

Sensory Physiology

External sensory information is processed by several types of **sensory receptors** in the body. These receptors respond to external stimuli, and that information is changed into an electrical signal (**action potential**) that is transmitted along the **sensory division (afferent pathway)** of the **peripheral nervous system (PNS)** to the **central nervous system (CNS)**. This sensory signal initially occurs by activation of a sensory receptor. Receptor activation stimulates the opening or closing of **ion-gated channels**, which generates an action potential. The CNS, or integrating center, processes the information and then sends a response via **motor division (efferent pathway)** to **effectors** (muscle cells or glands) of the PNS for either a movement or secretory response, respectively.

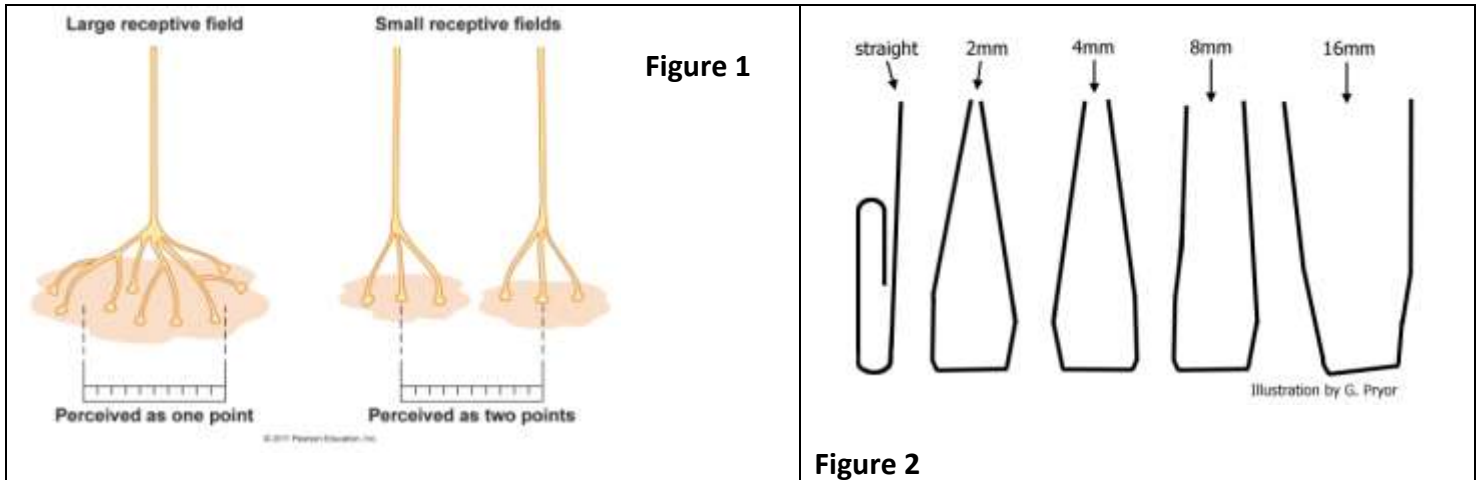
The sensory (afferent) division of the nervous system includes:

- 1) Somatic sensory division** = transmission of sensory information from skin, fascia, joints, and skeletal muscles for balance and muscle movement to the CNS for interpretation. CNS will issue motor commands as needed to modify movements based on stimuli. The somatic sensory division can be involved in receiving sensory information that regulated involuntary and voluntary movement. In the skin there are several types of somatosensory receptors: mechanoreceptors, thermoreceptors, and nociceptors. **Mechanoreceptors** are found in the skin, tongue, joints, and the bladder. They they detect pressure, vibration, and stretch. **Thermoreceptors** are found in the skin and hypothalamus; they can be divided into warm and cold receptors. **Nociceptors** are found in the skin, cornea, visceral, joints, and skeletal muscles, and they are pain receptors that can be activated by mechanical, chemical, and even temperature extremes.
- 2) Visceral sensory division** = receives sensory information from viscera (thoracic and abdominal organs) and transmits to CNS for interpretation. CNS will issue motor command as needed.
- 3) Special senses division** = receives sensory information on sight, sound, balance, pressure, and taste and transmits them to the CNS for interpretation. The CNS will issue motor commands as needed.

Part 1. Mechanoreceptors (Somatic Sensory Division)

There are six different classes of mechanoreceptors; they are defined based on their location in the skin, mechanism eliciting response (vibration vs. pressure), and whether they are slowly adapting or rapidly adapting receptors. Rapidly adapting receptors quickly respond to a new signaling environment and quickly become attenuated to it. For example, the rapidly adapting receptors in your skin respond immediately to touch, but then quickly stop signaling, and you essentially “ignore” the stimulus.

Mechanoreceptors are found at variable distances from one another. The closer the receptors are together, the greater the tactile acuity of that region. One way to determine tactile acuity is by a **two-point discrimination test**, which is the ability of a person to perceive two fine points pressed against the skin. In order for someone to make this distinction, two afferent neurons must be stimulated. If the neuronal processes of only one afferent neuron are stimulated, this is perceived as one point (Figure 1).



Procedure:

1. Obtain a set of 5 paperclips that have been prepared for this experiment. The space between 2 points of the paperclips should vary between 16, 8, 4, and 2 mm, and one paperclip straightened into a single point (Figure 2). Confirm the distance between the points with a ruler and adjust as needed.
2. Have your partner close his/her eyes. At random, choose a paperclip and touch your partner's fingertip and ask if they perceive one or two points. Record (-) for wrong answer and (+) for correct answer.
3. Repeat procedure with all paperclips and on the palm and forearm. Record your data in table 1 below. Choose at random the different width spaces and the place of perception, and choose a straight point in between testing with 2 points also at random intervals.

PAPERCLIP TYPE	FINGERTIP	PALM	FOREARM
Straight			
Straight			
Straight			
2 mm space			
4 mm space			
8 mm space			
16 mm space			

Questions:

1. Which region(s) were most sensitive in distinguishing between 1 vs 2 points?
-

2. What does this say about the relative number of mechanoreceptors per square inch of skin in each of the different body regions?
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Part 3: Thermoreceptors:

Two main classes of thermoreceptors are present in the superficial portion of all skin: warm receptors and cold receptors. Warm receptors are activated at $\sim 40^{\circ}\text{C}$; cold receptors are activated at temperatures below 25°C . Cold receptors are also activated at very hot temperatures ($>45^{\circ}\text{C}$). Perception of cold at these high temperatures is known as paradoxical cold. Both types of receptors display a rapid **adaptive response**.

Procedure:

1. Obtain 2 1L beakers. Fill one ½ full with water from the hot water tap. The water should be approximately 45° C. Fill the other one ½ full with ice water (~15°C). Fill a plastic tub with room temperature water (~25°C).
2. Place your left hand in the hot water and your right hand in the cold water.
3. Allow your hands to get used to the new temperature.
4. Place both hands into the central tub at 25°C.
5. Record how each hand perceives the temperature.

Left hand previously in hot feels _____.

Right hand previously in cold feels _____.

Question:

What does this tell you about how the brain perceives temperature? _____

Thermoreceptors are also responsive to certain chemicals. Place the substances listed below on your forearm and record which thermoreceptor (warm or cold) is activated. Be sure to place on different regions of your forearm and don't get it in your eyes!

Substance**Receptor activated**

1. Menthol gel
2. Capsaicin
do not use if you have a sensitivity to hot peppers
3. Campho-Phenique
4. Icy-Hot

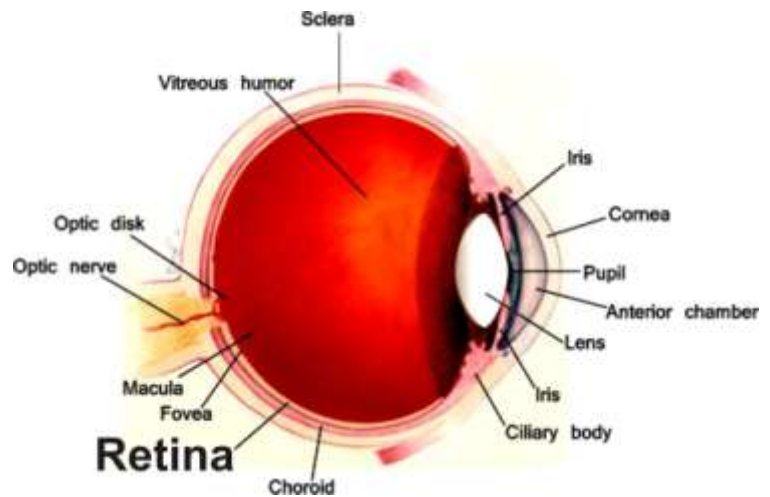


Figure 3: The regions of the eye. Note the optic disk.

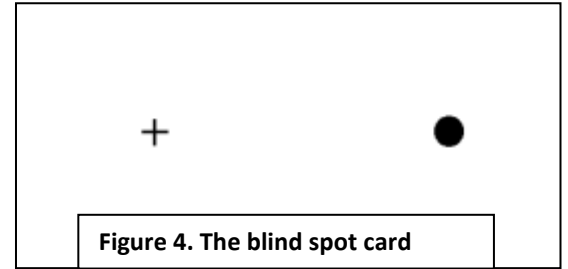
Part 4. Special Senses: Photoreceptors

Light and color perception are detected by the **retina** within the eye (Fig. 3). Two types of detection cells, **rods and cones**, process information coming through the lens of the eye and send it down the optic nerve to the brain. **Rod cells** (~ 100 million of them) detect the degree of light entering the eye and their sensitivity depends on the pigment **rhodopsin**, which is itself generated within the cells. However, rhodopsin is destroyed by bleaching with light exposure and it takes time to regenerate. (If you've ever been in a bright room and then enter a dark room you are momentarily blinded because your rhodopsin in rod cells has been bleached and you cannot see. Therefore, rod cells work best in low light situations rather than with bright light due to rhodopsin bleaching. **Cone cells** (~ 3 million of them) are also sensitive to light levels but retain their function under high light through the pigment **iodopsin**. Detection of color is a function of the three types of cone cell that detect the visible color spectrum. Each cone cell type is sensitive to a different range of wavelengths with maximums corresponding to **red** (long), **green** (medium) or **blue** (short). The **optic disk** (Fig. 3) is where the neuronal processes of the photoreceptors of the eye (the rods and cones) exit the retina to merge into the optic nerve. This creates a "blind spot" in the field of vision (Fig. 4).

In the following three experiments you will examine your "blind spot", the negative afterimage (relying on rod cells) and the color afterimage (relying on cone cells).

Illustration of the “blind spot”

1. Place your hand over your left eye.
2. With your right hand, hold the blind spot card and extend your arm. The black circle should be in front of your closed left eye and focus your open right eye on the black circle (Fig. 4).
3. Slowly bring the card toward your face, maintaining your focus on the black circle. If you focus at all on the cross, the experiment will not work.
4. Continue to move card toward your face until the cross disappears. At this point, the portion of your retina focusing on the cross is the optic disk. Continue to move the cross toward your eye until it reappears. It has now passed through the blind spot.
5. Repeat procedure with your right eye closed and left eye open.



Afterimages

An **afterimage** (or **ghost image** or **image burn-in**) occurs after you stare at an original image for a period of time and then look away, at perhaps a blank paper, and you experience an optical illusion of that image. A common form of afterimages is the bright spot that seems to float before your eyes after staring at a bright light source for a few seconds. There are also black and white (negative) afterimages and color afterimages.

Black and White Negative Afterimage

A **negative afterimage** is visual afterimage in which light portions of the original sensation are replaced by dark portions and dark portions are replaced by light portions. In essence the afterimage is the negative of the original image. The light that strikes the **rod photoreceptors** of the eye stimulates a photochemical reaction in these receptors. In this reaction the pigment **rhodopsin** dissociates into two distinct pigments. This dissociation causes action potentials to be generated, and visual signals sent to the brain. Once all of the rhodopsin has dissociated, that neuron cannot fire again until more rhodopsin in a chemical reaction involving vitamin A1 (remember your mama told you to eat your carrots for better vision). Once the rod's rhodopsin has been “bleached” by an image, that image will persist until more rhodopsin can be synthesized.

Procedure:

1. Stare at the negative afterimage card for 60 seconds. Concentrate entirely on the image and don't let your focus stray.
2. After 60 seconds quickly focus your eyes on a plain white piece of paper. What do you see?

Questions:

What would be the effect of staring at a bright light, then closing your eyes? _____

What photoreceptors (rods or cones) are being bleached? _____

Color Afterimage

Remember that rods are important in black/ white vision, while **cones** are important in color vision. There are three systems of cones that respond respectively to red, green, and blue/violet and all other colors are seen by the brain's interpretation of mixtures of impulses from these three. The color **opponent process** is a color theory that states the staring at one color will bleach the **iodopsin** pigment for that color, and if you stare at a white piece of paper after focusing on these colors it will produce an afterimage in the complementary color. If you stare at red the afterimage is green whereas if you stare at blue the afterimage is yellow, and vice versa. The complementary color afterimage is called “**chromatic adaptation**”.

Procedure:

1. Stare at one of the color afterimage squares for 60 seconds.
 2. Quickly shift your gaze to a white piece of paper. What color do you see?
- Repeat with the other colors.

Card: _____ **Afterimage:** _____

Blue _____

Red _____

Green _____

Question:

1. How can you explain the color of the afterimage that you see? _____

Part 5. Somatic Sensory and Special Senses: Vestibular-Cochlear System**Auditory system**

The auditory system is primarily mediated by **hair cells** located in the **spiral organ of Corti**, found in the **cochlea**. Sound waves pass through the tympanic membrane, which generates vibrations in small bones (the **auditory ossicles**: the incus, malleus, and stapes) found in the middle ear. These bones press open an opening in the cochlea called the oval window, and this produces movement in the fluid-filled inner ear. **Stereocilia**, located on the hair cells, bend in response to the fluid movement and transducer the information by opening ion channels. Thus, hearing is mediated by mechanoreceptors. **However, the fluid in the inner ear can be made to vibrate in response to sound waves conducted through the skull bones**, bypassing the middle ear and auditory ossicles entirely. This makes it possible to differentiate between **conduction deafness**, resulting from damage to the middle ear and auditory ossicles, and **sensory deafness**, resulting from damage to the cochlea and auditory nerve. Two clinical tests, the Rinne test and the Weber test, can test for conductive versus sensory deafness.



Figure 5: Structures of the external, middle and inner ear

Procedures:**Rinne test**

1. Strike a tuning fork (preferable a 512Hz) with a rubber mallet to produce vibrations.
2. Place the handle of the vibrating fork against the mastoid process of the temporal bone (the bony prominence behind the ear) with the tuning fork pointed down and behind the ear. When the sound has almost died away, move the tuning fork (by the handle) near the external auditory meatus. If there is no damage to the middle ear, the sound will reappear.
3. Simulate conductive deafness by repeating the test with cotton in the ear.

Weber’s test

1. Place the handle of a vibrating tuning fork (preferable a 256Hz) on the middle sagittal line of the head.
2. Repeat Weber’s test with on ear plugged with your finger.
3. In which ear is the sound louder?

Question:

1. In some people with hearing loss, hearing aids are placed over the mastoid process. Would this type of hearing aid be beneficial to an individual with either sensory or conduction deafness? Why or why not?
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Vestibular system

The inner ear is also important in mediating balance. Another type of hair cell is located in the **vestibule** and the **semicircular canals**. These cells have stereocilia that bend in response to acceleration of the head. This bending of the stereocilia opens or closes ion channels to generate action potentials. The information is sent to the CNS to integrate information about our location in space (proprioception), balance and eye movement.

Procedures:

(Please do not engage in these experiments if you have known equilibrium problems!)

1. Have the subject walk in a straight line, placing one foot directly in front of the other in a heel to toe manner [*Kind of like a field sobriety test! – Not that you would know what that is, right?*]

Does the subject experience any wobbling or dizziness? _____
If not, this indicates a properly functioning equilibrium apparatus.

2. Have **the subject stand with his/her back to the blackboard**. Draw straight and parallel lines on each side of their body with chalk. (If blackboard not available do against a wall and use tape to mark parallel lines.) The subject should stand straight, eyes open, for about 2 minutes while you observe.

Do you notice any obvious swaying movements in the subject? (Side to side or forward and backward?)

3. Now – repeat the test, this time with **the subject standing with one side facing the blackboard**.

Do you notice any obvious swaying movements in the subject? (Side to side or forward and backward?)

4. Repeat steps 2 and 3, this time with the subject’s eyes CLOSED. What difference do you notice in their body movement with their eyes closed?

5. Have the subject **stand on one foot for about one minute**, eyes open. Then try it with eyes closed. What difference do you notice in their body movement with their eyes closed?

Questions:

1. Do you think that the subject's equilibrium apparatus was working equally well in all of the tests? _____

2. Do you think the subject's proprioceptors (of the somatic sensory division) were working? _____

3. What conclusions can you draw about which factors are necessary for maintaining balance and equilibrium?
