The Physiology of the Senses
Lecture 7 – Touch, Pain, Taste and Smell

http://www.tutis.ca/Senses/

Contents

Objectives

1. List the sequence of events that converts pressure on the skin into neuronal activity.

2. Evaluate unique qualities that are detected by each receptor type.

3. Contrast the connectivity of the Internet and the touch receptors to the cortex.

4. Describe 3 ways in which the activity from the skin is transformed in the dorsal column nuclei.

5. Specify the distinguishing feature in each of the 4 maps of the body in the somatosensory cortex.

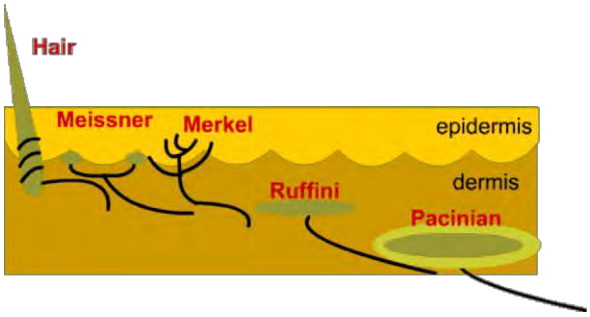
6. Compare the processing of taste and smell.

The sense of touch is underappreciated.

As in vision, we can use touch to distinguish edges, feel textures, read letters, and recognize objects as complex as faces.

And, as in vision, we can do this with very few receptor types.

There are five receptors sensitive to touch. The first to be considered is the Pacinian receptor.



In addition to these skin receptors there are those that sense pain and temperature.

How touch is electrically encoded.

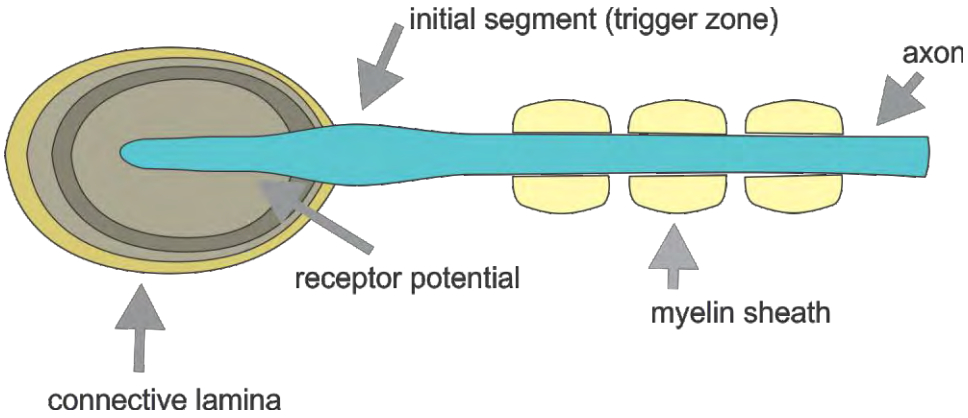
Let's use the Pacinian receptor as an example.

a) How is mechanical energy transformed into electrical activity?

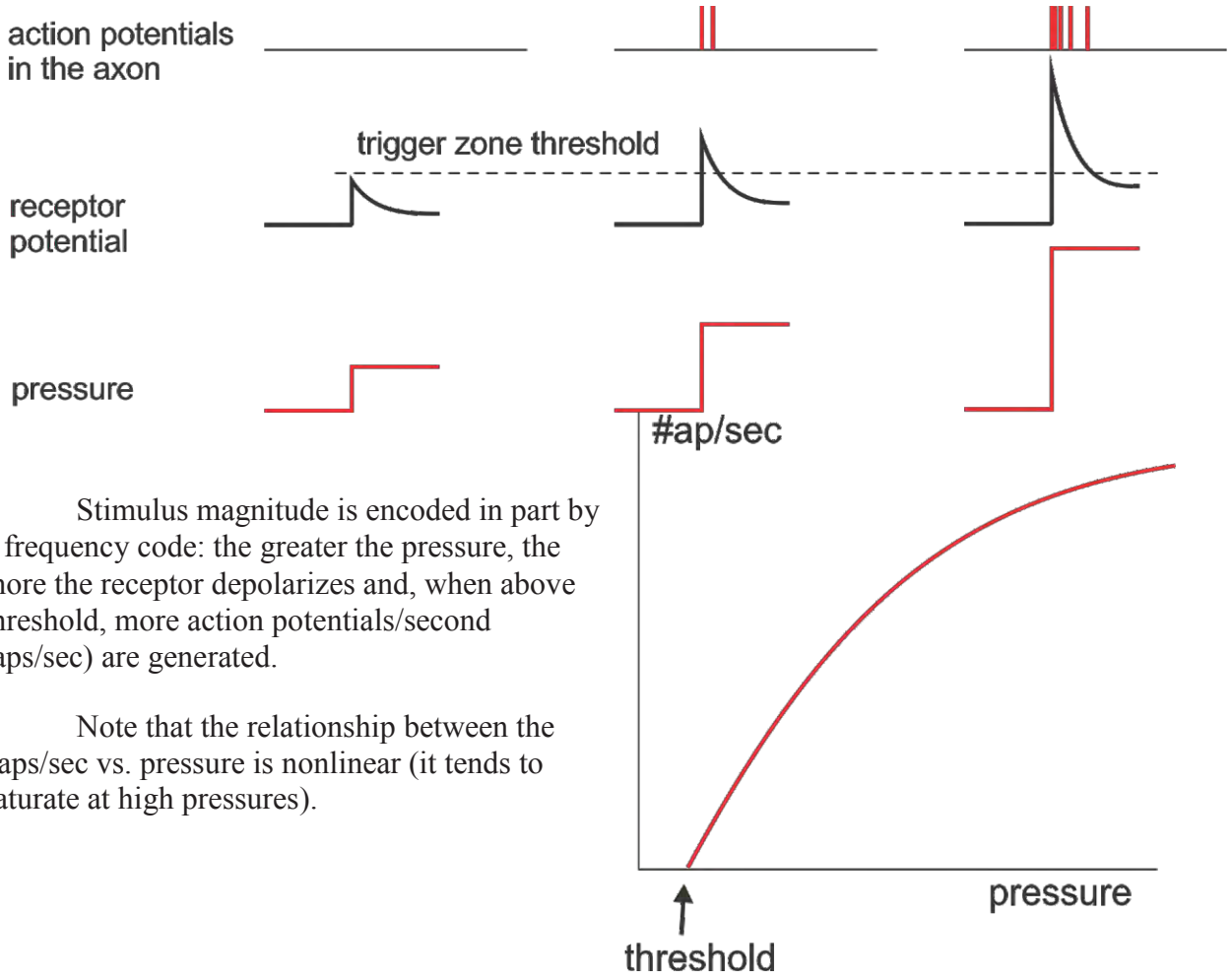
Step 1: Mechanical stimulus (e.g. pressure) deforms the receptor's onion like membrane.

Step 2: Channels open and Na+ flows through membrane. The inside of the receptor depolarizes (voltage becomes more +).

Step 3: If the graded potential summed at the initial segment is above threshold, action potentials are generated and propagated down the axon. Most touch afferents have myelinated axons in which action potentials hop from gap to gap, thus speeding up conduction.



b) How is the magnitude of the stimulus encoded?



Stimulus magnitude is encoded in part by a frequency code: the greater the pressure, the more the receptor depolarizes and, when above threshold, more action potentials/second (aps/sec) are generated.

Note that the relationship between the #aps/sec vs. pressure is nonlinear (it tends to saturate at high pressures).

c) The response to the stimulus adapts. How does this occur and why?

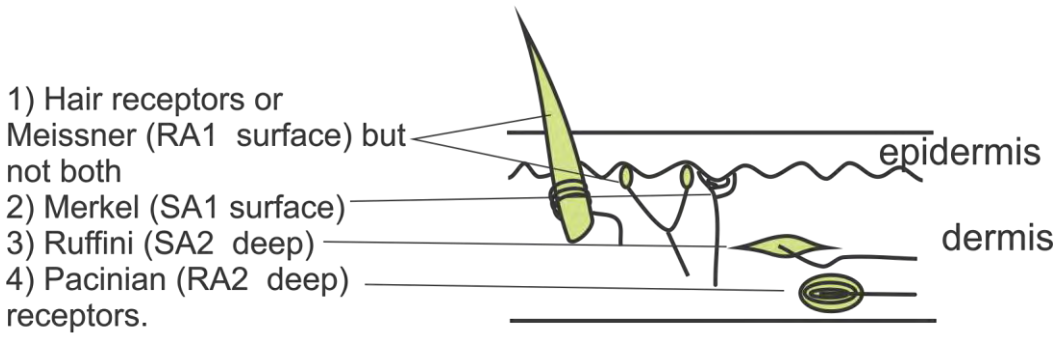
How: The #aps/sec adapts because the receptor potential adapts. Receptor potential adapts in part because the onion-like laminae slip back, closing the channels.

Why: Adaptation enhances the detection of changes in pressure. Constant pressure, such as that exerted by your clothes, is not as readily detected.

Other receptors for touch?

In **any one** part of your skin you will find 4 receptors:
1) Hair receptors (back of hand) or Meissner (palm of hand)
2) Merkel
3) Ruffini
4) Pacinian

a) Which receptors are rapidly adapting (RA) and which are slowly adapting (SA)?



Thus both surface and deep layers of the skin contain both RA and SA receptors. We will use the label 1 for surface and 2 for deep.

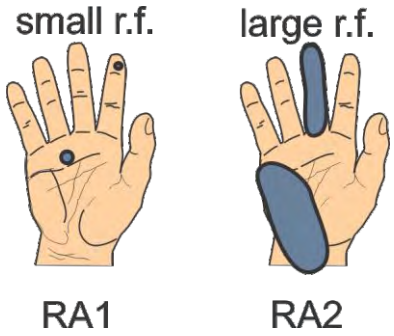
b) Which receptor has the largest receptive field size?

Receptive field size increases with depth in the skin. Pacinian corpuscles have the largest receptive fields.

Recall that three types of cones allow us to distinguish between 2,000,000 colors.

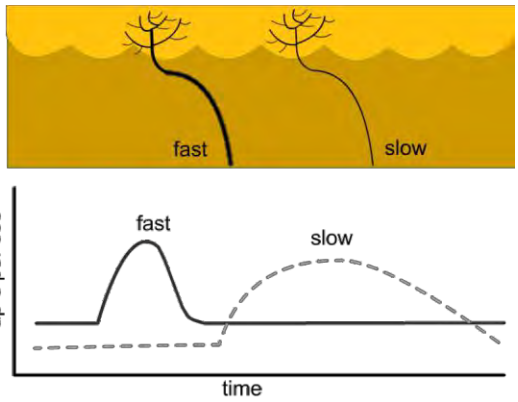
Likewise we need a variety of touch receptors to code a large variety of touch stimuli (possibly in the millions).

Without 5 different types of touch receptors
touch would be like being color blind
feeling in greys rather than vivid colors.



Pain and Temperature receptors.

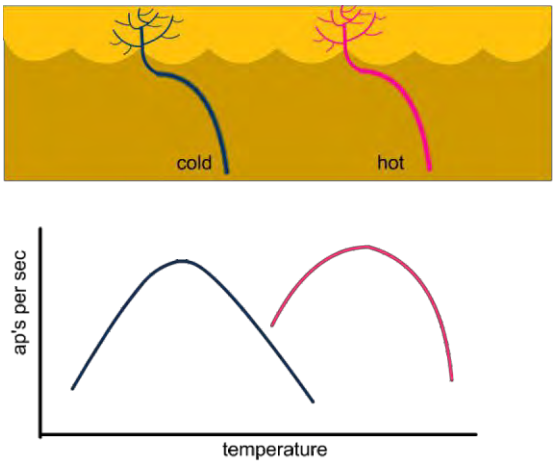
In addition there are 2 types of free nerve endings that are sensitive to painful stimuli.



1) A fast conducting myelinated fiber that signals an early, localized, intense pain. This also mediates the sensation of itching.

2) A slow conducting unmyelinated fiber that signals a later, poorly localized, long-lasting, dull pain.

As well there are 2 types of free nerve endings that are sensitive to temperature stimuli.

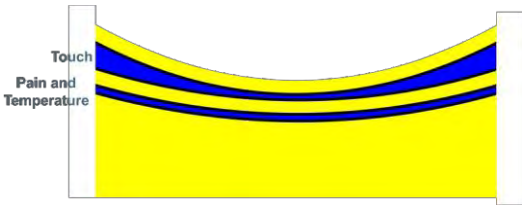


1) a fast conducting myelinated fiber that fires most for hot but not burning stimuli.

2) a fast conducting myelinated fiber that fires most for cold but not freezing stimuli.

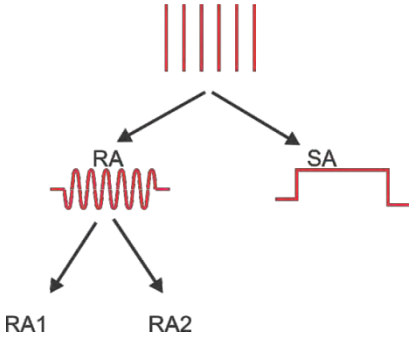
Burning or freezing stimuli activate pain receptors.

Touch afferent fibers have large diameters. Pressure first blocks the conduction of action potentials in large fibers. Your limb "falls asleep". But the sense of temperature and pain, which is mediated by small diameter fibers, is often preserved.



Labeled Lines

In the brain, the same response often signals very different sensations. How do we know what the stimulus is?



Suppose that action potentials at the top are the response of an afferent that sends a signal to the brain. What is the stimulus?

It could be a RA afferent activated by vibration.

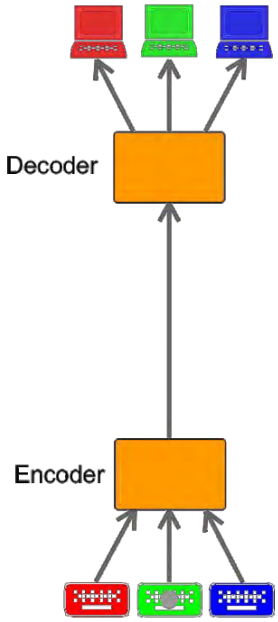
It could also be a SA afferent activated by a steady pressure.

If it is a surface afferent, then it could be something small.

If the afferent comes from deep tissue, then it could be something big.

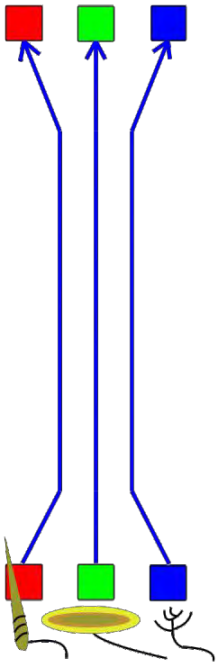
For the brain to recognize that a stimulus is a vibration that is coming from the surface of the skin, the brain must label the afferent type that has been activated as a RA1 afferent.

A similar problem occurs on the Internet. When you use the Internet, your message, as well as those of many others, travels down a shared common line. To separate your message from that of others, each packet of information is given a tag or label. At the end of the line, a decoder separates your packet from that of others.



The sense of touch solves this same problem in a different way. It gives each type of touch sensor its own private line. This is called its labeled line. Because of this, there is no reason for encoding and decoding each packet of information.

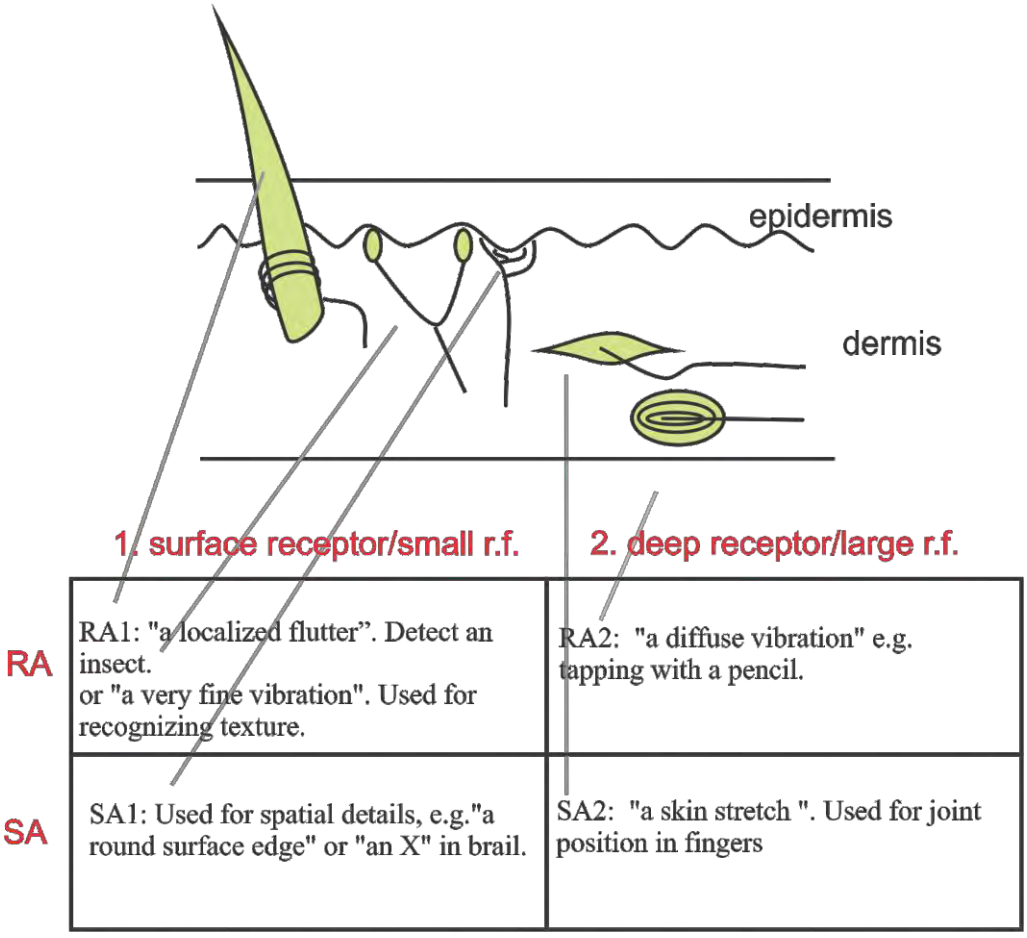
But you do need lots of lines in your spinal cord



Each afferent input to the CNS is given a labeled line (e.g. RA1). We perceive a stimulus as a vibration from the surface of the skin because of the label that is attached, by experience, to the activated fibre. A definition of a labeled line is: “a label attached to each afferent fibre as to what sub-modality it is (e.g. RA1 or RA2)”.

This is similar to place coding in the auditory system. We know the frequency of a sound not by how fast a fibre is firing but by which fiber it is, i.e. from where on the basilar membrane it originates. Labeled lines illustrate an important principle as to how the brain codes information for touch and for the other senses. We have seen that information here is encoded in two ways: 1) the firing frequency of a particular neuron and 2) which neuron this is. A good example of this same principle is the representation of numbers, say the number 88. Both 8's are the same number, but each eight means something different.

Summary



Experiment on texture detection

Take two sheets of sandpaper of slightly different grades

By rubbing your fingertips over the surface you can easily distinguish which is rougher. The rubbing is necessary to activate the RA1 receptor.

Rubbing produces vibrations as grains repeatedly pass over each receptor. RA1 receptors have small receptive fields and thus fine spatial discrimination.

Now place your fingertips steadily on each sheet. Note that it hard to say which is rougher.

This is because the RA1 receptors rapidly adapt to steady pressure.

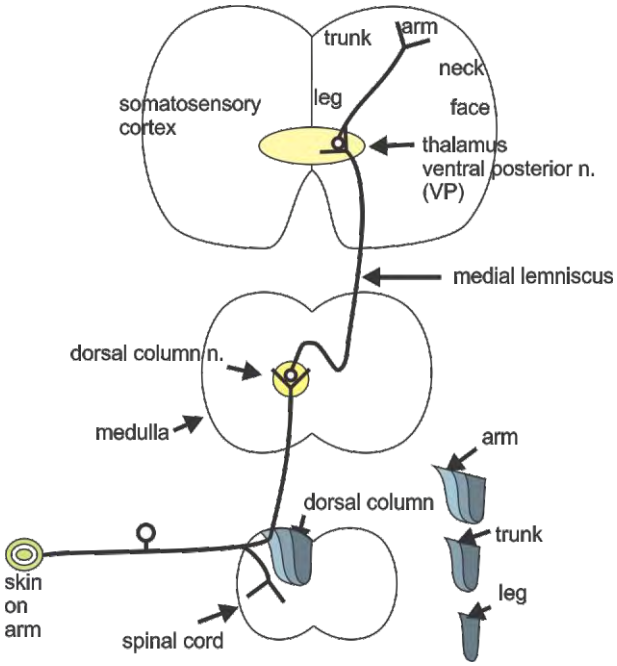
If you do not have sand paper, rub your fingertips over a table top. Try to find a small scratch. Compare this sensation to that produced by just placing your finger tips on the table.

The pathway to the primary sensory cortex.

The pathway for transmission of touch is the dorsal column medial lemniscal system.

This is the path for the labeled line to the cortex, e.g., the path from an RA1 afferent, located on the arm, to the first stage in the cortex.

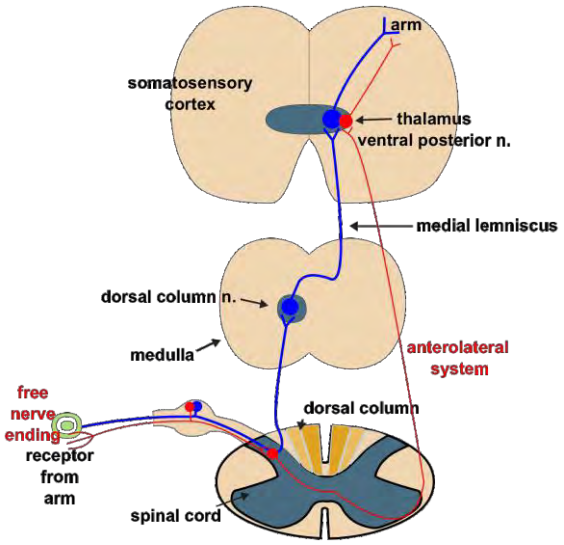
In the spinal cord, the dorsal column is the first stage in the development of a somatotopic organization. In the lower segments, only afferents from the leg are found. As one moves up the spinal cord, new afferents enter laterally. Thus in high segments of the spinal cord one finds that leg afferents are medial, arm afferents lateral, and trunk afferents in the middle.



The pathway for transmission of pain and temperature information to the primary sensory cortex is the anterolateral system.

The anterolateral system first makes a synapse in the spinal cord and then crosses at the same segment.

It ends in the same region of cortex as touch.



The 3 functions of the dorsal column nuclei (DCN).

Are they predominantly relay nuclei, or do they transform incoming information?

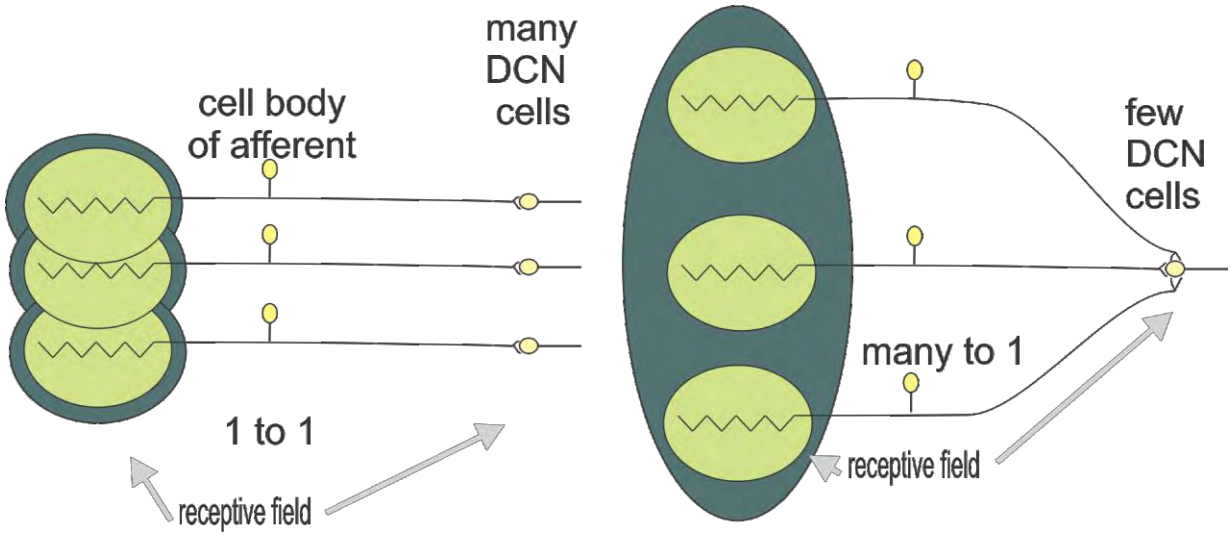
Contrary to popular anatomical terminology, there is no such thing as a relay nucleus. Neurons form synapses in a nucleus in order to transform or change the incoming signal. There are three distinct transformations that take place in the DCN.

Function 1 of the DCN: Convergence

The skin on your back has a **low** afferent density. **Many** afferents converge onto a single DCN neuron. Because of these **two factors** only a **few DCN neurons** are required to represent a given area of skin on the back. The consequence is large receptive fields and a low tactile discrimination (like the peripheral retina).

The skin on your fingertip has a **high** afferent density. **Few** afferents converge onto a single DCN neuron. Because of these two factors **many DCN** neurons are required to represent a given area of skin. The consequence is small receptive fields and a high tactile discrimination (like the fovea).This is why you use your finger tip to read Braille (100 times more resolution than your back).

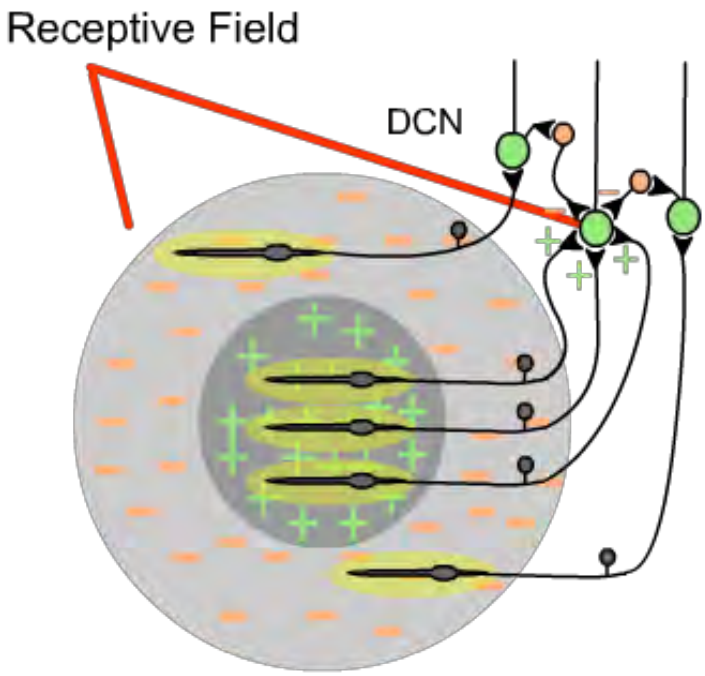
The representation of the body begins to become distorted; some parts becoming large others small.



Experiment: Take a paper clip and bend it into a loop (like a U). Start with the tips of the U far apart. Touch your skin with both tips. Can you tell whether there are two tips or just one? Move the tips closer together and try again. The distance at which the tips first feel like one is your two point discrimination. Compare this for different parts of body, e.g., fingertips, arm, back, lips, tongue.

Function 2 of the DCN: Inhibitory surround

As with retinal ganglion cells, a stimulus in the center will activate a DCN neuron while a stimulus in the surround, through inhibitory feedback, will inhibit the same DCN neuron.

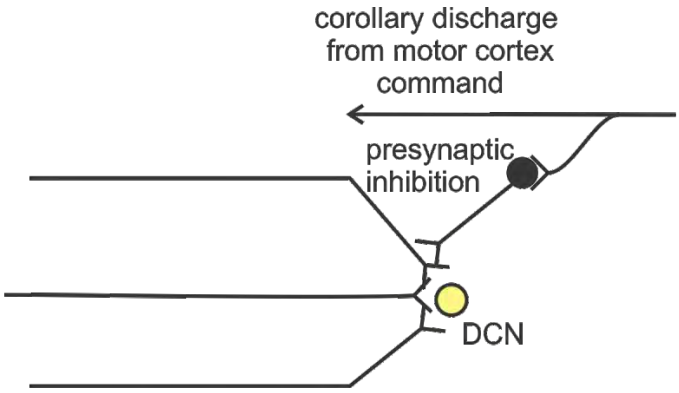


This inhibitory surround 1st occurs, not the skin, but in the DCN. In contrast to the skin, the retina, being part of the brain, can be organized into a complex neural network while the skin cannot.

The function is the same as in vision: it accentuates the activity associated with the edge of an object. In this manner it also enhances two-point discrimination.

Function 3 of the DCN: Cortical gating

When you initiate a movement, a copy of the command (corollary discharge) inhibits the touch signals ascending through the DCN.



The purpose of this inhibition is to block some of the touch signals from the skin arising from the movement itself.

This inhibition is presynaptic. Why?

Post synaptic inhibition directly on the DCN neuron would turn off all three afferents. Presynaptic inhibition can be directed to just one.

In summary three transformation are performed in the DCN

1) Differential convergence leads to a distorted somatotopic representation of the body. Many neurons represent tactile important body parts such as the finger tips and the lips.

2) Lateral inhibition accentuates the changes in touch stimuli.

3) Corollary discharge selectively gates input based on motor output.

Three features of the somatosensory cortex.

Feature 1: Somatotopic organization.

Primary somatosensory cortex (S1) is somatotopically organized with the body surface laid down sequentially on the postcentral gyrus.

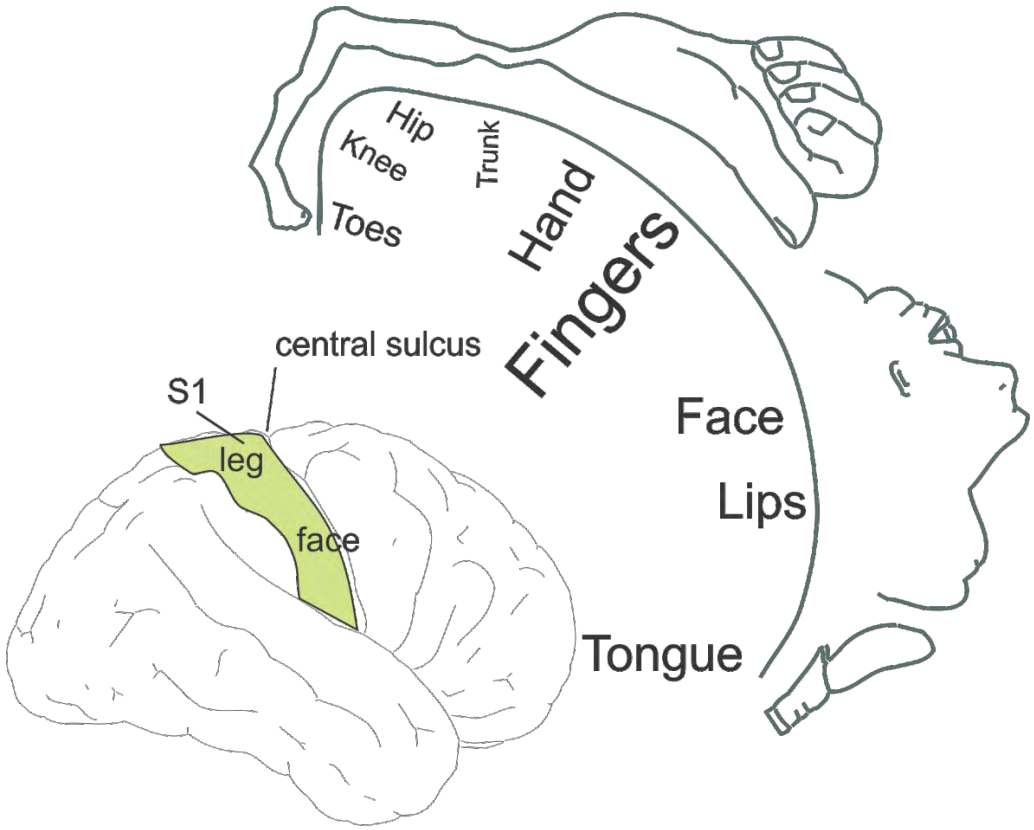
This body map is distorted with the lips, tongue and fingertips having a large representation. This distortion reflects that of the DCN.

The skin of the back has a small representation because of the high convergence (and large receptive fields) in DCN neurons.

Phantom Limbs

Patient X had an arm amputated up to the shoulder. About a year later the patient complained of a phantom sensation of his hand coming from his cheek.

The face area is adjacent to the arm area in somatosensory cortex. Because the arm area no longer receives input, it is gradually taken over by the face area. As it does so, it sometimes surrounds the arm area, temporarily leaving an island. This demonstrates that the somatotopic organization of this area retains a great deal of plasticity even in adulthood.



Feature 2: Multiple maps

S1 is subdivided into 4 parallel strips: areas 3a, 3b, 1, and 2. Thus the homunculus is repeated 4 times. Areas 3b, 1 and 2 code touch. Area 3a codes the signals from muscles and joints; afferents that signal limb position and movement (the subject of the next lecture). Note that the hand representation is mirrored in areas 3b and 1 as is that of the rest of the body. This is similar to the mirroring of the retinotopic representation in V1 and V2.

Each area extracts different features.

Area 1 receives input from RA afferents from the skin surface. This area is important in recognizing texture.

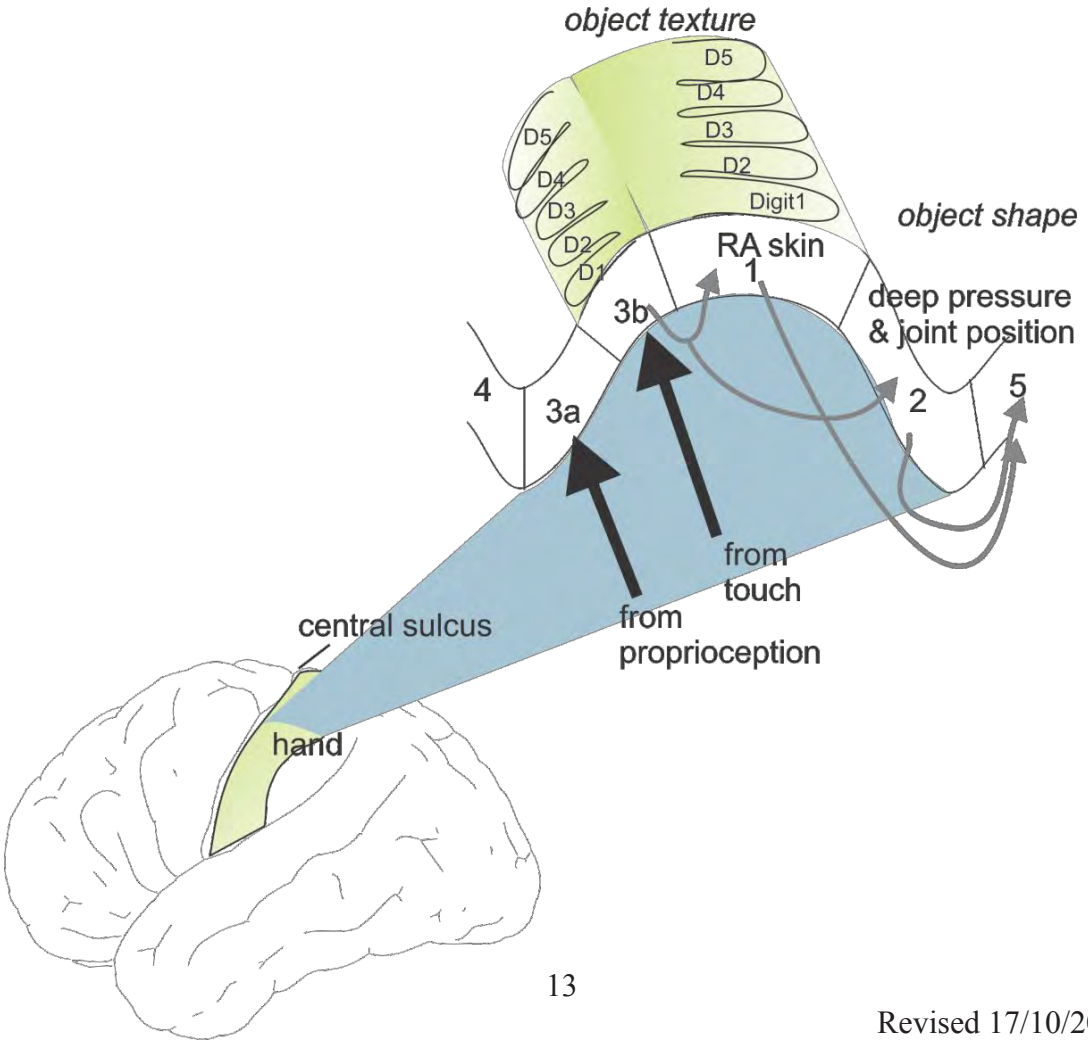
Area 2 receives input from SA afferents deep in the skin and is used to estimate joint position. Joint position is important in recognizing the size and shape of objects.

As one moves to areas 1 and 2, the cells' receptive field characteristics become more complex.

Area 3b cells have small simple circular surround receptive fields.

Area 1 cells have larger receptive fields that can encompass more than one finger and are orientation and movement direction selective.

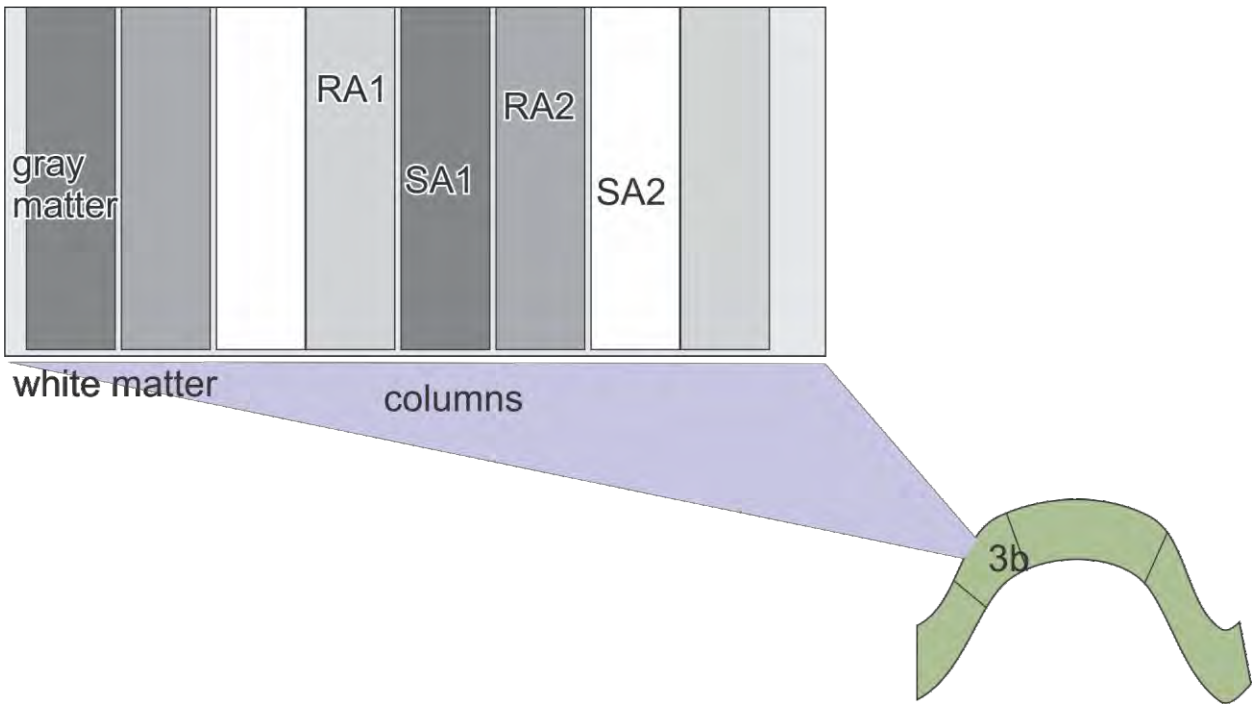
Somatosensory information is then sent to area 5 in the parietal association cortex where stereognosis takes place: the 3D identification of an object through touch.



Feature 3: Columns

If one looks more closely at area 3b, one finds modality specific columns. Each column receives input from one afferent type.

This separation of afferent types into columns is what produces labeled lines. A light vibration will excite the cells of one column type and not others. Activation of this column, and not another, is associated with a light vibration.



Different column types predominate in different areas.

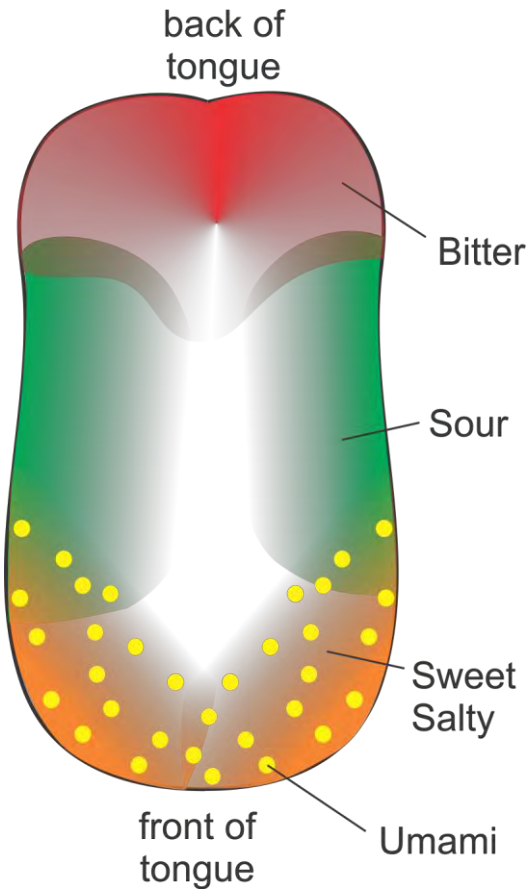
For example in area 1 most columns would receive RA1 afferents. This allows this area to specialize in distinguishing texture.

In area 2, columns receiving joint afferents or deep pressure would be important in determining the shape of objects (you need to know the configuration of your fingers in order to determine the shape of an object held by your hand).

Taste

The 5 basic tastes

The tongue is as sensitive to touch, temperature, and pain as is the thumb. In addition, the tongue performs a chemical analysis of substances dissolved in the saliva. It senses 5 basic tastes**: bitter, sour, salty, sweet and umami**.



Each taste can be sensed everywhere on the tongue but different areas show preferences. Note that the middle of the tongue has relatively few taste cells.

Sourness (H+) and saltiness (Na+) act on cell ion channels directly.

Bitterness, sweet and umami tastes are amplified by specific **G protein-coupled receptors** which activate second messenger cascades to depolarize the cell, as in the retina receptors.

Umami receptors are activated by monosodium glutamate and other amino acids and give bacon a savory taste.

Each receptor site is rather specific for a particular molecule like a lock that can only be opened by a specific key. For example, there is one specific site for glucose and other receptor sites for other sweet molecules. The goal of the artificial sweetener industry is to make a molecule that looks like a sugar but has no nutritional value.

The taste bud

On the tongue one finds **taste buds**, a cluster of about 100 taste cells.

Each taste cell is most sensitive to one of the 5 tastes.

Because the tongue is exposed to hazards such as heat, infections and toxins, these taste cells are constantly being replaced. Over a 2 week life span, basal cells become supporting cells which become taste cells

Taste cells need innervation to survive. If the afferent fibers are damaged, taste cell degenerate. Axonal transport along fibers provide some important trophic factor.

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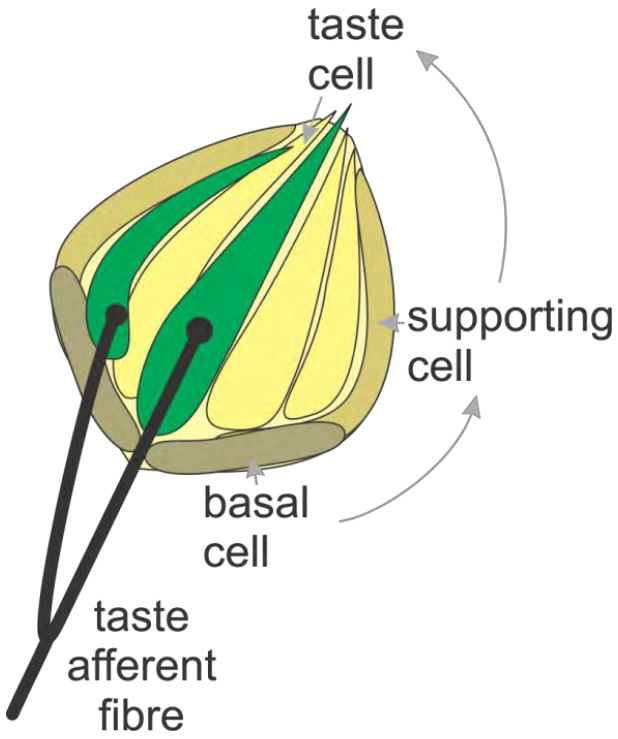
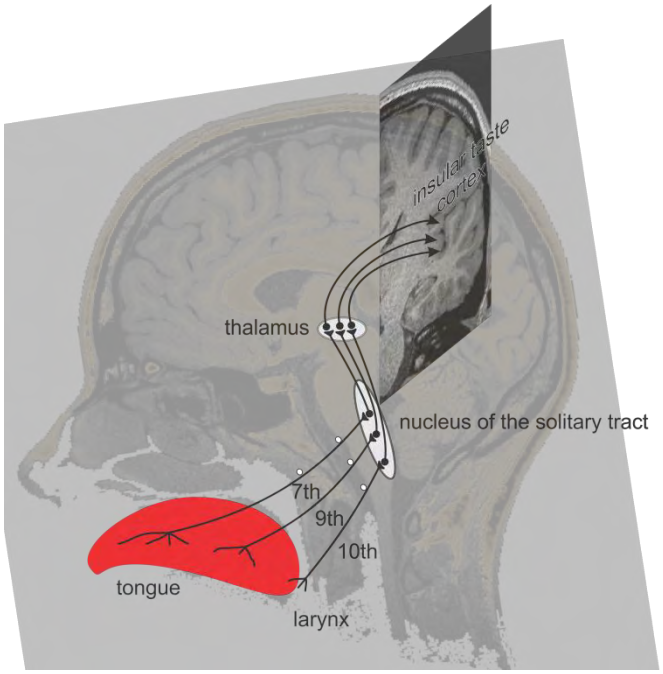


Taste Pathway

Taste afferent project via cranial nerves 7, 9 and, 10 to the **nucleus of the Solitary tract**. From there the signal projects to the ventral posterior medial nucleus of the thalamus and then to several areas of the cortex including the **hypothalamus** which regulates hunger and **insular taste cortex** which has a rough topographic representation of different tastes. The taste signal is projected to the cortex using a labeled line system similar to that of touch.



Revised 17/10/2012

Inborn hunger.

We have an inborn ability to compensate for diet deficiencies by selecting foods that will compensate for these deficiencies. For example, at the beginning of this century there were frequent cases of lead poisoning in young children. It was found that in most cases, they suffered from a calcium dietary deficiency. These children would often attempt to compensate for calcium deficiencies by eating the plaster from the walls. The walls were unfortunately painted with lead based paints.

Genetic taste deficiencies.

Taste deficiencies can be genetic (as are forms of color blindness). Genes code the development of particular receptor sites. Some individuals cannot detect different forms of bitterness because of the absence of a particular receptor on the tongue. For example, some individuals cannot detect a form of bitterness found in cabbage.

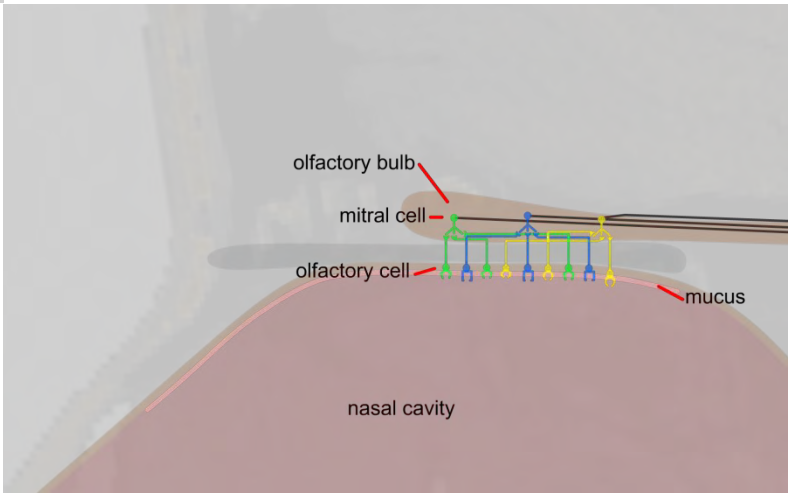
Learnt taste aversion.

If a rat is given a particular food combined with a tasteless poison that results in nausea, the rat will be conditioned to avoid that particular food. If you go to a restaurant and develop food poisoning, you may also develop an aversion to that particular food. The aversion to the food can last a life time. This is not quite the same as classical conditioning because you would not become aversive to the music that was playing at the restaurant or the people you were with.

Smell

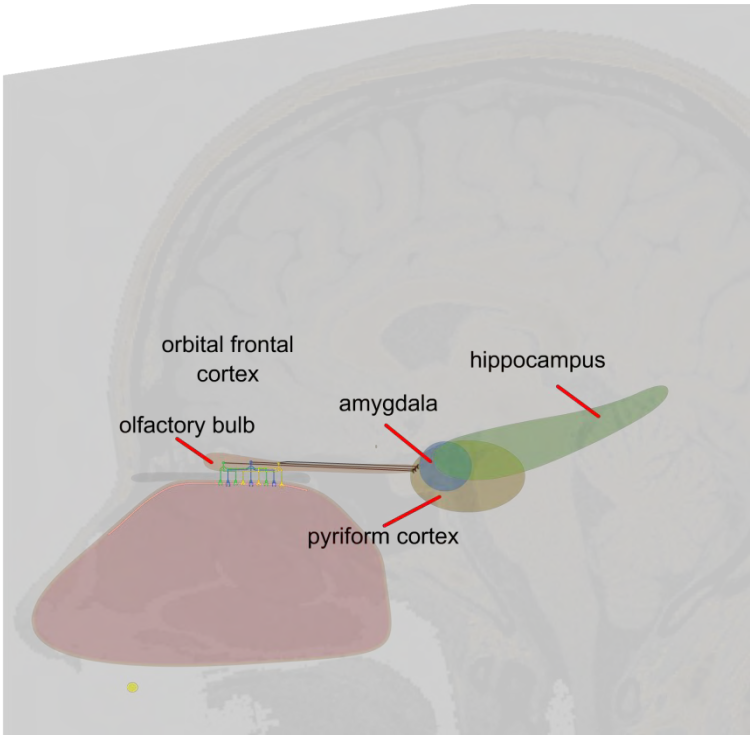
This is the oldest of all the senses. The combination of smell and taste give food their **flavour**. Our sense of smell becomes less sensitive with age and this can lead to a loss of appetite and sometimes weight loss.

Odorants (smells) enter the roof of the nasal cavity, dissolve in the moist mucosal protective layer and are recognized by receptors on the dendrites of olfactory cells. These cells project directly to mitral cells of the olfactory bulb, a part of the cortex.



Olfactory cell axons are **unmyelinated** because the distance to the olfactory bulb is short and speed is not important. It takes time for an odor molecule to diffuse across the mucus film and attach to a particular receptor site.

The mitral cells in turn project to the **pyriform cortex** which codes mixtures of odorants present in a particular smell (e.g. a particular perfume). The pyriform cortex then sends information to the **amygdala** and **hippocampus** and through the **medial dorsal thalamus** to the **orbital frontal cortex**.



Smell is the only sensory system in which there is a projection from the periphery **directly to neocortex**, not through thalamus.

The amygdala activates the **pleasant or unpleasant** aspects of odors, the hippocampus facilitates the storage of **odor memories**, and the orbital frontal cortex combines the sense of taste with smell, producing the multimodal **perception of taste**.

When we sniff, different odor molecules diffuse across the mucus film at different rates. Because of this, the response at any particular time provides little information as to the odor. One needs to remember the **temporal pattern** of the whole sniff. For this reason memory is an important element is recognizing odors. Conversely, odors often elicit strong memories.

Are there basic smell qualities?

No. Unlike taste, smell does not seem to have a small number of basic receptor types.

In smell, there appears to be a very large number of receptor subtypes matching the configuration or other properties of the multitude of odors in our environment. This is somewhat like a child's game in which blocks of particular shapes fit only into particular holes.

In smell, a large gene family programs the creation of hundreds of different subtypes of receptors, each of which is most sensitive to one particular smell but the sensitivity is broad in that each also responds to many other smells. Humans can detect many thousands of different odors.

It is similar to the immune system where receptor molecules can recognize millions of antigens. The amplification of receptor sensitivity involves a molecular cascade mechanism similar to that found in retinal receptors.

The mapping of smell in the olfactory bulb.

Unlike other modalities, the nasal cavity is not mapped somatotopically onto the olfactory bulb. Rather the olfactory bulb is arranged in a topographical map of smells.

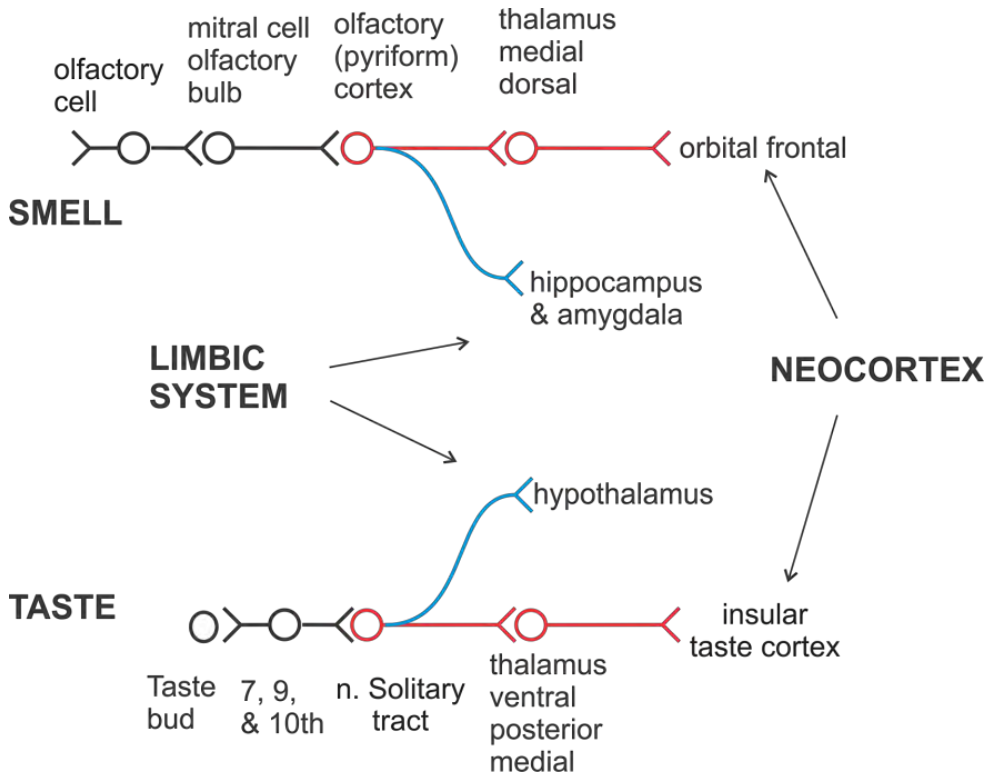
Each mitral cell receives input from the olfactory cell that expresses the same genetic receptor subtype.

When olfactory cells are damaged due to a virus or toxic substance they are replaced within a period of 1 month from basal cells. These then grow into a particular region of the olfactory bulb that is most sensitive to that particular odor.

Summary of taste and smell.

Both olfactory cells and taste cells in the taste bud are constantly replaced.

Both taste and smell project to the newer cerebral cortex, the neocortex for perception, and to the older cortex in the limbic system for automatic responses of hunger, pleasure, etc.



See problems and answers posted on

http://www.tutis.ca/Senses/L7Touch/L7TouchProb.swf