The Senses

we spend our lives in an ocean of sensory stimuli:
- light
- gravity
- electrical currents
- vibrations
- time

our survival depends on our ability to **perceive**, **interpret** and **respond** to these signals

Reception vs **Perception**

Reception is the mechanism and structures involved in detecting and transmitting sensory information

our body has millions of **sensory receptors**

All sensory receptors are "connected to" our CNS by way of sensory neurons

these neurons travel through the Cranial or Spinal nerves to the brain or spinal cord

Perception is the conscious awareness of sensory stimuli

is a higher level process of integration and interpretation

depends on how the brain processes the signals it is receiving:

1. most sensory stimuli, we never consciously perceive (eg. reticular system)

2. generally perceive stimuli coming from outside the body

3. individual sensitivities, eg colorblindness
   → unusual pathways, eg synesthesia

eg. Our perception of vision is very different from what our eyes actually perceive:

→ blind spot is filled in

→ eye movements and blinking add up to over 4 hours each day where no visual data is coming in yet the brain seamlessly fills in these lapses

→ inattention "blindness" and the "invisible gorilla"

Reception of a Stimulus

Reception of a sensation is determined by:

1. Source of Sensory Stimuli

we can classify receptors by their location or the source of the stimulus they respond to:

a. **exteroceptors**
- near surface of body
- monitor external environment
- most special senses

b. **visceroceptors (interoceptors)**
- deep
- monitor internal environment
- 99% of receptors in body

c. **proprioceptors**
- (specialized kind of visceroceptor)
- monitors relationship of external to internal environment
- position and movement
- orientation wrt gravity

2. Kind of Transducer

sensory receptors are **transducers**

→ receptors convert one form of energy into another that the brain can interpret

sensory receptors are designed to respond best to a single kind of stimulus:

photoreceptor	- light
chemoreceptor	- chemicals
mechanoreceptor	- bending, pressure, touch
thermoreceptor	- temperature
osmoreceptor	– salt/water conc
baroreceptor	**-** fluid pressure

each sensory receptor is designed to transduce only **one kind of stimulus** regardless of how it is stimulated

eg hard hit on head → "see stars"
eg. spicy food
eg. menthol cough drop

3. Intensity of stimulus

increase in stimulus intensity
→ increased **frequency of firing**

[strength of stimulus is encoded in frequency of action potential]

very intense stimuli may activate receptors that normally would not respond to those stimuli
eg. rub eyes → see spots
eg. afterimages

if over stimulated – become pain receptors

4. Duration of Stimulus & sensory adaptation

tonic receptors = the sensory neuron fires as long as it is being stimulated

eg. taste, pain, body position, chemicals in blood

phasic receptors = continuous stimulation of receptors eventually results in loss of response

→**sensory adaptation**

important in detecting *changes* in stimuli, not *duration* of the same stimulus

eg. smell, touch, temperature

5. Structure of Sensory Receptor

Sensations can be produced by very simple kinds of receptors or complex sense organs

receptors for General Senses are relatively simple

A. Free Nerve Endings

Direct stimulation of sensory neurons

the sensory neuron is also the receptor
→ dendrites of sensory neurons

eg. Unmodified Neurons
dendrites
in all body tissue especially epithelial and connective tissues

eg. Merkel Discs
disk like structures at dendrite
mechanoreceptors
found in deeper layers of skin

eg. Root hair plexus
entwine hair follicles
triggered by hair movement

B. Encapsulated Receptors

a simple receptor encapsulated in layers of connective tissue

eg. Meissners Corpuscles
egg shaped

eg. Pacinian Corpuscles
largest simple receptor cells (2mm, naked eye)
mechanoreceptors

C. Receptor Cells that synapses with sensory neurons

eg. taste cell synapses with neuron

D. Complex Sense Organs

Receptor Cells are part of more **complex sense organ**

components of rather elaborate sense organs
eg. eye, ear, etc

Anatomy of Sensory Organs

A. <u>Cutaneous Sensations (="Touch")</u>

"touch" is a combination of perceptions from a variety of simple receptors

especially free nerve endings and encapsulated receptors

located in skin, connective tissue and mucous membranes

~64 million sensory receptors in skin

they deliver more kinds of information than any single receptor of the special senses

Elements of Sense of "Touch"

1. Touch
   esp fingertips, palms, soles, tongue, lips, nipples, penis
2. Pressure
   Pacinian corpuscles
3. Vibration
4. Itch and Tickle
   free nerve endings
5. Temperature
   heat and cold are separate receptors

6. Pain
   nocioceptors

B. <u>The Nose</u>

smell receptors are free nerve endings

chemoreceptors

receptors are located in roof and walls of nasal passages

10-20 Million olfactory neurons in olfactory mucosa in an area about the size of a postage stamp

the sensory neurons pass through the cribriform plate of the ethmoid bone and plug into the olfactory bulb of the brain

the individual sensory neurons are considered together as the "olfactory" crainial nerve

C. <u>Taste Buds & Taste</u>

also due to **chemoreceptors**

but different structure than those of nose:

spindle-shaped **taste cells** (gustatory cells) synapse with sensory neurons

these receptors are bundled into **tastebuds**

each taste bud is a cluster of 50-150 **taste cells**

4000 - 10,000 taste buds

mostly on tongue papillae

each papilla contains up to 200 taste buds

a few on cheeks, soft palate and in throat

D. <u>Anatomy of</u> <u>The Eye</u>

eye might be considered our most important sense organ

of all the nerve fibers making up the 12 pairs of cranial nerves:

38% of them are contained in the optic nerve

we usually use data from our other senses only to supplement visual information

<u>Structure</u>

the eyeball is spherical

consists of 3 layers:

1. sclera

tough white fibrous connective tissue

anterior portion is clear = **cornea**

no blood vessels in cornea

2. choroid

middle layer

contains numerous blood vessels

highly pigmented with **melanin**

anteriorly, choroid is modified into 2 **sphincter** muscles:

1. **iris** – smooth muscle in doughnut shape

pupil – opening in center of iris

2. **ciliary muscle** – ring of muscle behind iris

lens – held in place by **suspensory ligaments**

3. retina

innermost layer of eyeball

contains the actual receptors for vision:

photoreceptors: rods & cones

fovea = area of our most acute vision

optic disc: neurons from rods and cones converge to form **optic nerve**

at the point of convergence there are no receptors

→ creates a "**blind spot**" in each eye

The eyeball contains two **cavities**:

anterior cavity (=segment)

extends from cornea to lens

contains a clear watery fluid

= **aqueous humor**

aqueous humor circulates

is secreted from capillaries in ciliary body

is reabsorbed by veins at Canal of Schlemm (near jct of cornea and sclera)

increased pressure in aqueous humor = **glaucoma**

posterior cavity (segment)

behind lens

fills most of eyeball

contains gelatinous **vitreous humor (=vitreous body)**

maintains pressure to prevent eyeball from collapsing

helps to hold retinal in place

eg. detached retina

<u>Accessory Eye Structures:</u>

extrinsic eye muscles

3 pairs of muscles that move eye

superior & inferior rectus
→ move eyeball up & down

medial & lateral rectus
→ move eyeball side to side

superior and inferior oblique
→ rotate eyeball

lacrimal apparatus

lacrimal gland & **nasolacrimal duct**

produces and drains tears that lubricate and rinse eyeball and remove and kill bacteria

only humans cry at sad thoughts; apparently has a profound effect on those around them

eg. new evidence has shown that tears contain pheromones that reduce sexual interest in men

conjunctiva

transparent **mucous membrane** that covers inner surface of eyelid and outer surface of eyeball, except cornea

richly innervated, highly sensitive to pain

heavily vascular → bloodshot

eyelids & eyelashes

close to moisten eye with tears and in sleep

eyelashes are guard hairs that help keep debris out of eye

eyebrows

protect from sweat and glare

nonverbal communication

E. Anatomy of The Ear

ear is divided into 3 regions:
outer ear
middle ear
inner ear

1. Outer Ear

pinna = external flap of tissue

ear canal (Auditory Canal) passes through the temporal bone

protects eardrum:

→ contains wax (ceruminous) glands to trap dust and bacteria

sometimes wax builds up and blocks ear canal

→ maintains more constant temp and humidity on ear drum for optimal performance

→ also collects & amplifies sound waves and directs them to eardrum

2. Middle Ear

separated from outer ear by ear drum =**tympanum**

contains 3 bones:

malleus (hammer)
incus (anvil)
stapes (stirrup)

two muscles for protection from loud noises:

tensor tympani → pulls on eardrum
stapedius → pulls on stapes

both contract due to loud noises to dampen vibrations of the ossicles = tympanic reflex

auditory tube (=eustachian tube)

connects the middle ear to throat

equalizes pressure to protect eardrum

middle ear cavity also continuous with **mastoid air spaces** (in temporal bone)

→ sometimes ear infections spread to mastoid = **mastoiditis**

3. Inner Ear

communicates with middle ear by two small membranes:

oval window - stapes pushes on oval window

round window – below oval window

consists of two series of fluid filled sacs and passageways:

a. bony labyrinth

b. membranous labyrinth

between the two is a cushion of fluid =**perilymph**

within the membranous labyrinth is more fluid =**endolymph**

a. bony labyrinth

the actual cavity in temporal bone that contains the soft tissue of the inner ear

vestibule - chamber just inside oval & round windows

cochlea - coiled canal attached to vestibule

semicircular canals - 3 "U-shaped" tubes at right angles branching from vestibule

b. membranous labyrinth

inside the bony labyrinth

the soft membranes and sacs that comprise the functional structures of the inner ear

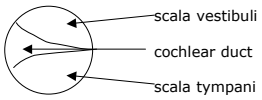
utricle & saccule - within vestibule

cochlear duct - within cochlea

semicircular ducts - within SC canals

cochlear duct is only portion of inner ear actually involved in sense of hearing

it forms shelf across cochlea dividing it into 3 sections:



on the floor of the cochlear duct is the **Organ of Corti**, the actual organ of hearing

The **Organ of Corti** consists of:

a group of **hair cells** (mechanoreceptors)

a **tectorial membrane** that sits on the hair cells

Sensory Physiology

A. <u>Cutaneous Sensations (="Touch")</u>

most skin receptors are **mechanoreceptors** that detect various kinds of vibrations and pressure

the receptors for all touch sensations are due to either free nerve endings or encapsulated receptors:

eg. light touch is mediated by **Merkel Discs** and **Meisner Corpuscles**

eg. pressure is detected by **Pacinian Corpuscles**

eg. heat & cold stimuli trigger **free nerve endings**

eg. pain receptors are also due mostly to **free nerve endings**

touch receptors are not evenly distributed over surface of body

most ↑	tip of tongue
	lips
	fingertips
	nose
	back of hand
least ↓	back of neck

braille exploits high tactile acuity of fingertips

all somatesthetic information goes to the postcentral gyrus (parietal lobe) = sensory cortex

B. <u>Smell</u>

receptors are **free nerve endings**

receptors are located in roof and walls of nasal passages

10-20 Million olfactory neurons in olfactory mucosa in an area about the size of a postage stamp

olfactory neurons are the only neurons in the body directly exposed to external environment

neurons pass through **cribiform plate** and connect to **olfactory bulb** on anterior ventral surface of brain

are **chemoreceptors**

smell → detects airborne chemicals that enter nasal cavity

a chemical can be smelled only if it is volatile (=ie. able to become airborne)

mostly small molecules

a long range sense

since they are neurons, they are replaced only very slowly and not as quickly as they are lost

→ some replacement
→ but overall, we loose ~1%/yr
→ loose sense of smell as we get older

olfactory receptors are extremely sensitive

we are able to detect >10,000 different chemicals (most: 2000 – 4000)

we have ~350 distinct kinds of receptor proteins

→ seem to be grouped into 15 – 30 "families" of odors

some can detect a single molecule of certain chemicals

eg. can smell mercaptans (skunks) 1pt in 30 Billion

women are more sensitive to smells than are men

though smell receptors are very sensitive, they adapt quickly

some applications of olfactory physiology:

eg. Morning Sickness

during pregnancy sense of smell becomes much more acute due to action of estrogen which increases during pregnancy
→ may lead to morning sickness

almost all stimuli for nausea are odors

esp smell of cooking foods, esp meats and bacon

sometimes also coffee, perfumes, cigarette smoke, petroleum products, etc

eg. Military use of smell for crowd control

C. Taste Buds & The Physiology of Taste

each taste cell acts as a **chemoreceptor**

→ presence of specific chemical initiates nerve impulse

taste cells detects chemicals in foods and drink

short range; requires direct contact with "food"

taste receptors are much less sensitive than smell receptors

the molecule must be water soluble

eg. starch powder in insoluble → has no taste

taste cells are replaced every 7-10 days

→continually replaced throughout life

Flavors detected by taste receptors:

sweet - respond to sugars, some amino acids
sour - respond to acids
bitter - respond to alkaloids (eg. quinine, nicotine, caffeine)
salty - respond to inorganic salts and metal ions
umami - (='delicious, savory') respond to meaty flavor, glutamate, aspartate, MSG

all primary taste sensations are detected in all areas of the tongue

in spite of "**taste maps**" of the tongue:

there is no evidence of any clear spatial separation of our actual perceptions of different flavor, if any it is apparently slight

tonic receptors → don't adapt quickly

also, we have differing sensitivities to different flavors

eg. **sucrose** must be present in 1 pt in 200 to be detected (least)
eg. saltiness can be detected in 1:400 ↓
eg. quinine can be detected in 1:2,000,000 (most)

the **sense of taste** also involves additional receptor types:

thermoreceptors (spicy hot, menthol)

mechanoreceptors (texture)

nocioceptors (spicy)

also, **many flavors depend on smell**

→ taste is up to 80% smell

hold nose to take medicine

older people complain of lost taste but actually are losing smell

interaction of all these kinds of receptors produces all the flavors of food and drink

→ scientists have recently (2010) found **taste cells** in the stomach, intestine, pancreas & colon

they seem to help prepare the digestive system for the specific food that is eaten

eg. when the gut detects sugar it sends a "prepare for fuel" message that cranks up insulin levels in blood

eg. when hit by bitter (potentially toxic) substances the gut reacts by slowing absorption

→ bitter taste receptors have also been found in **lung** tissue

responds to bitter substances by causing airways to dilate

might be a way to get bitter toxins to be coughed out of lungs more easily

potential use as asthma medicine since the reaction is stronger than those now in use

D. The Physiology of Vision

light is electromagnetic energy

→spectrum of energies (400nm to 700 nm)

what we "see" is the light that bounces off of various objects and enters our eyes

VISION consists of several interacting processes:

1. Control of Light Intensity

light is a relatively **high energy** source

→ much of the anatomy of the eye is designed to control or reduce the amount of light entering the eye

amount of light entering eye must be regulated to allow enough in to stimulate receptors

while preventing too much that might cause overstimulation

A. Pupillary Constriction and Dilation

iris is a sphincter muscle that acts as "f-stop" of camera

pupil = opening in center of iris muscle

iris allows appropriate amount of light to enter eyeball

prevents overstimulation of retina in daytime (bright light)

increases the amt of light entering at night (dim light)

controlled by autonomic motor neurons

B. choroid layer

melanin absorb excess light that enters the eye

albinos → no pigment in choroid layer → difficulty in daylight

2. Refraction of Light Rays

as light passes through materials of different density and curvatures it is bent (=refracted)

eg. spoon in glass of water

light rays are bent as they pass through cornea, aqueous humor, lens, vitreous humor

also image is reversed

the light rays converge to form an image on the **retina** at the back of the eye

the actual image is "upside down and backwards" as in a camera

the brain takes this image and turns it upright for proper 'perception'

eg. experiments with reversed image

in many the eyeball is not shaped properly to get image to converge on retina:

nearsightedness – eyeball is elongated; image is focused before it reaches the retina

farsightedness – eyeball is compressed; image is not focused before it reaches retina

astigmatism – bump or depression on cornea or lens that refracts only some of the light rays incorrectly

3. Accommodation of Lens

in order to be able to focus on near or far objects the lens must change shape

accomplished by **ciliary muscle** and **suspensary ligaments:**

ciliary muscle contracts

→ release tension on suspensary ligaments & lens

→ lens thickens for near vision

ciliary muscle relaxes

→ pulls suspensary ligaments which pull on lens
→ causes lens to thin for far vision

as one gets older the lens becomes less flexible

→ doesn't thicken as much as it should

→ require reading glasses for near vision

4. Depth Perception (Convergence of Eyes)

extrinsic eye muscles and reflex centers in brain allow individual eyes to converge on same object

would produce double vision if both eyes are not focused on same scene

(this happens sometime when adjusting the bifocal ocular lenses on the microscope)

those with crossed eyes learn to suppress one image

produces depth (3-D) perception

→ both eyes are looking at same scene but from slightly different angle

those with only one eye have no depth perception

5. Stimulation of Photoreceptors

>130 Million photoreceptors in each eye

two types of photoreceptors:

rods 130M/retina
cones 6.5 M/retina

<u>Rods</u>

-rods produce "**colorless**" vision (b/w vision)

-rods are much *more* sensitive to light

need less light to function

→ best in dim light (**night vision**)

in daytime, rods "bleach" out & shut down

-rods contain light active pigment = **rhodopsin** (derived from vitamin A)

when light strikes pigment

→ causes chemical change

→ triggers nerve impulse

reduction in rhodopsin of only 0.6% from its maximum level decreases rod sensitivity ~3000x's

→ night blindness

caused by deficiency of Vitamin A

Approximately 250,000 to 500,000 malnourished

children in the developing world go blind each year from a deficiency of vitamin A,

approximately half of whom die within a year of becoming blind.

-up to 1000 rods are connected to single neuron in optic nerve

→ helps to amplify dim image

→ but **less acuity**

-rods are most dense at **periphery** of retina

become less numerous toward fovea

Cones

-cones produce **color vision**

-cones are much *less* sensitive to light

need more light to function

→ best in bright light (**day vision**)

at night – not enough light to stimulate cones

-each cone contains one of three pigments:

red-green-blue

combinations of the three produce color vision

→ eg. all 3 = white

-most cones are individually connected to neuron

→ poor for dim light

→ much **greater acuity** in bright light

-cones are densest at fovea (10,000 cones, no rods)

less numerous at periphery

switching between rods & cones can cause temporary blindness

→ receptors must adapt

eg. turning lights off or on in a dark room

Rods	Cones
b/w vision	color vision
100's x's more sensitive → takes less light to stimulate them	less sensitive to light → takes more light to stimulate them
night time, low light vision	day time, high light vision
less acute vision (many rods/ neuron)	more acute vision (1 cone/ neuron)
periphery sharpest vision	fovea sharpest vision

E. The Physiology of Hearing

the ear is a multiple sense organ

sound is due to vibrations of air molecules

in hearing: **mechanoreceptors** convert vibration of air molecules (=sound waves) into nerve impulses

sound waves are relatively low energy waves

→ much of the anatomy of the ear is designed to amplify them

1. **outer ear** collects and focuses sounds toward the eardrum and amplifies sounds

   eg. megaphone

2. causes **ear drum** to vibrate

   converting sound waves to vibration of membrane helps to amplify the sound

   very small vibrations: some the diameter of a hydrogen atom

3. **ear ossicles** resting on eardrum vibrate

   sound has been converted from vibrations of air to vibrations of solid bone

   → further amplify the sound

bone conducts sound much more strongly

damage to ossicles → conduction deafness

4. **Stapes** pushes in and out on **oval window**

5. This sets fluid of inner ear (perilymph & endolymph) in motion

   also causing round window to bulge in and out

   the vibration of water further amplifies the sound

   → sound especially lower pitches travels very well in water

6. On floor of cochlear duct is **organ of Corti** (actual organ of hearing)

   contains mechanoreceptors (=hair cells)

   their 'hairs' press against **tectorial membrane**

   as endolymph sloshes it causes the cells to rub on **tectorial membrane**

   as hairs bend initiates nerve impulses

   sound can vary in:

   loudness = measured in decibels

0 db = weakest sound heard
30 db = whisper in quiet room
60 db = normal conversation
90 db = sustained exposure causes hearing loss
95 db = jackhammer at 50'
125 db = painful
137 db = symphonic music peak
140 db = jet engine at 100'; short exposure leads to permanent damage
150 db = loudest rock/heavy metal music
172 db = .357 magnum revolver

Aging causes gradual hearing loss, mostly in the high frequencies.

The incidence of hearing loss in classical musicians has been estimated at 4-43%, in rock musicians 13-30%.

pitch

human ear can perceive pitch between 16 – 20,000 Hz (cps)

16 = lowest sound perceived by humans
18 = lowest organ note
70 = barking dog
250 = lawnmower
1050 = highest note producible by human voice
2000 = chainsaw
4185 = highest nnote on a piano
8000 = motorcycle
15,000 = most people over 40 can't hear
20,000 = highest sound perceived by humans
50,000 = highest sound perceived by dogs
200,000 = highest sound perceived by dolphins

detecting loudness of sound

greater bending of hair cells & more hair cells involved

→ perceived as louder sounds

detecting pitch of sound

different hair cells respond to different pitch

cells near **beginning** of cochlear duct respond best to **high pitched** sounds

cells near **end** (apex) of cochlear duct respond best to **low pitched** sounds

→ the pattern of firing of hair cells along the cochlear duct is interpreted as differences in pitch

7. nerve impulses travel through vestibulocochlear nerve for processing in temporal lobe of cerebrum

F. <u>Proprioceptors</u>

equilibrium and balance are maintained by complex interactions between simple receptors and complex proprioceptor organs and vision

a. simple receptors embedded in deep tissues; muscles, tendons, joints monitor:

→slight changes in pressure as we shift positions

→stretching of various internal organs

→ positions of limbs wrt rest of body

b. more complex proprioceptor organs are found in the inner ear as part of special senses

c. our eyes provide additional information on our position, orientation and motion

in addition to hearing, the ear also contains two kinds of **proprioceptors**

static equilibrium

→ orientation wrt gravity: position, orientation

dynamic equilibrium

→ *changes* in movement

Static Equilibrium

within vestibule of inner ear is fluid filled sac
= **utricle**

contains patches of hair cells = **macula**

embedded in gelatinous matrix

also in gelatinous material are small particles of calcium carbonate = **otoliths**

as head moves these otoliths shift positions and stimulate different hair cells

tells position and orientation with respect to gravity

Dynamic Equilibrium

semicircular canals branch off vestibule

fluid filled

each canal is oriented along a different plane

→ at right angles to each other

at bases of each are swelling = **ampulla**

each ampulla contains a patch of hair cells

= **crista ampullaris**

movement of fluid in these canals causes bending of crista ampullaris

→ detect acceleration and deceleration

→ detect turning, changes in motion

→ detect direction of the change

continuous movement in same direction cannot be detected
eg. we are spinning on surface of earth at ~1000 mph

eg. elevator

Motion Sickness & Vertigo

proprioceptors in our skin, joints and inner ear interact with vision to determine our relationship to the environment

when the brain is getting conflicting or uninterpretable signals it confuses the brain and generates motion sickness or vertigo

the nausea and vomiting are triggered by excess histamines produced by the brain stem and hypothalamus

most treatments involve various kinds of antihistamines that counteract their effects

Disorders of the Major Senses

Disorders of the Eye

an American goes blind every 11 minutes (AAS 1994)

Macular Degeneration

loss of central field of vision; sometimes loss of side vision

usually both eyes

inability to see clearly near or far

in advanced stages objects seem bent or distorted

colors may look different

supporting tissue around macula degenerates

associated with arteriosclerosis, hereditary factors, eye trauma

most common for Caucasians, people >60; rare among blacks

diagnosed early → laser treatments may prevent further degeneration

Glaucoma

slow loss of peripheral vision, no pain in early stages

later may be pain and blindness

due to increased pressure in eye leads to damage to optic nerve

blacks at much higher risk; also diabetics those with eye injuries or eye surgeries or very near sighted

if diagnosed and treated early may be no injury; but half with glaucoma don't know they have it

Floaters

small spots seen occasionally in field of view; spots appear as dots, threads or cobwebs that move as eye moves

caused by shrinkage of vitreus, which detaches from retina causing bleeding

sometimes result from eye injury or disease

those >40 more susceptible, also those with cataract surgery

Diabetic Retinopathy

progressive disease of blood vessels supplying retina
→ small blood vessels weaken and break or are blocked

esp in diabetics; more common in long term diabetics(>15 yrs)

pregnancy, high BP and smoking can exacerbate condition

Cataracts

clouding of lens

blurred or double viison, spots, ghost images, impression of a film over eyes, problems with lights

may develop rapidly over a few months or very slowly over periodof years

exact cause unknown

age related, diabetics, some medications and eye injury may increase risks; may be genetic component

treatment: cataract surgery – quick outpatient procedure; then lens implant, contact lenses or cataract eyeglasses