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. It is a higher level process of integration and interpretation. It 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. visceroreceptors (interoceptors) deep
      monitor internal environment
      99% of receptors in body

   c. proprioceptors (specialized kind of visceroreceptor)
      monitors relationship of external to internal
      gravity
      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
e.g. 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
  
  e.g. 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**

**B. Encapsulated Receptors**

a simple receptor encapsulated in layers of connective tissue

- **Merkel Disks**
  - disk-like structures at dendrite mechanoreceptors
  - found in deeper layers of skin

- **Root Hair Plexus**
  - entwine hair follicles triggered by hair movement

**C. Receptor Cells** that synapses with sensory neurons

- **Taste Cell Synapses with Nerve**

**D. Complex Sense Organs**

Receptor Cells are part of more complex sense organs

- **Components of Rather Elaborate Sense Organs**
  - eg. eye, ear, etc

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**Anatomy of Sensory Organs**

**A. Cutaneous Sensations (“Touch”)**

“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

**B. The Nose**

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” cranial nerve

**C. Taste Buds & Taste**

- 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. Anatomy of The Eye

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

Structure
the eyeball is spherical
consists of 3 layers:
1. sclera
tough white fibrous connective tissue

2. cornea
   anterior portion is clear
   no blood vessels in corne

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

Accessory Eye Structures:
extrinsic eye muscles
3 pairs of muscles that move eye
   1. superior & inferior rectus
      → move eyeball up & down
   2. medial & lateral rectus
      → move eyeball side to side
   3. 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
e.g. 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 \(\rightarrow\) 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**

The 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 eardrum (=**tympanum**)
- contains 3 bones:
  - **malleus** (hammer)
  - **incus** (anvil)
  - **stapes** (stirrup)
- two muscles for protection from loud noises:
  - **tensor tympani** \(\rightarrow\) pulls on eardrum
  - **stapedius** \(\rightarrow\) pulls on stapes
- both contract due to loud noises to dampen vibrations of the ossicles = tympanic reflex

**3. Inner Ear**

- 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)
  - \(\rightarrow\) sometimes ear infections spread to mastoid = **mastoiditis**

**E. Anatomy of The Ear**

**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
Sensory Physiology

A. Cutaneous Sensations (="Touch")

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

tongue

least

nose

back of hand

back of neck

braille exploits high tactile acuity of fingertips

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

B. Smell

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 (=i.e. 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 detect 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.

- Example: 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 (e.g., 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 flavors, if any it is apparently slight.

- Tonic receptors don’t adapt quickly.

- Also, we have differing sensitivities to different flavors.

  - **Sucrose** must be present in 1 pt in 200 to be detected least.
  - **Saltiness** can be detected in 1:400.
  - **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.

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 amount 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

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 suspensory ligaments:
  ciliary muscle contracts
  → release tension on suspensory ligaments & lens  
  → lens thickens for near vision  
  ciliary muscle relaxes  
  pulls suspensory 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

Rods
- 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

<table>
<thead>
<tr>
<th>Rods</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>b/w vision</td>
<td>color vision</td>
</tr>
<tr>
<td>100's x's more sensitive</td>
<td>less sensitive to light</td>
</tr>
<tr>
<td>takes less light to</td>
<td>takes more light to</td>
</tr>
<tr>
<td>stimulate them</td>
<td>stimulate them</td>
</tr>
<tr>
<td>night time, low light vision</td>
<td>day time, high light vision</td>
</tr>
<tr>
<td>less acute vision</td>
<td>more acute vision</td>
</tr>
<tr>
<td>(many rods/neuron)</td>
<td>(1 cone/neuron)</td>
</tr>
<tr>
<td>periphery sharpest vision</td>
<td>fovea sharpest vision</td>
</tr>
</tbody>
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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 note 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
   - 150,000 = highest sound perceived by dolphins

   **detecting loudness of sound**
   greater bending of hair cells & more hair cells involved

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

F. **Proprioceptors**

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 swellings = 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 vision, spots, ghost images, impression of a film over eyes, problems with lights
may develop rapidly over a few months or very slowly over period of 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