Sensation & Perception

Intro Psychology
Georgia Tech
Instructor: Dr. Bruce Walker

Today

- Sensation
- Perception
- Sensory Systems
- Stimuli
- Processing
- Phenomena

Sensation ≠ Perception

- Sensation: Transduction of physical stimuli into neural signal
  - Seeing, hearing, smelling, etc.
- Perception: Translation of neural signal into "meaning"
  - Recognition, parsing the world, identification

Outline of Sensory Systems

- Physical stimulus or energy
- Receptors / receptor system
- Neural pathway
- Cortical receiving area
- Cortical projections

- Phenomena
- Problems

Vision

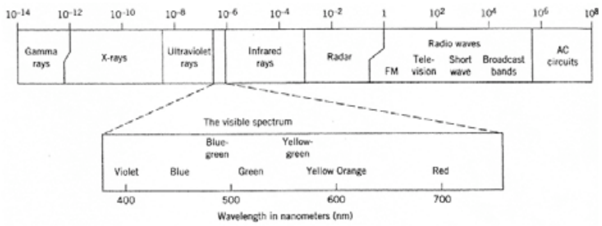
The Visual System

- The Eye
- Receptive Fields
- Visual Pathways
- Visual Cortex

The Stimulus (Light)

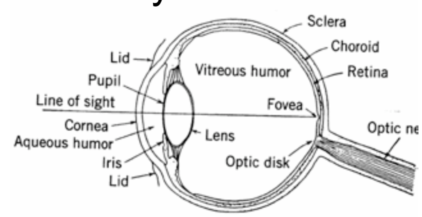
- Wavelength
  - Meters or nanometers
  - "short" ~ violet ~ 400 nm
  - "long" ~ red ~ 700 nm

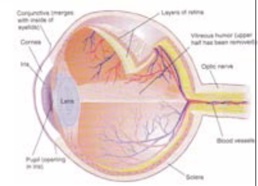
•Perceptual dimensions
–Color
–Intensity



The Eye

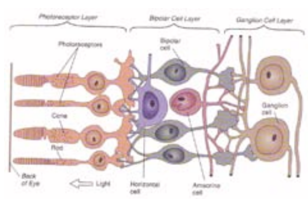
- Sclera
- Cornea
- Choroids
- Iris
- Lens
- Pupil
  - Whytt's reflex
  - Pupillometry
- Retina
- Blind spot

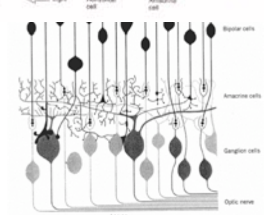




The Retina

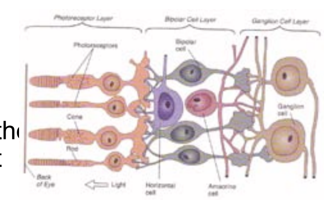
- Rods (120 million, periphery)
- Cones (6 million, fovea)
- Fovea
  - Note: eye is "backwards"
- Bipolar cells
- Ganglion cells
- Horizontal cells
- Amacrine cells
  - Note: lateral inhibition
- Sensitivity
- Spatial summation
- Acuity





Receptive Fields (in the Cortex)

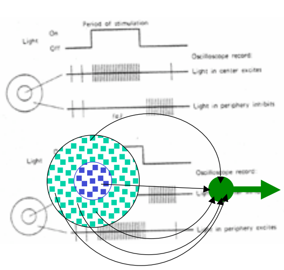
- Ganglion cells
  - Combine info from a region of the retina (th receptive field of that ganglion)
  - Foveal ganglion cells have small receptive fields
    - Input from only one or a few fovea receptors (mostly cones)
  - Peripheral ganglion cells have larger receptive fields
    - Input from an *area* of the retina (mostly rods)



Aside on cones & rods

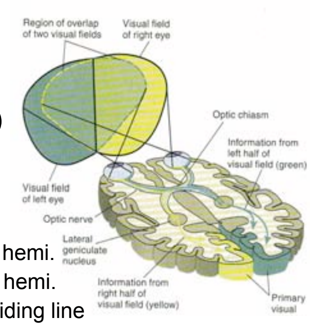
Receptive Fields, cont'd

- Center-surround field
  - ON cell
    - Center On, surround Off
  - OFF cell
    - Center Off, surround On
  - ON/OFF cell
    - Responds to flashed light
- "Wiring" to ganglion cell



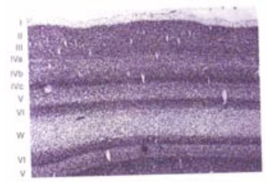
Visual Pathways

- Eye
- Optic nerve
- Optic chiasm (from χ)
  - Cross-over & split
    - "Nasal nerves cross"
  - Visual fields
    - Left visual field -> right hemi.
    - Right visual field -> left hemi.
    - Midpoint of fovea is dividing line



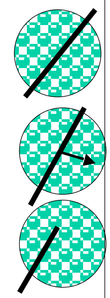
Visual (Striate) Cortex

- Occipital lobe
- Six layers
- Retinotopic layout
  - contralateral half of visual field
- Simple feature detection



Striate Cortex, cont'd

- Feature detection
  - Cortical cells respond to specific types of input
  - Orientation and movement detectors
    - Detect coincidence of ganglion firings
    - Extract features like line orientation
  - Simple cells
    - Responds to specific **orientation** and static **location**
    - Stops firing if stimulus moves
  - Complex cells
    - Respond to specific **orientation** and **movement** type
  - Hyper complex cells
    - Respond to the **end of a line** on the receptive field



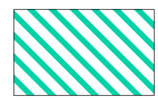
Striate Cortex, cont'd

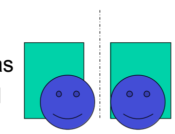
- More feature detectors
  - Spatial frequency
    - Actually, cortical feature detecting cells respond to a grating, or series of light and dark regions
  - Note: uses of spatial frequency information:
  - Long-range vision uses low spatial frequency
  - Near, details uses high spatial frequency

?? Squinting ??

Striate Cortex, cont'd

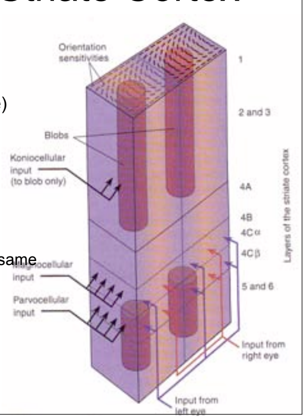
- Yet more features…
  - Texture
    - Spatial frequency + orientation
  - Retinal disparity
    - Difference in image on the two retinas
    - Recall, it will be the same visual field
    - Binocular (need both eyes)
  - Color
    - Regions of cortex respond to different cone input





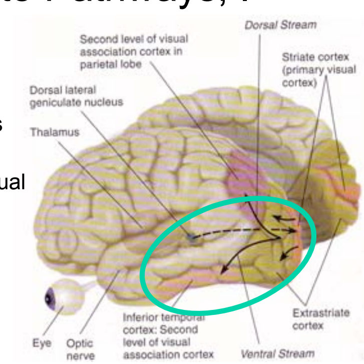
Organization of Striate Cortex

- Modules (~2500), each with 150,000 neurons
  - Consist of CO (cytochrome oxidase) blobs and surrounding neurons
  - Overlapping visual fields
- CO blobs – color resolution
- Outside blobs – feature detector
  - Column
    - Cells in vertical column respond to same orientation
    - Either left or right eye dominates a column
  - Hypercolumn
    - Set of columns



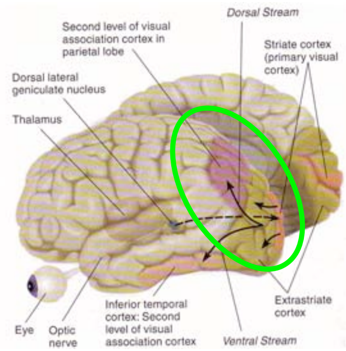
Extrastriate Pathways, I

- Ventral system
  - "What" pathway
  - Perception of objects and form
  - Damage leads to visual agnosias



Extrastriate Pathways, II

- Dorsal system
  - “Where” or “How” pathway
  - Perception of movement, location, orientation

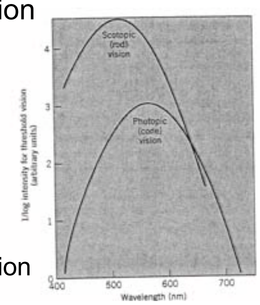


Visual Functions Overview

- Sensitivity
- Acuity
- Eye Movements
- Temporal Factors

Sensitivity

- Scotopic vs Photopic vision
  - Scotopic
  - Photopic
- Dark adaptation
  - Moving from light to dark
  - Chemical cycle of regeneration of rhodopsin
  - Red light for dark adaptation



Acuity

- Types
  - Detection
  - Vernier
  - Resolution
  - Recognition
  - Dynamic
  - Distance from fovea

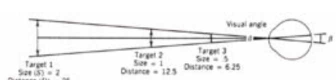
Acuity, cont’d

- Visual angle
  - As object moves away, it needs to get bigger to maintain the same level of acuity (up to a point)
  - Formula (small angles—most vision purposes)

    tan(ß) = S/D
  - Thumb example

    S=2cm

    D=50cm



tan(ß)=2/50 = 0.04
ß = 2.2 degrees

Acuity, cont’d

- Eye charts
  - Define: normal = 1 minute of arc is the minimum visual angle for recog’n acuity = 1/60 of a deg. = 0.0167 deg.
- Snellen acuity
  - 20/20 defines “normal”
  - 20/200 defines legally blind

Temporal Factors

- After effects
  - Brief stimulus
  - Prolonged stimulus
    - Tilt after effect
    - Curvature after effect
    - Due to fatigue of retinal or ganglion cells
    - Note: Color after effects discussed next section

(b)

Color Vision Overview

- Color vision in nature
- Color mixture
- Effects
- Theories
- Defective color vision

Describing Color

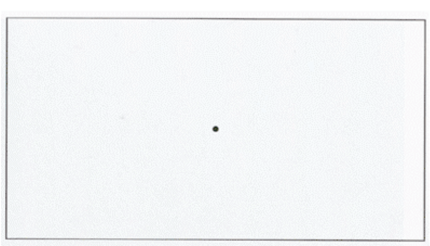
- Hue
  - Perception of wavelength
    - Why is the sky blue, anyway?
    - Why is the sky reddish at dusk?
      - Note Martian sunset is blue
    - Rainbow, ROYGBIV & Newton
- Brightness
  - Perception of intensity
  - Brightness/intensity relationship depends on hue (wavelength)
  - Similar to loudness/intensity depends on frequency
- Saturation
  - Perception of purity (like timbre)
  - A pure light is monochromatic

Colors

- Primary colors
  - Red, green, blue
    - Are these 3 colors “special” because of something in our visual system?
    - Why 3 primary colors? Why not 4, 5?
- Secondary colors
  - Mixture of primary colors
  - Yellow, cyan, magenta (between two rainbows)
  - Brighter (two sets of cones stimulated)
  - Key for mixes, paints, printing (CYMK, not RGB)
- Tertiary colors
  - Mixture of primary and secondary
  - Orange raspberry aquamarine purple lime cobalt

Effects in color vision

- After images
  - Negative after image



Effects in vision, cont’d

- Memory color
  - Top-down process (memory, expectation) influences perception of color
- Color constancy
  - Perception of an object’s color seems to remain constant across illumination types
    - e.g., white paper seems white, regardless of actual color of light reflecting off it

Defective color vision

- Monochromatism
  - Only one cone
  - True color blindness - only shades of light/dark
- Dichromatism
  - Protanopia
    - Lack L (red) cone
  - Deuteranopia
    - Lack M (green) cone
    - Both protanopes & deuteranopes confuse red & green
  - Tritanopia
    - Lack S (blue) cone
    - Sees only reds & greens
    - Confuse shades of yellows, grays, blues
- Achromatopsia
  - Cortical color blindness (rare)
  - Congenital (retinal) achromatopsia (1 in 33,000)

Camouflage

- A combination of visual functions (form, shape, color, texture, etc.)
- Camouflet (Fr, 16th c.)
  - From *chault mouflet*, the old smoke-in-the-nose prank
  - Then, a small explosive charge to collapse tunnels
- Camoufler (Fr, 19th c.)
  - To dress up or disguise (theater; deception)
- Camouflage (Eng. 1917)
  - "The act of hiding anything from your enemy is termed 'camouflage'."

Camouflage Fundamentals

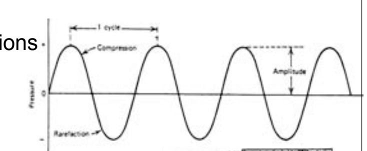
- Basic approaches to (visual) camouflage:
  1. High similarity camouflage
     - Blend with the background
  2. High difference camouflage (disruptive patterns)
     - Destroy object continuity
     - Erratic surface and edge cues
  3. Mimicry
     - Look like something else

Mimicry: Natural, and by Humans

- Plenty of examples of blending, foreground-background, disruptive patterns, and mimicry
- Mimicry
  - Look like background (essentially like other camo)
  - Look like something else that is similar
  - Look like something else entirely

Audition

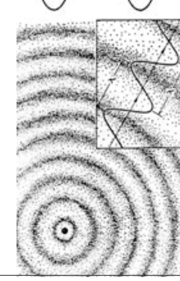
Physical Stimulus: Sound



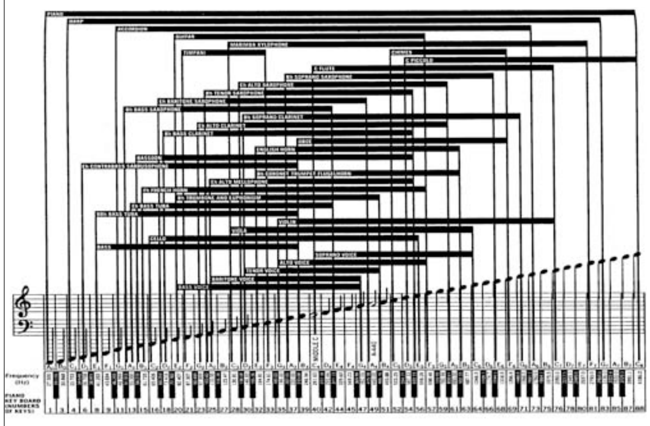
- Physics of sound: vibrations
- Frequency (Hz)
  - Pitch
- Wavelength (m)
- Amplitude (dB)
  - Loudness

$$\text{deciBel} = 20 \log \frac{P_{sound}}{P_{threshold}}$$

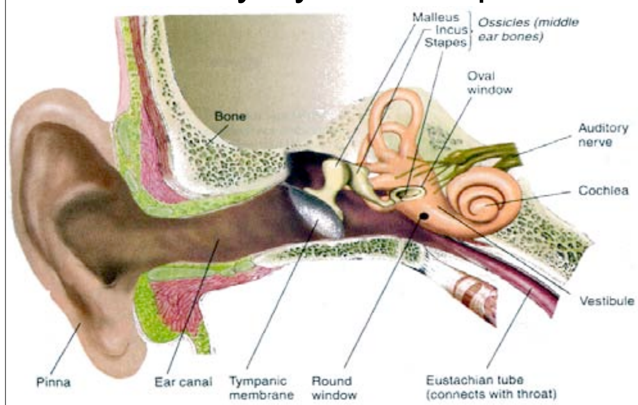
- Complexity
  - Timbre
  - Harmonics



Frequency Ranges



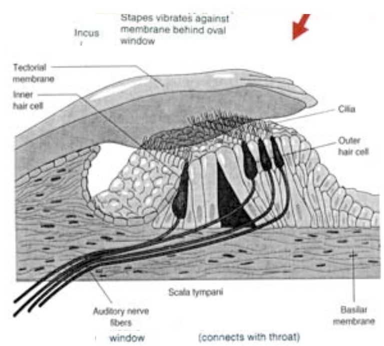
Auditory System Graphic



Pinnae

Inner Ear (Cochlea)

- Basilar membrane
- Hair cells
  - Inner (3500)
  - Outer (12,000)
- Tectorial membrane
- Auditory nerve



Cilia Bundles of Hair Cells

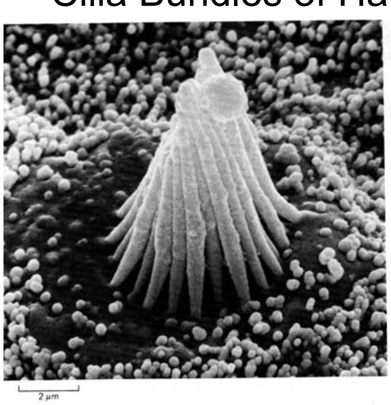
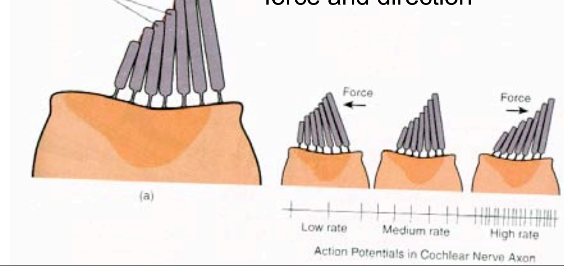


Figure 4–14 Scanning electron micrograph of the organ-pipe-like arrangement of stereocilia projecting from the surface of hair cells in the inner ear. (Courtesy of R. Jacobs and A. J. Hudspeth.)

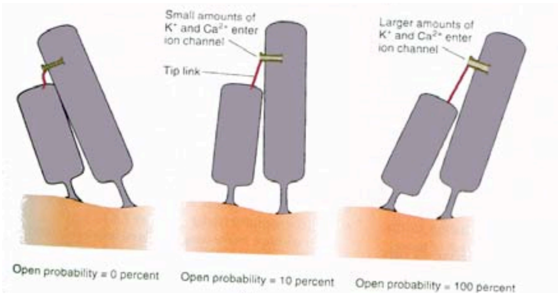
Hair Cell Functioning

- Sets of cilia connected by tip links
- Movement of basilar membrane “bends” cilia bundles
  - Firing rate depends on force and direction



Hair Cell Functioning

- Tip links pull open ion channel



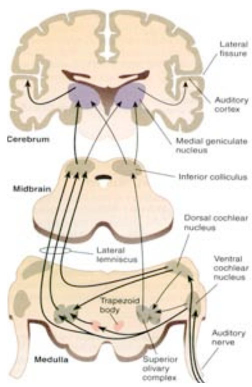
Characteristic Frequency

- Each fiber of the auditory nerve fires maximally to a particular frequency
- Basically related to the location along the cochlea (basilar membrane) that the nerve connects to
- “Tonotopic” layout along the basilar membrane
  - In general terms, the fiber represents the frequency (frequencies) in the sound

Auditory Pathway

- Central auditory pathway
  - Auditory nerve
  - Cochlear nucleus
  - Superior olivary nucleus
  - Inferior colliculus
  - Medial geniculate nucleus
  - (Primary) auditory cortex

  (“SONIC MG”)

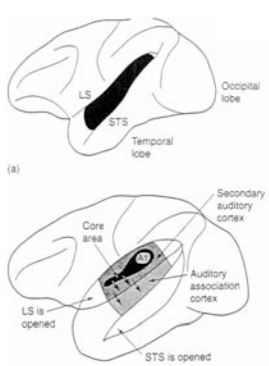


Auditory Cortex Areas

- Primary Auditory Receiving Area (A1)
  - Temporal lobe, both hemispheres
  - Buried inside lateral sulcus (LS)
- Core: A1 + some surrounding cortex (“belt”)
- Secondary auditory cortex
- Auditory association cortex

} “parabelt”

Auditory Cortex Layout



Auditory Cortex Attributes

- Tonotopic map
  - Each area of cortex corresponds to one characteristic frequency, preserving the tonotopic arrangement from the auditory nerve fibers
- Columnar arrangement
  - Descending down into the brain from the surface, neurons share same characteristic freq., but respond to different aspects of the sound
    - e.g., location in space

Cortical Tonotopy

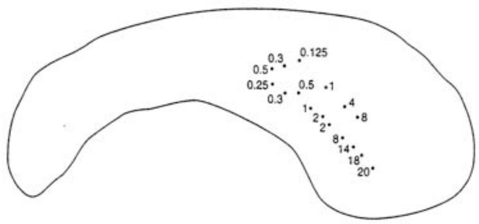


Figure 10.45
The outline of the core area of the monkey auditory cortex, showing the tonotopic map on the primary auditory receiving area, A1, which is located within the core. The numbers represent the characteristic frequencies (CF) of neurons in thousands of Hz. Notice that CFs range from 250 Hz on the left to 20,000 Hz on the right. (Adapted from Kosaki et al., 1997.)

Plasticity of Perception

- Area of the cortex (# of neurons) can change with differential usage.
- More usage --> more neurons being "recruited"
  - e.g., monkey trained on 2500 Hz tone had a larger region of auditory cortex devoted to 2-4 kHz sounds
  - Musicians have larger auditory processing area

Critical Bands & MP3

- Sounds within the same "critical band" can cause masking of other sounds in the same critical band (i.e., even though the two sounds are there in the signal, the human ear cannot hear them both)
- Psychoacoustic model of human auditory perception can determine which sounds will not be heard, and remove them, or at least reduce the number of bits (information) devoted to describing them
- Leads to perceptual-based compression, ~10:1
- Advanced Audio Coding (AAC, or MPEG-4 AAC): better models, filters, huge compression, with awesome sound

Threshold shifts

- Auditory fatigue
  - Temporary loss of sensitivity during / immediately following exposure
  - Due to prolonged exposure to loud or constant sound
  - Neurons in auditory system are overworked, and go into refractory period

Threshold shifts

- Threshold shift
  - A measure of auditory fatigue/hearing loss
  - Change in hearing thresholds, especially for masked sounds
  - Temporary
    - A few minutes, hours, even days
  - Permanent
    - Long-lasting or permanent
    - A form of hearing loss

Choice Point:

- Auditory Pathology
- Speech
- Touch
- Pain
- Taste, Smell, Flavor

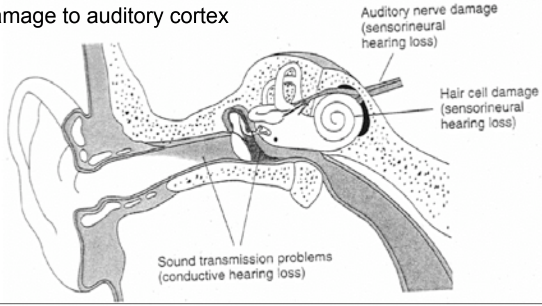
Auditory Pathology

Overview

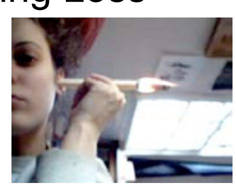
- Conductive Loss
- Neural Loss
- Cortical Trauma
- Measuring Hearing Loss

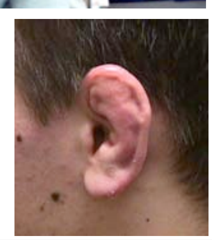
Types of Hearing Problems

1. Delivery to sound receptors
2. Damage to receptors
3. Damage to neural transmission system/pathway
4. Damage to auditory cortex



Conductive Hearing Loss



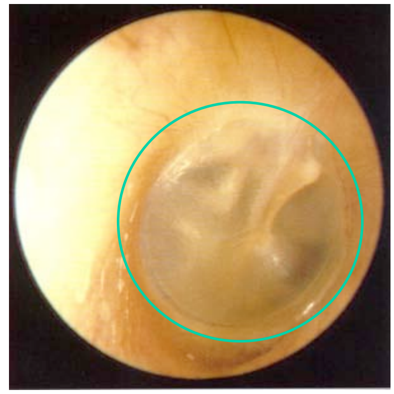


- Outer-ear disorders
  - Blockages
    - Ear wax, objects
  - Malformations
    - Closed outer ear
    - Cauliflower ear
  - Ruptured eardrum
    - Diving accident, fever, loud noise
  - Treated with medication, surgery

Conductive Hearing Loss

- Middle-ear disorders
  - Otitis media
    - Middle ear infection, leads to fluid buildup
    - Cholesteatoma - like a scar
    - Treatment: antibiotics, surgery
  - Otosclerosis
    - Growth of bone in the middle ear affects stapes
    - Genetic - Beethoven had it
    - Stapedectomy
  - Note: can still have bone conduction with these types of conductive hearing loss

Healthy Tympanic Membrane

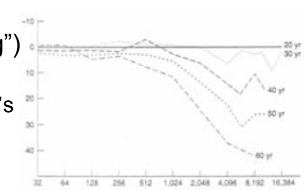


Otitis Media

Cerumen (Wax) in Ear Canal

Ruptured Tympanic Membrane

Sensori-neural Hearing Loss



- Presbycusis ("old hearing")
  - Loss of sensitivity
  - Greater loss at higher freq's
  - Accompanies aging
  - Due to deterioration of hair cells, neural fibers
  - Influenced by cultural, environmental exposure (in addition to just aging)
  - Can contribute to social/psychiatric issues
    - Worse with gradual onset
  - Compare to presbyopia

Sensori-neural Hearing Loss

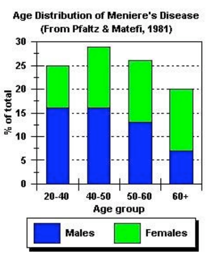
- Noise-induced hearing loss
  - Refer back to permanent threshold shifts
  - Loud or continuous noises damage hair cells
    - Can be specific area or widespread
  - Damage can be sudden or cumulative
    - e.g. Steven Sills, Pete Townsend - partially deaf
  - Acoustic trauma
    - e.g. Fire cracker exploded near a student's ear, caused 50 dB loss above 3000 Hz, and ringing even 2 years later!

Sensori-neural Hearing Loss

- Tinnitus
  - Latin for "tinkling"
  - Chronic ringing in the ears (quite mysterious)
  - Very disturbing!
  - Affects ~36 million Americans!
  - Can be caused by loud noises, food, allergies, drugs, infections
  - Treatment…
    - Not much :(
    - Tinnitus masker - added noise source via hearing-aid type device

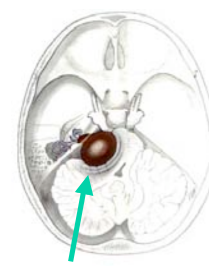
Sensori-neural Hearing Loss

- Meniere's Disease
  - Disease causes buildup of fluid inside the cochlea and semicircular canals
  - Results in "attacks" of fluctuating hearing loss, tinnitus, vertigo
  - Treatment
    - Not much :(
    - Antibiotics, hearing aids



Sensori-neural Hearing Loss

- Neural Hearing Loss
  - Tumors or other damage to the auditory nerve or pathway
    - Tumors ("acoustic neuroma") often benign, can be removed
    - Intracanalicular, cisternal, brainstem compressive, and hydrocephalic
    - Other effects like numbness, twitch, vertigo
  - Treatment
    - Surgical removal, radiation, chemotherapy



Sensori-neural Hearing Loss

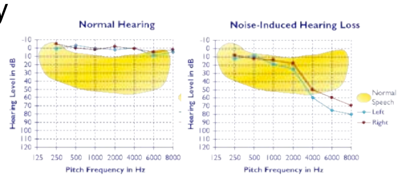
- Drugs (antibiotics)
  - e.g., streptomycin, gentamycin, neomycin, kanamycin
    - Fast-acting, but predictable damage to the hair cells
  - e.g., aspirin, quinine, carbon monoxide, tobacco
    - Note: smoking --> greater rate of hearing loss

Neural Transmission & Cortex

- Tumors
- Lesions (damage)
- Head trauma, meningitis, gunshot wounds
- "Cortical deafness"
- "Auditory agnosia"
  - Poor scores on speech reception threshold (SRT), or word recognition scores (WRS) portions of audiogram
- Note: auditory tract is quite deep, medial, so trauma-induced hearing loss usually accompanies other loss…but also hard to detect

Measuring Hearing Loss

- Audiologist
- Otorhinolaryngologist (ENT)
- Ear exam
- Medical history
- Audiogram
  - Pure tone
  - Speech
  - Threshold



Speech

Relevance of Speech

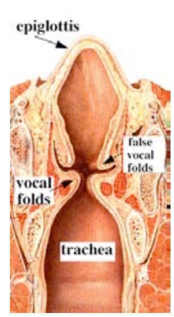
- Clearly important to humans
- Unique in animal kingdom?

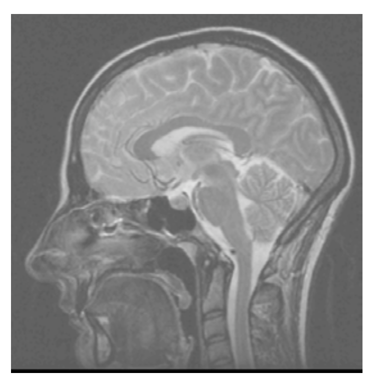
Speech Sounds

- Special sounds unlike other sounds in nature
- Dues to unique physics of vocal tract

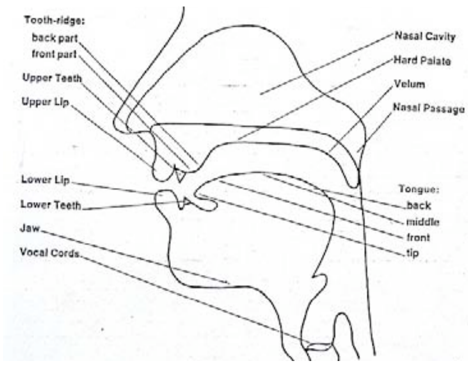
Speech Production

- Vocal Tract





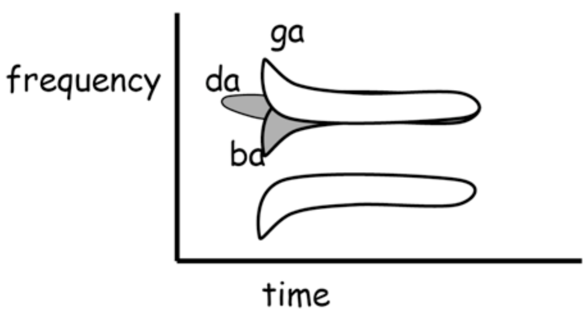
Speech Production



Production

- Resonant Frequency
  - Males ~ 500 Hz
  - Females ~ 727 Hz
  - Children ~ 850 Hz
- Articulators
  - Parts of the vocal tract like palate, lip, teeth
  - Shape sound
- Formants
  - Peaks in the spectrum of a speech sound
  - Most below 6500 Hz
  - Critical information 1000-5000 Hz

Formants



Operatic Tenor & Orchestra

Acoustic power in formants allow operatic singer to be heard over orchestra.

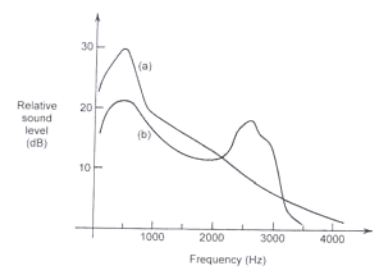


FIGURE 14.16 Long-term average sound output at different frequencies for (a) typical orchestral music and (b) an operatic tenor. The tenor is heard above the orchestra partly because of his strength in the singer's formant at 2500–3000 Hz. (After Sundberg.)

D. Hall, **Musical Acoustics**

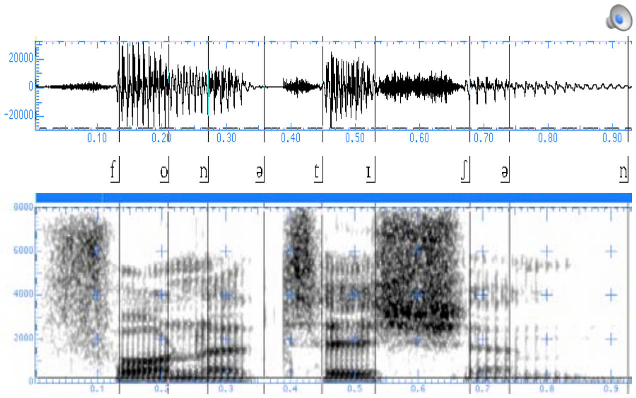
Phonemes

- Limited set of valid speech sounds for a language
- Overlap across languages, but different sets for each language
- Vowels
  - Produced by vocal cord
  - Resonances with open mouth
  - Low frequencies, below 3000 Hz
- Consonants
  - Include a constriction of vocal tract
  - Shorter, more dynamic sounds
  - All over frequency range
    - Plosives in middle, fricatives higher frequencies

Spectrogram

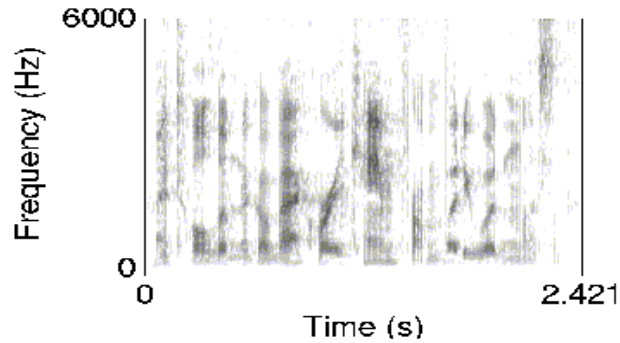
- Common plot of frequencies against time
- Points out formants
- Formant transitions
- Noise from fricatives
- Sustained low frequencies from vowels

Waveform & Spectrogram



Parsing Sentences

"I told him to go back where he came from, but he wouldn't listen."



Segmentation Problem

- Seems impossibly tough:
- “I owe you a yo-yo”
- Anna Mary candy lights since Imp Pull lay Things
- An american delights in simple things.

Variability Problem

- Phonemes change with context
  - “d” in “di” vs. “du”
- Phonemes change with different speakers
- Different types of speech
  - Whisper, shout, singing
  - Slow, fast

Neural Mechanisms

- Brain Areas
  - A1 - primary auditory cortex
  - Broca’s area - front of A1
    - Production
  - Wernicke’s area - posterior to A1
    - Comprehension

Neural Mechanisms, cont’d

- Neurons for Speech Sounds
  - Feature detectors for speech sounds
    - Formants, transitions
    - Monkey calls

Plasticity and Language

- Young listeners can tell difference between all phonemes
- By age 1 year, have lost much of this (due to not hearing all the speech sounds)
  - E.g., Japanese children

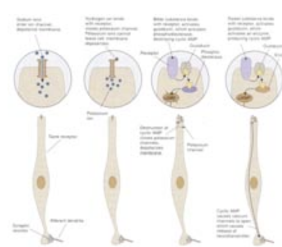
Chemical Senses

Taste

Overview

- Taste qualities
- Receptors & pathway
- Coding
- Thresholds

Tastes: “Basic” qualities



- Salty
  - Detect sodium (Na+) ions
  - Salary; elephants in caves
- Sour
  - Detect acids, hydrogen ions
  - Associated with decay
    - What not to eat
- Sweet
  - Detect sugars
  - Nearly all sweet foods are good to eat
- Bitter
  - Alkaloids, often associated with poisons

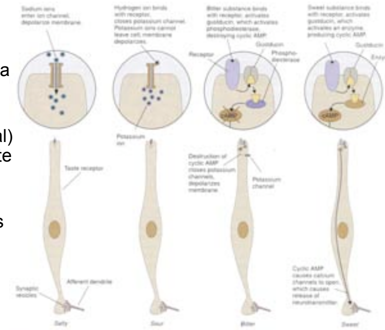
Tastes, cont'd

- Umami
  - From MSG
  - Present in many foods
  - Can accentuate sweet and salty flavors
  - Possibly a separate receptor for it
- Fatty-acid
  - Detect fats
  - Also seems to have separate receptors

- These are not universally recognized as tastes

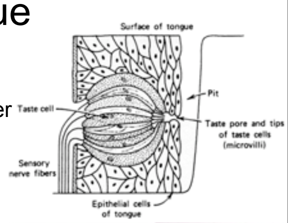
Receptors

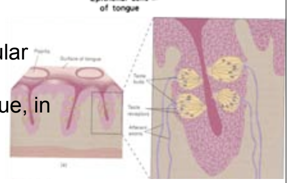
- Four types (at least)
- On the ends of taste cells
- Each receptor responds in a different way to different chemicals
- Likely all (or at least several) receptor types on each taste cell
- Note: not necessarily the case that each taste comes from only one receptor
  - How could this work?
  - Compare to metamers, timbres



Tongue

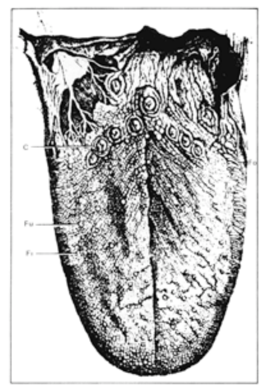
- Taste cells
  - Each connected to nerve fiber
- Taste buds
  - Clusters of taste cells
    - Like sections of an orange
  - 50-150 taste cells per bud
  - Compare to cupula in vestibular sense
  - Located near surface of tongue, in folds or valleys
  - ~10,000 taste buds





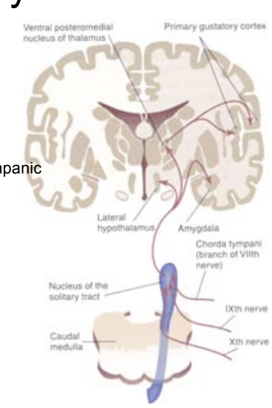
Tongue, cont'd

- Papillae
  - Fungiform papillae
    - Front 2/3 of tongue
    - Contain ~8 taste buds each
    - Also pressure, touch, temperature receptors
  - Circumvallate papillae
    - Back 1/3 of tongue
  - Foliate papillae
    - Sides and back folds
  - Filiform papillae
    - Front sides
    - Do not contain taste buds



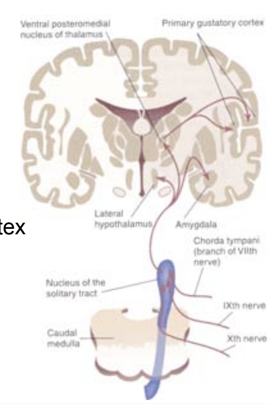
Pathway

- Nerves
  - Chorda tympani
    - Branch of 7th cranial nerve (facial)
    - From front (anterior) of tongue
    - Passes through middle ear near tympanic membrane
  - Glossopharyngeal nerve (9th)
    - Lingual branch
    - From posterior part of tongue
  - Vagus nerve (10th)
    - From palate and epiglottis



Pathway, cont'd

- Medulla
  - Nucleus of solitary tract
- Thalamus
  - Ventral posteromedial (VPM) thalamic nucleus
- Primary gustatory cortex
  - Frontal insula & opercular cortex
- Secondary gustatory cortex
  - Orbitofrontal cortex
- Note: pathway is ipsilateral



Coding

- Nerve fibers tend to respond to one taste quality better than to others, but not to only one
- Taste seems to be a combination of of specific innervation and distributed signal summation
  - "Afferent code"
  - Across a population of fibers
- Neurons in cortex -- some respond to only one taste; others respond to several tastes

Thresholds

- Temperature
  - Very warm or very cold causes higher threshold
  - Note: When cooking, season at the eating temperature
  - Effects: cold pizza is saltier; cold wine is less sweet
- Genetics
  - Some people are less sensitive
  - Some cannot tase certain things at all
    - e.g., PTC tasters vs. non-tasters
    - e.g., bitter supertasters

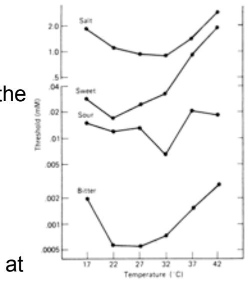


figure 17.5 Threshold values for the four taste qualities, each represented by a different sample compound, taken at six temperatures. (Salt: NaCl; sweet: Dulcin; sour: HCl; bitter: QSO_4. Note that the threshold concentrations are given in units of millimolars, mM.) (Source: Based on McBurney et al., 1973.)

Thresholds, cont'd

- Age
  - Thresholds rise dramatically with age
    - Foods taste bland; grandma's mashed potatoes
  - Can cause problems for hypertension & diabetes
  - Note: no salt taste until ~4 months after birth
- Culture
  - Some aspects (e.g., sweet) not learned
  - Some are learned
    - e.g., cerain spices, foods, condiments are an "acquired taste"
    - Note: this is separate from the ability to digest or tolerate foods
      - e.g., alcohol, milk/lactose in Asian cultures

Olfaction

Overview

- Smell phenomena
- Anatomy and physiology
- Pathway
- Coding
- Pheromones
- Flavor

Functions and Facts

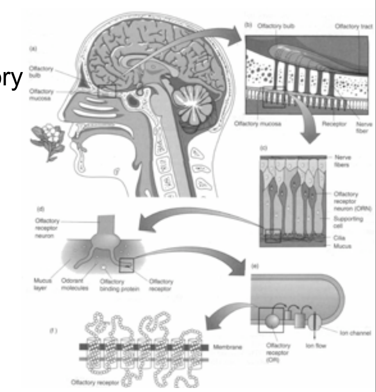
- Distal sense
  - Beneficial in detection of predator, prey, mate, chocolate sundae
- Long-term
  - Stimulus could have been there hours, days, weeks before
- Biologicaly motivated
  - Most odors are organic in origen
  - Many odors come from animals and plants
- Food seeking
  - Helps locate, identify, and assess food *before* eating it

Odor Quality

- Approximately 10,000 different odors can be discriminated
- Chemicals in the air lead to odors
  - Must be volatile
    - Molecular weight ~15-300
  - Must be soluble
    - In both water and lipids (fats)
  - Usually organic
    - Elemental substances are usually non-odorous
- Classification schemes try to define “core” or “primary” odors (e.g., Henning; Amoore, 1965)
  - No scheme has proved satisfactory

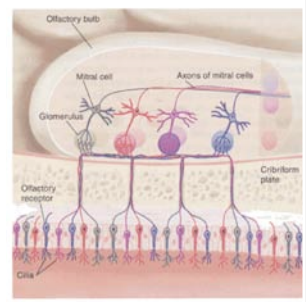
Anatomy and Physiology

- Chemicals inhaled
- Dissolved in olfactory epithelium
- Receptors
- Direct links to brain



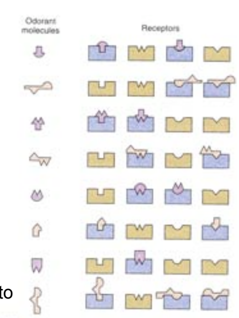
Anatomy, cont’d

- Olfactory Epithelium
  - Located on top surface (roof) of the nasal cavity
  - Cribriform plate
    - Porous bone
    - Separates sinus from brain
    - Cribriform: latin for seive
  - Mucosa contains olfactory receptor cells
    - Cilia on bottom (sinus) end
    - Nerve fibers on top end, which lead straight to the brain (olfactory bulb)
  - Olfactory bulb
    - Projection of the brain, just on top of cribriform plate



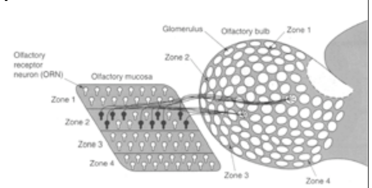
Anatomy

- Receptors
  - Olfactory cells with cilia spread through mucosa
  - Chemicals in the air absorbed into mucosa
  - Receptor sites on cilia correspond to different molecular shapes
  - “Lock and key” arrangement similar to taste
    - But thousands of different receptor types
  - Receptors respond in different amounts to many chemicals - not specific



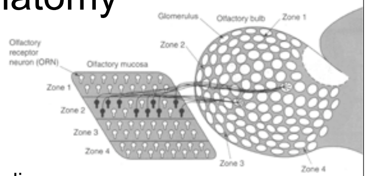
Anatomy

- Organization of receptor cells in the mucosa
  - 4 zones in mucosa
  - Each particular type of receptor is found in only one zone
    - Randomly spread throughout the zone
    - Multiple receptor types in each zone
  - Axons from one zone all go to same area (“zone”) of olfactory bulb



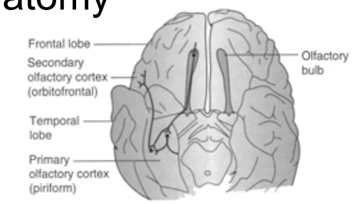
Anatomy

- Olfactory bulb
  - Brain projection
    - A direct pathway!
  - Composed of glomeruli
    - Receiving point for receptor nerve fibers
    - Inputs to a given glomerulus come from a single type of receptor, and from a single zone on the mucosa
    - About 1000-2000 glomeruli
    - Note: Many-to-one reduction, which leads to sensitivity (like rods in retina)



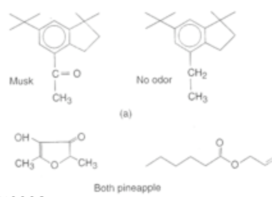
Anatomy

- Pathway
  - Olfactory bulb
    - Brain projection
  - Primary olfactory cortex (piriform)
  - Secondary olfactory cortex (orbitofrontal)
  - Amygdala
    - Deep in cortex
    - Related to emotions (limbic system)



Neural coding

- Intensity
  - Many receptor cells
  - Therefore, more chemical means more intense smell
- Quality
  - Pattern of activity
  - Set of responses, across a range of cells and a range of regions of mucosa
  - Some fibers/receptors are quite specific
  - Others have broad responses (many odors)
  - Not clear how nearly identical chemicals can smell very different; nearly same smells can have very different chemicals



Thresholds

- Detection
  - On a cell-by-cell basis, we're as good as could be expected
    - We can detect one molecule !
  - We can detect 1 molecule of mercaptan in 50 trillion molecules of air
    - Used as an odorant in natural gas (why?)
  - Dogs have 200 times more receptor cells, and each one has more cilia

Thresholds

- Gender
  - Males and females have different thresholds
    - Depends on the odor, and the state of the smeller
      - e.g., menstual cycle, mating season, age
    - e.g., Exaltolide - a base used in perfumes
      - Women (particulary at peak levels of estrogen) can detect 1000 times better than men and pre/post-menstrual women
      - Seems to mimic a pheromone (more later)

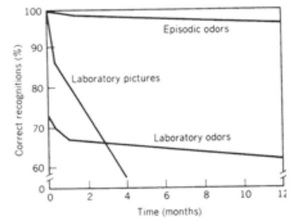
Thresholds

- Age
  - Detection declines with age
  - A problem for detecting bad food, leaking gas, personal hygiene, diet
  - Safety and health issues
    - (Such as?)

Thresholds

- Adaptation
  - Prolonged exposure reduces awareness of a smell
    - e.g., baking - you don't realize how good those cookies smell!
    - e.g., personal odor - you don't realize how unlike those fresh cookies *you* smell !

Odor and Memory



- Can serve as a very potent and long-lasting memory cue
- Episodic odor
  - Associated with real events
  - Can trigger emotional and even visceral reactions
  - Often related to food aversions, unpleasant places or experiences
    - e.g., hospital smell, barber smell
    - "Nothing like the smell of napalm in the morning…"

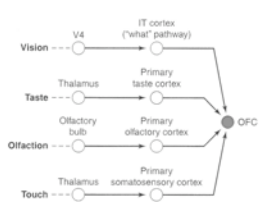
Pheromones

- Chemical communication
- Exit the body to signal other beings
  - Releaser pheromones
    - Produce an immediate & direct effect
      - e.g., attracts male to female in heat
  - Primer pheromones
    - Produce or change a long-lasting state
      - e.g., smells from both men and other women can change menstrual cycles
  - Marker pheromones
    - Mark a trail, indicate a path or status of a resource
      - e.g., ants mark trail to food until food is gone
  - Alarm pheromones
    - Certain states signaled by chemical signature
      - e.g., stress in rats is smelled by other rats
      - e.g., animals can "smell" fear in other animals

Common Chemical Sense

- Free nerve endings in the mucosal membranes
  - e.g., nose, mouth, eyes, respiratory tract
  - Branches of the trigeminal nerve
  - Detect irritants
    - e.g., pepper, ammonia, mustard
  - Pepper - capsaicin active ingredient
    - Why spray pepper in the face & eyes?
    - Frequent use or exposure can desensitize by destroying nerve endings
  - Smelling salts
  - "Wasabe head"
- Brain freeze
  - Combination of free nerve endings and direct stimulation of pain receptors
  - Goes straight to olfactory bulb
  - Why does rubbing the forehead help?

Flavor



- Combination of smell & taste
- Phenomena:
  - Holding nose while eating removes flavor (how?)
  - Flavor perception is reduced by tasting or smelling that flavor (e.g., bananas)
    - Reduced even more by ***eating*** that flavor
  - So both internal and external reduction of flavor
  - Thus: First bite of pie is the best - might as well stop after one bite (and give the rest to me)
- Physiology
  - Orbitofrontal cortex is where taste and smell combine
  - Also influenced by limbic system and hunger

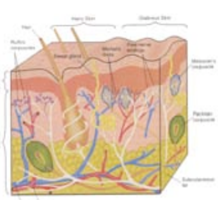
Skin Senses

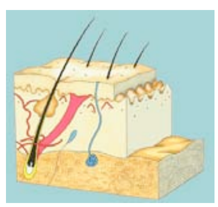
Overview

- The Skin and Receptors
- Neural Pathways
- Tactile Feature Detectors
- Tactile Object Recognition
- Summary

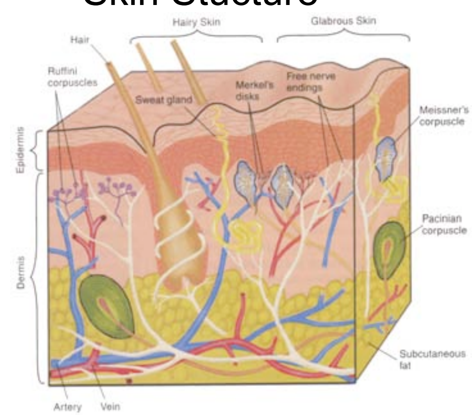
Skin

- Largest, heaviest organ
  - Note: surface of G-I tract is larger
- Role in thermoregulation
  - Heating, cooling (e.g., sweating)
- Keeps fluids things in, some things (e.g. bacteria) out
- Two primary layers
  - Epidermis
  - Dermis
- In these layers, there are sensors
  - Mechanoreceptors
  - Thermoreceptors



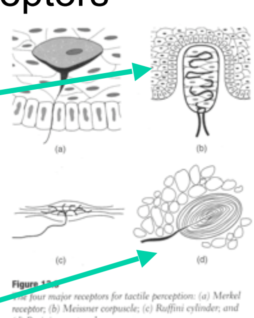


Skin Stucture



Mechanoreceptors

- Merkel receptor/disk
  - Disk shaped
  - Boundary of dermis/epidermis
- Meissner corpuscle
  - Stack of flattened cells
  - Nerve fiber winding through it
  - In dermis, near epidermis
- Ruffini corpuscle
  - Smaller, many-branched fiber
  - Inside spherical shell
- Pacinian corpuscle
  - Large, layered, onion-like capsule around nerve fiber
  - Deep in skin, also in joints & intestines



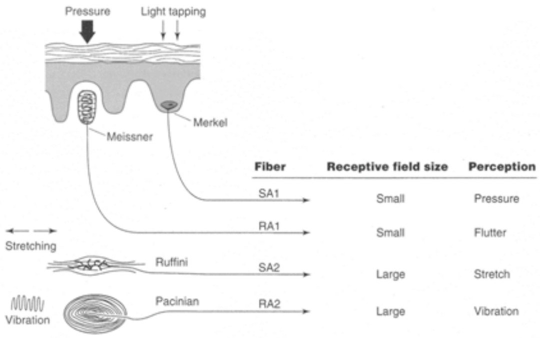
Mechanoreceptors, cont'd

- Respond to different frequencies
- Some are temperature-sensitive as well, or their frequency dependence is moderated by temperature

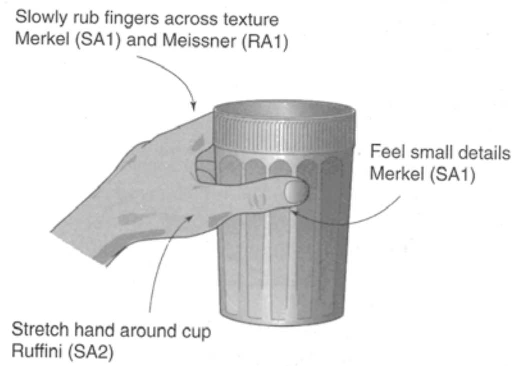
Deeper, higher frequencies

Receptors		ption
Merkel	0.3–3 Hz (slow pushing)	Pressure
Meissner	3–40 Hz	Flutter
Ruffini	15–400 Hz	Stretching
Pacinian	10–500 Hz (very rapid vibration at the upper range)	Vibration

Receptors & Fibers Summary



Variety of Receptors in Use

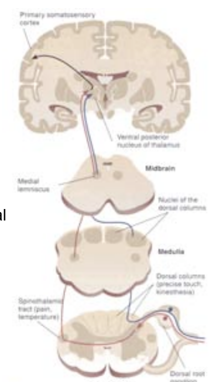


Thermoreceptors

- Not clear which receptors are responsible
  - Probably free nerve endings
- There are separate hot and cold receptors
  - At different levels/depths in skin and work independently
  - Bazett et al, 1932 determined this…
  - Note: Cold sensors are nearer the surface of the skin; hot sensors deeper
- "Paradoxical heat"
  - Touching both hot and cold objects simultaneously can cause the sensation of **<u>intense</u>** heat
    - e.g., radiators

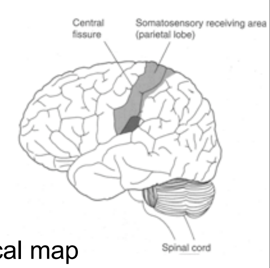
Neural Pathways for Touch

- Starts at receptors
- Goes through 4 types of fibers
- Two pathways up spinal cord
  - Medial lemniscal pathway
    - Large fibers, no synapses
    - Senses proprioception and touch
  - Spinothalamic pathway
    - Small fibers, synapse as soon as enter spinal cord
    - Transmit temperature and pain
- Fibers cross over to contralateral side of the brain
- Synapse in the thalamus
  - Which other senses arrive at thalamus?



Pathways, cont'd

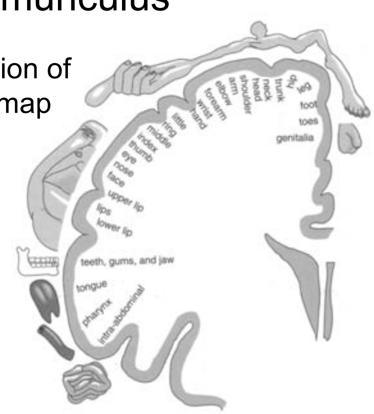
- Somatosensory cortex (S1)
  - Central fissure in parietal lobe
- Then to S2
  - Surrounding areas



- Disproportionate topographical map
  - Cortical area representative of sensitivity, not size, of skin region
  - Face, lips, mouth greatly over-represented

Homunculus

- Graphical depiction of somatosensory map



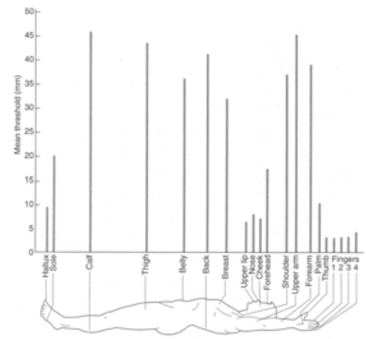
Tactile feature detectors

- Thalamic nuclei
  – Have center-surround features like vision
- Cortical neurons
  – Have some center-surround fields
  – Also can:
    - Detect edges
    - Detect patterns   (does this sound familiar?. . .)

  – Separation thresholds for detectors
    - (see next)

Tactile Feature Detectors

- Separation thresholds for detectors
  – Varies with the part of the body
  – How does this tie in to homunculus?



Tactile Object Recognition

- Passive vs. active touch
  – Object touches our skin without directed movement toward the object (passive)   vs.
  – Exploratory, investigative, intentional touching, integrating motor and sensory systems (active)
- Haptic perception
  – Explore 3D features of an object by touch
  – Combines sensory, motor, & cognitive system

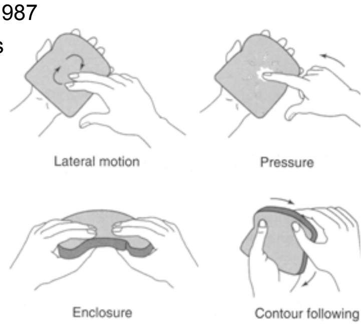
Touch: Additional Notes

- Tickling
  – Tickle \Tic"kle\, v. t. [imp. & p. p. Tickled; p. pr. & vb. n. Tickling.] [Perhaps freq. of tick to beat; pat; but cf. also AS. citelian to tickle, D. kittelen, G. kitzlen, OHG. chizzil[=o]n, chuzzil[=o]n, Icel. kitla. Cf. Kittle, v. t.]
    1. To touch lightly, so as to produce a peculiar thrilling sensation, which commonly causes laughter, and a kind of spasm which becomes dangerous if too long protracted.
  – Very rare to be able to tickle oneself. Why?
  – Active mode of touch inhibits the cognitive sensation of major sensory information

Touch: Additional Notes

- Four exploratory touching “procedures”
  – Lederman & Klatzky, 1987
  – Activate different fibers

  – Lateral motion
  – Pressure
  – Enclosure
  – Countour following



Pain

Overview

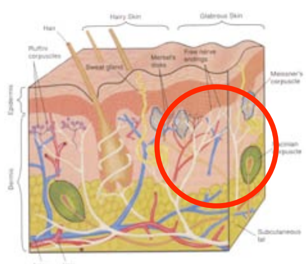
- Receptors & Pathway
- Cognitive Aspects
- Gate Control Theory
- Endorphins
- Summary

Phenomenon

- Multimodal experience involving many sensory systems
  - Touch, audition, olfaction, vision, etc.
- Emotional experience, as well
  - Melzack (1999) points out the words used to describe pain are highly emotional
    - Annoying, frightful, sickening
- Both annoying <u>*and*</u> biologically useful

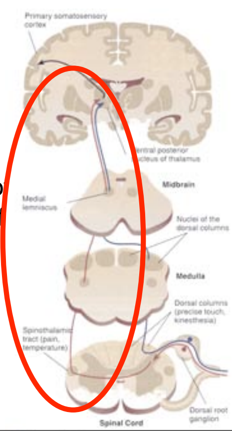
Receptors & Pathway

- Nocioceptors
  - Free nerve endings
  - Not well understood



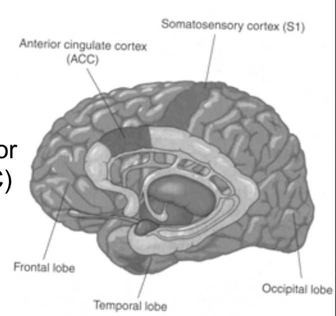
Pathway

- Spinothalamic pathway
  - Slow, small fibers
  - Synapse in the spinal cord
  - Cross over to opposite side of brain from receptor at level of spinal cord
    - (contralateral)



Brain regions

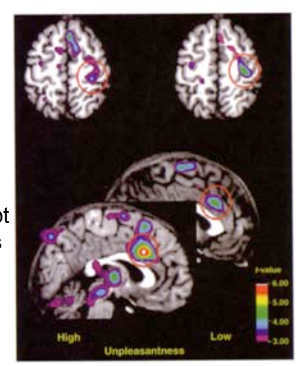
- Thalamus
- Hypothalamus
- Limbic system
- Also: Insula and anterior cingulated cortex (ACC)



Brain regions

- Multiple regions demonstrates multimodal experience
- Emotional aspects are associated with ACC
  - Post-frontal lobotomy patients feel pain but it is not as emotionally disturbing as it was before surgery

  (But…)



Cognitive Aspects of Pain

- Expectation
  - Knowing what is happening reduces pain
    - Surgery patients who are told what the procedure involves felt less pain
  - Placebos often effective
  - But anticipating the pain can make it worse
    - e.g., torture based on the threat

Cognitive Aspects

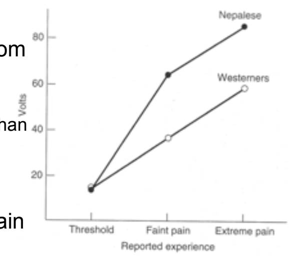
- Shifting attention
  - VR game used to “distract” burn patients
    - Hoffman et al. (2000)
  - Experienced less pain
  - Note: Nintendo was not as effective (why?)

Cognitive Aspects

- Distraction
  - Males looking at pictures that had been rated as “positive” (sports, attractive females) experienced less pain (ice emersion)
  - “Negative” images resulted in more pain
    - de Wied & Verbaten (2001)

Cognitive Aspects

- Individual differences
  - Shocks applied to people from different cultures
    - Western, Nepalese
    - Nepalese reported less pain than Western
    - Clark & Clark (1990)
    - Possible explanations?
  - Track athletes report less pain than non-athletes
    - Hall & Davies (1991)
    - Why?



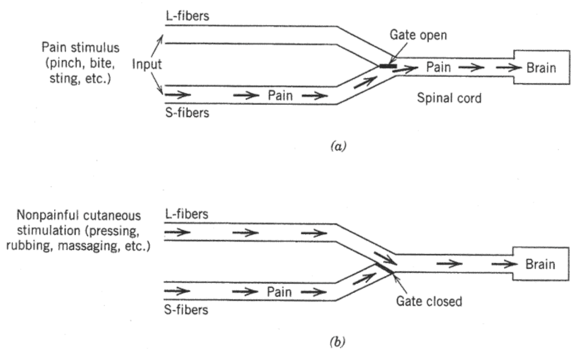
Cognitive Aspects

- Locus of Control
  - *Inescapable* pain (shocks to rats) led to analgesia (higher shock tolerance)
  - Pain that the rat *could avoid* did not lead to analgesia
    - Why?
  - Note: Adult children of alcoholics have higher than average tolerance for pain
    - Not clear if learned or genetic
    - Either way, it could be adaptive if pain (either frequent or inescapable, or both) is part of that person’s likely experience
      - Injury, disease, abuse, accidents, or emotional pain
    - Just food for thought…
    - See work by Robert Pihl

Gate Control Theory

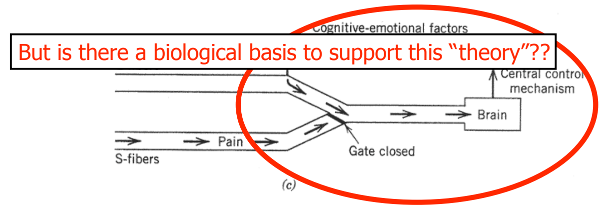
- Basics
  - Melzak & Wall, 1965, 1988
  - Large fibers carry non-pain touch info from cutaneous receptors to brain
  - Small fibers carry temperature & pain sensations
  - If the “less powerful” pain signal comes along, and no other signal is “flowing through the pipes”, the pain signal makes it through
  - If there is a simultaneous non-painful touch sensation from the same area, that can “close the gate”, or reduce the pain sensation
  - see schematic..

Gate Control Schematic



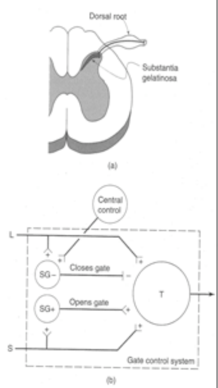
Gate Control Schematic

- Note: There is a top-down element (to explain cognitive and emotional factors)
  - Feeds back into large-fiber (touch) loop, which can either increase or decrease perception of pain



Gate Control, cont'd

- Biological Circuit
  - Substantia gelatinosa &
  - Transmission, or T-cells
    - In dorsal horn of spinal cord
    - Neural circuit containing these cells works as described in the theory
    - Substantia gelatinosa + and - cells work as a gate
    - T-cells transmit pain up spinal cord
  - Central control, necessary to explain how we can cognitively influence pain
  - But what causes the ***stimulus-produced analgesia*** (SPA)??
    - Rats with brain stimulation can undergo surgery without anethesia!



Endorphins

- "Endogenous opiates" (endogenous morphine)
  - In 1970s we found receptors for heroin, morphine
  - Figured there must be a natural substance like opiates
  - Endorphins are natural opiate-like substances
  - Exercise, stress, mating, pain, and other sircumstances cause release of endorphins
- Top-down circuit
  - Uses endorphins to reduce pain
    - Starts in the periaqueductal gray matter (in brain)
    - Goes to Nucleus Raphe Magnus
    - Then to the spinal cord gray matter, which is where the pain neurons synapse with the ascending pain pathway
    - Transmission cells (T-cells) (down spinal cord)
- Summary: pain has its place, but sometimes it is better to be able to carry on, despite pain or injury