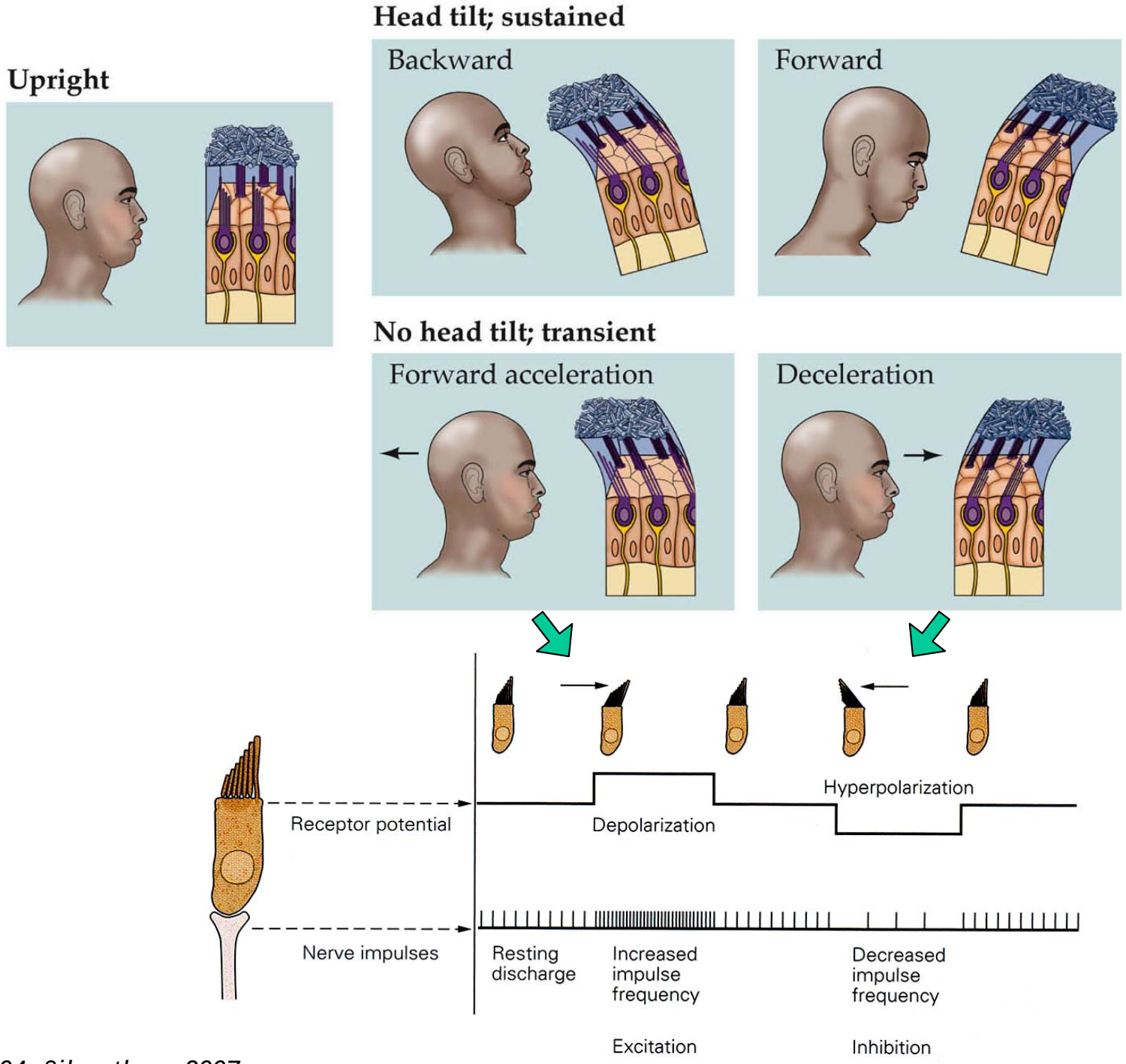






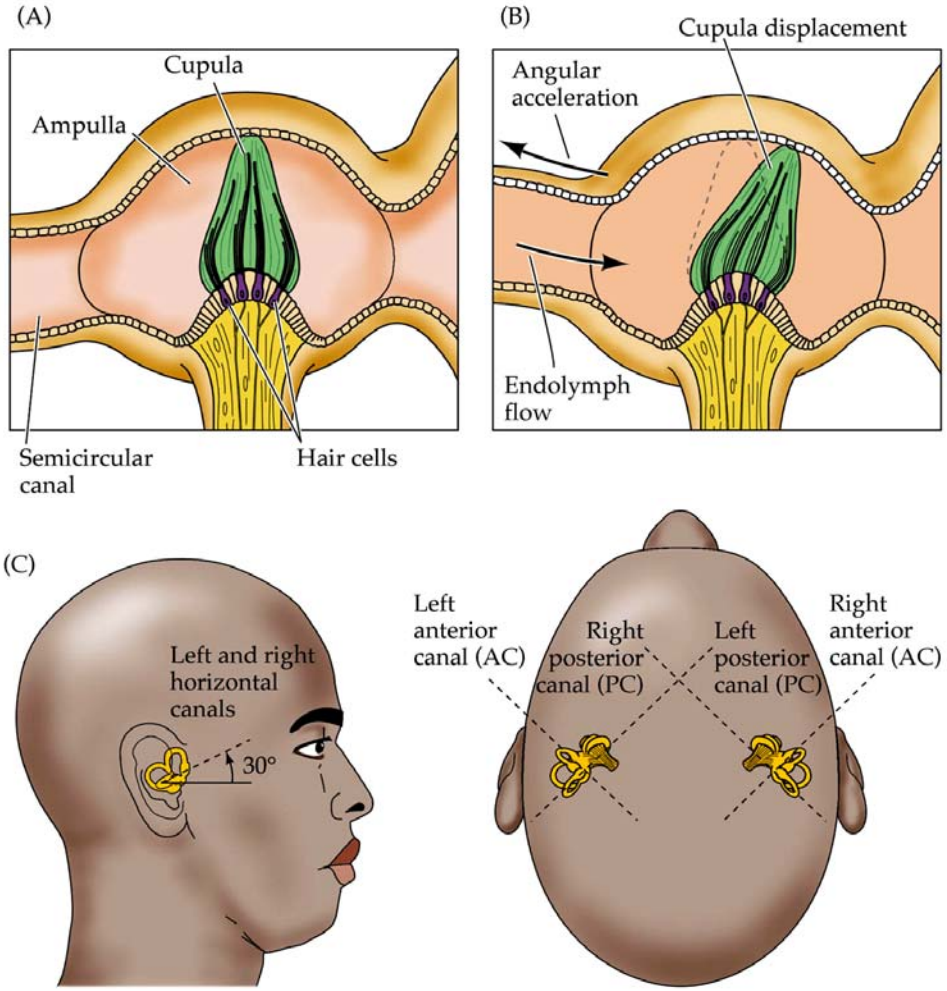
Figures: Purves 2004

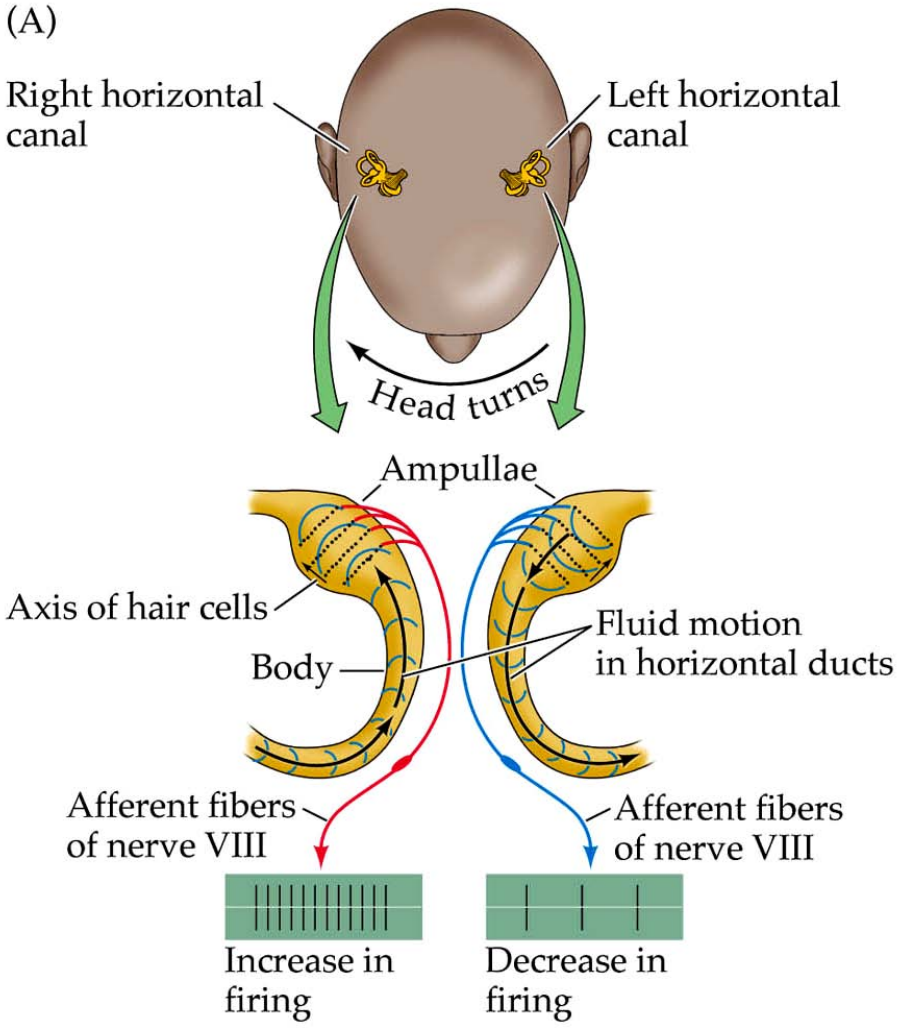
Transduction of a static head tilt and linear acceleration



Figures: Purves 2004; Silverthorn 2007

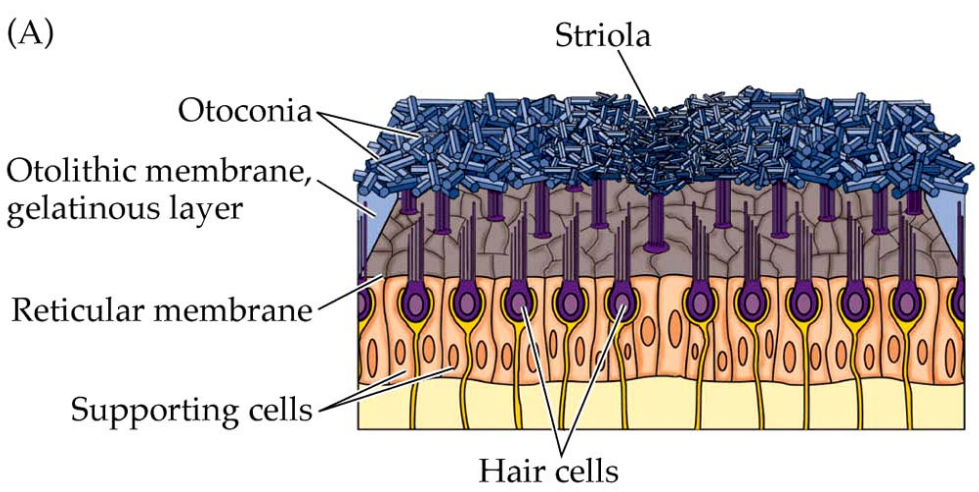
Transduction of angular acceleration

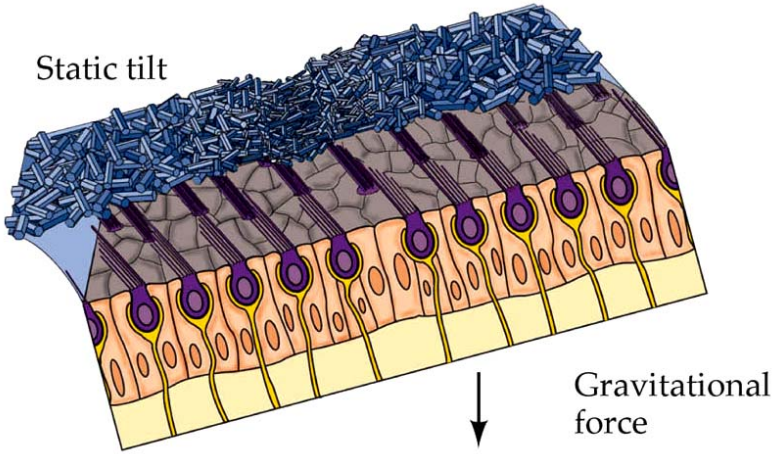




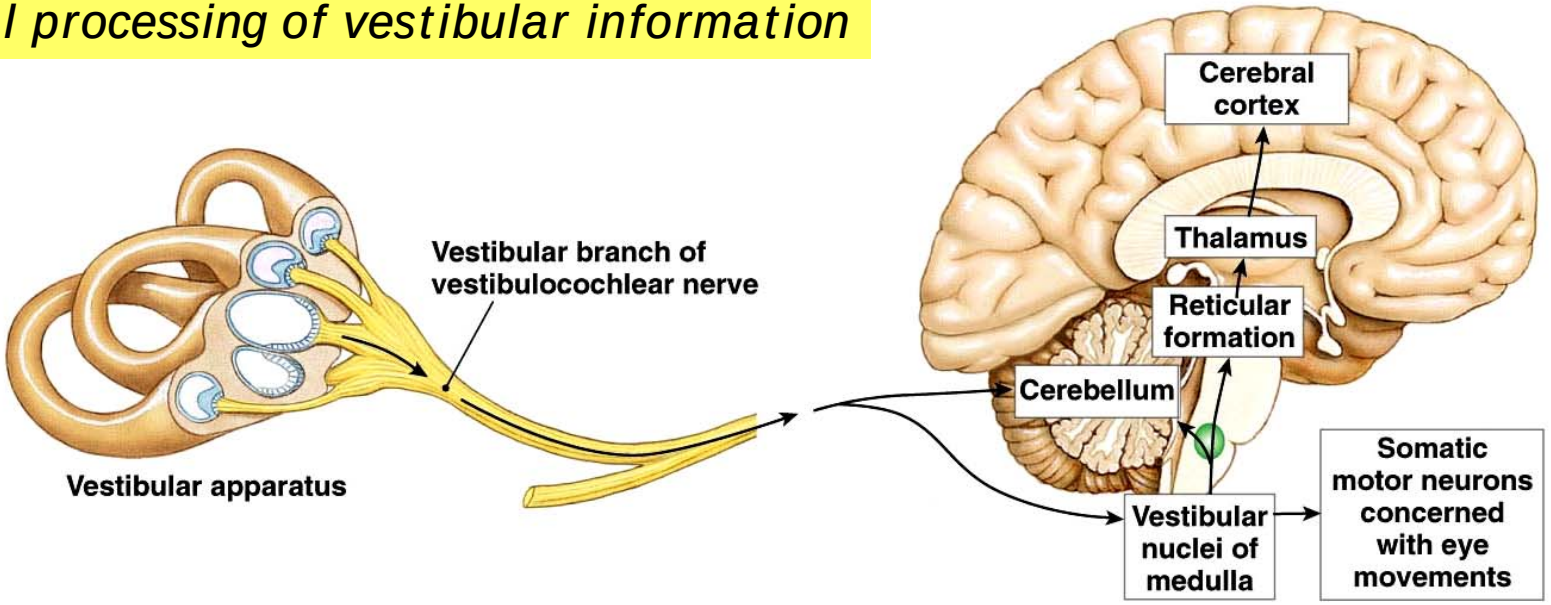
Figures: Purves 2004

Morphological polarization of hair cells in the utricule and saccule



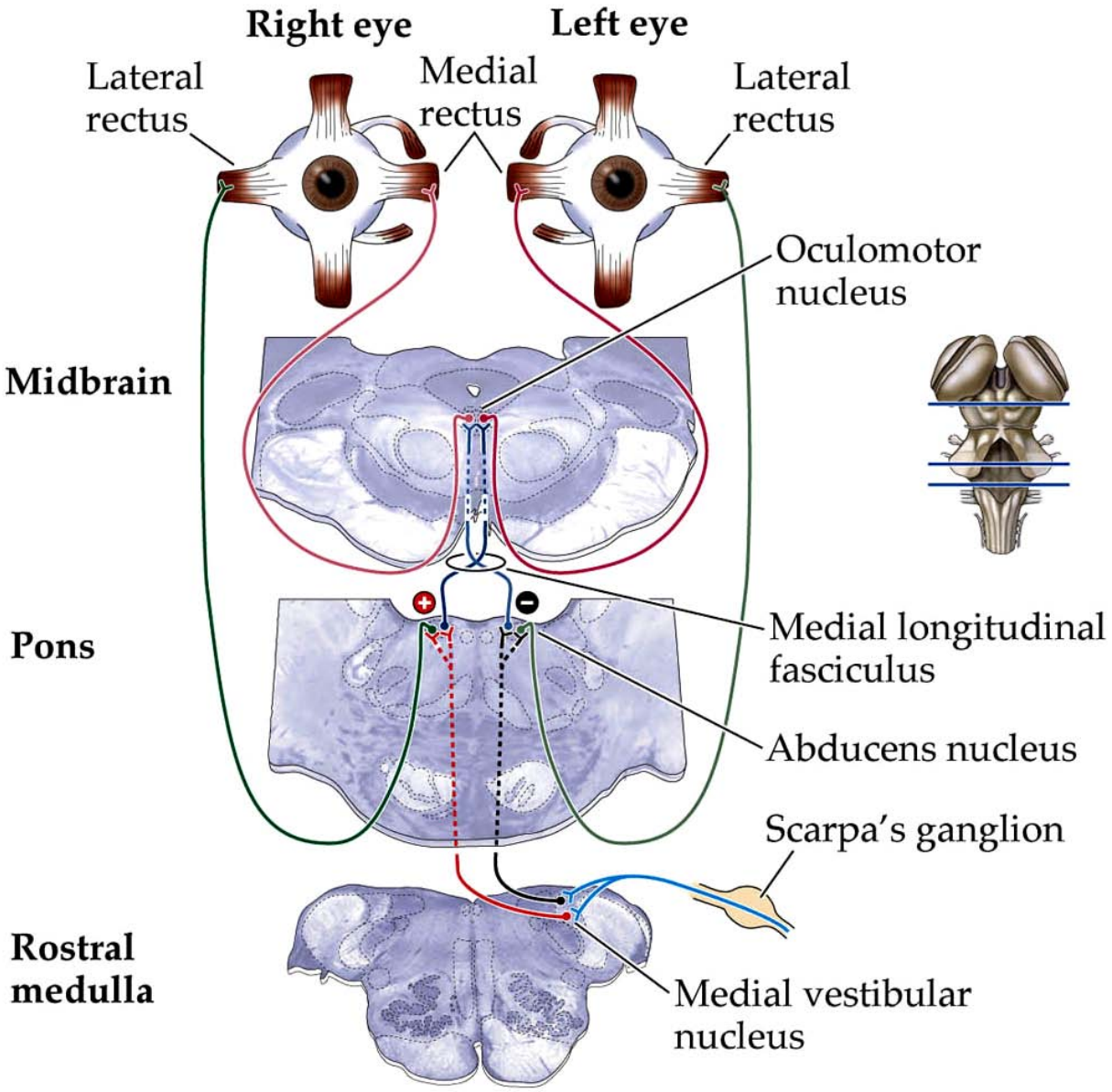


Central processing of vestibular information



Figures: Purves 2004; Silverthorn 2007

Connections underlying the vestibulo-ocular reflex



Figures: Purves 2004

TEMA 42. VISIÓN

1. Estímulo visual.
    - Espectro electromagnético, zona visible.

2. Estructura funcional del ojo.
    - Refracción ocular.
    - Funciones del cristalino. Acomodación

3. Estructura funcional de la retina.
    - Elementos celulares.
        - Fotorreceptores: conos y bastones.
        - Células bipolares, ganglionares, horizontales y amacrinas.
    - Zonas de la retina: Disco óptico, mácula, fóvea, retina periférica.
        - Grados de convergencia en el circuito según zona de la retina.

4. Fototransducción.
    - Cascada bioquímica.
        - Activación de moléculas por la luz. Fotopigmentos.
        - Reducción de la concentración de cGMP.
        - Cierre de canales iónicos. Hiperpolarización de los fotorreceptores.
    - Propiedades de la cascada de fototransducción.
        - Amplificación.
        - Adaptación a los cambios en intensidad lumínica: Papel del Ca^{2+}.
        - Respuesta temporal: Mecanismos de recuperación de los fotorreceptores.

5. Sistema de los conos. Sistema de los bastones. Especialización funcional.
    - Diferencias en la sensibilidad a iluminación.
        - Modalidades sensoriales visuales.
            - Visión diurna o fotópica. Visión nocturna o escotópica.
    - Diferencias en la fototransducción.
        - Tipos de pigmentos en los conos humanos: S (short), M (middle), L (long)
    - Diferencias en la velocidad de adaptación.
    - Diferencias en la resolución espacial. Campo receptor.
        - Distribución de los conos y los bastones en la retina.
        - Diferencias en las conexiones sinápticas. Circuitos en la retina.
        - Diferencias en las propiedades de las células ganglionares.

6. Procesamiento de la información en la retina.
    - Procesamiento en paralelo del color, la forma y el movimiento.
        - Células ganglionares M (magno), P (parvo) y K (konio).
    - Campo receptor de las células de la retina.
        - Antagonismo centro-periferia en el campo receptor.
            - Células ganglionares de “centro-on” y “centro-off”.
        - Vías paralelas de información sobre la luminancia.
        - Detección del contraste.

7. Procesamiento central de la información visual.
    - Representación retinotópica del campo visual.
    - Vía visual primaria.
        - Núcleo geniculado lateral del tálamo
        - Corteza visual primaria (Corteza estriada).
    - Otras vías visuales.
        - Área pretectal-Núcleo de Edinger-Westphal→ reflejo pupilar.
        - Vía retinohipotalámica → regulación de los ciclos día/noche.
        - Colículo superior → coordinación de movimientos de la cabeza y ojos.

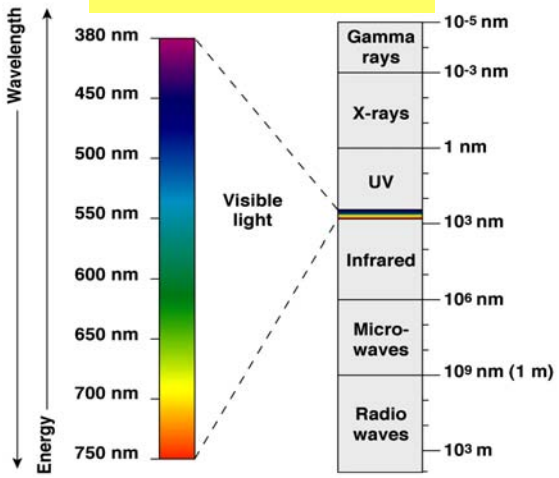
8. Organización funcional del NGL.
    - Representación retinotópica del campo visual en el NGL.
    - Vías paralelas: Sistema magnocelular → Información sobre el movimiento
      Sistema parvocelular → Información sobre el color.
    - Neuronas monoculares. Distribución en capas.
    - Campos receptores de las neuronas del NGL. Circulares y antagónicos.

9. Organización funcional de la corteza estriada.
    - Campos receptores de las neuronas de la corteza visual primaria.
        - Circulares-antagónicos. Rectilíneos con orientación selectiva.
            - Detección de bordes y de movimiento.
            - Neuronas simples y complejas.
    - Organización columnar de la corteza visual.
        - Columnas de orientación
        - Columnas de dominancia ocular
        - Visión estereoscópica.
        - Neuronas binoculares → Percepción de la profundidad de campo.

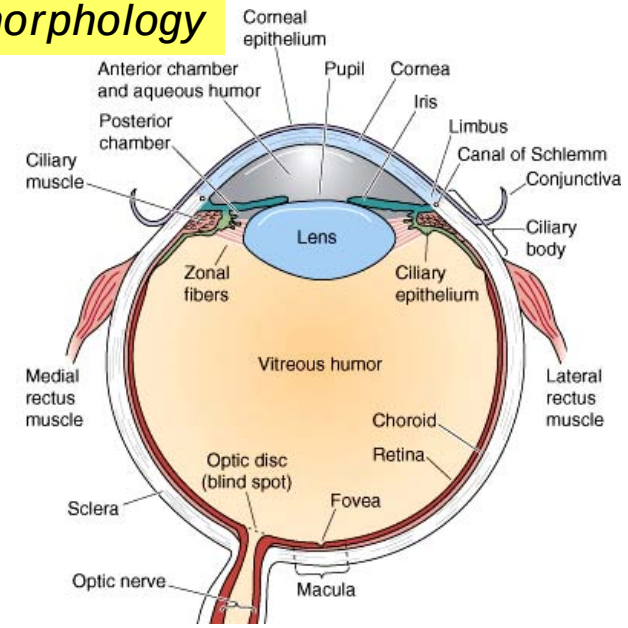
10. Flujos paralelos de información desde la retina hasta la corteza.
    - Procesamiento de la información en áreas visuales de asociación.
        - Vía dorsal: Visión espacial.
        - Vía ventral: Reconocimiento de objetos.

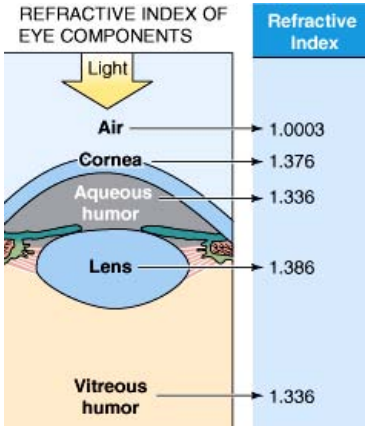
Visual system

Visual stimulus

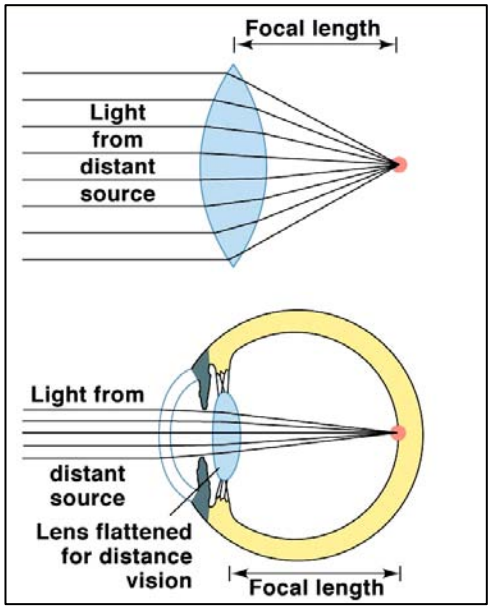


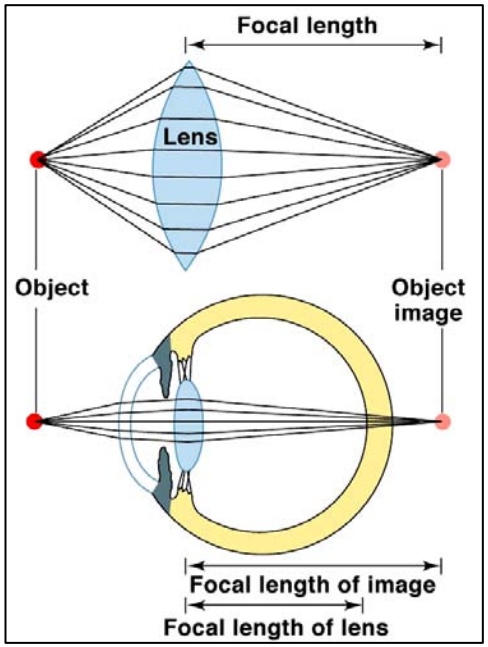
Functional morphology

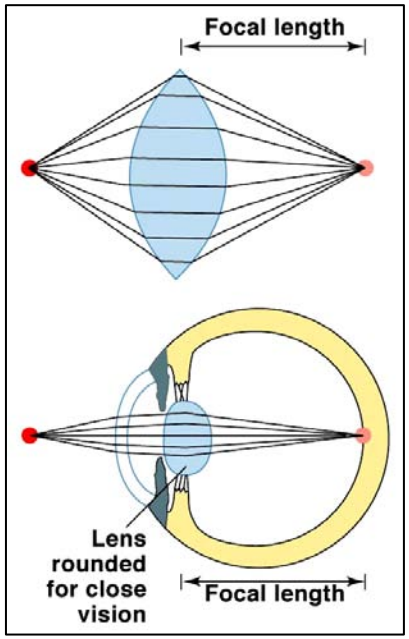


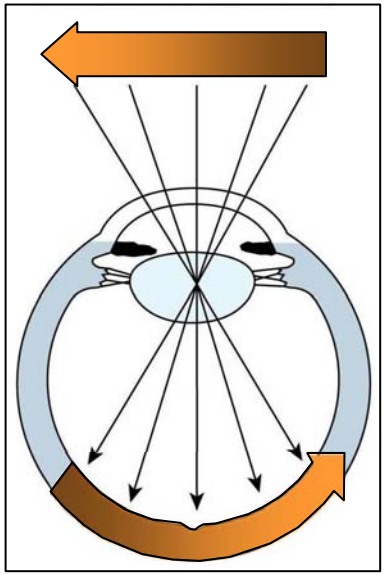


Refractive properties of the eye



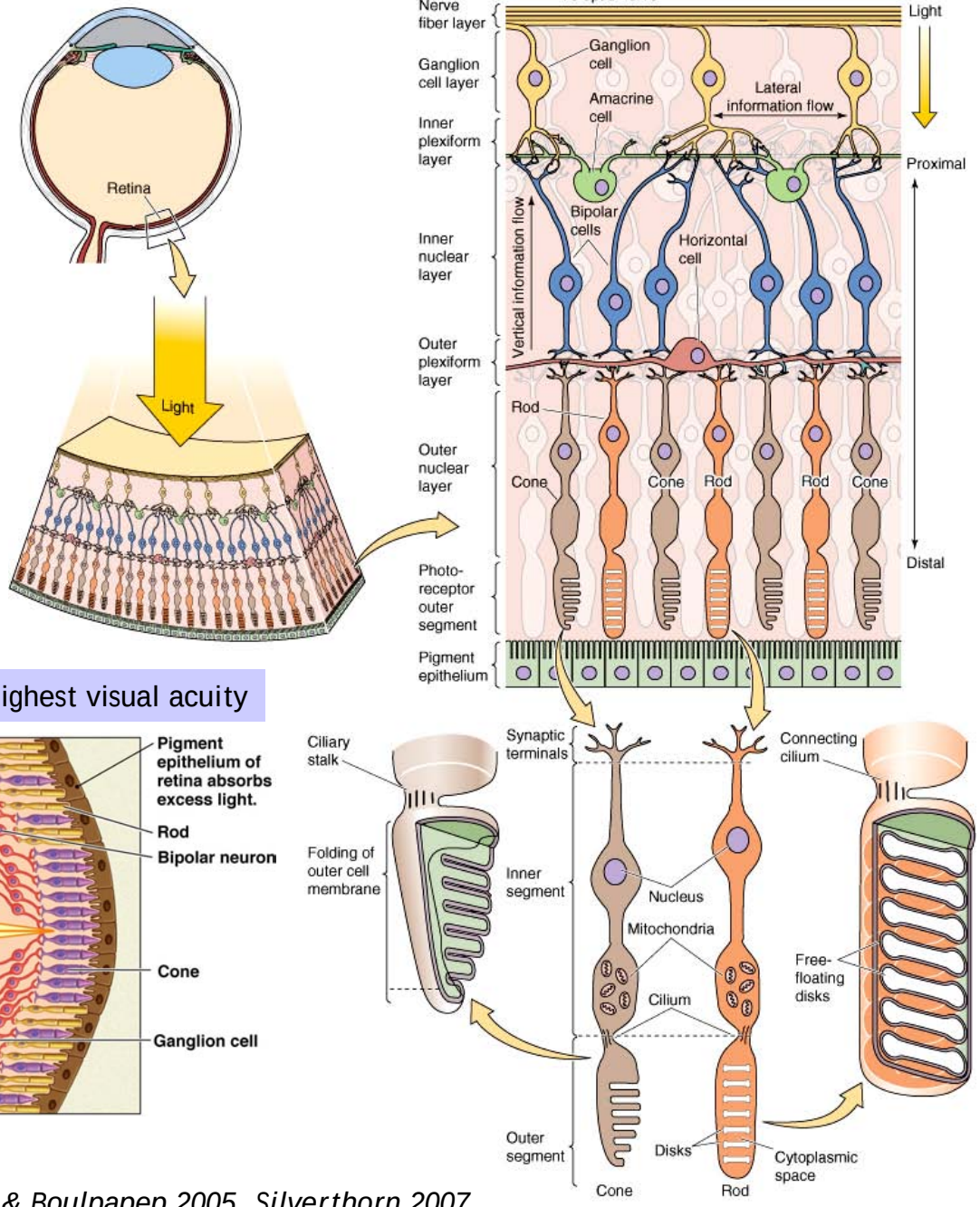




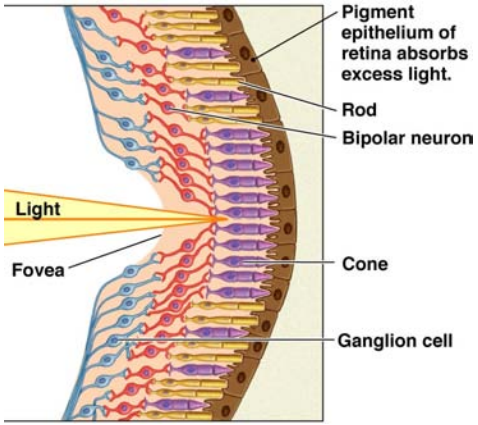


Figures: Boron & Boulpapep 2005, Silverthorn 2007

Functional morphology

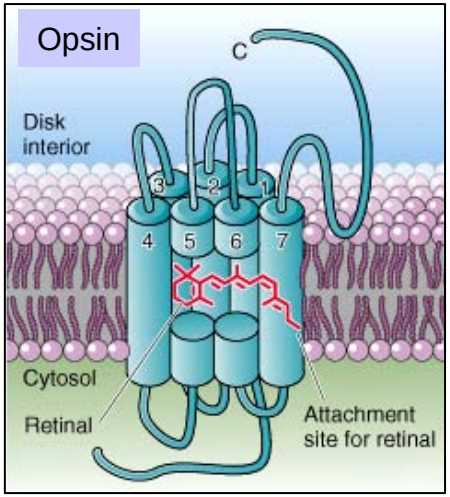


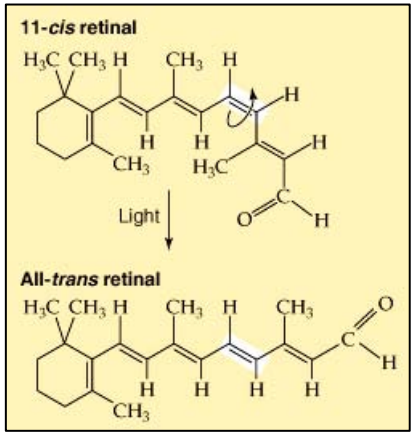
Macula → Highest visual acuity

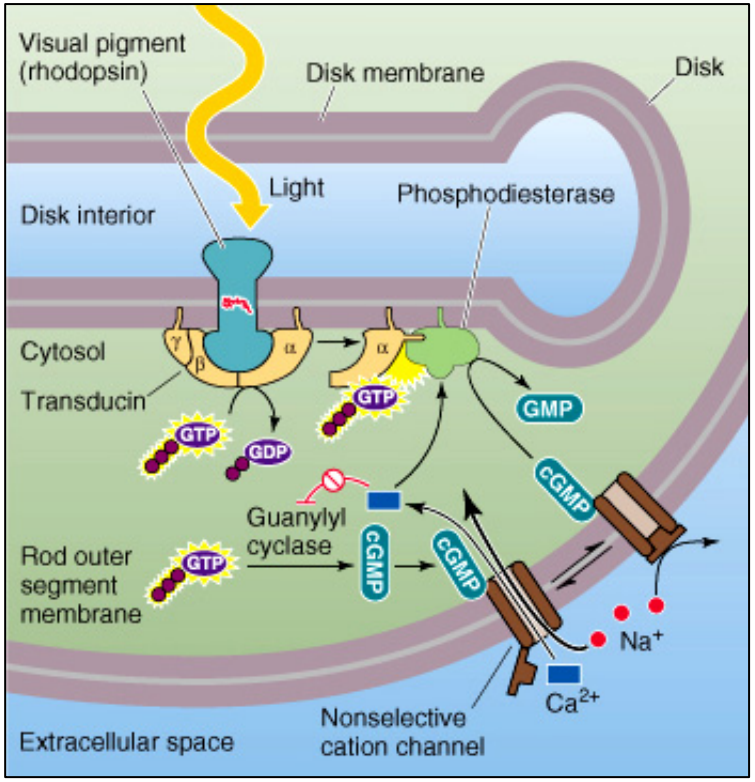


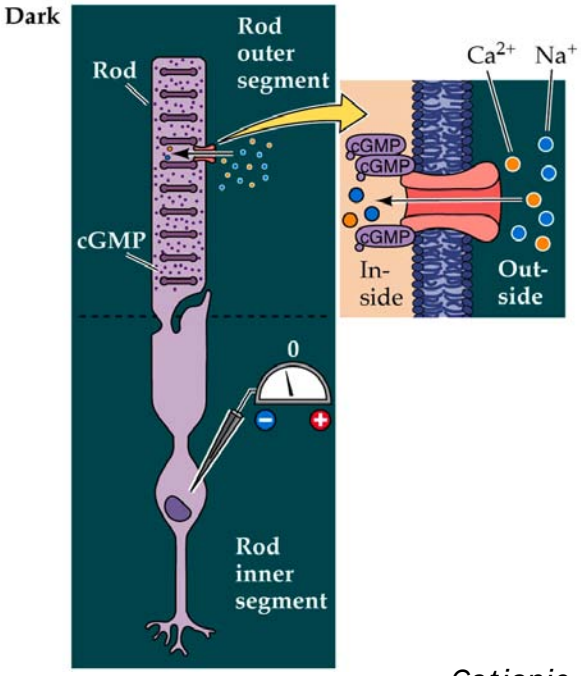
Figures: Boron & Boulpapep 2005, Silverthorn 2007

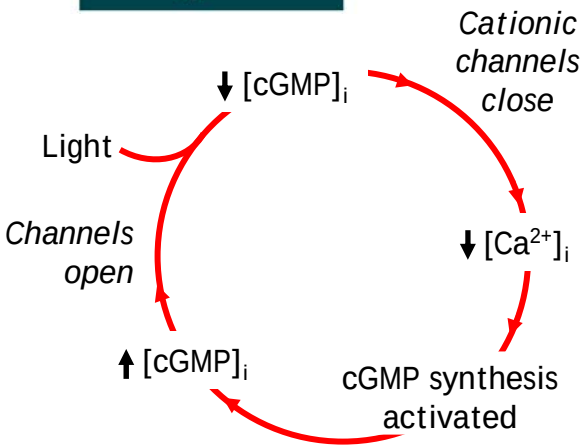
Visual transduction











Properties

1) Signal *amplification*.

2) *Adaptation* to the level of light → Ca^{2+} dependent modulation of the transduction cascade.

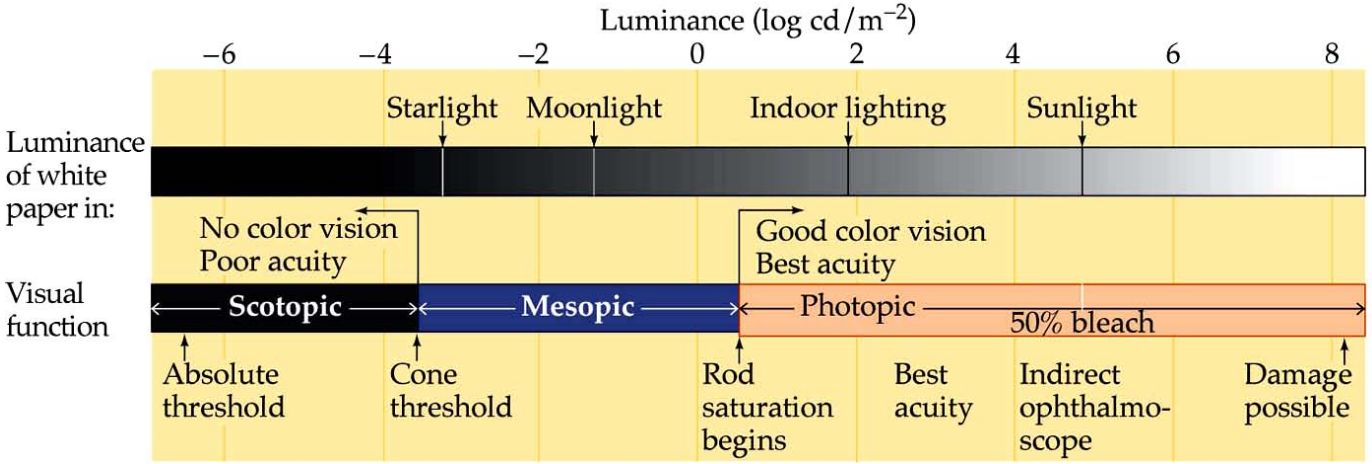
↑ Light → ↓ Sensitivity → Prevents photoreceptors from saturating.

3) Fast *temporal answer* → Restoring molecules to the inactive state.

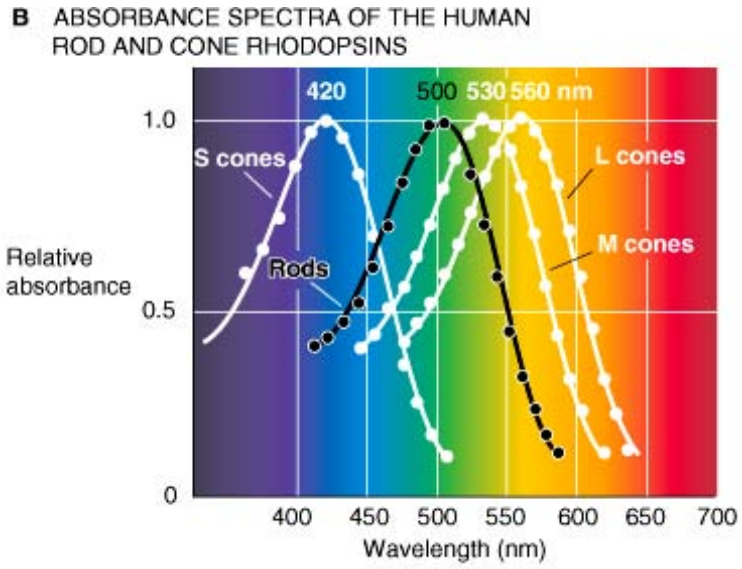
Figures: Purves 2004; Boron & Boulpapep 2005, Silverthorn 2007

Functional specialization: Rod and Cone Systems

Differences in the sensitivity to luminance



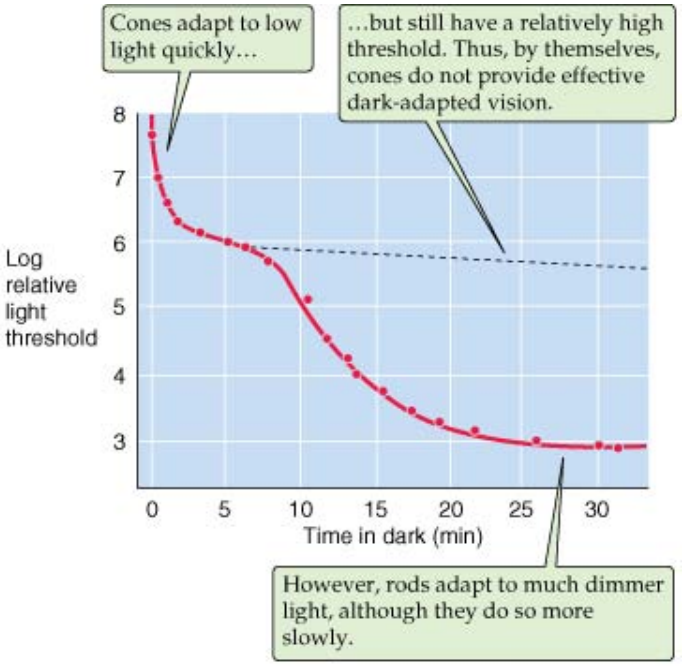
Differences in phototransduction



3 types of cone opsins
Each cone → 1 opsin

↓

Color vision based on comparisons



Figures: Purves 2004; Boron & Boulpapep 2005, Silverthorn 2007

Functional specialization: Rod and Cone Systems

Differences in spatial resolution

1) Density and location of photoreceptors.

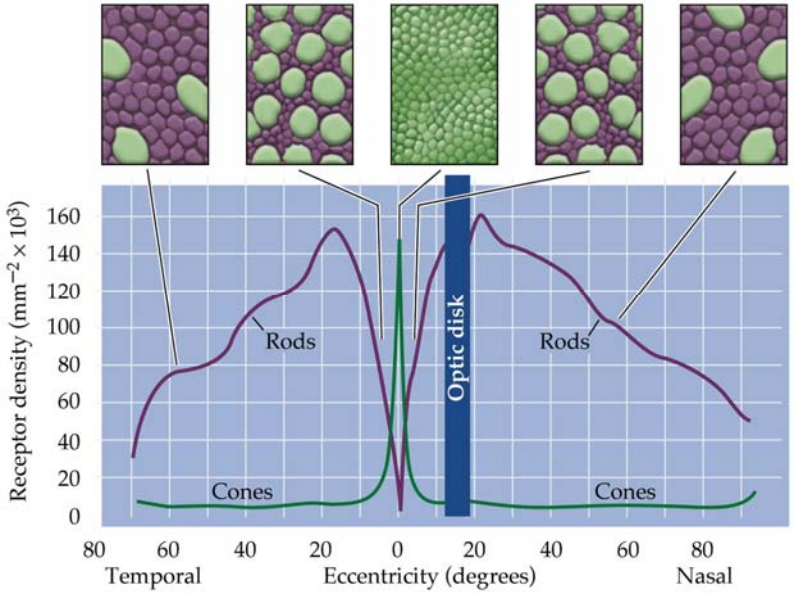
2) Morphology of photoreceptors.

3) Retinal circuits
(from photoreceptor to ganglion cells).

Rod system ⇒ High convergence
Cone system ⇒ Low convergence

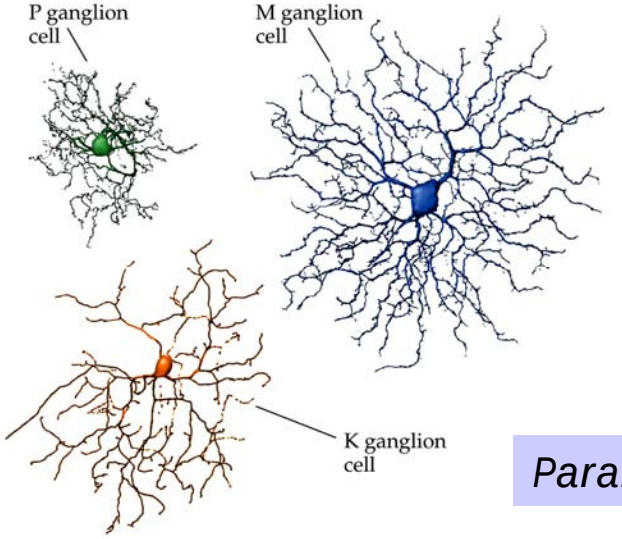
↓

Size of receptive field



Retinal processing of visual information

Types of retinal ganglion cells



P retinal ganglion cells:

- *Small receptor field*
- *Slow adaptation*
- *Selective response to specific wavelengths*

M retinal ganglion cells

- *Big receptor field*
- *Rapid adaptation*

K retinal ganglion cells:

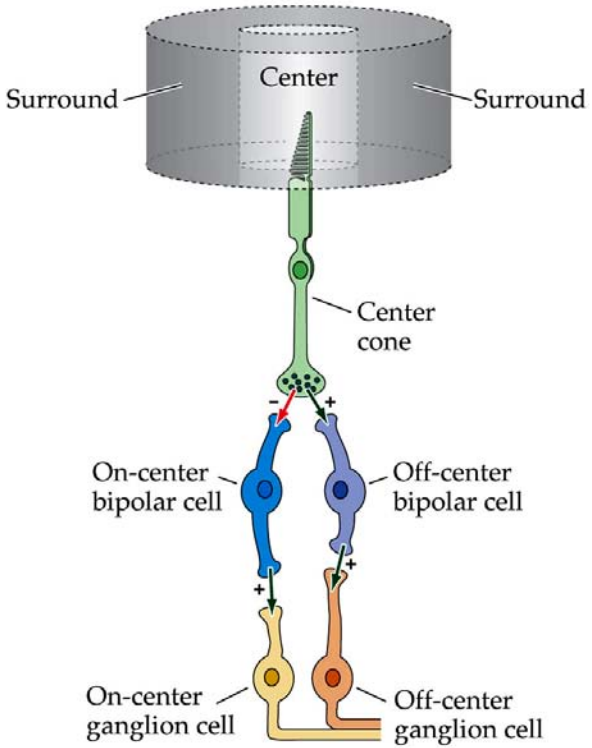
- *Selective response to specific wavelengths*

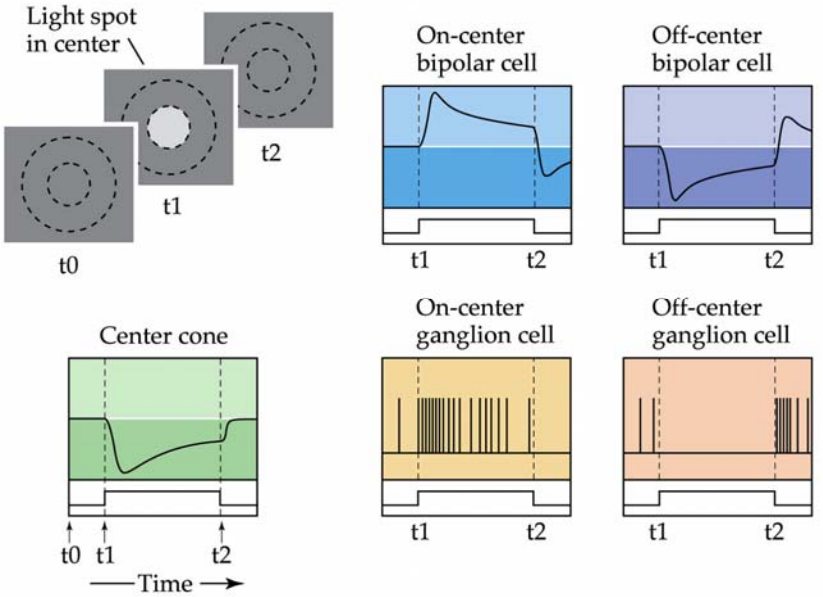
Parallel processing of color, shape and movement in the retina

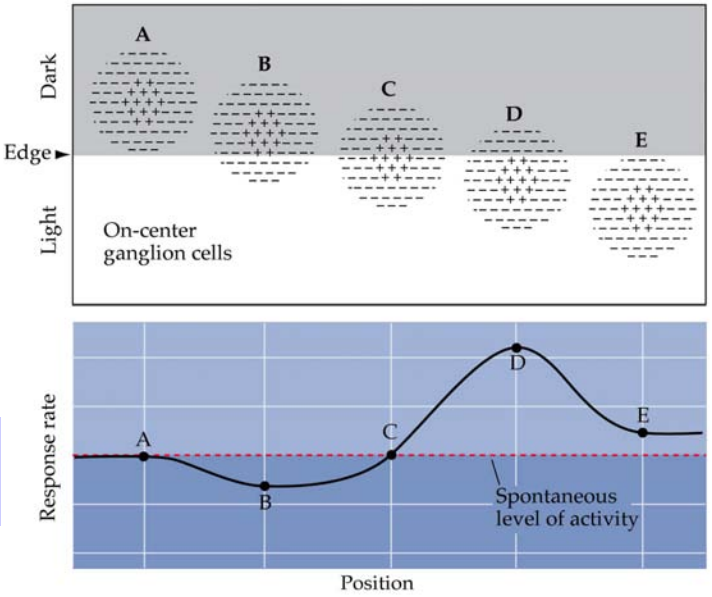
Figures: Purves 2004

Retinal processing of visual information

Response of retinal ganglion cells.
center-ON and center-OFF cells.







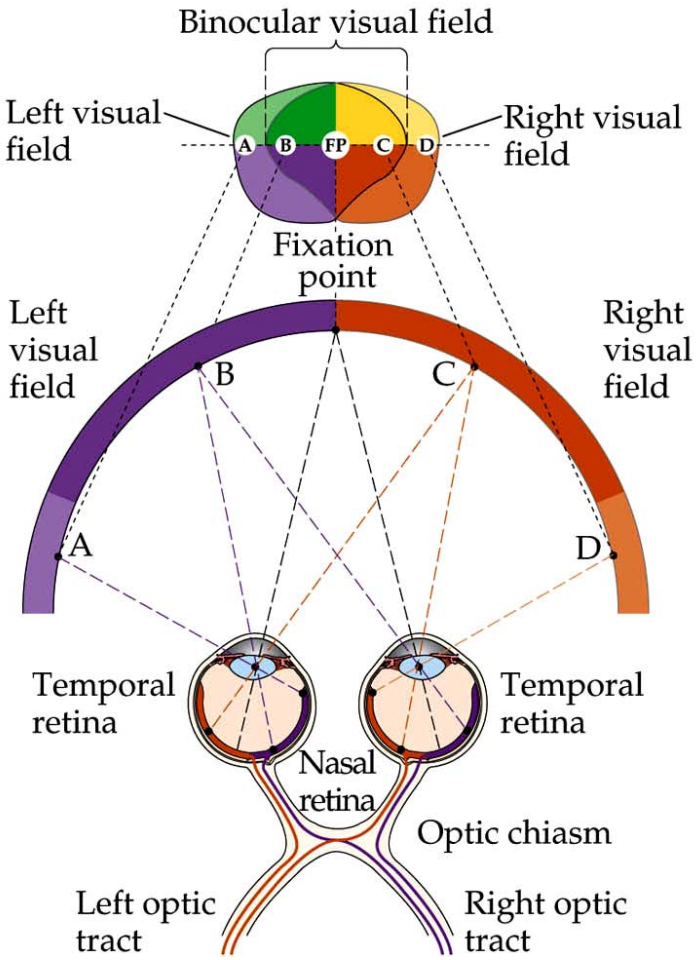
The visual system uses two channels to get information about luminance

RGC are specialized in contrast detection

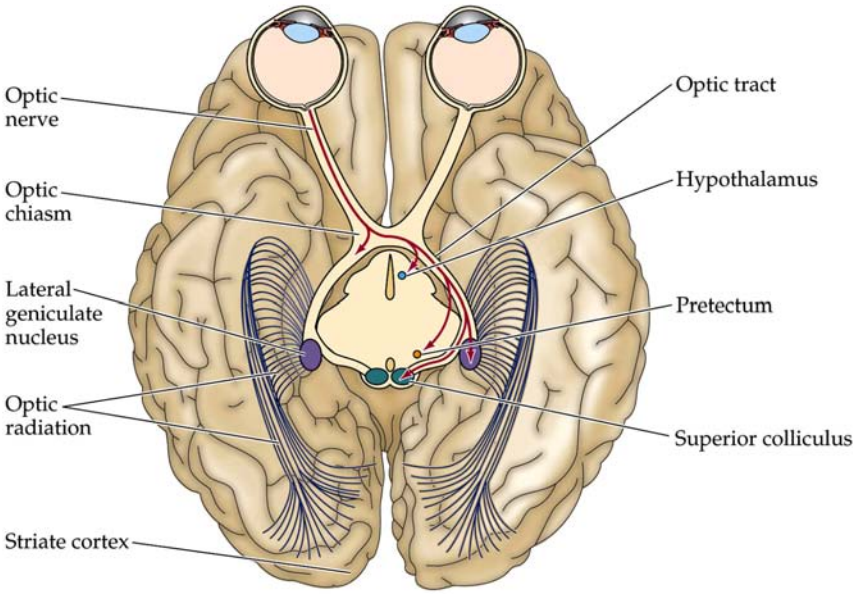
Figures: Purves 2004

Central processing of visual information

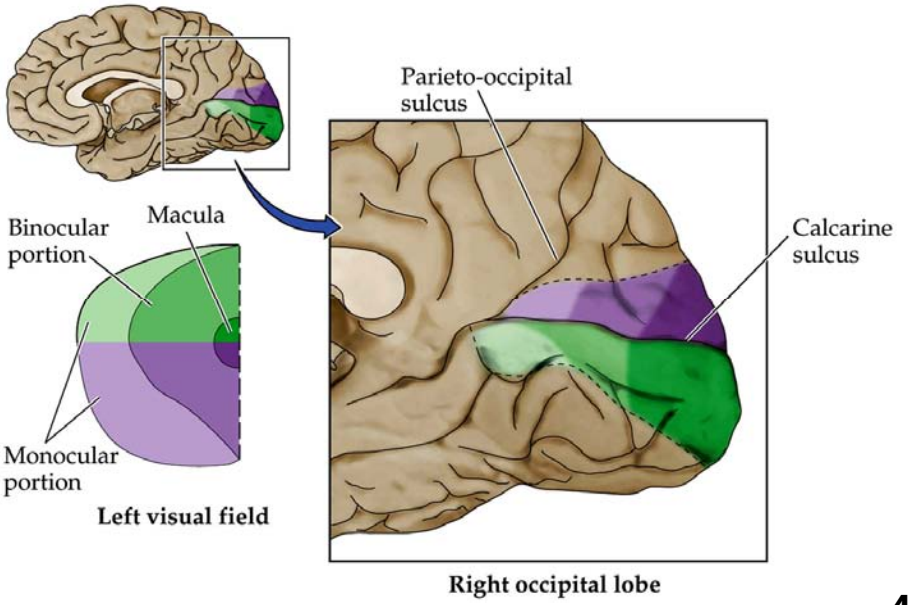
Retinotopic representation of the visual field in the retina



Central projections of retinal ganglion cells



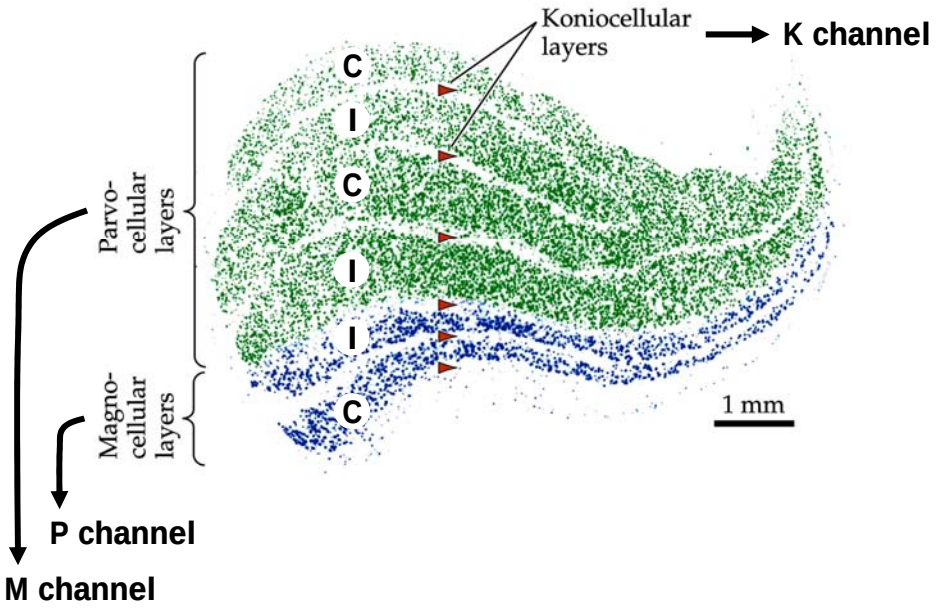
Representation of the visual field in the striate cortex



Figures: Purves 2004

Central processing of visual information

Functional organization of the LGN



Properties of LGN neurons

1) LGN neurons are monocular

2) Parallel pathways → Segregation of information about stimuli

3) LGN neurons have circular receptive fields (Center-ON and Center-OFF)

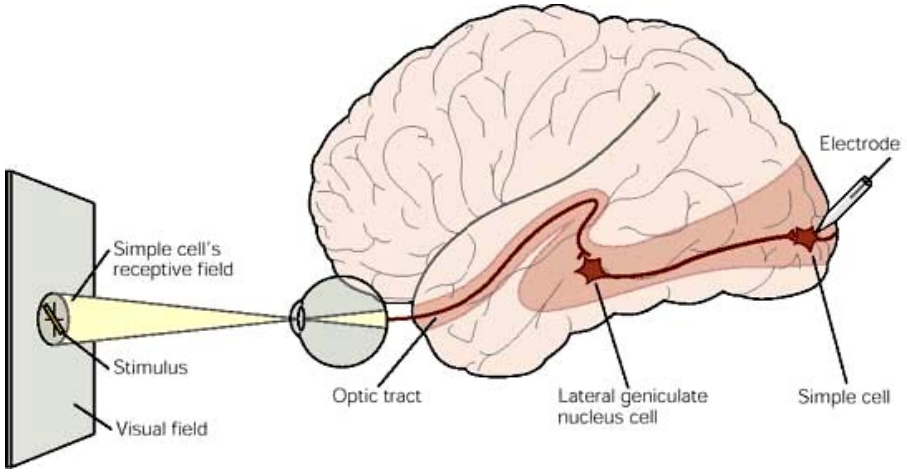
4) Retinotopy

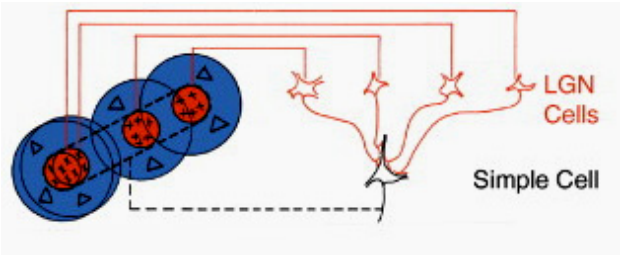
5) **P** channel → Color information
→ Form information (fine detail)

6) **M** channel → Movement information
→ Luminance contrast information
→ Form information (gross features)

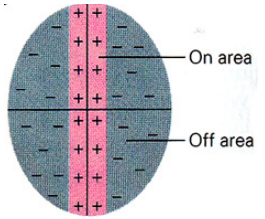
7) **K** channel → Color information

Functional organization of the Striate Cortex





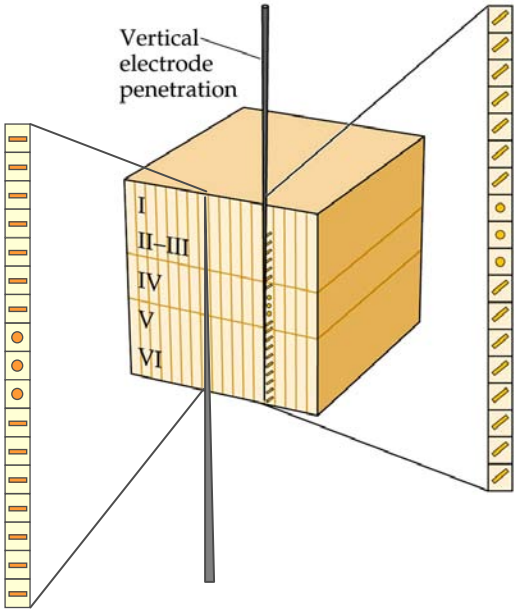
Receptive field of a simple cell

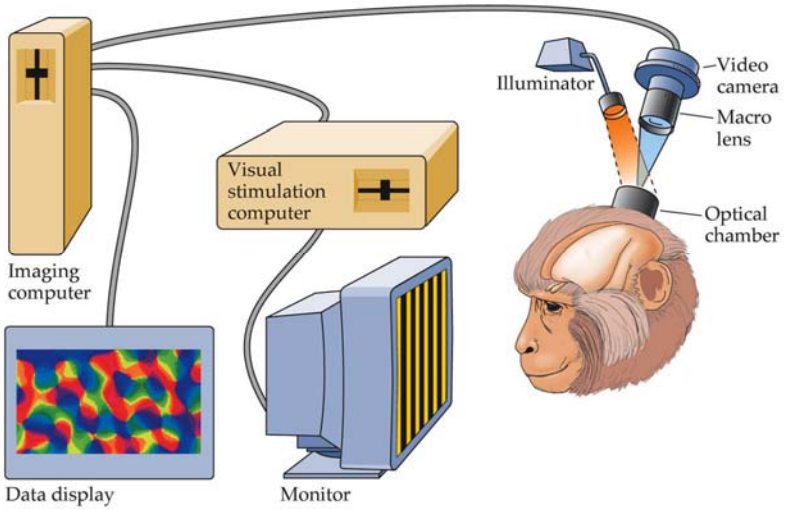


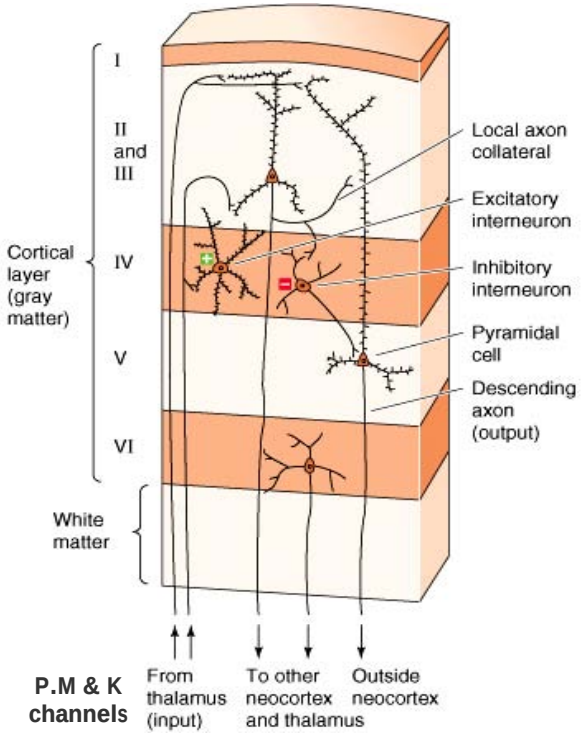
Figures: Kandel, 1999; Purves 2004

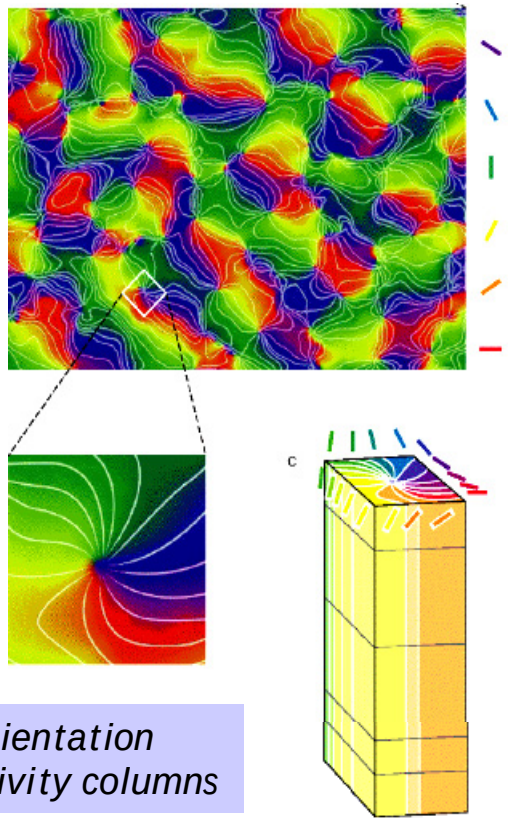
Functional organization of the Striate Cortex

Columnar organization







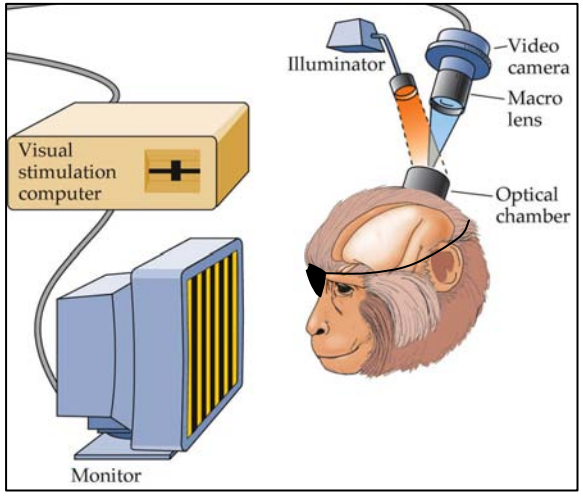


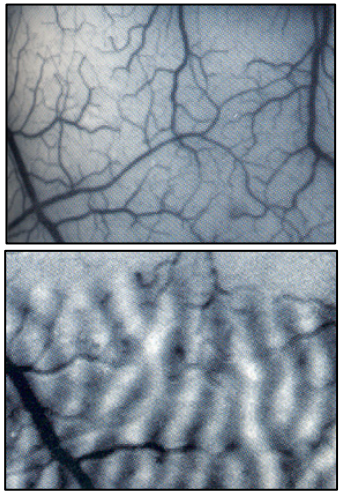
Orientation selectivity columns

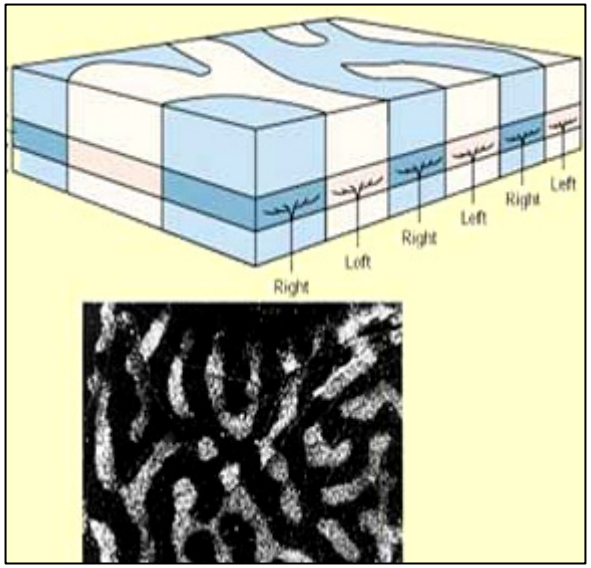
Figures: Purves 2004; Boron & Boulpaep, 2005

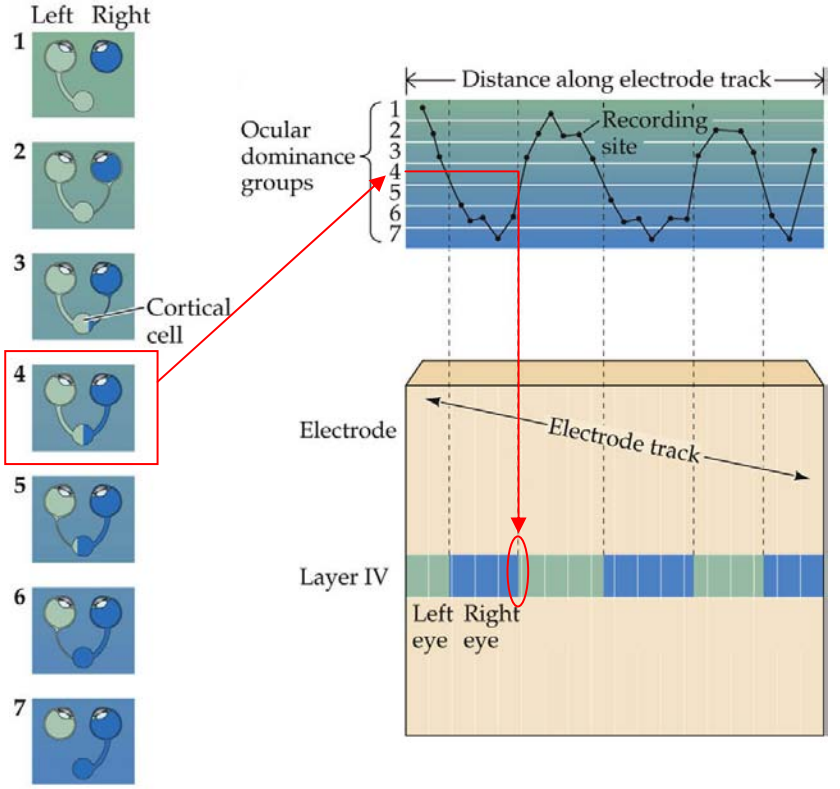
Functional organization of the Striate Cortex

Binocular domains in the visual cortex

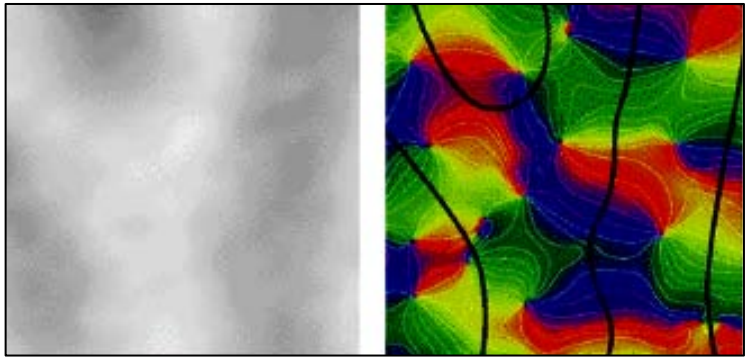








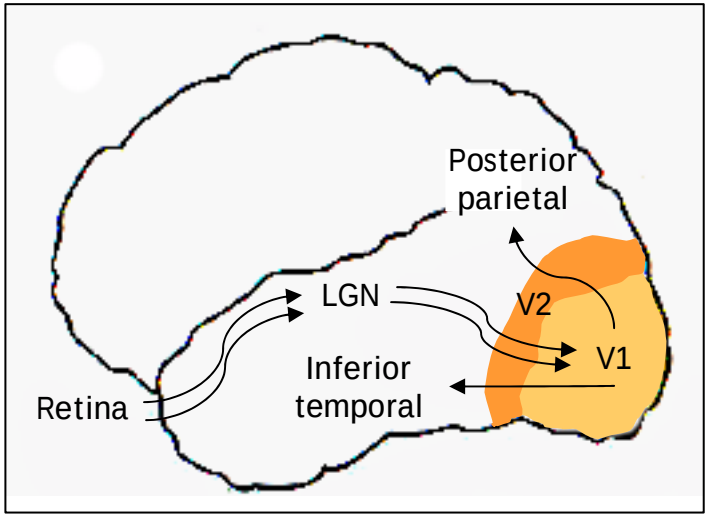
Functional domains in the Visual Cortex: a summary

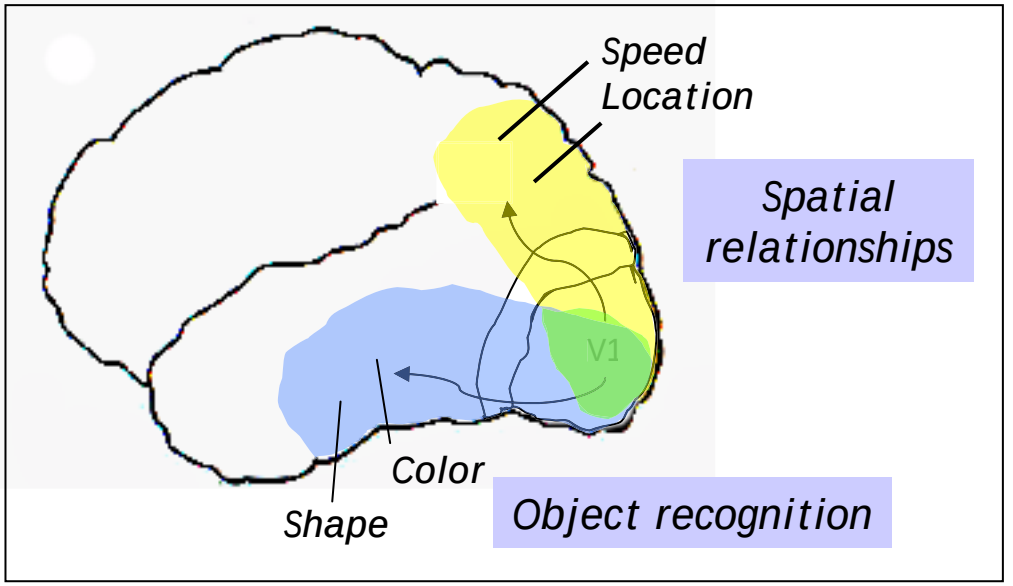


Figures: Kandel, 1999; Purves 2004

Functional organization of the Striate Cortex

Parallel pathways → Segregation of information about stimuli





Figures: Kandel, 1999