Senses

the five senses...
sight  sound  taste  touch  smell

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# Sensory modalities in human

<table>
<thead>
<tr>
<th>Sensory modality</th>
<th>Form of energy</th>
<th>Receptor organ</th>
<th>Receptor cell</th>
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<tbody>
<tr>
<td>Chemical</td>
<td></td>
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<tr>
<td>common chemical</td>
<td>molecules</td>
<td>various</td>
<td>free nerve endings</td>
</tr>
<tr>
<td>arterial oxygen</td>
<td>$O_2$ tension</td>
<td>carotid body</td>
<td>cells and nerve endings</td>
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<tr>
<td>toxins (vomiting)</td>
<td>molecules</td>
<td>medulla</td>
<td>chemoreceptor cells</td>
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<tr>
<td>osmotic pressure</td>
<td>osmotic pressure</td>
<td>hypothalamus</td>
<td>osmoreceptors</td>
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<tr>
<td>glucose</td>
<td>glucose</td>
<td>hypothalamus</td>
<td>glucoreceptors</td>
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<tr>
<td>pH (cerebrospinal fluid)</td>
<td>ions</td>
<td>medulla</td>
<td>ventricle cells</td>
</tr>
<tr>
<td>Taste</td>
<td>ions and molecules</td>
<td>tongue and pharynx</td>
<td>taste bud cells</td>
</tr>
<tr>
<td>Smell</td>
<td>molecules</td>
<td>nose</td>
<td>olfactory receptors</td>
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<tr>
<td>Somatosensory</td>
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<tr>
<td>touch</td>
<td>mechanical</td>
<td>skin</td>
<td>nerve terminals</td>
</tr>
<tr>
<td>pressure</td>
<td>mechanical</td>
<td>skin and deep tissue</td>
<td>encapsulated nerve endings</td>
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<tr>
<td>heat and cold</td>
<td>temperature</td>
<td>skin, hypothalamus</td>
<td>nerve terminals and central</td>
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<tr>
<td>pain</td>
<td>various</td>
<td>skin and various organs</td>
<td>neurons</td>
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<tr>
<td>Muscle</td>
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<td>vascular pressure</td>
<td>mechanical</td>
<td>blood vessels</td>
<td>nerve terminals</td>
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<td>mechanical</td>
<td>muscle spindle</td>
<td>nerve terminals</td>
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<tr>
<td>muscle tension</td>
<td>mechanical</td>
<td>tendon organs</td>
<td>nerve terminals</td>
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<td>joint position</td>
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<td>joint capsule and ligaments</td>
<td>nerve terminals</td>
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<td>Balance</td>
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<tr>
<td>linear acceleration</td>
<td>mechanical</td>
<td>vestibular organ</td>
<td>hair cells</td>
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<tr>
<td>(gravity)</td>
<td></td>
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<tr>
<td>angular acceleration</td>
<td>mechanical</td>
<td>vestibular organ</td>
<td>hair cells</td>
</tr>
<tr>
<td>Hearing</td>
<td>mechanical</td>
<td>inner ear (cochlea)</td>
<td>hair cells</td>
</tr>
<tr>
<td>Vision</td>
<td>electromagnetic</td>
<td>eye (retina)</td>
<td>photoreceptors</td>
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<td></td>
<td>(photons)</td>
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Sensory processing

Levels of organization underlying sensory processing:

I. Receptors
II. Sensory circuits and pathways
III. Sensory perception
Receptors

Oxygen  Taste  Smell  Somatosensory  Muscle  Hearing  Vision

stimulus  transduction of the sensory stimuli  impulse initiation
Receptor potential

Receptor potential in a muscle stretch receptor (mechanoreceptor). A. These receptors signal muscle length and the speed at which the muscle is stretched. The sensory fiber nerve endings respond to stretch of the muscle fibers. Mechanical deformation of the membrane opens the stretch-sensitive ion channels. The influx of Na+ and Ca2+ depolarizes the nerve ending, producing the receptor potential.

B. Upper records: depolarizing receptor potentials recorded from the sensory axon (APs have been blocked with TTX) when the muscle spindle is stretched to different lengths. Lower records: amplitude and rate of stretch. The initial depolarization of the receptor in response to change in muscle length (dynamic response) is proportional to both the rate and amplitude of stretch. When stretch is maintained, the receptor potential decays to a lower value proportional only to the amount of stretch (static response).

C. Patch clamp records of a single stretch-sensitive channel. As the pressure on the membrane is increased, the channel opens more often and remains in the open state for longer time intervals.
Stimulus potential and impulse frequency exhibit close correlation.

Intensive coding in skin touch receptors. Left: in slowly adapting mechanoreceptors, the firing rate is higher at the beginning of skin contact than during steady pressure. Right: rapidly adapting mechanoreceptors respond only at the beginning and end of the stimulus, signaling the rate at which the stimulus is applied or removed. The receptor is silent when the indentation is maintained at a fixed amplitude.
Hierarchical information processing

Basic rules:
I. Divergence
II. Convergence
III. Parallel processing
IV. Feedback
Connections

Connection patterns between neurons:

a) Convergrence
b) Divergence
c) Serial processing
d) Parallel processing
e) Selffeedback
f) excitatory positive feedback
g) inhibitory positive feedback
h) Negative feedback
Synaptic triad: input elements, relay neurons, intrinsic neurons,
Examples of synaptic triads in sensory systems. There are input elements (the receptors) and output neurons (A: ganglion cells, B: mitral cells). There are interneurons for straight-through transmission and there are interneurons for horizontal interactions. The horizontal connections are organized at two levels. In both cases there is provision for straight-through transfer of signals to the output neuron and local processing of signals through the interneurons.
Pattern of activity in population of ganglion cells in response to light – dark edge stimulus. The enhancement of response on the light side of the edge and depression on the dark side are due to inhibitory interactions at the level of biopolar cells and horizontal cells (not shown in the picture).
The Cafe Wall illusion
The Cafe Wall illusion

The original of the Café Wall, St Michael's Hill, Bristol.
The Cafe Wall illusion

The part of the line indicated by an violet circle is surrounded by a large white region. These areas will be dimmed in the retina. The part of the line indicated by a orange circle is surrounded by dark regions, and will be slightly brightened in the retina. The result is that each line acquires a slight diagonal striping, which develops into converging slopes.

http://www.positscience.com/brain-resources/brain-teasers/cafe-wall-illusion
Inputs from different sensory organs are processed in different areas in the brain. Information from different senses is integrated in associational cortices, which occupy large cortical areas.
### Sensory perception: detection

<table>
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<tr>
<th>Modality</th>
<th>Threshold</th>
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| Vision     | Intensity: 1 photon (energy: $3 \times 10^{-19}$ J; energy of small apple falling: 1 J)  
Wavelength: 400 nanometers |
| Audition   | Movement of eardrum: $10^{-8}$ cm (diameter of the hydrogen atom)          |
| Olfaction  | Ethyl ether: 5.83 mg/liter of air  
Artificial musk: 0.00004 mg/liter of air |
| Taste      | Sucrose (sweet): 7 g/liter  
NaCl (salty): 2 g/liter  
Quinine sulfate (bitter): 0.00015 g/liter |
| Somesthesia| Pressure (back of hand): 12 g/mm$^2$  
Pain (back of hand): 100 g/mm$^2$ |
Stimulus - response relationship

- Equal changes in strength do not produce equal change in sensations.

- For most senses (vision, audition) the relationship is logarithmic (equal percentage changes in stimulus strength result in equal changes in response). It expands the range of possible stimuli.

- For some senses (e.g., temperature) the relationship is power law. The range of stimulus values is smaller but extreme values are sensed more strongly.

Brightness of light  Lifted weight  Angle between two surfaces felt with hands  Warmth

![Graph A: Stimulus vs. Subjective Brightness (red and green)]
![Graph B: Weight vs. Subjective Weight]
![Graph C: Angle vs. Subjective Angle]
![Graph D: Temperature vs. Subjective Temperature]
Rules of perception

• Gestalt (*germ.* configuration or form) psychologists identified principles of perception. They proposed that the human senses perceive objects in as a whole before perceiving their individual parts, suggesting the whole is greater than the sum of its parts.

• Perception depends not only on the properties of the stimulus element but also on its interaction with other elements simultaneously present. (We recognize relationships, not the components).

• The brain makes certain assumptions about what is to be experienced. They derive in part from the experience and in part from built-in neural wiring.

• Perception is not gaining an objective impression of the world around us but it is a creative act of the mind.
Pattern recognition I
The array of identical dots in A is ambiguous and can be seen alternatively as a pattern of columns or rows. Dots in B, C are not ambiguous because of additional cues (B – colors, C - proximity).
Brain identifies part of the scene as a recognizable object and considers other parts as background. This process can by dynamic.

Bistable figures. As we focus on one pattern, the rest is relegated to the background. Perception alternates between two different possible percepts.
Filling-in

Brain is able to interpolate shape and structure from fragmented information. It can fill-in information that is not directly given in the sensory input.

The Kanizsa triangle. A triangle is perceived in the center of each drawing even though the outline of the triangle does not exist in the drawing and must be inferred from fragments of other objects in the drawing. A white triangle emerges from a white background and a black triangle from a black background.
Comparison to surroundings

Brain uses spatial relationships of objects to help to interpret image, e.g., it compares object to surroundings to judge its size.

Left: Both women appear to be the same size. Right: The second woman seems small, because the corridor and tiles around her are not proportional, as they are in the photo at left.
Knowledge-based inference

Perception is based on what we know about our world. This information is built into the wiring of the brain by genetic and developmental mechanisms.

Do we see spheres or cavities? We always assume the light source to be above. By reversing the image one can reverse the depth of these objects.
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Perception – dependence on experience

The silence of the lambs - poster
Perception – dependence on experience

The silence of the lambs - poster

The silence of the lambs - poster detail
Perception – dependence on experience

The silence of the lambs - poster

The silence of the lambs - poster detail

Salvador Dali *In Voluptas Mors*, 1951