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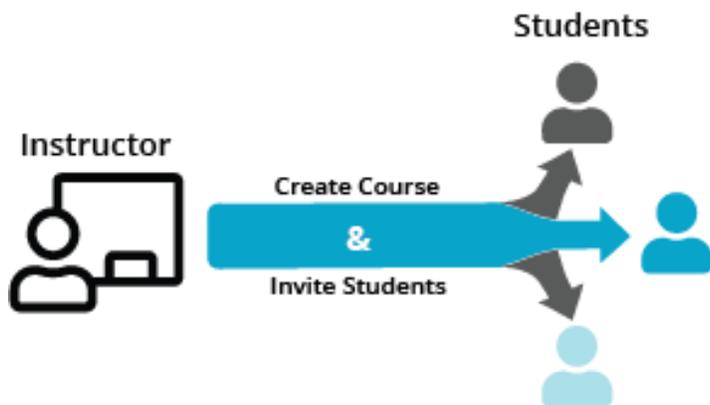
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Sensory Systems Lab

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Instruction Level

- Undergraduate lower division (Freshman, Sophomore)

Topic

- Sensory organs
- Signal transduction
- Receptor
- Vision
- Taste
- Touch
- Smell
- Hearing
- General Biology II

Instruction Type

- Traditional

Timeline

- **Procedure:** >2 Hours

Learning Objectives

- Students will understand the anatomy and physiology used for interpreting the environment both within and outside the body.
- Students will become familiar with the many different forms of perceived sensation.

Introduction

Background

In this lab, we will explore the anatomy & physiology used for interpreting the environment both within and outside our bodies. The essential component is neurons, the major functional cells in nervous tissue. In many sensory organs, additional cells and tissues will contribute to the process of *signal transduction*.

Signal transduction is the process of a *receptor* detecting specific forms of matter or energy, and activating chemical and electrical changes in neurons. The neurons can then communicate with other neurons in the nervous system via synapses and networks to coordinate responses.

A *receptor* is a term used for the part of a sensory organ that detects the signal. 'Receptor' can refer to specific protein molecules which first interact with the matter or energy, or it can refer to the cell(s) that contains those proteins, or an assembly of cells in the larger organ.

Sensory Organs

The major sensory organs can be grouped based on various characteristics, i.e. what type of matter or energy they detect, and subsequently 'transduce' to produce our perceptions (e.g. vision, taste). Eventually, there are electrical and chemical signals within our brains. Specific organs include:

Labs – Anatomy & Physiology: Sensory Systems

Sensory Organ (major receptor)	Matter/Energy detected by a receptor	General anatomy & physiology	Perceived sensation
Eye (retina)	Visible light (electromagnetic radiation)	Multilayered nervous sheet within the eye, with muscles and lenses for focusing.	Vision
Ear (cochlea)	Physical force (sound)	Flexible 'hair' cells that release signal molecules based on waves in fluid started by motion of the eardrum.	Hearing
Ear (semicircular canals, saccule, utricle)	Physical force	Flexible 'hair' cells that release signal molecules based on waves in fluid started by motion of the head.	Movement
Nose (olfactory epithelium)	Chemicals (odorants)	A layer of neurons at the top of the nasal cavity.	Smell ('olfaction')
Tongue (taste buds)	Chemicals	Clusters of epithelial cells that release signals to neurons if specific chemicals are present (e.g. sodium ions).	Taste ('gustation')
Skin (Mechanoreceptors)	Physical force	Various neurons that respond to physical movements.	Touch
Skin (Thermoreceptors)	Heat transfer	Specific neurons that respond to increases in temperature.	Hot
Skin (Thermoreceptors)	Heat transfer	Specific neurons that respond to decreases in temperature.	Cold
Muscles & Tendons	Physical force	Neurons respond to stretch and contraction of muscles & tendons	Body position (proprioception)
Most of the Body	Various signals	Neurons respond to physical force, temperature % specific chemicals to warn of (potential) damage.	Pain ('nociception')

Labs – Anatomy & Physiology: Sensory Systems

In order to investigate and understand sensory processes, we will investigate their anatomical structures (at macro- and microscopic levels) and physiological functions. An important distinction to consider is how humans can functionally separate Sensation (activation of the different receptors) as compared to Perception (the conscious awareness of the sensation). This distinction reveals how sensory deficits can result from damage in brain regions, even though the sensory organ is intact. Also, we may have perceptions that are only present in the brain, even though the sensory organs are silent.

VISION

The eye can focus light images on the retina using the cornea and the lens. Visible light only occupies a small portion of the *electromagnetic spectrum*. Other species and artificial technologies can detect other parts of this energy spectrum.

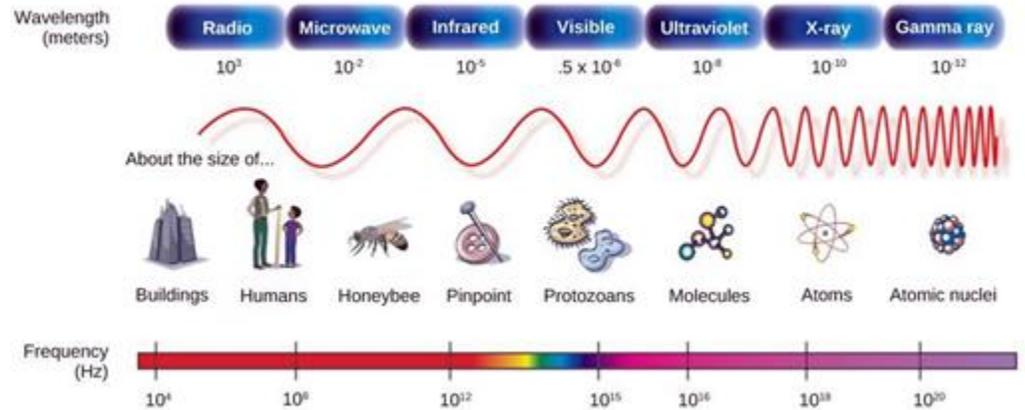
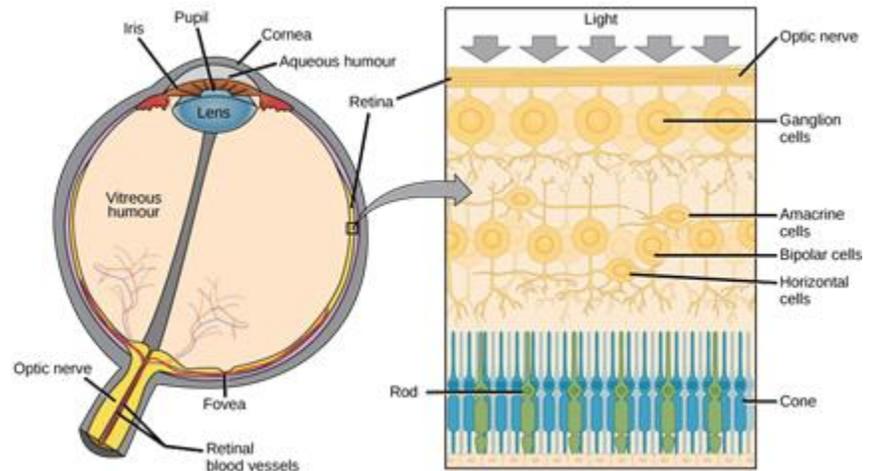


Image of the electromagnetic spectrum, visible light lies

between 380nm and 740 nm.

Light passes through the eyeball via the cornea, pupil, and lens. The humors are fluids filling the anterior and posterior chambers of the eye.

The focused image is directed toward the fovea (or fovea centralis), which contains the highest density of photoreceptor neurons. Muscles in the iris alter pupil size to vary light entering the eye. Choroid body muscles surround the lens. They alter the lens to aid focusing.



*The human eye is shown in cross section (left).
A blowup shows the layers of the retina (right).*

Pre-Lab Assignment

1. *Purpose Statement:* In one or two sentences, specifically describe the purpose of the day's experiment/lab work. What are you trying to learn or achieve, and how?
2. List the different forms of perceived sensation by the body and the corresponding sensory organ.
3. Define the following terms:
 1. Extra-ocular muscles
 2. Sclera
 3. Choroid
 4. Pigmented epithelium
 5. Fovea
 6. Vitreous humor
 7. Aqueous humor
 8. Iris
 9. Lens
 10. Choroid body
 11. Cornea
 12. Conjunctiva
 13. Optic nerve
 14. Blind spot (or *optic disc*)
 15. Retina
 16. Retinal neurons
 17. Ganglion cells
 18. Amacrine cells
 19. Bipolar cells
 20. Horizontal cells
 21. Photoreceptors (rods, cones)
 22. Occipital (*visual*) cortex of the brain

Procedure

Safety

If performing a dissection:

- Wear gloves and goggles.
- Use caution when handling dissection tools.

Protocol

Materials

Possible Specimens & Models for examination: (sheep or cow) eyeballs for dissection, microscope slides of retina, models of eyes.

Exercise 1

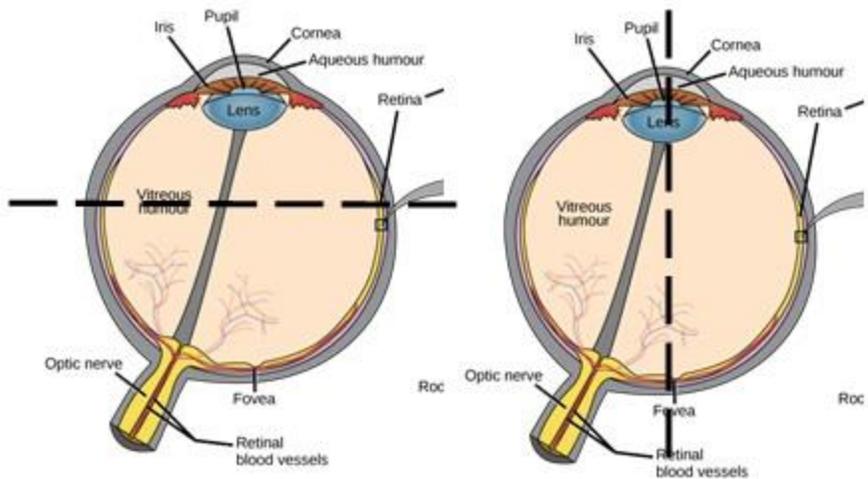
You are responsible for identifying these major anatomical structures of the eye: sclera, choroid, pigmented epithelium, fovea, vitreous humor, aqueous humor, iris, lens, choroid body, cornea, conjunctiva, optic nerve, blind spot (or *optic disc*), retina. You will have to identify these structures using both the sheep or cow eye and the models.

Dissection:

You will work in groups of two or three to dissect an eye. There are several ways to slice through an eye. Check with your instructor to determine which way they want you to cut the eye in half. Possible cuts include:

Note: To be able to best see the eye's structures, you should work very carefully. Many internal structures are delicate

and tear easily such as the retina. Some structures are quite tough including the lens and sclera (in Latin, sclera means 'tough!'). Practicing careful dissecting is an important skill. Take your time! In order to get to the first layer, the sclera, you may have to clear away some fat and connective tissue. Ask for help if you need it.

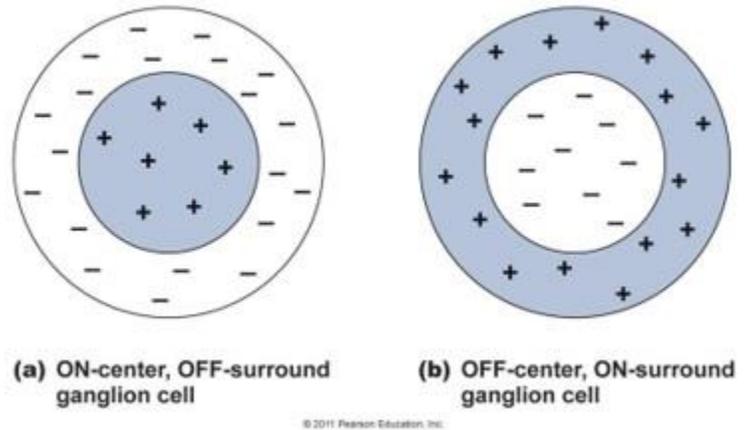


Physiology:

Light striking photoreceptor neurons activates networks of retinal neurons. One network of neurons in the retina sends signals to one ganglion cell. Action potentials from ganglion cells, whose axons form the optic nerves, represent patterns of light. Perception of the network of

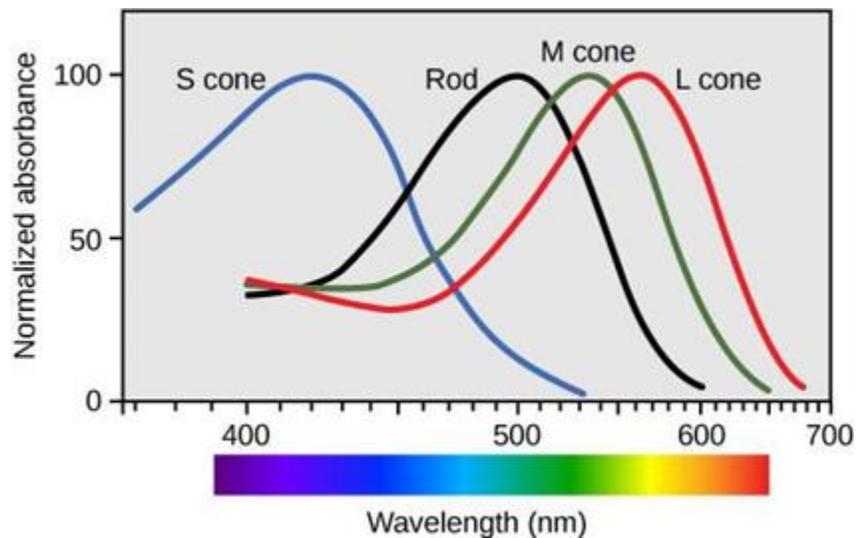
interconnected neuron signals is eventually perceived in the occipital cortex.

The receptive field for 1 ganglion cell



In this example, the ON-center cell will send a maximum rate of action potentials along its axon (in the optic nerve) to the brain if the brightest light is striking photoreceptors near the center of its portion of the retina, and the surrounding photoreceptors in that portion are receiving minimal light. Eventually, patterns of ganglion cells signals are integrated in the brain (in the occipital cortex) to generate the perception of complex images.

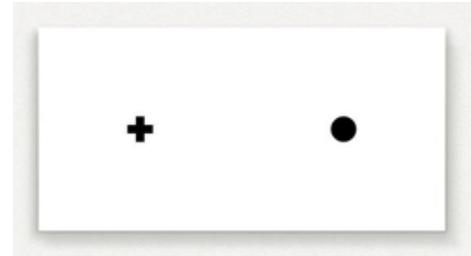
Color vision results from the interaction of 3 sub-types of cone photoreceptors. They preferentially absorb light at different wavelengths, shown in the figure.



Human rod cells and different types of cone cells each have an optimal wavelength. However, there is considerable overlap in the wavelengths of light detected.

Exercise 2

A: Blind spot test – The optic disk, the sight where ganglion cell axons exit the eye, does not contain photoreceptors. We do not perceive the blind spot because the brain interpolates information to fill in the gaps. You can locate the blind spot by moving the image below toward your head.



Standard blind spot test

Directions: With your right eye (left closed), stare at the cross, and move the paper towards your eyes until the circle disappears. Measure the distance from the image to your eye. You can repeat this with your left eye, staring at the circle. The cross will disappear at a distance related to the physical separation of your fovea and your optic disk. You can estimate this distance (d' , in mm) of your retinal structures by recording the distance when the image disappears (x), and measuring the distance between the cross and circle in the image (d). This is actually a 'reduced eye' model, which involves some approximations. Answer questions in results section.

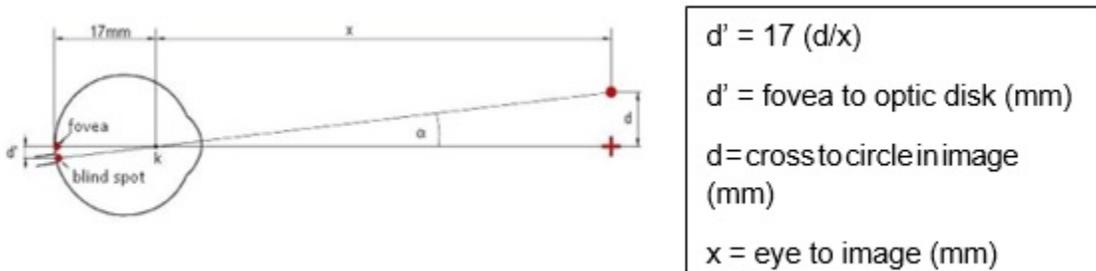


Diagram to show the measurement of blind spot to fovea.

B: Color-blindness test – Color-blindness can be tested with appropriate Standard Pseudoisochromatic plates (e.g. Ichikawa et al., ISBN 0-89640-030-1)

Directions: Using the plates are you able to detect the image present for the presented colors? Answer in results.

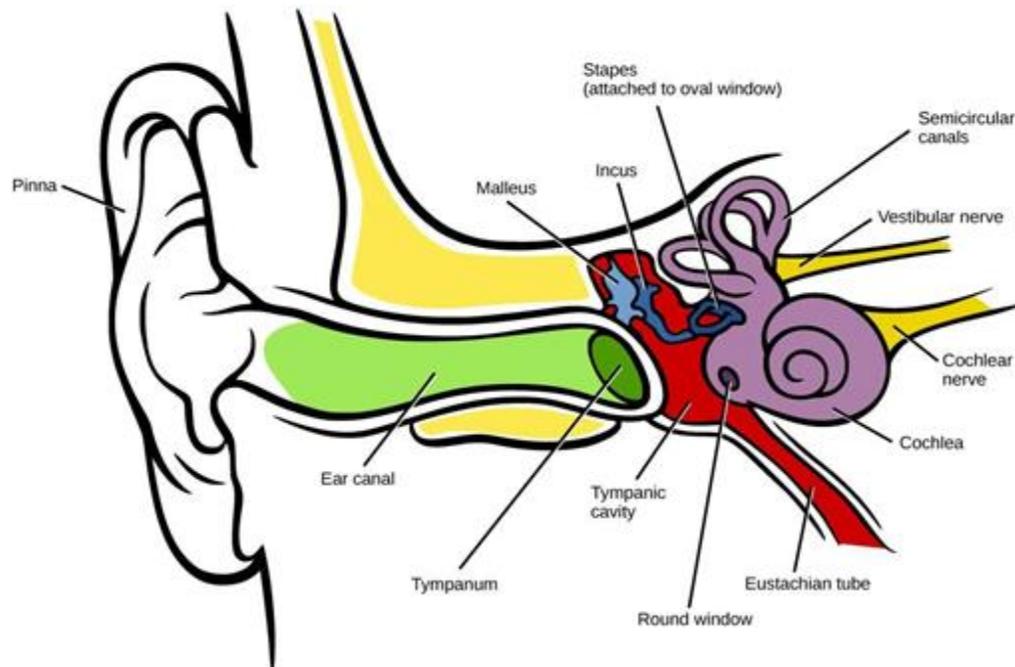
C: Visual acuity test – Visual acuity refers to the sharpness or clarity of vision, and is an indication of the focusing capacities of your eyes, especially the lens and cornea.

Directions: Use the standard eye chart (Snellen chart), at the appropriate distances (usually 20 feet), to measure your acuity. Comparisons on the chart will refer to this standard measure. To use the chart, find the red tape on the floor. Stand here and cover one eye without squinting. Have your partner stand near the chart and tell you which line to read starting from the top. Answer questions in results. **Note on corrective lenses:** If you have contacts, keep them in, but if you wear glasses you may want to try the test with and without them to see just how much your corrective lenses improve your vision!

D. Hearing – Hearing involves the signal transduction of mechanical waves into neural signals in the cochlea, within the inner ear.

Anatomy: The auditory receptors for the ear (shown below) include the:

- Outer ear - from pinna (or *auricle*) to tympanum (or tympanic membrane, or *ear drum*)
- Middle ear - contains 3 ossicles, anchored between tympanum & oval window. The *Eustachian* (or auditory) tube connects the middle ear cavity to the pharynx (it is an evolutionary descendant of pharyngeal pouches).
- Inner ear – Cochlea, which contains the *hair cells (receptors)* within the Organ of Corti



BALANCE & MOVEMENT (The Vestibular System)

Anatomy: Within the inner ear, the 3 semicircular canals are arranged at right angles to each other, and they contain hair cells and fluid similar to the cochlea. In addition, two separate clusters of hair cells – the saccule and utricle – are oriented to detect vertical and horizontal movements. Each of the hair cell clusters has a small collection of dense connective tissue attached to the hair cell membrane extensions (*stereocilia*) to add mass to the system.

Physiology: Movements of the head cause dislocations of the fluid in the chambers around the hair cells. Movements generate electrical signals in hair cells, which signal sensory neurons with released chemical neurotransmitters. Patterns of signals are integrated in the cerebellum and parietal cortex.

Labs – Anatomy & Physiology: Sensory Systems

Specimens & Models for examination: Models of the ear and cochlea.

Exercise 3

A: Identifying structures - Using the model of the ear find the following structures: ear canal, tympanum (tympanic membrane), ossicles (malleus, incus, stapes in order moving inward into the ear), cochlea, semicircular canals.

B: Sound localization – Using a tuning fork, have a subject sit with their eyes closed. Strike the fork so it makes a sound and move it to front, back, side and top of head at a constant distance, holding it to allow the subject to point out the location. Note the accuracy at each position of their pointing, and determine the most and least accurate positions for localization. Answer question in results.

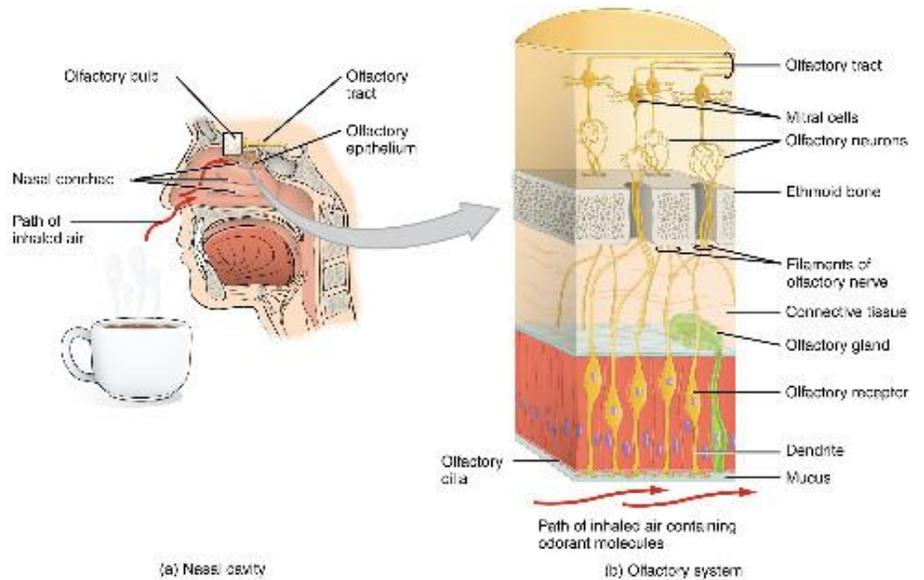
C: Romberg testing involves maintaining balance.

- A. Have the subject stand with their back to the white board. The board should be marked at approximately shoulder height with centimeter units covering ~1 meter.
- B. Note the shoulder positions of the subject.
- C. Have the subject stand and stare straight ahead for 2 minutes, and note the range of movement.
- D. Repeat with eyes closed.
- E. Repeat while standing with your right or left side closest to the board, and note front-to-back swaying, First with eyes open and then with eyes closed.

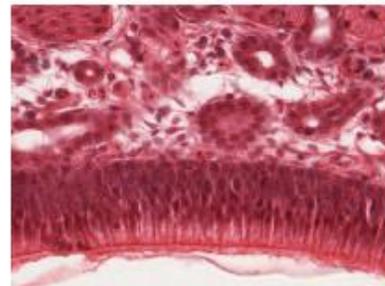
Fill in table in results section and answer questions.

SMELL

Anatomy: Sensory (olfactory) neurons are present at the top of the nasal cavity, extending their axons into the cranium. Olfactory signals are the only sensory system to send signals directly to the limbic system, which is integral to memory and emotional functions. In humans, from 100-200 different functional receptor proteins have been identified (there are over 1000 in rodents).



Physiology: Specific molecules (*odorants*) bind to receptor proteins and activate neural electrical signals (action potentials). Patterns of olfactory neuron activity can code for complex odors, integrated within the olfactory bulb and temporal cortex. Olfactory neurons will undergo adaptation and decrease signals to the brain with constant exposure to a stimulus.



A cross section of the tissues and structures involved in olfaction.

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Exercise 4

Humans consistently recognize certain odorants (e.g. spearmint, orange, anise). Specific oils for these are available, and can be prepared as serial dilutions. Students can then test for sensitivities for each by starting with a series at the low end of the concentrations. Odorants can be detected by some sensitive individuals at concentrations below the micromolar range. In the results section list the micromolar concentrations of mint and highlight the one where you can begin to smell the mint.

TASTE – Taste involves stimulation of receptor proteins on gustatory cells within taste buds. The perceived sensations correspond to common chemicals: Salty (Na^+), Sweet (disaccharides, e.g. sucrose), Bitter (various, common test is Ca^{2+}), sour (H^+), and umami (glutamate). Also, taste is often integrated as a perception with olfactory sensory input.

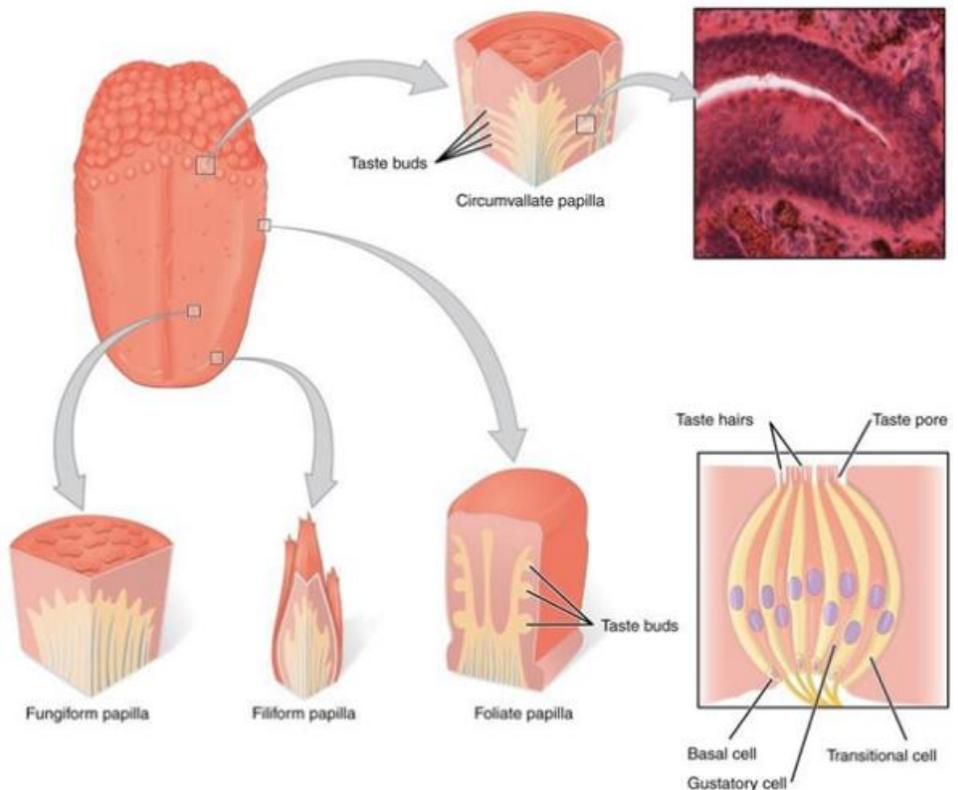
Anatomy & Physiology – Taste buds are arranged along the tongue epithelium. Sensory epithelial cells release neurotransmitter signal molecules to sensory neurons of cranial nerves. Information is integrated along the brain stem and in the temporal cortex.

The tongue is covered with small bumps, called papillae, which contain taste buds that are sensitive to chemicals in ingested food or drink. Different types of papillae are found in different regions of the tongue.

The taste buds contain specialized gustatory receptor cells that respond to chemical stimuli dissolved in the saliva. These receptor cells activate sensory neurons that are part of the facial and glossopharyngeal nerves.

Specimens & Models for examination – Histology slide of tongue/taste buds

Physiology – Taste can be identified using solutions of chemicals known to stimulate distinct receptor proteins. Solutions can be prepared from common ingredients to test for sensitivity.



Exercise 5

A: Histology Exploration – Use a microscope to explore the cellular aspect of a taste bud. Find an individual taste bud and draw it, take a picture of it and upload it into the results section.. Can you label any structures if you use the above diagram as a guide?

B: PTC Test - One bitter taste receptor protein is encoded by the PTC gene, or TAS2R38 (discovered in 2003). There are at least 30 different genes coding for bitter taste receptors. Phenylthiocarbamide (PTC), also known as phenylthiourea (PTU), is only detected by ~70% of the population on average. Tasting PTC is correlated with the dominant genotype.

- A. PTC tasting test kits provide material to survey the class. Testing is a simple positive response for bitter taste, while non-tasters will report no taste.

C: Taste Threshold Test - Similar to the olfaction tests, serial dilutions of basic chemicals can be used to test for variable sensitivity in subjects. Sucrose and NaCl are common tests for sweet and salty. Serial solutions can be applied with cotton swabs to the subjects tongue to test for sensitivity. Similar to the smell test, list the concentrations of the two substances in the results section and highlight the one where you can begin to taste the substance.

Results

Exercise 2

Part A

- 1. What is the distance between the fovea and the optic disk in your left eye? Right eye?
Average distance?

Part B

Plate #: _____ Image that you see: _____
Plate #: _____ Image that you see: _____

Part C

When you can no longer read a line accurately with one eye, then this is the acuity for that eye. Write it here: _____ Now do the other eye the same way. Write your acuity here: _____ .

Labs – Anatomy & Physiology: Sensory Systems

Exercise 3

Data	Eyes Open	Eyes Closed

Exercise 4

List the micromolar concentrations of mint and highlight the one where you can begin to smell the mint.

Concentration 1:

Concentration 2:

Concentration 3:

Concentration 4:

Concentration 5:

Exercise 5

Part A: Find an individual taste bud and draw it, take a picture of it and upload it below. Can you label any structures if you use the above diagram as a guide?

Part B: After placing the strip on your tongue do you taste anything? Yes or no? If you answered YES!, then you have the dominant genotype for the PTC gene!

Part C: List the concentrations of the two substances and highlight the one where you can begin to taste the substance.

Salt

Concentration 1:

Concentration 2:

Concentration 3:

Concentration 4:

Concentration 5:

Sucrose

Concentration 1:

Concentration 2:

Concentration 3:

Concentration 4:

Concentration 5:

Post-Lab Assignment

1. Are your eyes exactly the same? Hypothesize why or why not:
2. If you exhibit some degree of colorblindness, what type? What may be happening with your cone cells within your retinas?
3. Do you have the same acuity in both eyes? Why or why not?
4. Note the accuracy at each position of their pointing, and determine the most and least accurate positions for localization. Can you explain any differences? List the positions for localization from most to least accurate:
5. Describe any differences in relation to the sensory input required to maintain balance.
6. Do you and your lab partner vary in your sensitivities? If you differ, then provide a possible explanation as to why