Sensation: How Your Brain Interprets The World

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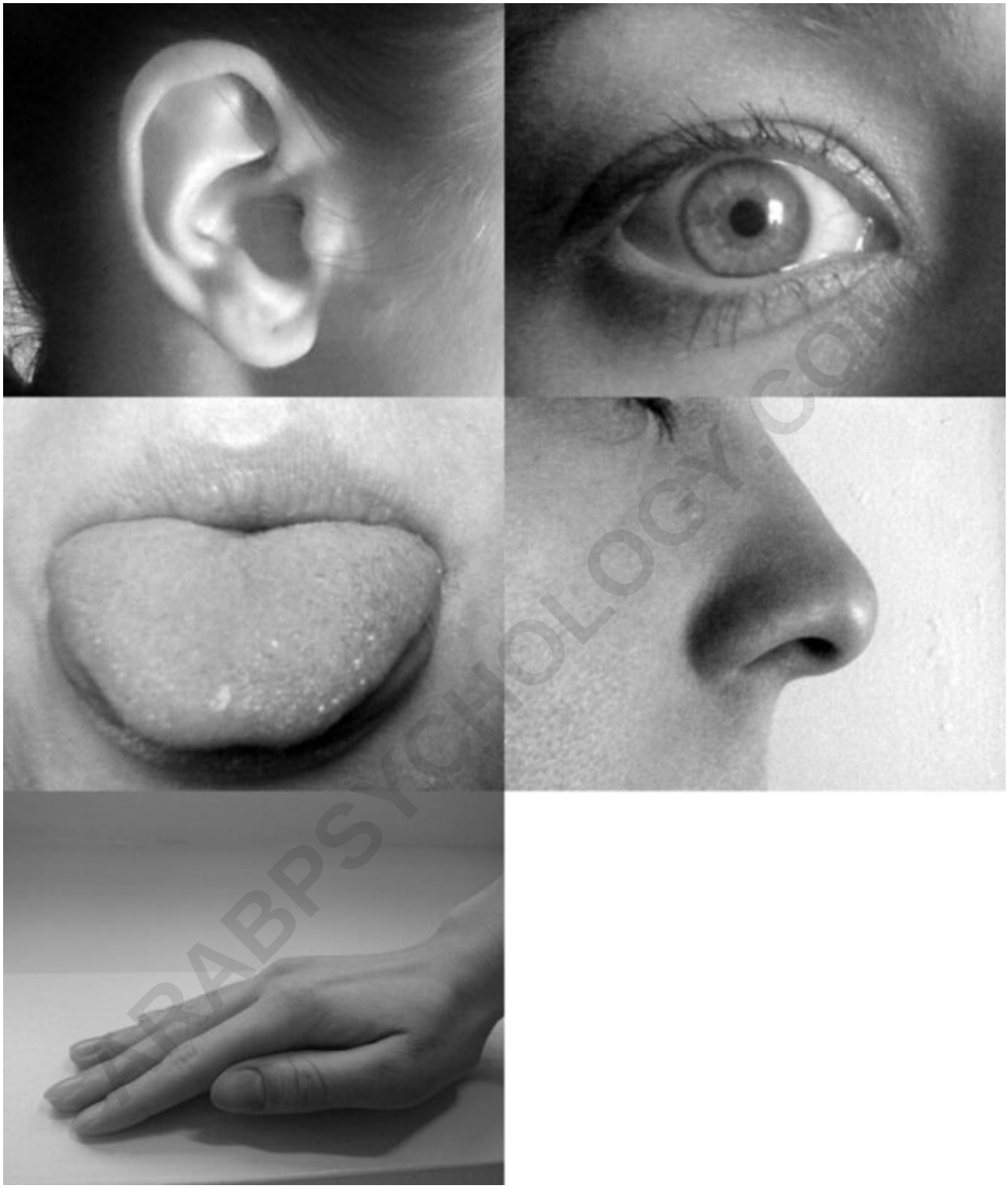
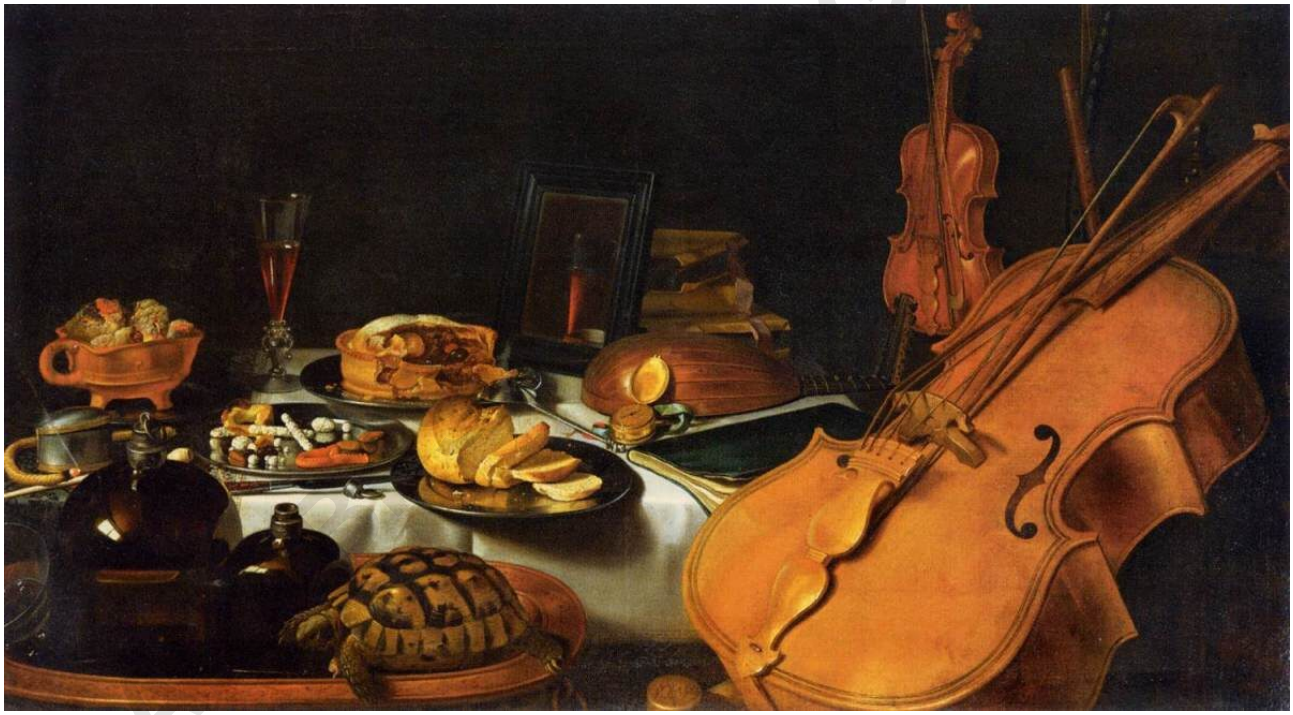


Five senses and the respective sensory organs inherent among Homo sapiens

A sense is a physiological capacity of organisms that provides data for perception. The senses and their operation, classification, and theory are overlapping topics studied by a variety of fields, most

notably neuroscience, cognitive psychology (or cognitive science), and philosophy of perception. The nervous system has a specific sensory nervous system, and a sense organ, dedicated to each sense.

Humans have a multitude of senses. Sight (vision), hearing (audition), taste (gustation), smell (olfaction), and touch (somatosensation) are the five traditionally recognized senses. The ability to detect other stimuli beyond those governed by these most broadly recognized senses also exists, and these sensory modalities include temperature (thermoception), kinesthetic sense (proprioception), pain (nociception), balance (equilibrioception), vibration (mechanoreception), and various internal stimuli (e.g. the different chemoreceptors for detecting salt and carbon dioxide concentrations in the blood, or sense of hunger and sense of thirst). However, what constitutes a sense is a matter of some debate, leading to difficulties in defining what exactly a distinct sense is, and where the borders between responses to related stimuli lie.

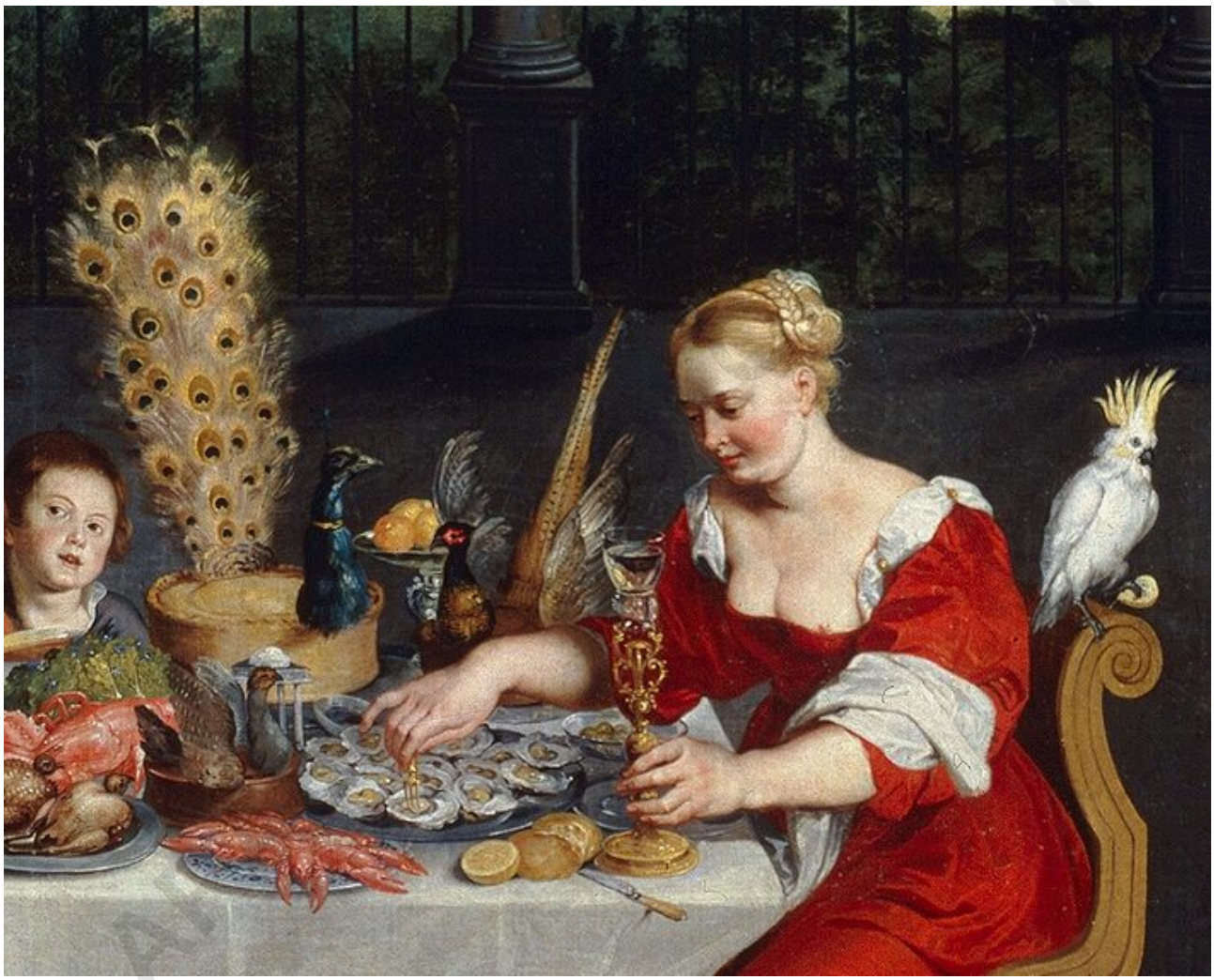


An allegory of five senses. Still Life by Pieter Claesz, 1623. The painting illustrates the senses through musical instruments, a compass, a book, food and drink, a mirror, incense and an open perfume bottle. The tortoise may be an illustration of touch or an allusion to the opposite (the tortoise isolating in its shell).

Other animals also have receptors to sense the world around them, with degrees of capability varying greatly between species. Humans have a comparatively weak sense of smell and a stronger sense of sight relative to many other mammals while some animals may lack one or more

of the traditional five senses. Some animals may also intake and interpret sensory stimuli in very different ways. Some species of animals are able to sense the world in a way that humans cannot, with some species able to sense electrical and magnetic fields, and detect water pressure and currents.

Definition



Detail of The Senses of Hearing, Touch and Taste, Jan Brueghel the Elder, 1618

A broadly acceptable definition of a sense would be "A system that consists of a group of sensory cell types that responds to a specific physical phenomenon, and that corresponds to a particular group of regions within the brain where the signals are received and interpreted." There is no firm agreement as to the number of senses because of differing definitions of what constitutes a sense.

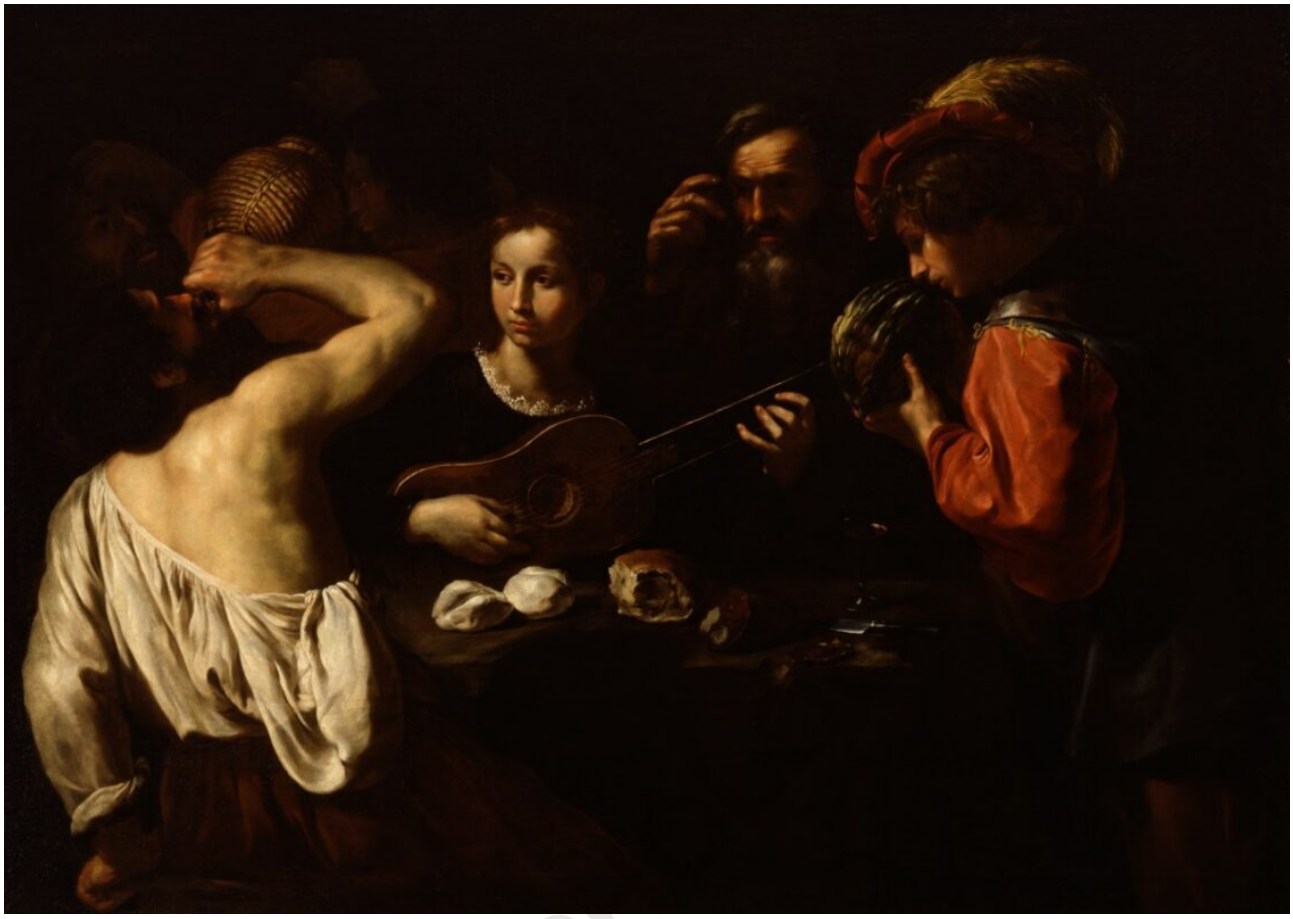
The senses are frequently divided into exteroceptive and interoceptive:

Exteroceptive senses are senses that perceive the body's own position, motion, and state, known as proprioceptive senses. External senses include the traditional five: sight, hearing, touch, smell and taste, as well as thermoception (temperature differences) and possibly an additional weak magnetoception (direction). Proprioceptive senses include nociception (pain); equilibrioception (balance); proprioception (a sense of the position and movement of the parts of one's own body).
Interoceptive senses are senses that perceive sensations in internal organs.

Non-human animals may possess senses that are absent in humans, such as electroreception and detection of polarized light.

In Buddhist philosophy, Ayatana or "sense-base" includes the mind as a sense organ, in addition to the traditional five. This addition to the commonly acknowledged senses may arise from the psychological orientation involved in Buddhist thought and practice. The mind considered by itself is seen as the principal gateway to a different spectrum of phenomena that differ from the physical sense data. This way of viewing the human sense system indicates the importance of internal sources of sensation and perception that complements our experience of the external world.

Traditional Senses



In this painting by Pietro Paolini, each individual represents one of the five senses.

Sight or vision (adjectival form: visual/optical) is the capability of the eye(s) to focus and detect images of visible light on photoreceptors in the retina of each eye that generates electrical nerve impulses for varying colors, hues, and brightness. There are two types of photoreceptors: rods and cones. Rods are very sensitive to light, but do not distinguish colors. Cones distinguish colors, but are less sensitive to dim light. There is some disagreement as to whether this constitutes one, two or three senses. Neuroanatomists generally regard it as two senses, given that different receptors are responsible for the perception of color and brightness. Some argue that stereopsis, the perception of depth using both eyes, also constitutes a sense, but it is generally regarded as a cognitive (that is, post-sensory) function of the visual cortex of the brain where patterns and objects in images are recognized and interpreted based on previously learned information. This is called visual memory.

The inability to see is called blindness. Blindness may result from damage to the eyeball, especially to the retina, damage to the optic nerve that connects each eye to the brain, and/or from stroke (infarcts in the brain). Temporary or permanent blindness can be caused by poisons or medications.

People who are blind from degradation or damage to the visual cortex, but still have functional eyes, are actually capable of some level of vision and reaction to visual stimuli but not a conscious perception; this is known as blindsight. People with blindsight are usually not aware that they are reacting to visual sources, and instead just unconsciously adapt their behaviour to the stimulus.

On February 14, 2013 researchers developed a neural implant that gives rats the ability to sense infrared light which for the first time provides living creatures with new abilities, instead of simply replacing or augmenting existing abilities.

Hearing

Hearing or audition (adjectival form: auditory) is the sense of sound perception. Hearing is all about vibration. Mechanoreceptors turn motion into electrical nerve pulses, which are located in the inner ear. Since sound is vibration, propagating through a medium such as air, the detection of these vibrations, that is the sense of the hearing, is a mechanical sense because these vibrations are mechanically conducted from the eardrum through a series of tiny bones to hair-like fibers in the inner ear, which detect mechanical motion of the fibers within a range of about 20 to 20,000 hertz, with substantial variation between individuals. Hearing at high frequencies declines with an increase in age. Inability to hear is called deafness or hearing impairment. Sound can also be detected as vibrations conducted through the body by tactition. Lower frequencies that can be heard are detected this way. Some deaf people are able to determine direction and location of vibrations picked up through the feet.

Taste

Taste or gustation (adjectival form: gustatory) is one of the traditional five senses. It refers to the capability to detect the taste of substances such as food, certain minerals, and poisons, etc. The sense of taste is often confused with the "sense" of flavor, which is a combination of taste and smell perception. Flavor depends on odor, texture, and temperature as well as on taste. Humans receive tastes through sensory organs called taste buds, or gustatory calyculi, concentrated on the upper surface of the tongue. There are five basic tastes: sweet, bitter, sour, salty and umami. Other tastes such as calcium and free fatty acids may also be basic tastes but have yet to receive widespread acceptance. The inability to taste is called ageusia.

Smell

Smell or olfaction (adjectival form: olfactory) is the other "chemical" sense. Unlike taste, there are hundreds of olfactory receptors (388 according to one source), each binding to a particular molecular feature. Odor molecules possess a variety of features and, thus, excite specific

receptors more or less strongly. This combination of excitatory signals from different receptors makes up what we perceive as the molecule's smell. In the brain, olfaction is processed by the olfactory system. Olfactory receptor neurons in the nose differ from most other neurons in that they die and regenerate on a regular basis. The inability to smell is called anosmia. Some neurons in the nose are specialized to detect pheromones.

Touch

Touch or somatosensation (adjectival form: somatic), also called tactition (adjectival form: tactile) or mechanoreception, is a perception resulting from activation of neural receptors, generally in the skin including hair follicles, but also in the tongue, throat, and mucosa. A variety of pressure receptors respond to variations in pressure (firm, brushing, sustained, etc.). The touch sense of itching caused by insect bites or allergies involves special itch-specific neurons in the skin and spinal cord. The loss or impairment of the ability to feel anything touched is called tactile anesthesia. Paresthesia is a sensation of tingling, pricking, or numbness of the skin that may result from nerve damage and may be permanent or temporary.

Non-traditional senses

Balance and acceleration

Balance, equilibrioception, or vestibular sense is the sense that allows an organism to sense body movement, direction, and acceleration, and to attain and maintain postural equilibrium and balance. The organ of equilibrioception is the vestibular labyrinthine system found in both of the inner ears. In technical terms, this organ is responsible for two senses of angular momentum acceleration and linear acceleration (which also senses gravity), but they are known together as equilibrioception.

The vestibular nerve conducts information from sensory receptors in three ampulla that sense motion of fluid in three semicircular canals caused by three-dimensional rotation of the head. The vestibular nerve also conducts information from the utricle and the saccule, which contain hair-like sensory receptors that bend under the weight of otoliths (which are small crystals of calcium carbonate) that provide the inertia needed to detect head rotation, linear acceleration, and the direction of gravitational force.

Temperature

Thermoception is the sense of heat and the absence of heat (cold) by the skin and internal skin passages, or, rather, the heat flux (the rate of heat flow) in these areas. There are specialized

receptors for cold (declining temperature) and for heat (increasing temperature). The cold receptors play an important part in the animal's sense of smell, telling wind direction. The heat receptors are sensitive to infrared radiation and can occur in specialized organs, for instance in pit vipers. The thermoceptors in the skin are quite different from the homeostatic thermoceptors in the brain (hypothalamus), which provide feedback on internal body temperature.

Proprioception

Proprioception, the kinesthetic sense, provides the parietal cortex of the brain with information on the movement and relative positions of the parts of the body. Neurologists test this sense by telling patients to close their eyes and touch their own nose with the tip of a finger. Assuming proper proprioceptive function, at no time will the person lose awareness of where the hand actually is, even though it is not being detected by any of the other senses. Proprioception and touch are related in subtle ways, and their impairment results in surprising and deep deficits in perception and action.

Pain

Nociception (physiological pain) signals nerve-damage or damage to tissue. The three types of pain receptors are cutaneous (skin), somatic (joints and bones), and visceral (body organs). It was previously believed that pain was simply the overloading of pressure receptors, but research in the first half of the 20th century indicated that pain is a distinct phenomenon that intertwines with all of the other senses, including touch. Pain was once considered an entirely subjective experience, but recent studies show that pain is registered in the anterior cingulate gyrus of the brain. The main function of pain is to attract our attention to dangers and motivate us to avoid them. For example, humans avoid touching a sharp needle, or hot object, or extending an arm beyond a safe limit because it is dangerous, and thus hurts. Without pain, people could do many dangerous things without being aware of the dangers.

Other internal senses

An internal sense also known as interoception is "any sense that is normally stimulated from within the body". These involve numerous sensory receptors in internal organs, such as stretch receptors that are neurologically linked to the brain. Interoception is thought to be atypical in clinical conditions such as alexithymia. Some examples of specific receptors are:

Hunger is a sensation that is governed by a set of brain structures (e.g., the hypothalamus) that are responsible for energy homeostasis.
Pulmonary stretch receptors are found in the lungs and control the respiratory rate.

Peripheral chemoreceptors in the brain monitor the carbon dioxide and oxygen levels in the brain to give a feeling of suffocation if carbon dioxide levels get too high.
The chemoreceptor trigger zone is an area of the medulla in the brain that receives inputs from blood-borne drugs or hormones, and communicates with the vomiting center.
Chemoreceptors in the circulatory system also measure salt levels and prompt thirst if they get too high; they can also respond to high blood sugar levels in diabetics.
Cutaneous receptors in the skin not only respond to touch, pressure, temperature and vibration, but also respond to vasodilation in the skin such as blushing.
Stretch receptors in the gastrointestinal tract sense gas distension that may result in colic pain.
Stimulation of sensory receptors in the esophagus result in sensations felt in the throat when swallowing, vomiting, or during acid reflux.
Sensory receptors in pharynx mucosa, similar to touch receptors in the skin, sense foreign objects such as food that may result in a gag reflex and corresponding gagging sensation.
Stimulation of sensory receptors in the urinary bladder and rectum may result in sensations of fullness.
Stimulation of stretch sensors that sense dilation of various blood vessels may result in pain, for example headache caused by vasodilation of brain arteries.
Cardioception refers to the perception of the activity of the heart.

Perception not based on a specific sensory organ

Time

Chronoception refers to how the passage of time is perceived and experienced. Although the sense of time is not associated with a specific sensory system, the work of psychologists and neuroscientists indicates that human brains do have a system governing the perception of time, composed of a highly distributed system involving the cerebral cortex, cerebellum and basal ganglia. One particular component, the suprachiasmatic nucleus, is responsible for the circadian (or daily) rhythm, while other cell clusters appear to be capable of shorter-range (ultradian) timekeeping.

One or more dopaminergic pathways in the central nervous system appear to have a strong modulatory influence on mental chronometry, particularly interval timing.

Agency

The sense of agency refers to the subjective feeling of having chosen a particular action. Some conditions, such as schizophrenia, can lead to a loss of this sense, causing a person to feel like a machine or even leading to delusions of being controlled from some outside source. The opposite extreme occurs too, with some people experiencing everything in their environment as if they had

decided that it would happen.

Even in non-pathological cases, there is a measurable difference between making a decision and the feeling of agency. Through methods such as the Libet experiment, a gap of half a second or more can be detected from the time when there are detectable neurological signs of a decision having been made to the time when the subject actually becomes conscious of the decision.

There are also experiments in which an illusion of agency is induced in psychologically normal subjects. In Wegner and Wheatley 1999, subjects were given instructions to move a mouse around a scene and point to an image about once every thirty seconds. However, a second person -- acting as a test subject but actually a confederate -- had their hand on the mouse at the same time, and controlled some of the movement. Experimenters were able to arrange for subjects to perceive certain "forced stops" as if they were their own choice.

Familiarity

Recognition memory is sometimes divided into two functions by neuroscientists: familiarity and recollection. A strong sense of familiarity can occur without any recollection, for example in cases of deja vu. The temporal lobe, in particular the perirhinal cortex, responds differently to stimuli which feel novel than to things which feel familiar. Firing rates in the perirhinal cortex are connected with the sense of familiarity in humans and other mammals. In tests, stimulating this area at 10-15 Hz caused animals to treat even novel images as familiar, and stimulation at 30-40 Hz caused novel images to be partially treated as familiar. Specifically, stimulation at 30-40 Hz led to animals looking at a familiar image for longer periods, as they would for an unfamiliar one; but it did not lead to the same exploration behavior normally associated with novelty. Recent studies on lesions in the area concluded that rats with a damaged perirhinal cortex were still more interested in exploring when novel objects were present, but seemed unable to tell novel objects from familiar ones -- they examined both equally. Thus, other brain regions are involved with noticing unfamiliarity, but the perirhinal cortex is needed to associate the feeling with a specific source.

Non-human senses

Analogous to human senses

Other living organisms have receptors to sense the world around them, including many of the senses listed above for humans. However, the mechanisms and capabilities vary widely.

Smell

Most non-human mammals have a much keener sense of smell than humans, although the

mechanism is similar. An example of smell in non-mammals is that of sharks, which combine their keen sense of smell with timing to determine the direction of a smell. They follow the nostril that first detected the smell. Insects have olfactory receptors on their antennae.

Vomeronasal organ

Many animals (salamanders, reptiles, mammals) have a vomeronasal organ that is connected with the mouth cavity. In mammals it is mainly used to detect pheromones of marked territory, trails, and sexual state. Reptiles like snakes and monitor lizards make extensive use of it as a smelling organ by transferring scent molecules to the vomeronasal organ with the tips of the forked tongue. In reptiles the vomeronasal organ is commonly referred to as Jacobsons organ. In mammals, it is often associated with a special behavior called flehmen characterized by uplifting of the lips. The organ is vestigial in humans, because associated neurons have not been found that give any sensory input in humans.

Taste

Flies and butterflies have taste organs on their feet, allowing them to taste anything they land on. Catfish have taste organs across their entire bodies, and can taste anything they touch, including chemicals in the water.

Vision

Cats have the ability to see in low light, which is due to muscles surrounding their irides-which contract and expand their pupils-as well as to the tapetum lucidum, a reflective membrane that optimizes the image. Pit vipers, pythons and some boas have organs that allow them to detect infrared light, such that these snakes are able to sense the body heat of their prey. The common vampire bat may also have an infrared sensor on its nose. It has been found that birds and some other animals are tetrachromats and have the ability to see in the ultraviolet down to 300 nanometers. Bees and dragonflies are also able to see in the ultraviolet. Mantis shrimps can perceive both polarized light and multispectral images and have twelve distinct kinds of color receptors, unlike humans which have three kinds and most mammals which have two kinds.

Balance

Many invertebrates have a statocyst, which is a sensor for acceleration and orientation that works very differently from the mammalian's semi-circular canals.

Sensing gravity

Some plants (such as mustard) have genes that are necessary for the plant to sense the direction of gravity. If these genes are disabled by a mutation, a plant cannot grow upright.

Not analogous to human senses

In addition, some animals have senses that humans do not, including the following:

Echolocation

Certain animals, including bats and cetaceans, have the ability to determine orientation to other objects through interpretation of reflected sound (like sonar). They most often use this to navigate through poor lighting conditions or to identify and track prey. There is currently an uncertainty whether this is simply an extremely developed post-sensory interpretation of auditory perceptions or it actually constitutes a separate sense. Resolution of the issue will require brain scans of animals while they actually perform echolocation, a task that has proven difficult in practice.

Blind people report they are able to navigate and in some cases identify an object by interpreting reflected sounds (especially their own footsteps), a phenomenon known as human echolocation.

Electroreception

Electroreception (or electroception) is the ability to detect electric fields. Several species of fish, sharks, and rays have the capacity to sense changes in electric fields in their immediate vicinity. For cartilaginous fish this occurs through a specialized organ called the Ampullae of Lorenzini. Some fish passively sense changing nearby electric fields; some generate their own weak electric fields, and sense the pattern of field potentials over their body surface; and some use these electric field generating and sensing capacities for social communication. The mechanisms by which electroceptive fish construct a spatial representation from very small differences in field potentials involve comparisons of spike latencies from different parts of the fish's body.

The only orders of mammals that are known to demonstrate electroception are the dolphin and monotreme orders. Among these mammals, the platypus has the most acute sense of electroception.

A dolphin can detect electric fields in water using electroreceptors in vibrissal crypts arrayed in pairs on its snout and which evolved from whisker motion sensors. These electroreceptors can detect electric fields as weak as 4.6 microvolts per centimeter, such as those generated by contracting muscles and pumping gills of potential prey. This permits the dolphin to locate prey from the seafloor where sediment limits visibility and echolocation.

Body modification enthusiasts have experimented with magnetic implants to attempt to replicate this sense. However, in general humans (and it is presumed other mammals) can detect electric fields only indirectly by detecting the effect they have on hairs. An electrically charged balloon, for instance, will exert a force on human arm hairs, which can be felt through tactition and identified as coming from a static charge (and not from wind or the like). This is not electroreception, as it is a

post-sensory cognitive action.

Magnetoception

Magnetoception (or magnetoreception) is the ability to detect the direction one is facing based on the Earth's magnetic field. Directional awareness is most commonly observed in birds, which rely on their magnetic sense to navigate during migration. It has also been observed in insects such as bees. Cattle make use of magnetoception to align themselves in a north-south direction. Magnetotactic bacteria build miniature magnets inside themselves and use them to determine their orientation relative to the Earth's magnetic field.

Hygroreception

Hygroreception is the ability to detect changes in the moisture content of the environment.

Infrared sensing

The ability to sense infrared thermal radiation evolved independently in various families of snakes. Essentially, it allows these reptiles to "see" radiant heat at wavelengths between 5 and 30 μm to a degree of accuracy such that a blind rattlesnake can target vulnerable body parts of the prey at which it strikes. It was previously thought that the organs evolved primarily as prey detectors, but it is now believed that it may also be used in thermoregulatory decision making. The facial pit underwent parallel evolution in pitvipers and some boas and pythons, having evolved once in pitvipers and multiple times in boas and pythons. The electrophysiology of the structure is similar between the two lineages, but they differ in gross structural anatomy. Most superficially, pitvipers possess one large pit organ on either side of the head, between the eye and the nostril (Loreal pit), while boas and pythons have three or more comparatively smaller pits lining the upper and sometimes the lower lip, in or between the scales. Those of the pitvipers are the more advanced, having a suspended sensory membrane as opposed to a simple pit structure. Within the family Viperidae, the pit organ is seen only in the subfamily Crotalinae: the pitvipers. The organ is used extensively to detect and target endothermic prey such as rodents and birds, and it was previously assumed that the organ evolved specifically for that purpose. However, recent evidence shows that the pit organ may also be used for thermoregulation. According to Krochmal et al., pitvipers can use their pits for thermoregulatory decision making while true vipers (vipers who do not contain heat-sensing pits) cannot.

In spite of its detection of IR light, the pits' IR detection mechanism is not similar to photoreceptors - while photoreceptors detect light via photochemical reactions, the protein in the pits of snakes is in fact a temperature sensitive ion channel. It senses infrared signals through a mechanism involving warming of the pit organ, rather than chemical reaction to light. This is consistent with the thin pit membrane, which allows incoming IR radiation to quickly and precisely warm a given ion

channel and trigger a nerve impulse, as well as vascularize the pit membrane in order to rapidly cool the ion channel back to its original "resting" or "inactive" temperature.

Other

Pressure detection uses the organ of Weber, a system consisting of three appendages of vertebrae transferring changes in shape of the gas bladder to the middle ear. It can be used to regulate the buoyancy of the fish. Fish like the weather fish and other loaches are also known to respond to low pressure areas but they lack a swim bladder.

Current detection is a detection system of water currents, consisting mostly of vortices, found in the lateral line of fish and aquatic forms of amphibians. The lateral line is also sensitive to low-frequency vibrations. The mechanoreceptors are hair cells, the same mechanoreceptors for vestibular sense and hearing. It is used primarily for navigation, hunting, and schooling. The receptors of the electrical sense are modified hair cells of the lateral line system.

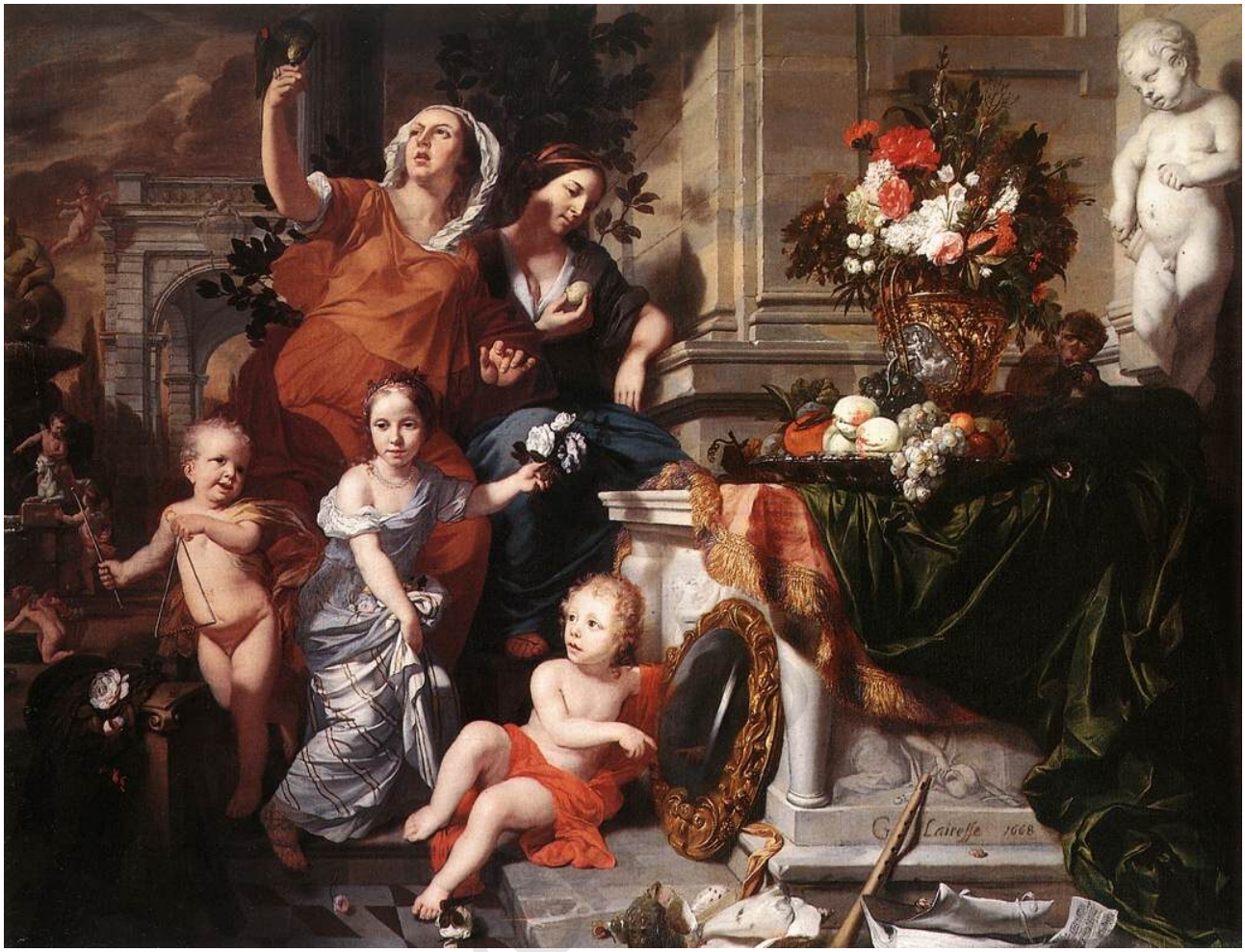
Polarized light direction/detection is used by bees to orient themselves, especially on cloudy days. Cuttlefish can also perceive the polarization of light. Most sighted humans can in fact learn to roughly detect large areas of polarization by an effect called Haidinger's brush, however this is considered an entoptic phenomenon rather than a separate sense.

Slit sensillae of spiders detect mechanical strain in the exoskeleton, providing information on force and vibrations.

Plant senses

By using a variety of sense receptors, plants sense light, gravity, temperature, humidity, chemical substances, chemical gradients, reorientation, magnetic fields, infections, tissue damage and mechanical pressure. The absence of a nervous system notwithstanding, plants interpret and respond to these stimuli by a variety of hormonal and cell-to-cell communication pathways that result in movement, morphological changes and physiological state alterations at the organism level, that is, result in plant behavior. Such physiological and cognitive functions are generally not believed to give rise to mental phenomena or qualia, however, as these are typically considered the product of nervous system activity. The emergence of mental phenomena from the activity of systems functionally or computationally analogous to that of nervous systems is, however, a hypothetical possibility explored by some schools of thought in the philosophy of mind field, such as functionalism and computationalism.

Culture



Lairesse's Allegory of the Five Senses

In the time of William Shakespeare, there were commonly reckoned to be five wits or five senses. At that time, the words "sense" and "wit" were synonyms, so the senses were known as the five outward wits. This traditional concept of five senses is common today.

The traditional five senses are enumerated as the "five material faculties" (pañcanna? indriy?na? avakanti) in Hindu literature. They appear in allegorical representation as early as in the Katha Upanishad (roughly 6th century BC), as five horses drawing the "chariot" of the body, guided by the mind as "chariot driver".

Depictions of the five traditional senses as allegory became a popular subject for seventeenth-century artists, especially among Dutch and Flemish Baroque painters. A typical example is Gérard de Lairesse's Allegory of the Five Senses (1668), in which each of the figures in the main group alludes to a sense: Sight is the reclining boy with a convex mirror, hearing is the cupid-like boy with a triangle, smell is represented by the girl with flowers, taste is represented by the woman with the

fruit, and touch is represented by the woman holding the bird.

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