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Physiology, Sensory Receptors

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Introduction

The human body can achieve an understanding of the world through its **sensory** systems. **Sensory** systems are widespread throughout the body including those that detect the world directly from the outside (exteroreceptors), those that detect information from internal organs and processes (interceptors), and those detecting sense of position and load (proprioception).

Sensory receptors occur in specialized organs such as the eyes, ears, nose, and mouth, as well as internal organs. Each **receptor** type conveys a distinct **sensory** modality to integrate into a single perceptual frame eventually. This information is achieved by conversion of energy into an electrical signal by specialized mechanisms. In this report, we will discuss a basic overview of **sensory** systems, focusing on **sensory receptors**.

Issues of Concern

All impulses from the **receptors** transmit as nerve signals and what ultimately determines how we perceive the stimulus is where the nerve fiber terminates in the central nervous system. It is important to realize that what one senses is dependent on the **receptor** and any damage occurring from the beginning of the path to its end.

Cellular

The following is a detailed discussion of major **sensory receptor** types.

Receptors of vision

Retinal is the principal molecule of vision in the retina. It can absorb different frequencies of light. Its isomer (Cis-retinal) is present in rhodopsin, which is a photosensitive transmembrane G-protein that exists in rods and cones; it contains both cis-retinal and opsin.

Light is the stimulus and retinal is the **receptor**. The absorption of energy transforms cis-retinal into trans-retinal. With this conformational change, rhodopsin transforms into an activated form called meta-rhodopsin. Signal transduction then involves transducin, a multisubunit protein, by binding it to rhodopsin and causing conversion of GDP to GTP; this leads to the release of the alpha subunit allowing it to bind to cGMP phosphodiesterase - which lowers levels of cGMP. This signals closure of sodium channels that are otherwise open when it is dark. Interestingly, in this scenario, it is hyperpolarization that occurs with light signaling. This hyperpolarization results in a decreased amount of glutamate released to the postsynaptic membrane, signaling a change to the brain.[1]

Receptors of hearing

To discuss how sound **receptors** work, first, we must mention the order of events. Sound waves travel to the ear creating a vibration in the tympanic membrane. This energy transforms into mechanical energy to the malleus, incus, and stapes. The stapes is in close proximity to the oval

window, and it amplifies the mechanical energy to the cochlea, a fluid-filled structure with a fluid called perilymph, by directly pushing on it. The cochlea has three layers called scala vestibuli (the ascending portion), scala media, and scala tympani (the descending portion). The organ of Corti is on the basilar membrane surface, and it contains hair **cells** which are the primary **receptors** in sound signal creation. There are two varieties of hair **cells**: inner and outer. Inner **cells** transmit information to the auditory nerve, and outer **cells** mechanically amplify low-level sound entering the cochlea.

Inner hair **cells** have an attachment with a tectorial membrane to which they bend against with movement of the cochlear duct membranes and fluids. When the stereocilia on the hair **cells** bend towards the longest cilia, potassium and voltage-gated calcium channels open and ion influx increases resulting in depolarization. This depolarization allows for neurotransmitter release at the auditory nerve in the postsynapse, generating nerve impulses to be propagated from stereocilia of hair **cells** to the central nervous system via glutamate transmission. Discrimination of sound is via the location of the original nerve impulses from different areas of the cochlea.[1]

Receptors of balance

The inner ear senses balance. With head motion or pressure impulses of sound, the endolymph vibrates and creates a stimulus for the **receptors** of the vestibular system - the utricle and saccule. Inside the utricle and saccule are maculae containing hair **cells** with a membranous covering of microscopic otoconia that detect motion of the endolymph. Those in the saccule help sense vertical accelerations whereas those in the utricle sense horizontal accelerations. With changes in position, and thus changes in fluid motion, the shifting of these hair **cells** causes opening of **receptor** channels leading to action potentials propagating from the hair **cells** to the auditory nerve. The rate of fluid motion, plus the quality of the fluid, gives us more information about the motion. While the utricle and saccule detect linear motion, the semicircular ducts detect rotations in a similar fashion.[2]

Receptors of taste

Taste buds on the tongue and oropharynx help us enjoy and discriminate what we ingest.[3] The different tastes include sweet, salty, bitter, umami, and sour. A taste bud is a collection of taste **cells** that elongate at a tip to create a pore where stimuli may enter. Along these elongations are microvilli that protrude into the lumen of the mouth. On the other side of taste **cells**, there are nerve fibers that will eventually transmit the chemical gustatory message to the brain.

Just like most nervous tissue, with stimuli binding to the **receptor**, the **receptor** depolarizes and releases a neurotransmitter for a postsynaptic cell to uptake and transmit the message. Interestingly, higher concentrations create higher action potentials. The stimulus binding to each **receptor** varies for each taste. Sweet, umami, and bitter tastes are detected by G-protein coupled **receptors** (GPCRs). These **receptors** recognize and can discriminate a wide variety of substances by attaching to different domains on the **receptor** complex. Both saccharides, as well as proteins, trigger sweet sensations. Monosodium glutamate and aspartate in humans mostly trigger umami flavors. Because most bitter tastes are considered to be from toxic environmental compounds, these **receptors** can recognize a wide variety of stimuli; they include approximately 30 GPCR types. Sodium is the stimulus for salty taste, and protons are the stimulus for sour tastes. These stimuli cause ion channels to open, leading to depolarization and nerve signaling. Each taste bud has a variety of types of taste **cells**, and it depends on the concentration to determine which taste is perceived more strongly. When the **receptor** first encounters a signal, it displays a sharp increase in discharge, but then it steadily acclimates with continual exposure to the stimulus. Saliva, however, continually washes stimuli away from **receptors**. The terminal

destination for these signals located is in the primary gustatory cortex in the frontal and insular lobes.[4]

Receptors of smell

Smell occurs by binding of odorant molecules to **receptors** on the membrane of the cilia, causing an action potential that sends this information to the brain. These systems utilize G-protein **receptors** along with adenylate cyclase. Initially, scientists believed that molecules bound directly to **receptors** and that each **receptor** potentially identified a specific type of smell. However, Yoshioka et al. proposed a more plausible theory, because hydrogen and its isotope are sensed as entirely different smells. The authors relate this to a postulate called the "molecule vibration model." When a substance is bound to its **receptor**, the substrate allows electrons to go down their gradient, and through their specific vibrational energies, it causes a flow of chemical changes and subsequent signaling to the brain.[1]

Receptors on the skin

What follows is a discussion of the various **receptors** in the skin. Signals from the skin may be conveyed by physical change (mechanoreceptors), temperature (thermoreceptors), or pain (nociceptors). **Sensory receptors** exist in all layers of the skin.

Mechanoreceptors

There are six different types of mechanoreceptors detecting innocuous stimuli in the skin: those around hair follicles, Pacinian corpuscles, Meissner corpuscles, Merkel complexes, Ruffini corpuscles, and C-fiber LTM (low threshold mechanoreceptors).[5] Mechanoreceptors respond to physical changes including touch, pressure, vibration, and stretch. Hair follicles can detect light touch; Meissner corpuscles in the dermal papillae detect indentation and slipping of objects; Pacinian corpuscles in the deeper dermis detect vibration; Merkel complexes in the basal epidermis create an understanding of structure and texture; Ruffini corpuscles detect stretch; C-fiber LTMs detect pleasant, light tactile sensations.[5] Encapsulated **receptors** include Meissner corpuscle and the Pacinian corpuscle. In **receptors** that respond to stretch, there is a presence of “stretch-activated channels” that leads to depolarization via sodium influx.[6] With smaller receptive fields, there is more precision in the detection of shape, form, and texture of stimuli.

Receptors that do not signal pain have lower thresholds of signaling activity. They use A fiber beta-type nerves and those with higher thresholds that signal pain use A-delta and C-fibers. The C and A-delta fibers respond to painful temperatures, mechanical forces, and chemicals.[7]

Proprioceptors are also mechanoreceptors. Examples include muscle spindles and the Golgi tendon organ which respond to muscle contraction/relaxation and muscle strain respectively.

Thermoreceptors

The body has both warm and cold thermoreceptors. These **receptors** display a constant discharge to their specific temperatures, and when an experience of the opposite temperature occurs, there is a sudden ceasing of **receptor** discharge.

Cold **receptors** mainly sense temperatures between 25 to 30C. Temperatures below this cause release of bursting discharges. In touching dangerously hot objects (greater than 45C), there can be a brief sensation of cold due to the paradoxical firing of cold **receptors**. Warm **receptors** respond to the approximate temperature range of 30 to 46C. Higher temperatures may result in the decreased firing of these **receptors**.[5]

Noxious heat is detectable by TRPV1, TRPM3 or ANO1 proteins, as well as capsaicin [8]. However, TRPV3 may be more responsible for detecting warm temperatures. There is

redundancy in **receptors**; their exact mechanisms are unknown.

In contrast, for colder temperatures, it is believed that TRPM8 ion channels are one of many **receptors** responsible. These **receptors** are capable of detecting temperatures from below 16C to 26C. The belief is that other undiscovered **receptors** also have a role in cold detection.[8]

Nociceptors

Nociceptors help signal pain that is related to temperature, pressure, and chemicals. As Dubin et al. discusses, most **sensory receptors** have low sensitivity to dictate all sensations to the brain. However, when it comes to pain, nociceptors only signal when the body has reached a point of tissue damage. Inflammatory markers increase during tissue damage, bind to **receptors**, and initiate pain signaling either externally or in the viscera. One of the ion channels families that are present on nociceptive neurons is called TRP (transient **receptor** potential) ion channels. Those signals that activate nociceptive **receptors** include extremes of temperatures, high pressures, and chemicals causing tissue damage [9]. Different fibers relay pain information; these are A-delta and C fibers. These fibers differ in their myelination and nerve diameter and thus speed of transmission. Painful temperatures, uncomfortable pressures, and chemicals mostly use C-fibers. C-fibers vary to be able to sense all three types of stimuli. A-delta fibers are small and unmyelinated and are primarily involved in thermal and mechanosensitive pain. Nociceptors utilize mostly glutamate but also substance P, calcitonin gene-related peptide, and somatostatin to signal pain.[9]

Additionally, the gate theory of pain proposes that innocuous stimuli may trump painful stimuli if both are present simultaneously.

Organ Systems Involved

Many sensations are generated and transmitted via specialized **sensory** organs, others, as viscera, contain nociceptors that activate following inflammation and tissue damage.

The **sensory** organ of the eye is the retina. In concert with the cornea and lens, light focuses on the vision board where information can transform from physical matter into electrical energy that lends itself to interpretation and understanding of the external world by the brain.

The skin possesses many **sensory receptors** in the epidermis, dermis, and hypodermis, which allows for discrimination of touch such as pressure differences (light vs. deep). Other qualities of the external world assessed by skin **sensory receptors** includes temperature, pain, and itch.

The inner ear houses hair **cells** in the cochlea to transduce sounds and the vestibule which mediates our sense of balance.

Smell is perceived through the binding of molecules to the chemoreceptors in the cilia of the olfactory epithelium in the nose.

The mediation of the sense of load and position is through the specialized structures of muscle spindles and joint capsules which contain mechanoreceptors that detect joint angle, muscle length, and force.

Taste appreciation occurs by dissolving of molecules in the taste buds in the mouth and oropharynx.

Function

These **sensory** systems are responsible for helping maintain homeostasis in the body and for allowing the body to best react to internal and external events.

Mechanism

All **sensory** signals begin as **receptor** potentials. These potentials lead to a release of a neurotransmitter that excites its corresponding nerve to send information to the brain. Just as with regular nerve signal transduction, creating a **receptor** potential requires surpassing a threshold level in the membrane potential. Interestingly, with **sensory receptors**, the more the threshold is exceeded, the higher the frequency of action potentials. All **receptors** share the property that they can detect signals that are weak and intense. However, there is a drop-off, or plateau when the stimulus has reached a level of maximum stimulation. At that point, the **receptor** is unable to increase its firing potential.

Sensory receptors display properties that are common to almost all **receptor** types, here we discuss some of them.

Receptive field

The site of a **sensory** neuron within its surrounding neuronal population is vital to determine the location of its neural message, whether tactile, visual, auditory, or others. The bodily area where a stimulus can affect a **sensory receptor** is called *receptive field*. This attribute in form of a physical dimension is vital to encode an accurate location of a stimulus. Areas that contain a higher number of small **receptor** fields can achieve better spatial resolution, evident in the fovea of the retina and portions of the skin such as fingertips and lips.

Labelled line principle

Sensory systems function by responding only to stimuli they are specific for and subsequently transducing it into a neural message which follows a discrete path to the brain. This constitutes the labelled line principle, which reserves the specificity of a **receptor** class in encoding a **sensory** modality to the designated brain area. This applies to somatosensory systems, as well as other specialized systems such as visual and auditory.

Adaptation

Adaptation is a common property of all **sensory receptors**. As a stimulus constantly excites the **receptor**, there will be a decrease in the rate of action potentials. Although **receptors** can adapt to a constant, unchanging stimulus, if there is a change, whether loss of the stimulus or change in intensity, the **receptor** is able to respond.

Topographical representation

Primary **sensory** cortical areas contain neurons that construct a location-specific or a quality-specific organization. Somatotopic representation displays in the primary **sensory** cortex by representing a distorted anatomical version of the body called **sensory** homunculus. Another example is the auditory system, where it displays a tonotopic map in the primary auditory cortex pertaining to sound frequencies.

Clinical Significance

Understanding the vast amount of **sensory** systems of the body is critical in the field of medicine. By discovering **sensory receptors** and investigating their mechanisms, we can understand the pathophysiology of various disorders that present. One of the highly-relevant topics is chronic pain syndrome, where the understanding nociceptors is vital in designing new pharmaceutical solutions and treatment plans for this debilitating problem.

Questions

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