Function of the Nervous System

- The nervous system is a coordination and control system that helps the body maintain homeostasis. It
  - Gathers information about the internal and external environment (sense organs, nerves)
  - Relays this information to the spinal cord and the brain
  - Processes and integrates the information
  - Responds, if necessary, with impulses sent via nerves to muscles, glands, and organs
Neuron Structure

- Dendrites bring impulses TO the soma
- Soma is the 'processing' part of the neuron
- Axon carries impulses AWAY from the soma
- Synaptic knobs contain ntx
- Myelin is found on axons
- Neurons conduct nerve impulses

*Initial segment – where action potentials (nerve impulses) begin*

Structural Classification of Neurons

Bipolar
- two processes
- sense organs

Unipolar
- one process
- ganglia

Multipolar
- many processes
- most neurons of CNS

**Classification is based on the number of processes coming directly from the cell body**

Functional Classification of Neurons

Sensory Neurons
- afferent, ascending
- carry impulse to CNS
- most are unipolar
- some are bipolar

Interneurons
- link neurons
- integrative
- multipolar
- in CNS

Motor Neurons
- efferent, descending
- multipolar
- carry impulses away from CNS
- carry impulses to effectors

Notice the directionality – one-way
### Table of Neuroglia

<table>
<thead>
<tr>
<th>Name of Cell</th>
<th>Location</th>
<th>Function(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Cells</td>
<td>Ganglia of PNS</td>
<td>Regulate microenvironment of neurons</td>
</tr>
<tr>
<td>Astrocytes</td>
<td>CNS</td>
<td>Regulate microenvironment of neurons; scar tissue in CNS</td>
</tr>
<tr>
<td>Schwann Cells</td>
<td>PNS</td>
<td>Myelination of axons; structural support for non-myelinated axons</td>
</tr>
<tr>
<td>Oligodendrocytes</td>
<td>CNS</td>
<td>Myelination of axons; structural framework</td>
</tr>
<tr>
<td>Microglia</td>
<td>CNS</td>
<td>Phagocytes of the CNS</td>
</tr>
<tr>
<td>Ependymal Cells</td>
<td>CNS</td>
<td>Assist in producing and controlling composition of CSF</td>
</tr>
</tbody>
</table>

### Neurophysiology

If you are still a little ‘fuzzy’ about this material or want a bit more detail, be sure to look at the Supplemental Study Notes for Neurophysiology (on the Web site under Lecture 18 Supporting Materials)

Neurophysiology is summarized using the most important points in your Nervous System Study Notes for Final Exam (a completed study guide for the nervous system) on the Web site under Exam Study Guides

### Membrane Channel Proteins

1. **Passive channels** are ALWAYS open
   - Also called ‘leak’ channels
   - Passive K⁺ channels always allow K⁺ through
2. **Active (gated) channels** open or close in response to signals
   a. **Mechanical** – respond to distortion of membrane
   b. **Ligand-gated** (Chemically-gated)
      - Binding of a chemical molecule, e.g., ACh on MEP
      - Present on dendrites, soma, sometimes on axons
   c. **Voltage-gated**
      - Respond to changed in electrical potential
      - Found on excitable membranes, e.g., axons, sarcolemma
Transmembrane (Resting) Potential

A potential difference of -70 mV exists in the resting neuron due to the electrochemical gradient = Transmembrane Potential

- inside negative relative to outside
- polarized at rest
- Na⁺/K⁺ ATPase pump restores proper ion balance after its disturbed

Potential difference of -70 mV exists in the resting neuron due to the electrochemical gradient = Transmembrane Potential.

Postsynaptic Potentials

Excitation
- depolarizes membrane of postsynaptic neuron
- postsynaptic neuron becomes more likely to become depolarized and generate its own action potential

Inhibition
- hyperpolarizes membrane of postsynaptic neuron
- postsynaptic neuron becomes less likely to become depolarized and generate its own action potential

One neuron acts on the next, postsynaptic, neuron by changing the resting membrane potential of the postsynaptic neuron; either de- or hyperpolarizing it.

Changes in Membrane Potential

- If membrane potential becomes more positive than its resting potential, it has depolarized (Movement of ? charges causes this?)
- A membrane returning to its resting potential from a depolarized state is being repolarized (Movement of ? charges causes this?)
- If membrane potential becomes more negative than its resting potential, it has hyperpolarized
Action Potential and Refractory Period

- Action Potential begins in initial segment of neuron
- Absolute Refractory Period (ARP)
- Relative Refractory Period (RRP)
- Influx of Na\(^+\) (Depolarization)
- Outflow of K\(^+\) (Repolarization)

**Great summary graphic to know for exam!**

Action Potentials

Shown at left is an example of continuous propagation (~ 1m/s)

What keeps the action potential going in ONE DIRECTION, and not spreading in all directions like a graded potential?

**Absolute refractory period** of the previously depolarized segment.

Local (Graded) Potential Changes

- Caused by various stimuli
  - chemicals
  - temperature changes
  - mechanical forces
- Cannot spread very far (~ 1 mm max)
  - weaken rapidly
- Uses ligand-gated Na\(^+\) channels
  - On membranes of many types of cells including epithelial cells, glands, dendrites and neuronal cell bodies
  - General response method for cells
- Can be summed (so that an action potential threshold is reached; change in membrane potential \(\propto\) stimulus strength

**Starting point for an action potential**
Saltatory (Leaping) Conduction

Myelin acts as an insulator and increases the resistance to flow of ions across neuron cell membrane.

Ions can cross membrane only at nodes of Ranvier.

Impulse transmission is up to 20x faster than in non-myelinated nerves. Myelinated axons are primarily what makes up white matter.

---

Chemical Synaptic Transmission

Neurotransmitters (ntx) are released when impulse reaches synaptic knob.

This may or may not release enough ntx to bring the postsynaptic neuron to threshold.

Chemical neurotransmission may be modified.

Ultimate effect of a ntx is dependent upon the properties of the receptor, not the ntx.

How is the neurotransmitter neutralized so the signal doesn’t continue indefinitely?

---

Postsynaptic Potentials

**EPSP**
- **Excitatory postsynaptic potential**
- **Depolarizes** membrane of postsynaptic neuron
- Postsynaptic neuron becomes more likely to become depolarized

**IPSP**
- **Inhibitory postsynaptic potential**
- **Hyperpolarizes** membrane of postsynaptic neuron
- Postsynaptic neuron becomes less likely to become depolarized

One neuron acts on the next, postsynaptic, neuron by changing the resting membrane potential of the postsynaptic neuron; either de- or hyperpolarizing it.
Summation of EPSPs and IPSPs

• EPSPs and IPSPs are added together in a process called summation.

• Summation can be temporal (over time) or spatial (within a certain space).

• Summation uses graded potentials.

Neurotransmitters

<table>
<thead>
<tr>
<th>Neurotransmitter</th>
<th>Location</th>
<th>Major Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylcholine</td>
<td>CNS, PNS</td>
<td>Involved in control of skeletal muscle actions</td>
</tr>
<tr>
<td>Dopamine</td>
<td>CNS</td>
<td>Stimulates skeletal muscle contractile at neuromuscular junctions; May excite or inhibit at autonomic nervous system synapses</td>
</tr>
<tr>
<td>Serotonin</td>
<td>CNS</td>
<td>Creates a sense of feeling good; low levels may lead to depression</td>
</tr>
<tr>
<td>Histamine</td>
<td>CNS</td>
<td>May excite or inhibit autonomic nervous system actions, depending on receptors</td>
</tr>
<tr>
<td>Serotonin</td>
<td>CNS</td>
<td>May excite or inhibit autonomic nervous system actions, depending on receptors</td>
</tr>
<tr>
<td>GABA</td>
<td>CNS</td>
<td>Generally inhibitory</td>
</tr>
<tr>
<td>Adrenaline</td>
<td>CNS</td>
<td>Generally excitatory</td>
</tr>
<tr>
<td>Substance P</td>
<td>PNS</td>
<td>Excitatory pain perception</td>
</tr>
<tr>
<td>Endorphins, enkephalins</td>
<td>CNS</td>
<td>Generally inhibitory; reduce pain by inhibiting substance P release</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>CNS, PNS</td>
<td>May play a role in memory and learning</td>
</tr>
</tbody>
</table>

Neuromodulators: Influence release of ntx or the postsynaptic response to a ntx, e.g., endorphins, enkephalins.

Protection of the Brain

• The brain is protected
  – Mechanically by
    • The skull bones
    • The meninges (singular: meninx)
    • The cerebrospinal (CSF) fluid
  – Biochemically by the blood-brain barrier
    • Capillaries interconnected by tight junctions
    • Astrocytes/ependymal cells control permeability of general capillaries/choroid capillaries
    • May be obstacle to delivery of drugs
    • May become more permeable during stress
Meninges of the Brain

- **dura mater** – outer, tough (anchoring dural folds)
- Subdural space – like interstitial fluid
- arachnoid mater – web-like
- Subarachnoid space – CSF*
- pia mater – inner, delicate

Blood-brain barrier - Capillaries interconnected by tight junctions, astrocytes/ependymal cells control permeability of general capillaries/choroid capillaries

Cerebrospinal Fluid

- secreted by choroid plexus of ventricles (~500 ml/day)
- circulates in ventricles, central canal of spinal cord, and subarachnoid space
- completely surrounds brain and spinal cord
- nutritive and protective
- helps maintain stable ion concentrations in CNS
- ependymal cells are glial cells that play a role in generating CSF

Flow of CSF

1. The choroid plexus of each ventricle produces CSF.
2. CSF flows through the ventricles and into the subarachnoid space via the median and lateral apertures.
3. CSF flows through the subarachnoid space.
4. CSF is absorbed into the dural venous sinuses via the arachnoid villi.
Overview of Cerebral Cortex

The cerebrum can be divided into several functional areas:
- Motor (frontal cortex)
- Sensory (parietal, occipital, and temporal cortex)
- Association (all lobes)

Cortex = Conscious Awareness

The Homunculi shown here are associated with the CORTEX of the cerebrum

<table>
<thead>
<tr>
<th>Part of Brain</th>
<th>Main Function</th>
</tr>
</thead>
</table>
| Motor areas   | Primary motor cortex (Precentral gyrus)  
voluntary control of skeletal muscles |
|               | Broca's area (motor speech area)  
controls muscles needed for speech |
|               | Frontal eye field  
controls muscles needed for eye movement |
| Sensory areas | Cutaneous sensory area (postcentral gyrus)  
receives somatic sensations |
|               | Visual area (occipital lobe)  
receives visual sensations |
|               | Auditory area (temporal lobe)  
receives auditory sensations |
|               | Association areas (all lobes)  
analyze and interpret sensory experiences; coordinate motor responses; memory, reasoning, verbalization, judgment, emotions |
| Basal nuclei  | Subconscious control certain muscular activities, e.g., learned movement patterns; a nucleus is a collection of neuron cell bodies in the CNS; putamen, globus pallidus, caudate |
| Limbic system | controls emotions, produces feelings, interprets sensory impulses, facilitates memory storage and retrieval (learning!) |
| Diencephalon  | Thalamus  
gateway for sensory impulses heading to cerebral cortex, receives all sensory impulses (except smell) |
|               | Hypothalamus  
vital functions associated with homeostasis |
| Brainstem     | Midbrain  
major connecting center between spinal cord and brain and parts of brainstem; contains corpora quadrigemina (visual and auditory reflexes) |
|               | Pons  
helps regulate rate and depth of breathing, relays nerve impulses to and from medulla oblongata and cerebellum |
|               | Medulla Oblongata  
contains cardiac, vasomotor, and respiratory control centers, contains various nonvital reflex control centers (coughing, sneezing, vomiting) |
|               | Reticular formation (system)  
filters incoming sensory information; habituation, modulates pain, arouses cerebral cortex into state of wakefulness (reticular activating system) |
| Cerebellum    | subconscious coordination of skeletal muscle activity, maintains posture |
Memory

- A “Memory” is the persistence of knowledge that can be accessed (we hope!) at a later time.
- Memories are not stored in individual “memory cells” or neurons; they are stored as pathways called engrams, or memory traces that use strengthened or altered synapses.

Immediate memory lasts a few seconds, e.g., remembering the earliest part of a sentence to make sense of it.

Short-term memory (STM) lasts a few seconds to a few hours
  - Working memory is a form of this (repeating a phone number over to yourself just long enough to dial it – and then forget it!)
  - Limited to a few ‘bits’ of information (about 7-9). So, ‘chunk up’!

Long-term memory (LTM) can last a lifetime
  - Can hold much more information than STM
  - Declarative (events and facts); Procedural (motor skills)
  - Remembering childhood events as an adult

Spinal Cord Structure

- Functions of spinal cord:
  - is a center for spinal reflexes
  - aids in locomotion
  - is a conduit for nerve impulses to and from the brain

- cauda equina - Begins around L2 and extends to S5. Good area for lumbar puncture and collection of CSF.

Organization of Spinal Gray Matter

Cell bodies of sensory neurons are in dorsal root ganglion

Cell bodies of motor neurons are found here
Tracts of the Spinal Cord

- **Ascending** tracts conduct **sensory** impulses to the brain
- **Descending** tracts conduct **motor** impulses from the brain to motor neurons reaching muscles and glands

Tract: Contains axons that share a common origin and destination

Tracts are usually named for their place of origin (1st) and termination (2nd)

---

1st, 2nd, and 3rd Order Sensory Neurons

**Examples of sensory (ascending) tracts** (note how the names tell you where they're coming from and where they are going to...)

- Spinothalamic
- Spinocerebellar
- Fasciulus cuneatus/gracilis

1st order neuron – from receptor to the spinal cord (cell bodies are located in the dorsal root ganglion)

2nd order neuron – from spinal cord to thalamus

3rd order neuron – from thalamus and terminate in the cerebral cortex

---

Descending Tracts

- **Examples of descending spinal tracts**
- corticospinal
- reticulospinal
- rubrospinal

Upper MN – Cerebral cortex to spinal cord

Lower MN – Spinal cord to effector muscles
Reflex Arcs

Reflexes – automatic, subconscious, quick, stereotyped responses to stimuli either within or outside the body, and occur in both the somatic and autonomic division

The 3 different somatic reflexes we discussed in class:

1. Knee-jerk monosynaptic, ipsilateral
2. Withdrawal: polysynaptic, ipsilateral
3. Crossed extensor: polysynaptic, contralateral

Peripheral Nervous System

• Cranial nerves arising from the brain
  • Somatic fibers connecting to the skin and skeletal muscles
  • Autonomic fibers connecting to viscera

• Spinal nerves arising from the spinal cord
  • Somatic fibers connecting to the skin and skeletal muscles
  • Autonomic fibers connecting to viscera

The Cranial Nerves

<table>
<thead>
<tr>
<th>Numeral</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Olfactory (OLD)</td>
<td>Olfaction/smell</td>
</tr>
<tr>
<td>II</td>
<td>Optic (OPIE)</td>
<td>Vision</td>
</tr>
<tr>
<td>III</td>
<td>Oculomotor (OCCASIONALLY)</td>
<td>Move eye</td>
</tr>
<tr>
<td>IV</td>
<td>Trochlear (TRIES)</td>
<td>Move eye (superior oblique)</td>
</tr>
<tr>
<td>V</td>
<td>Trigeminal (TRIGONOMETRY)</td>
<td>Chewing, mastication and sensory from face (major sensory nerve of face)</td>
</tr>
<tr>
<td>VI</td>
<td>Abducens (AND)</td>
<td>Move eye</td>
</tr>
<tr>
<td>VII</td>
<td>Facial (FEELS)</td>
<td>Facial expression (major motor nerve of face)</td>
</tr>
<tr>
<td>VIII</td>
<td>Vestibulocochlear (VERY)</td>
<td>Hearing and equilibrium</td>
</tr>
<tr>
<td>IX</td>
<td>Glossopharyngeal (GLOOMY)</td>
<td>Move muscles of tongue and pharynx</td>
</tr>
<tr>
<td>X</td>
<td>Vagus (VAGUE)</td>
<td>Innervate viscera/vagal smooth muscle in thorax/abdomen; motor for speech/swallowing</td>
</tr>
<tr>
<td>XI</td>
<td>Accessory (AND)</td>
<td>Move neck muscles</td>
</tr>
<tr>
<td>XII</td>
<td>Hypoglossal (HYPOACTIVE)</td>
<td>Move tongue</td>
</tr>
</tbody>
</table>

You should know this table
Classification of Nerve Fibers

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatic fibers</td>
<td>Innervate skin, skeletal muscles, bones, and joints</td>
</tr>
<tr>
<td>Visceral fibers</td>
<td>Innervate blood vessels, glands, and viscera</td>
</tr>
<tr>
<td>General fibers</td>
<td>Innervate widespread organs such as muscles, skin, glands, viscera, and</td>
</tr>
<tr>
<td></td>
<td>blood vessels, and muscles of chewing, swallowing, and facial expression</td>
</tr>
<tr>
<td>Special fibers</td>
<td>Innervate more localized organs in the head, including the eyes, ears,</td>
</tr>
<tr>
<td></td>
<td>olfactory and taste receptors, and muscles of chewing, swallowing, and facial</td>
</tr>
<tr>
<td></td>
<td>expression</td>
</tr>
</tbody>
</table>

Table from: Saladin, Anatomy & Physiology, McGraw Hill, 2007

Structure of a Peripheral Nerve

- **Epineurium** — surrounds entire nerve
- **Perineurium** — surrounds a bundle of nerve fibers = fascicle
- **Endoneurium** — surrounds each axon (nerve fiber)

Similar to the naming of the CT around muscle!!

Spinal Nerves

- Spinal nerves contain mixed (motor/sensory) nerves
- 31 pairs
  - 8 cervical (C1 to C8)
  - 12 thoracic (T1 to T12)
  - 5 lumbar (L1 to L5)
  - 5 sacral (S1 to S5)
  - 1 coccygeal (C0)

THIRTY ONEderful flavors of spinal nerves!
Nerves Plexuses

Nerve plexus – complex network formed by anterior (ventral) branches of spinal nerves; fibers of various spinal nerves are sorted and recombined

Contains both sensory and motor fibers

<table>
<thead>
<tr>
<th>Name of Plexus</th>
<th>Spinal nerves</th>
<th>Major nerves/innervation</th>
<th>Major actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>C1 – C4</td>
<td>Musculocutaneous nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ulnar nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial nerve</td>
<td>Extension forearm/hand</td>
</tr>
<tr>
<td>Brachial</td>
<td>C5 – T1</td>
<td>Musculocutaneous nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ulnar nerve</td>
<td>Flexion forearm/hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial nerve</td>
<td>Extension forearm/hand</td>
</tr>
<tr>
<td>Lumbosacral</td>
<td>T12 – S4</td>
<td>Obturator nerve (Lumbar Plexus)</td>
<td>Movement of thigh and hip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Femoral nerve (Lumbar Plexus)</td>
<td>Movement of thigh and hip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saphenous nerve (Lumbar Plexus)</td>
<td>Movement of thigh and hip</td>
</tr>
<tr>
<td>Sciatic</td>
<td>L5 – S3</td>
<td>Sciatic nerve (Sacral plexus)</td>
<td>Movement of thigh and foot</td>
</tr>
<tr>
<td>Pudendal</td>
<td>L5 – S4</td>
<td>Pudendal nerve (Sacral plexus)</td>
<td>Movement of thigh and foot</td>
</tr>
</tbody>
</table>

Spinal Cord and Nerve Roots

Ventral root - axons of motor neurons whose cell bodies are in spinal cord
Dorsal root - axons of sensory neurons in the dorsal root ganglion
Dorsal root ganglion - cell bodies of sensory neurons

Somatic vs. Autonomic Nervous Systems

### Review of Autonomic Nervous System

<table>
<thead>
<tr>
<th>Branch of ANS</th>
<th>PARASYMPATHETIC</th>
<th>SYMPATHETIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Function</td>
<td>* &quot;rest and digest&quot; * (SLUDD); Salivation, lacrimation, urination, digestion, defecation</td>
<td>* &quot;fight or flight&quot; * E situations: Emergency, exercise, embarrassment, excitement</td>
</tr>
<tr>
<td>Origin of Preganglionic fiber</td>
<td>cranial region of brain or sacral region of spinal cord (craniosacral outflow)</td>
<td>thoracic or lumbar region of spinal cord (thoracolumbar outflow)</td>
</tr>
<tr>
<td>Location of Ganglia</td>
<td>within or near effector organ</td>
<td>alongside or in front of spinal cord (paravertebral ganglia; collateral ganglia)</td>
</tr>
<tr>
<td>NTs secreted by postganglionic fiber</td>
<td>acetylcholine</td>
<td>Norepinephrine (some acetylcholine; sweat glands, smooth muscle on blood vessels, brain)</td>
</tr>
</tbody>
</table>

Good summary chart to know

---

### Sympathetic Division of ANS

Figure from: Saladin, *Anatomy & Physiology*, McGraw Hill, 2007

---

### Autonomic Plexuses

Figure from: Martini, *Fundamentals of Anatomy & Physiology*, Pearson Education, 2004

---

Autonomic plexuses contain sympathetic and parasympathetic postganglionic fibers
### Actions of Autonomic Neurotransmitters

- **Cholinergic receptors**
  - bind acetylcholine
  - nicotinic
    - excitatory
  - muscarinic
    - excitatory or inhibitory

- **Adrenergic receptors**
  - bind norepinephrine
    - alpha (Types 1 and 2)
      - different responses on various effectors
    - beta (Types 1 and 2)
      - different responses on various effectors

### Sensory Receptors

- **Sensory Receptors**
  - specialized cells or multicellular structures that collect information (transduce information into nerve impulses)
  - stimulate neurons to send impulses along sensory fibers to the brain (receptor vs. generator [action] potentials)

  - **Chemoreceptors** (general)
    - respond to changes in chemical concentrations

  - **Pain receptors or nociceptors** (general)
    - respond to stimuli likely to cause tissue damage

  - **Thermoreceptors** (general)
    - respond to changes in temperature

  - **Mechanoreceptors** (general, special)
    - respond to mechanical forces

  - **Photoreceptors** (special)
    - respond to light

### Mechanoreceptors

- Sense mechanical forces such as changes in pressure or movement of fluid

- **Two main groups**
  - baroreceptors – sense changes in pressure (e.g., carotid artery, aorta, lungs, digestive & urinary systems)
  - proprioceptors – sense changes in muscles and tendons
Stretch Receptors - Proprioceptors

- Muscle spindle - initiates contraction (stretch reflex)
- Golgi tendon organ - inhibit contraction

Temperature Sensors (Thermoreceptors)

Warm receptors
- sensitive to temperatures above 25°C (77°F)
- unresponsive to temperature above 45°C (113°F)

Cold receptors (3-4x more numerous than warm)
- sensitive to temperature between 10°C (50°F) and 20°C (68°F)
- unresponsive below 10°C (50°F)

Pain receptors are activated when a stimulus exceeds the capability (range) of a temperature receptor
- respond to temperatures below 10°C
- respond to temperatures above 45°C

Sensory Adaptation

- reduction in sensitivity of sensory receptors from continuous stimulation (painless, constant)
- stronger stimulus required to activate receptors
- smell and touch receptors undergo sensory adaptation
- pain receptors usually do not undergo sensory adaptation (at level of receptor)
- impulses can be re-triggered if the intensity of the stimulus changes
The Middle Ear (Tympanic Cavity)

Typanic reflex: Elicited about 0.1 sec following loud noise; causes contraction of the tensor tympani m. and stapedius m. to dampen transmission of sound waves.

Auditory Tube

- eustachian, auditory, or pharyngotympanic tube
- connects middle ear to throat
- helps maintain equal pressure on both sides of tympanic membrane
- usually closed by valve-like flaps in throat

When pressure in tympanic cavity is higher than in nasopharynx, tube opens automatically. But the converse is not true, and the tube must be forced open (swallowing, yawning, chewing).

Physiology of Hearing

Know pathway for exam:

- Tympanic membrane → malleus → incus → stapes → oval window
- → scala vestibuli → scala tympani → round window
**Cochlea**

- Scala vestibuli
  - upper compartment
  - leads from oval window to apex of spiral part of bony labyrinth
- Scala tympani
  - lower compartment
  - extends from apex of the cochlea to round window
  - part of bony labyrinth

**Organ of Corti – in Cochlear Duct**

- Group of hearing receptor cells (hair cells)
- On upper surface of basilar membrane
- Different frequencies of vibration move different parts of basilar membrane
- Particular sound frequencies cause hairs (stereocilia) of receptor cells to bend
- Nerve impulse generated

**Vestibule**

- Utricle
  - Communicates with saccule and membranous portion of semicircular canals
- Saccule
  - Communicates with cochlear duct
- Macula
  - Contains hair cells of utricle (horizontal) and saccule (vertical)

Utricle and saccule provide sensations of: 1) gravity and 2) linear acceleration

These organs function in static equilibrium (head/body are still)
Macula & Static Equilibrium

• responds to changes in head position
• bending of hairs results in generation of nerve impulse

These organs function in static equilibrium (head/body are still)

Semicircular Canals

• three canals at right angles
  • ampulla (expansion)  
  • swelling of membranous labyrinth that communicates with the vestibule
• crista ampullaris  
  • sensory organ of ampulla  
  • hair cells and supporting cells
  • rapid turns of head or body stimulate hair cells

Acceleration of fluid inside canals causes nerve impulse

These organs function in dynamic equilibrium (head/body are in motion)

Crista Ampullaris & Dynamic Equilibrium

Semicircular canals respond to rotational, nonlinear movements of the head = Dynamic Equilibrium
Eyelids

- palpebrae = eyelids
- composed of four layers
  - skin
  - muscle
  - connective tissue
  - conjunctiva

orbicularis oculi – closes eye (CN VII)

levator palpebrae superioris – raises eyelid (CN III)

tarsal (Meibomian) glands – secrete oil onto eyelashes; keep lids from sticking together

conjunctiva – mucous membrane; lines eyelid and covers portion of eyeball

Lacrimal Apparatus

- lacrimal gland
  - lateral to eye
  - secretes tears
- canaliculi
  - collect tears
- lacrimal sac
  - collects from canaliculi

nasolacrimal duct
  - collects from lacrimal sac
  - empties tears into nasal cavity

Tears:
- supply oxygen and nutrients to cornea (avascular)
- are antibacterial (contain antibodies and lysozyme)
- lubricate and bathe the conjunctiva

Extraocular Eye Muscles & their CN

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Action</th>
<th>Controlling cranial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral rectus</td>
<td>Moves eye laterally</td>
<td>VI (abducens)</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>Moves eye medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Superior rectus</td>
<td>Elevates eye and turns it medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>Depresses eye and turns it medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Inferior oblique</td>
<td>Elevates eye and turns it laterally</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Superior oblique</td>
<td>Depresses eye and turns it laterally</td>
<td>IV (trochlear)</td>
</tr>
</tbody>
</table>

(c) Summary of muscle actions and innervating cranial nerves

Which cranial nerves innervate each of the muscles in the diagram above? LR6SO4AO3
Lens
- transparent, avascular
- biconvex
- lies behind iris
- largely composed of lens fibers
- enclosed by thin elastic capsule
- held in place by suspensory ligaments of ciliary body
- focuses visual image on retina (accommodation)

Loss of lens transparency = cataracts

Aqueous Humor
- fluid in anterior cavity of eye
- secreted by epithelium on inner surface of the ciliary processes
- provides nutrients
- maintains shape of anterior portion of eye
- leaves cavity through canal of Schlemm (scleral venous sinus)

Accommodation
- changing of lens shape to view objects nearby
- ciliary muscles (intrinsic) change shape of lens

Far vision (emmetropia) (20 ft. or greater)

Presbyopia is the loss of the ability to accommodate with age
Iris

- composed of connective tissue and smooth muscle (intrinsic muscles)
- pupil is hole in iris
- dim light stimulates (sympathetic) radial muscles and pupil dilates
- bright light stimulates (parasympathetic, CN III) circular muscles and pupil constricts

How would viewing near objects affect pupil size?

Visual Receptors

Rods
- long, thin projections
- contain light sensitive pigment called rhodopsin
- hundred times more sensitive to light than cones
- provide vision in low light/darkness
- produce colorless vision
- produce outlines of objects
- view off-center at night
- outward from fovea centralis

Cones
- short, blunt projections
- contain light sensitive pigments called erythrolabe, chlorolabe, and cyanolabe (photopsins)
- provide vision in bright light
- produce sharp images
- produce color vision
- in fovea centralis

Dark adaptation by the rods takes approximately 30 minutes. This adaptation can be destroyed by white light in just milliseconds.

Optic Disc (Blind Spot)

Optic disc(k) – Exit of optic nerve; no photoreceptors = no vision
Macula lutea – area immediately surrounding fovea centralis
Fovea centralis – contains only cones; area of most acute vision
The right side of the brain receives input from the left half of the visual field.
The left side of the brain receives input from the right half of the visual field.

Outer (Fibrous) Tunic

Cornea
- anterior portion
- transparent
- light transmission
- light refraction
- well innervated
- avascular

Sclera
- posterior portion
- opaque
- protection
- support
- attachment site for extrinsic eye muscles

Transverse section, superior view

Middle (Vascular) Tunic = Uvea

1. Iris
   - anterior portion
   - pigmented CT
   - controls light intensity
2. Ciliary body
   - anterior portion
   - pigmented
   - holds lens
   - muscles reshape lens for focusing
   - aqueous humor
3. Choroid coat
   - provides blood supply
   - pigments absorb extra light

This layer contains the intrinsic muscles of the eye
- Regulate the amount of light entering the eye
- Regulate the shape of the lens

Figure from: Hole's Human A&P, 12th edition, 2010