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. visceroreceptors (interoceptors)
      deep
      monitor internal environment
      99% of receptors in body

   c. proprioceptors
      (specialized kind of visceroreceptor)
      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
**tomic 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

### 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**
3. **Vibration**
4. **Itch and Tickle**
5. **Temperature**
6. **Pain**

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**

taste receptors located in **tastebuds**

→ 4000 – 10,000 taste buds

→ most on tongue → on papillae
  - each papilla contains up to 200 taste buds

some on soft palate and in throat, cheeks

each taste bud is a cluster of 50-150 spindle shaped **taste cells** (= gustatory cells)
taste cells synapse with sensory neurons

**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
   - anterior portion is clear = cornea
   - no blood vessels in cornea

2. **choroid**
   - middle layer
   - contains numerous blood vessels
   - highly pigmented
   - anteriorly is modified into 2 sphincter muscles:
     1. **iris** – smooth muscle in doughnut shape
     2. **ciliary body** – ring of muscle behind iris
     - lens – held in place by suspensory ligaments

3. **retina**
   - innermost layer of eyeball
   - contains the actual receptors for vision
   - 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

**Accessory Eye Structures:**

extrinsic eye muscles

3 pairs of muscles that move eye

**E. Anatomy of The Ear**

ear is divided into 3 regions:

1. **Outer Ear**

2. **Middle Ear**

3. **Inner 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
  ➔ 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 equals pressure to protect eardrum

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 endolymph

a. bony labyrinth

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

vestibule = chamber just inside oval window

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:

scala vestibuli
cochlear duct
scala tympani

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. 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:

- Light touch is mediated by Merkel Discs and Meissner Corpuscles.
- Pressure is detected by Pacinian Corpuscles.
- Heat and cold stimuli trigger free nerve endings.
- Pain receptors are also due mostly to free nerve endings.

Touch receptors are not evenly distributed over the surface of the body:

- Most: tip of tongue, lips, fingertips, nose.
- Least: back of hand, back of neck.

Braille exploits high tactile acuity of fingertips.

B. Smell

are chemoreceptors.

- Smell detects airborne chemicals that enter the 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.

Receptors are free nerve endings.

Olfactory neurons are the only neurons in the body directly exposed to the external environment.

Since they are neurons, they are replaced very slowly and not as quickly as they are lost.

- Some replacement.
- But overall, we lose ~1% per year.
- 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.

At least 1000 smell genes that encode “odorant binding proteins” are switched off and ~350 receptor proteins are actually made and used.

Some can detect a single molecule of certain chemicals.

- Eg. can smell mercaptans (skunks) 1 part in 30 billion.

Women are more sensitive to smells than are men.

Though 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.

- Eg.: 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

Taste cells detect chemicals in foods and drink.

Must be water soluble.

- Eg.: starch powder in insoluble has no taste.

Short range; requires direct contact with “food.”

Taste receptors are much less sensitive than smell receptors.

- Taste cells are replaced every 7-10 days.

Continually replaced throughout life.

- Each taste bud acts as a chemoreceptor.

- Presence of specific chemical initiates nerve impulse.

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 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. quinine can be detected in 1:2,000,000
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)
a relatively high energy source
what we "see" is the light that bounces off of various objects and enters our eyes
ie. light that is not absorbed by an object
much of the anatomy of the eye is designed to control or reduce the amount of light entering the eye
The process of vision consists of several distinct processes:
1. Control of Light Intensity
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
pupil = opening in center of iris muscle
iris acts as "f-stop" of camera
allows appropriate amount of light to enter eyeball
prevents overstimulation of retina in daytime
→ prevents extraneous rays that cannot be focused from entering eye
→ or reduces the amount of stimulation of retina
allows adequate light in at night
controlled by autonomic NS:
B. choroid layer
also helps absorb excess light
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
if everything is normal the eye is designed to
cause image to converge on the back of the
eye
to form an "image" on the retina
in many the eyeball is not shaped properly to get
image to converge on retina:

- nearsightedness
- farsightedness
- astigmatism – bump or depression on cornea or lens that
refracts light rays incorrectly

3. Accommodation of Lens

in order to be able to focus on near or far objects
the lens must change shape (similar to
adjusting lenses on camera)

normal eyes can adjust focus by changing shape
of lens to see both near and far

accomplished by ciliary muscle and suspensory
ligaments:

- contraction
  - release tension on lens
  - lens thickens 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

- 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: contain pigment = rhodopsin

eg. turn off or on lights
  - receptors must adapt

cones are densest at fovea (10,000 cones, no
rods) less numerous at periphery

rods are much more sensitive to light
best in dim light

cones are less sensitive to light, need more light to
work properly, best in daylight

in daytime, rods "bleach" out & shut down
at night – not enough light to stimulate cones

<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>
</table>

(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

carried by deficiency of Vitamin A

- >1000 rods are connected to single neuron in optic
  nerve
    - helps to amplify dim image
    - but lose acuity: larger receptive field

rods are most dense at periphery of retina, less numerous toward fovea

cones: also contain pigments

- three kinds of cones:
  - erythrolabe (red-orange-yellow)
  - chlorolabe (green)
  - cyanolabe (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

switching between 2 different receptors can cause
temporary blindness
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

2. causes ear drum to vibrate

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

3. ear ossicles resting on eardrum vibrate and further amplify the sound

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

   bone conducts sound much more strongly

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 travels very well in water

6. On floor (=basilar membrane) 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 fires nerve impulses

   sound can vary in:

   loudness = measured in decibels

   "normal sound" ~ 60 db

   barely audible = 0 db

   10 x’s louder = 10 db

   100x’s louder = 20 db

   1M x’s louder = 60 db

   pitch (frequency of vibrations)

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

    dogs: to 50,000

dolphins: to 150,000

    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. 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

seismic 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

tiny 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 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