Sensory Receptors

An adaptive advantage of our complex nervous system involves being able to sense changes in our environment. We receive signals to our central nervous system via the afferent division of our peripheral nervous system. In general, these are the signals we receive from our 5 senses: sight, hearing, touch, taste, and smell. We also have a multifaceted sense of equilibrium. The next exercises will look at some of these senses in more depth to determine how they work to send signals to your brain.

Exercise 1: Cutaneous Receptors

Aim: Test mechanoreceptors and thermoreceptors in the skin.

Background

Touch receptors are not evenly distributed throughout all parts of the body. When a constant stimulus is applied to a sensory receptor, it responds best initially, and the response then usually decreases (**sensory adaptation)**. In order for sensory receptors to respond to a wide range of stimulus intensities, they are often designed to detect a change in intensity that is a certain fraction of the initial intensity, rather than the absolute change (i.e., they work on a log scale rather than a linear scale). **Referred pain** is the phenomenon of perceiving pain in one area of the body when another area is actually receiving the painful stimulus.

The following exercises will illustrate these principles.

Procedure

A. Tactile Distribution: Two-Point Sensibility

1 Have the subject sit with their eyes closed.

2 Use the compass to apply tactile stimuli to the subject's fingertip (be gentle enough to not draw blood, but deliberate enough pressure for the subject to be able to give a response). Start with the two points close together and then increase the distance between them until the subject feels *two distinct points.* Be sure that the two points are applied simultaneously each time. Occasionally, use one point instead of two, to ensure that the subject is not guessing.

3 Record the point distance (in mm) for the following four body areas:

Fingertip	Palm of hand
Forearm (palmer surface)	Back of neck

B. Tactile localization

1 Again with the subject's eyes closed, touch the subject's fingertip with a pointed pencil to leave an indentation (there is no need to cause pain to the subject in order to leave an indention). Take the pencil away. Then, with eyes still closed, have the subject try to touch this exact spot using another pencil, moving the pencil until indicating that it is in the same spot. Measure the error of location (in mm).

2 Record the localization error distance for the same four body regions used in the previous test.

C. Adaptation of Touch Receptors

1 With the subject eyes closed, have a lab partner place a coin on the inside of the subject's forearm.

2 Determine how long (in seconds) the initial pressure sensation persists.

3 Repeat the experiment at a different forearm location, and when the sensation disappears have your partner add two more coins of the same size. Does the pressure sensation return, and if so, how long does it last with the added coins compared to one coin alone?

D. Weber's law

1 With eyes closed, have the subject place one hand on a table, palm up. Place an index card with a 50g weight on the subject's fingers.

2 After the subject feels the weight, remove the card and weight simultaneously, add or subtract weights of 1 to 20g, and replace the cardboard and weights on the fingers. The subject then indicated if the weight feels heavier, lighter, or the same. Make sure to go back to the reference (50g) weight each time to remind the subject what it feels like.

3 Continue to add/subtract these weight increments until you have determined how much change in weight (higher or lower) is needed for the subject to *consistently* be correct.

4 Repeat the experiment, using an initial weight of 200g.

5 For each initial weight, calculate the "just noticeable difference" (Weber's fraction), the smallest weight difference where the subject can accurately and repeatedly tell the difference, divided by the initial weight.

E. Temperature Receptors: Adaptation and Negative Afterimage

1 Place one hand in the ice water (O-5℃), and your other hand in the warm water (45℃) for two minutes (or as long as you can), paying attention to your sensation of cold or warmth in each hand. Which hand seems to adapt fastest?

2 Now, remove your right and left hands from their beakers and rapidly place them both in the room temperature water, and note your sensations in each hand.

F. Referred Pain

1 Place your elbow in ice water and, over a period of time, note any changes in the location of perceived sensations.

NOTE: The ulnar nerve, which controls the ring finger, little finger, and inner side of the hand, passes over the elbow joint.

Questions

Which areas of the body have skin with the smallest **receptive fields**?

What is meant by sensory adaptation? What is its function? Do receptors vary in their ability to adapt?

Does it take more weight for a person to perceive a weight change with a smaller initial weight or larger (i.e. is Weber's fraction larger with a smaller or larger initial weight)?

Are the sensations of hot and cold absolute?

Does referred pain change location? If so, where is it felt?

Exercise 2: Nystagmus

Aim: The following activities are designed to illustrate how the vestibular system plays a role in the orientation of the body during movement, and how vestibular reflexes effect certain muscular movements, including eye movement, to aid in the maintenance of equilibrium.

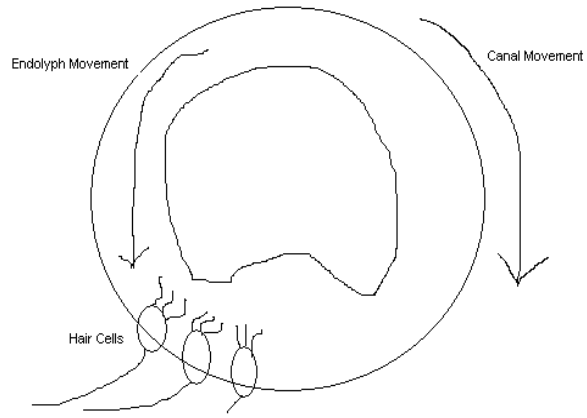
Background

The vestibular system includes 3 **semicircular canals** and the vestibule where these come together. Spinning of the body (head) is detected by specialized sensory receptors called **hair cells** located in the semicircular canals. The "hairs" of the sensory receptors extend into the **endolymph**, the fluid in the semicircular canals. When the canals move (i.e. the head moves), the endolymph initially stays still (think inertia) and therefore bends the hairs. The bending of the hairs depolarized the neuron's plasma membrane and sends nerve impulses to the brain, which interprets these signals to indicate you are spinning.

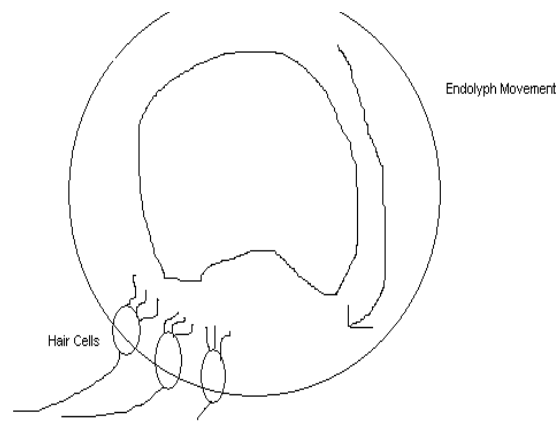
One of the functions of the semicircular canal mechanism described above is to aid in visual fixation while the head is moving. Reflex responses result in movement of the eyes, called **nystagmus.** Nystagmus has a fast and a slow components. The fast phase is designated as the direction of the nystagmus. While spinning, the eyes will move very slowly in one direction, as though to maintain fixation on a moving target, and then rapidly jump back in the other direction. This effect is **rotary nystagmus**, and this reflex is initiated by the hair cells in the semicircular canals. What are the "effectors" in the nystagmus reflex?

Sensory adaptation can also occur that will stop the neurons from sending nerve impulses to the brain that the body is spinning. Once a constant velocity is reached, the speed of the movement of the endolymph will equal the speed of the movement of the semicircular canal. If the endolymph and canal are moving in sync, the hair cells no longer bend and no longer send nerve impulses to the brain – at this point, you will still be spinning, but will no longer have the sensation that you are spinning.

If the constant velocity is disrupted (i.e. you stop spinning), the canal is then stationary but the endolymph continues to move (again, think inertia) in the opposite direction. This is call **post-rotatary nystagmus**. What spinning sensation do you think will accompany this?



What will happen to the hairs on the hair cells in this scenario? What signal will this send to the brain?



In this scenario the subject stopped spinning (i.e. the canal stopped moving). What will happen to the hairs on the hair cells? What signal will be sent to the brain?

Figure 1: The canal and endolymph will be spinning in the same direction and speed if a constant rotation is maintained.

Procedure

A. Rotary Nystagmus

1 Seat the subject in an office swivel armchair from which the casters have been removed.

2 With the subject's feet off the floor and head tilted slightly downward (30^{o}), and with eyes *open*, rotate the subject to the right at the rate of one rotation every 2 seconds for 10 turns. Watch the eyes as the subject rotates past you. Note the direction of fast and slow eye movement.

B. Post-rotary Nystagmus

1 Rotate the subject in the same way, but with eyes closed. Have the subject use one thumb to indicate the direction the perceived sensation of spinning. Do this for approximately 20 spins. Stop and/or switch direction of rotation several times. Then, stop the subject from spinning (gently, not abruptly) and continue to observe the direction noted with the thumb. When does the perceived direction not match actual rotation?

2 Rotate the subject steadily in the same way (eyes closed) for 10 turns. Stop the rotation suddenly, tell the subject to open his/her eyes, and observe the motion of the eyes immediately after stopping. Note the direction of nystagmus (fast eye movement).

3 Repeat the rotation with the head bent to the right shoulder at an angle close to 90°. What is the direction of post-rotary nystagmus?

C. Past Pointing

1 Start this exercise with practice; have the subject extend a finger to touch the pencil of a lab partner, then put the hand down, and with the eyes closed, have the subject attempt to touch the pencil again. Practice five times.

2 Now rotate the subject as before.

3 Stop the rotation abruptly and let the subject reach out with eyes open to touch the lab partner's pencil. As in the practice, the subject immediately closes his/her eyes and tries to touch the pencil. In which direction was the subject off? How does this relate to the direction of the spin?

Exercise 3: Hearing

Aim: The following activities are designed to illustrate how the auditory system detects and processes sound.

Background

The auditory system includes the outer, middle, and inner ear. The inner ear contains the cochlea for detection of sound (via hair cells) in addition to the vestibular apparatus described above for detecting rotation. The outer and middle ear only serve to help focus the sound energy on the basilar membrane within the cochlea. This membrane divides the cochlea into upper and lower chambers filled with endolymph. As it vibrates up/down, the hair cells on the basilar membrane are bent to initiate action potentials that travel along the auditory nerve to the brain centers which process sound information.

Procedure

A. Watch Tick Test for Auditory Acuity

NOTE: This activity should be performed in a quiet room. You may want to go to the back of the room or in the stairwell to perform this part of the exercise.

1 Have the subject plug one ear with cotton and close his or her eyes.

2 Hold a watch in line with the subject's ear. Gradually move the watch away from the ear until the subject just loses the ability to hear the ticking. Measure the distance (in cm) between watch and ear and record.

3 Move the watch farther away and then begin moving it nearer the subject's ear until the subject first hears the ticking. Is this distance the same as when the watch is moving away?

4 Test the other ear in the same manner to determine whether the acuity is the same for both ears.

B. Localization of Sound

1 With the subject seated and eyes closed, bring a ticking watch within hearing range from several different angles around the subject's head.

2 Ask the subject to point to the direction from which he or she hears the sound. Record the actual and perceived direction each time to ascertain whether the subject's judgment is better in the front, above, or on the side of the head.

C. Auditory Adaptation

1 While the subject has a stethoscope in her/his ears, have a lab partner strike a tuning fork on the heel of his/her hand to make it vibrate, and place it near the bell of the stethoscope so that the sound seems equally loud to both ears.

2 Remove the tuning fork and wait a minute or two. Again, you may need to move to a quiet place to complete this exercise.

3 Pinch the tube to one ear to close off the tube and place the vibrating tuning fork in its former position near the bell.

4 When the sound becomes nearly inaudible to the open ear, open the pinched tube. Pay attention to what is heard in both ears, and then relate this to "sensory adaptation".

D. Tuning Fork Tests

NOTE: There are two simple hearing tests to distinguish between conduction and nerve deafness. In conduction deafness, transmission of sound waves through the middle ear is impaired. In nerve deafness, transmission of nerve impulses from the cochlea to the auditory cortex is impaired. Performing just one of the following tests will not allow you to diagnose a hearing problem: it is necessary to do them both and then comparing your results to Table 1 (below).

1 **Weber Test.** This test should be performed in a room with a normal noise level (not quiet). Strike the tuning fork and place the tip of the handle against the middle of the subject's forehead. Determine if the sound is louder on one side than the other (lateralization), or if it sounds the same in both ears.

2 **Rinne Test.** This test compares air conduction of sound with bone conduction of sound. It should be performed in a quiet area. Locate the mastoid process of the temporal bone behind the ear of the subject. Strike the tuning fork and place the handle against the mastoid at the level of the upper portion of the ear canal. As soon as the sound is no longer audible through the bone, hold the vibrating prongs of the tuning fork about 1 inch from the ear, and see if the subject can again hear the sound.

Table 1. Guide for interpreting Weber and Rinne tests.

Condition	**Finding**	
	Weber Test	Rinne Test
No hearing loss	No lateralization	Sound heard longer via air conduction
Conduction deafness	Lateralization to the deaf ear	Sound heard as long or longer via bone conduction
Nerve deafness	Lateralization to the normal ear	Sound heard longer via air conduction

Exercise 4: Vision

Aim: The following activities are designed to illustrate how the visual senses function.

Background

The eye is composed of many structures, but most of these only function to optimize light energy to the retina. The pupil regulates the amount of light entering the eye, and the lens focuses this light. To produce a sharp image on the retina, the lens of the eye must be able to change its focusing power for viewing objects at different distances. When viewing a near object, the lens becomes more spherical than when viewing a distant object. As we age, the lens becomes less elastic and therefore less able to form the spherical shape needed for near vision. Determination of the near point for the eye gives us a measure of the elasticity of the lens and its ability to accommodate. A loss of flexibility is known as **presbyopia**.

The retina is where the **photoreceptors** (rods & cones) are located (though not evenly distributed). When the **photopigment** in these cells react with light, it alters the chronic release of neurotransmitter, leading to a change in action potential frequency being sent to the brain. The audio-cortex then interprets this as light. Rods detect light/dark, while the three types of cones (called blue, green and red cones) allow us to distinguish between different wavelength of light, and therefore to see colors.

The blind spot is an area in the visual field of an eye where you can not see. This is because the optic nerve and blood vessels enter and leave in the corresponding location in the back of your eye, and hence where there are no rods or cones for visual reception there. If the other eye can not see what is there, the brain "fills in" this spot in your visual field with whatever background is surrounding this blind spot.

The test you will perform in this section will help you "see" different facets of how the eye works.

Procedure

A. Accommodation Reflexes

NOTE: Accommodation reflexes are often studied under the topic of reflexes because they represent a programmed response to a stimulus.

1 Observe the pupil of your partner's eye under normal lighting. Then shine a light into the eye and notice the constriction of the pupil. The purpose of this reflex is quite obvious.

2 Now have your partner focus on an object across the room and observe the size of the pupil. Then have your partner focus on an object 6 in. from the eye. Observe what happens to pupil size.

B. Near Point of Accommodation

1 With your lab partner holding the other end, balance one end of a ruler on the bridge of your nose, and with one eye closed, hold the card with the letter at eye level and an arms length away.

2 Slowly move the card towards your face until the image becomes blurred once again. Then move the card away until the image is clear again. The distance at which the image comes into focus is the near point. Measure the distance from the card to your eye, and repeat the test for your other eye.

3 Compare your near point measurements with the normal values in Table 2.

Table 2. Normal values for minimum focal distances ("near point")

Age (Years)	Near Point (cm)
10	9
20	10
30	13
40	18
50	53
60	83
70	100

C. Binocular Vision and Space Perception

1 Hold a die 3 inches in front of your nose and focus on it. Close one eye, open it, and then close the other. Note whether the views seen with the right and left eyes appear different. [The image of the die that doesn't change position is your dominant eye.]

2 Try to thread a needle, first with both eyes open and then with one eye closed. [These simple experiments illustrate the advantage of binocular vision in providing depth of field and space perception.]

D. Blind Spot

1 Close your left eye and focus your right eye on the following image of the cross on the left (Figure 2).

2 Hold the paper about 15 inches from the eye and slowly bring it closer until the image of the dot disappears (make sure to keep your focus on the cross). At this distance, the dot image is in your blind spot, and its image is on area of the retina of the right eye where there are no rods or cones to perceive it.

Figure 2. Graphic used to illustrate blind spot.

3 Repeat this with both eyes open to see if the blind spot still exists or not.

4 Close one eye and look around the room. Do you notice your blind spot?

E. Visual Acuity and Astigmatism

NOTE: Visual acuity is the power to perceive visual details. You can test your visual acuity by using the **Snellen test** (see Figure 3). The numbers that are assigned on each side of the lines (i.e. the score you receive for being able to determine the letters correctly for the line) are in reference to normal vision. For example, line 1 of the test should be read easily at 200 ft, and line 8 at 20 ft. If the lowest line you can read is line 8, your eye is normal and is rated as 20/20. If you can only read line 3 at 20 feet, your visual acuity is below average, rated at 20/70.

1 Without any corrective eye wear, stand 20 ft. from the full-sized Snellen chart on the wall. Cover one eye and attempt to read whichever lines you can. Repeat the test for the other eye and record your results.

2 Test with corrective lenses to see how much they help.

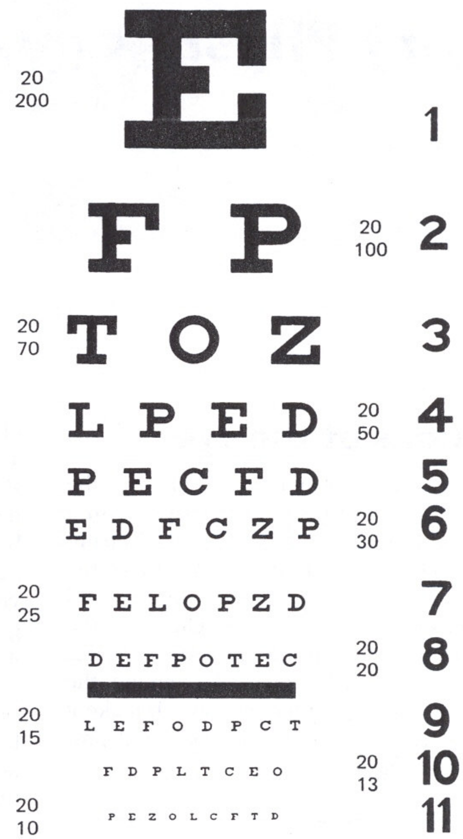


Figure 2: Snellen Eye Chart.

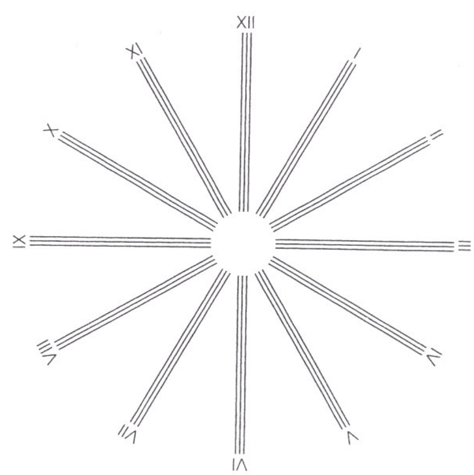


Figure 3. Astigmatism Eye Chart

NOTE: Astigmatism is a condition in which there is an uneven curvature of the surface of the lens or cornea. This causes a greater bending of light rays as they pass through one axis of the lens or cornea than when light passes through another axis. This causes the image viewed to be blurred in one axis and sharp in the other axes.

1 Remove any corrective lenses, cover the left eye, and look at the center of the full size astigmatism test chart (see Figure 3) posted on the wall beside the Snellen chart. If some of the lines appear blurred or lighter, this indicates that an astigmatism is present. If all lines are equally sharp and black, no astigmatism exists. Repeat the test with the right eye.

4 Test with corrective lenses to see how much they help.

F. Negative Afterimages: Complementary Colors

NOTE: A negative "afterimage" is a false image seen in which the light areas of the original scene appear dark and the dark areas appear light. This is due to the fact that while you are viewing the bright scene, cones receiving light from the bright areas become **adapted**, and when you shift your gaze to the white paper, these cones do not send impulses as well. Therefore, the round shape of the flashlight appears dark. The unadapted cones are still sensitive and are stimulated by the white background.

Color vision is initiated by the activation of cone cells in the retina that are most sensitive to red, green, or blue wavelengths of light. The color white contains all the visible wavelengths of light (all colors), and the three types of cones are equally stimulated unless one type of cone is adapted and is not functioning as well as the other two types. "Color" is an interpretation made in the brain, based on the relative number of action potentials received from the three cone types.

1 With the other eye closed, look into a flashlight with a clear lens for around 30 seconds, then shift your gaze quickly to a blank white sheet of paper. Note what color and shape you perceive.

2 Trade the clear lens of the flashlight for a red lens, and stare with your open eye at the bright red color for a minute. Then shift your gaze to a blank white sheet and note the color of the afterimage. Repeat this procedure using a green, a yellow, and a blue color lens.

G. Tests for Color Blindness

NOTE: Color blindness is an abnormality that is transferred genetically, resulting from the lack of a particular gene in the X chromosome. Therefore, males are more likely to express this recessive gene. The most common type is red-green color blindness, in which the person lacks either the red or the green cones in the retina. If the red cones are lacking, red wavelengths of light stimulate primarily green cones and the person perceives red as green. If the green cones are missing, the person will perceive only red colors in these wavelengths of light.

1. **Ishihara Test.** These test charts are probably the most widely used in the testing of color blindness. Each chart contains different-colored dots arranged so that the person with normal color vision reads one number and the color-blind person perceives a different number. Compare what your lab partners see in the test book.

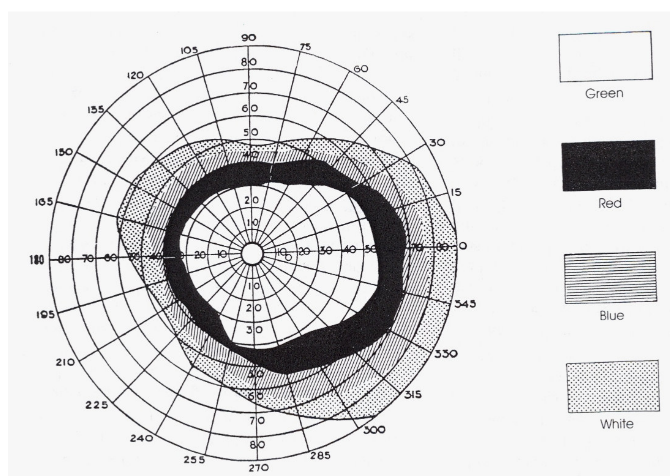
H. Visual Fields of the Eye: Perimetry

1 Have one subject stand 12 inches away from the front blackboard. Draw a dot using chalk in front of his or her face, at eye level. The subject is to stare at the dot with one eye closed while performing the test.

2 Have a lab partner hold the modified meter stick with the white dot facing outward, and slowly move this meter stick from the outer right edge of the board (at subject's eye level) towards the dot on the board until the subject notices the white dot (the subject should be focused on the blackboard, and should indicate when he/she notices an actual white dot, not just the presence of the stick). Place an "X" on the board at this location. Do this for the 8 major compass directions, mapping where the subject perceives the while dot though his/her peripheral vision.

3 Repeat the test by having the lab partner flip over the meter stick to map the peripheral vision of the subject using the red dot and placing a star at the location of perception along the 8 compass axes. Again, the subject should be focused on the blackboard with the same eye closed and should note when he/she perceives a red dot, not just a dot).

4 Measure the distance from the original dot on the board to each of the "X" marks and stars, so that you can draw a map of the subject's visual field for each color, as seen in Figure 4.



Exercise 5: Propriception

Aim: Observe how the removal of sensory receptors will affect the ability to “balance”.

Background

Proprioception is the knowledge of the body orientation (basically, where your limbs are in space), and the sensory ability required to know this. Without this, it would even be hard to stand up straight and still. Many different sensory receptors are involved in this ability, and in information is somewhat redundant. However, removing one source of information (not using those sensory receptors) makes it harder to remain standing. In the tests below, consider which sensory receptors and which effectors are involved.

Procedure

1 Have the subject hold his/her arms stretched straight out from the body at shoulder height and then try to bring the fingertips together in front of the body. Compare this ability with the subject's eyes open and with the eyes closed.

2 Have the subject stand with feet together and arms stretched straight out from the body at should height with eyes open and observe any body movements. Have the subject repeat the test with eyes closed and observe any body movements.

3 Then, have the subject stand on one foot and observe body movements. Again perform the test with the eyes closed and with eyes open.

4 Next, have the subject look at the ceiling and stand on one foot. Finally, have the subject stand on one foot, with his or her head in the same position as before, but this time with eyes closed.

5 For fun, have a subject put on the simulated “drunk” goggles. Have one of the lab partners wad up a piece of paper and throw it to the subject to try and catch it, and then throw it back. Have the subject try to walk a straight line.

Figure 4. Perimeter chart of the right eye