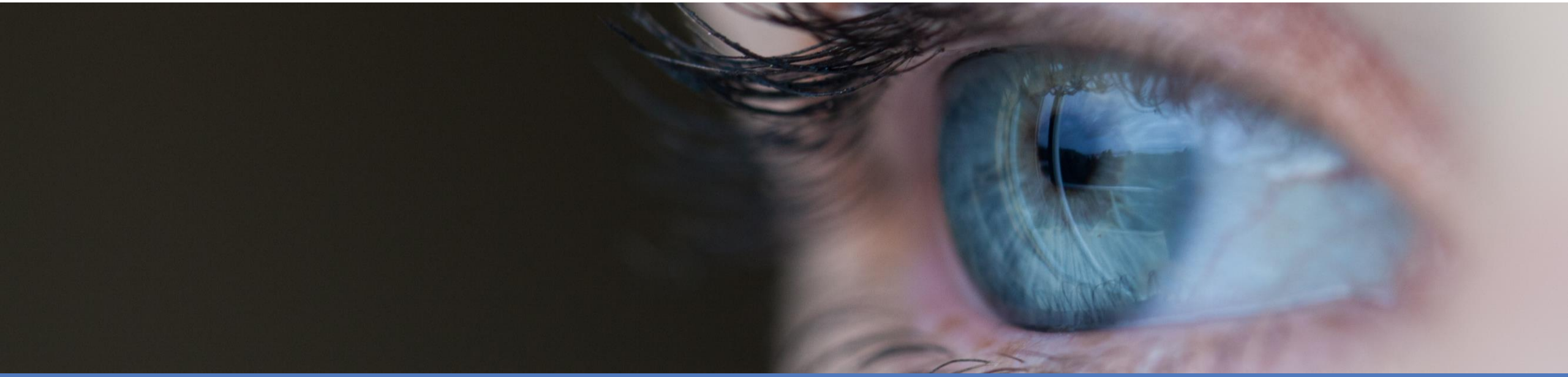
FRANKFURT UNIVERSITY OF APPLIED SCIENCES



Perception

Human-Computer Interaction Lecture

Slides adapted from hci-lecture.org (A. Schmidt, N. Henze, K. Wolf, V. Schwind), Image from: https://pxhere.com/de/photo/956874

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Learning Goals

- Understand …
  - perception and sensual processes
  - principles of human and multi-sensory perception
  - perceptual channels such as vision, hearing, smell & taste, haptics
  - how HCI addresses human perception
- Be able to explain …
  - explain human perceptual channels
  - how HCI can utilize perception

What is perception?

Why do we need perception?
Image from https://pxhere.com/de/photo/971434

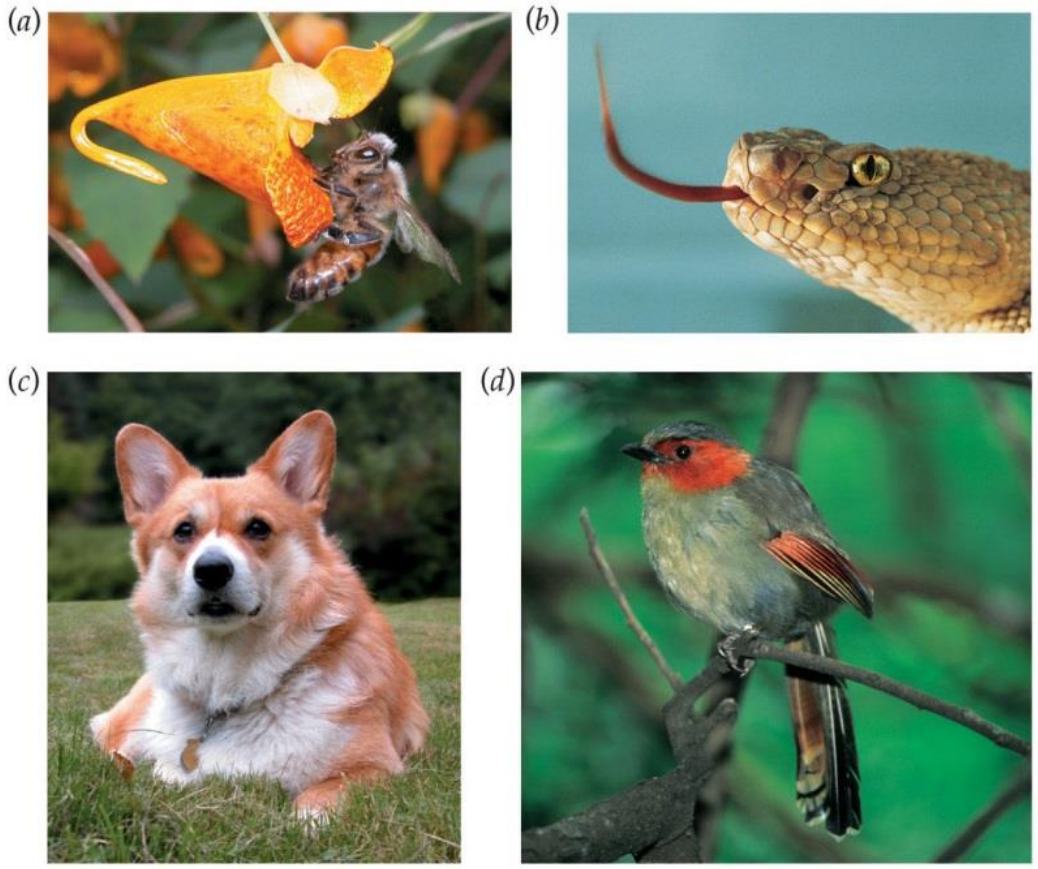
What is reality?

Reality

- **Requires existence of one‘s self**
- The **aggregate of all that is real or existent**
  - opposed to that which is imaginary
- Our understanding of “reality” includes physical objects
  - However, reality is for humans **fundamentally immaterial** (e.g., idealism, some numbers, and hypothetical entities)
  - The fields concerned with the real world belong to the **empirical science** as sources and methods to objectively investigate reality
- Does reality truly exist?
  - Quantum physicists would say: reality is defined when you measure it
- In our everyday life, **perception determines reality**

Animals

- Some species sense energies that humans cannot perceive:
  - Bees see ultraviolet lights
  - Rattlesnakes sense infrared energy
  - Dogs and cats can sense sounds with higher frequencies
  - Birds, turtles, and amphibians use magnetic fields to navigate
  - Elephants can hear very low-frequency sounds, which are used to communicate



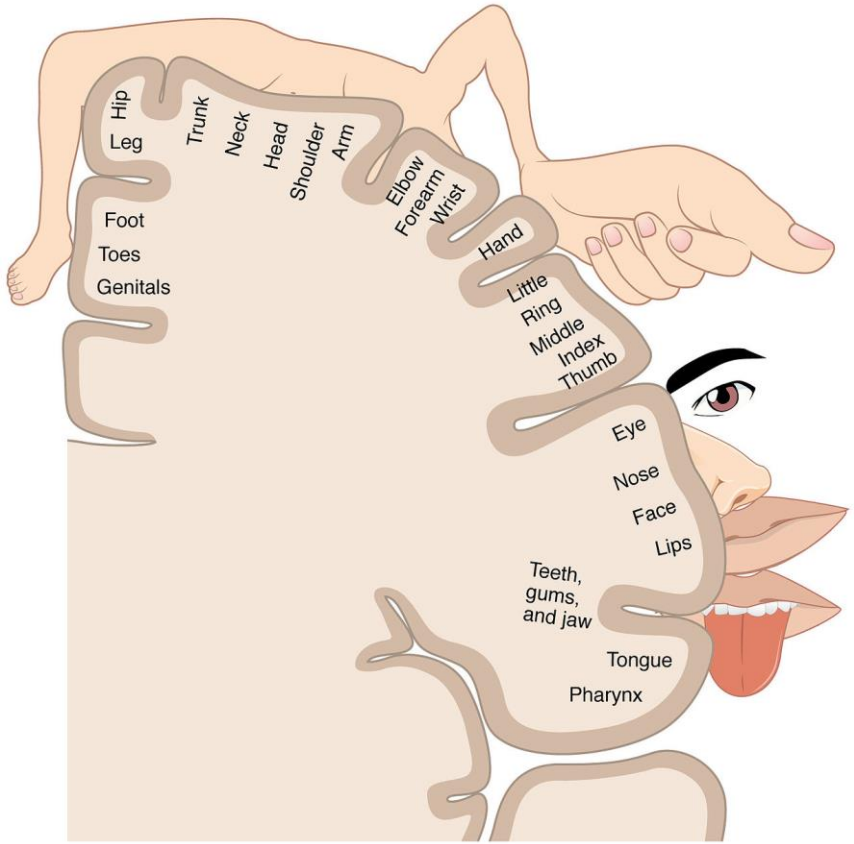
SENSATION AND PERCEPTION, **Figure 1.4** © 2006 Sinauer Associates, Inc.

Evolution and Perception

- Biological systems **do not have the mental capacity** to fully perceive and process the physical world
  - Creatures with a great breadth of perception are generally going to extinct
  - To perceive reality as it is (all electromagnetic signals) would be an evolutionary disadvantage
- The **specialization and filtering by perception** on certain electromagnetic waves is an essential part of evolution
  - This is also one of the reasons for the **diversity on the planet**, as several species do not compete for the same resources
- The relatively small range of perception has given humans an evolutionary advantage in the development of other mental processes (cognition)

The Cortical Homunculus

- Illustrates the concept of a representation of the human body lying within the brain
  - **The sensory homunculus** represents dedicated sensory processing for different anatomical divisions of the
  - **The motor homunculus** represents the processing for different anatomical divisions of the body
  - **The somatosensory homunculus** also depicts erogenous stimulations or perception of genitals
- **Do perceptual channels perceive the world independently from each other?**



OpenStax College - Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/, Jun 19, 2013.

McGurk Effect

Image from https://pxhere.com/de/photo/46518

Senses

- The ability to actively **absorb, process, and extract information through senses**
- All perception **involves signals coded and transmitted through the nervous system**, which emerge from physical (e.g., light, sound) or chemical (molecules) stimulation
  - **Vision**: Object identification/recognition for navigation, depth and motion perception through the **eyes**
  - **Sound**: Object identification/recognition, object localization with the **ears**
  - **Touch**: Object identification/recognition, pain (detection of tissue damage) with a somatosensory perception combined by the **skin surface** and **proprioception**
  - **Taste**: Chemical detection/identification of flavor, nutrition, and poison using the **tongue**
  - **Smell**: Chemical detection/identification of odors, pheromones, and hazards using the **nose**
- **Do we have more senses?**

More Senses

- **Agency**: The mind's feeling of chosen an action and bodily control (making of a decision and free will)
- **Balance**: The vestibular system maintains the centre of mass within minimal postural sway
- **Breath**: The sensation of getting and removing air in the throat, nose, mouth, and lungs
- **Faces**: A high-level cognitive process referring to identification and perceiving individuals
- **Gravity**: Related to the proprioceptive and vestibular system of the human body
- **Hunger**: Sensory cells in the stomach and GI tract (and hormones) motivate the consumption of food
- **Speech**: A high-level cognitive process to extract words and meaning from phenomes in audio
- **Pain**: Sensory (and emotional) experience that can be perceived all over the body (and beyond)
- **Posture**: Mainly driven by the proprioceptive system through mechanoreceptors detecting pressure
- **Rectal**: Part of the GI tract regulating defecation
- **Sexual arousal**: A combined and complex response of mental and physical stimuli on sexual tissues
- **Temperature**: Detected by thermoreceptors throughout the body
- **Time**: The brain is governing the perception of time and the circadian rhythm (internal clock)
- **Urinary Bladder**: Regulates urination and retention as part of the GI tract

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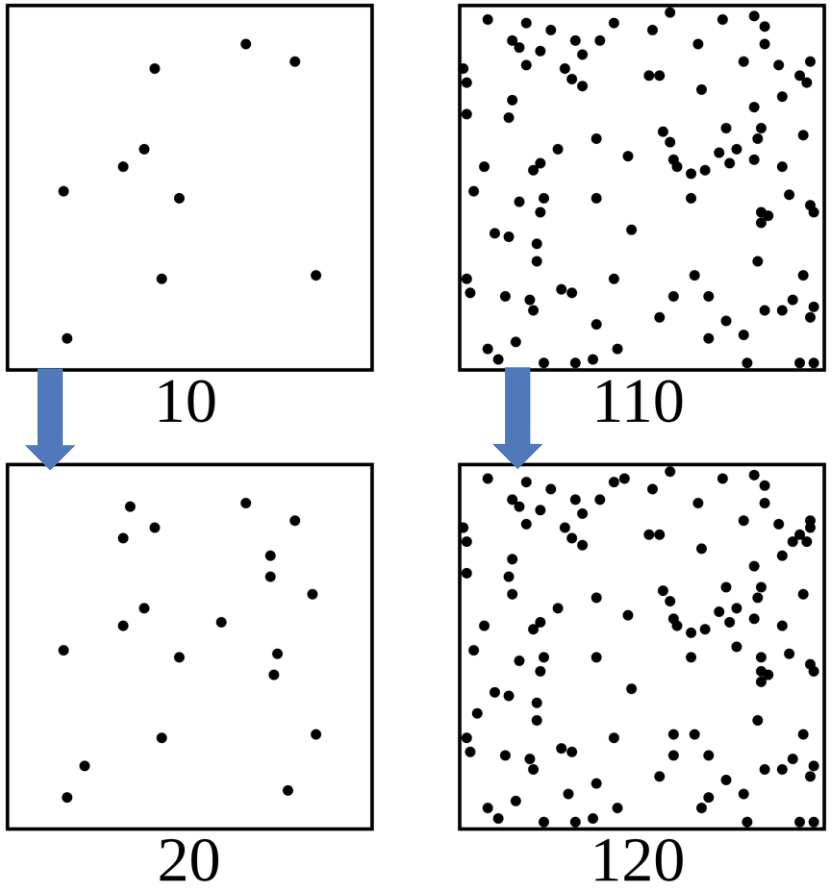
Require higher mental processing (see Cognition)

Sensual Acuity

- **Each sense requires a threshold** of stimulation to **extract information from noise**
  - The absolute threshold is the level at which a stimulus will be detected a specified percentage: often 50% of the time
- Sensual acuity refers to a **sensory threshold of a physiological response** and **determines the boundary of perception**
  - All senses have perceptual thresholds
  - Scientist call they **limen** (difference threshold, or least perceptible difference)
  - On one side of a limen (or threshold) a stimulus is perceivable, on the other side it is not



On each side, the lower square contains 10 more dots than the upper one. However the perception is different: On the left side, the difference between upper and lower square is clearly visible. On the right side, the two squares look almost the same.

Senses have Thresholds

- For many sensory modalities we can determine the upper and lower limits of perception: **the just-noticeable difference (JND)** – a fixed proportion of the reference sensory level
- The **smallest change** that can be perceived is the **JND**
  - Weber [1] states that the JND between two stimuli is **proportional to the stimuli**
    - e.g., for a 100g weight the JND is 5g ($5g/100g = 0.05$ → The JND for $200g * 0.05 = 10g$)
  - Fechner [2] found that the relationship between stimulus and perception is **logarithmic**
    - An individual's perception of e.g., brightness (or loudness) is proportional to the logarithm of the actual intensity (measured with a physical measurement instrument)
- Thresholds systematically increase with age

[1] Ross, H.E. and Murray, D. J.(Ed. and Transl.) (1996)E.H.Weber on the tactile senses. 2nd ed. Hove: Erlbaum (UK) Taylor & Francis;
[2] Fechner, Gustav Theodor (1966) [First published .1860]. Howes, D H; Boring, E G (eds.). Elements of psychophysics [Elemente der Psychophysik]. Vol. 1. Translated by Adler, H E. United States of America: Holt, Rinehart and Winston.

Weber-Fechtner-Law

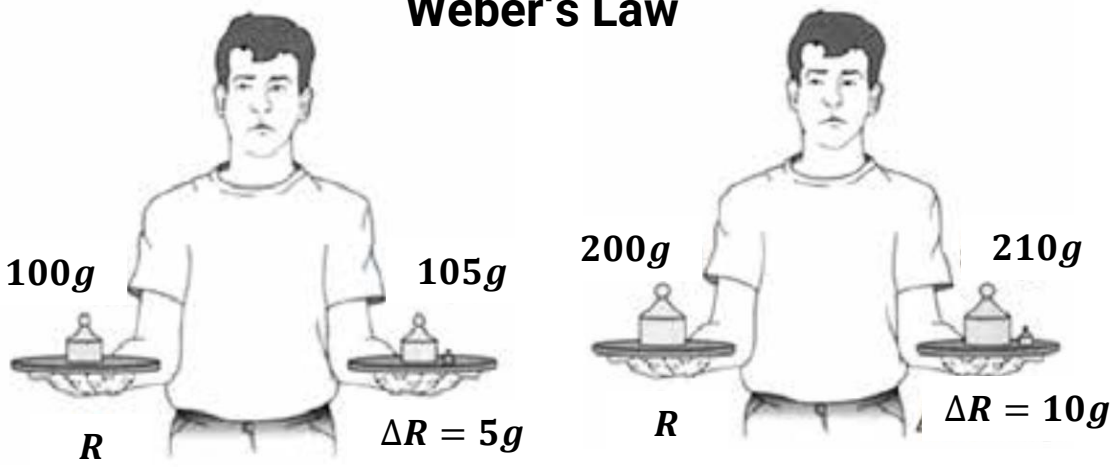
- Weber **compared** the JNDs between **two weights**
  - The weight increase of an object with 50 g is noticeable when it increases by 1 gram: 51 g.
  - 500g of weight must increase by 10g to appear heavier: 510 g
  - The JND to the stimulus intensity is: $\frac{\Delta R}{R} = \frac{1}{50} = \frac{10}{500} = 0.02 = 2\%$.
- **Fechner** assumed that JNDs remain subjectively equal, and **argued that this would produce a logarithmic relation** between the stimulus intensity and the sensation
  - $S = k \log R$: where S is the perceived intensity of the stimulus, R is the intensity of the stimulus, and k is a perceptual constant

Weber Constants

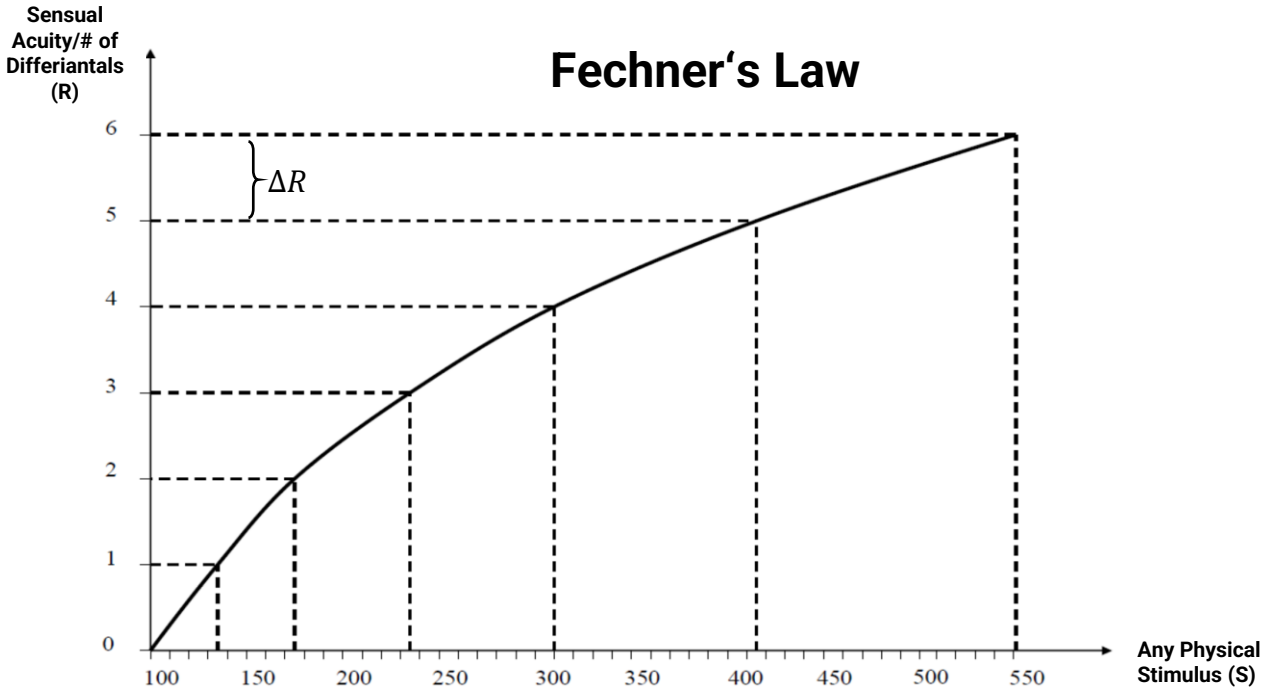
Dimension	c (Weber-Constant)
Electric Current	0.013 (1.3%)
Weight	0.050 (5.0%)
Brightness	0.016 (1.6%)
Taste (of Salt)	0.083 (8.3%)
Hearing	0.048 (4.8%)
Pain (Thermal)	0.033 (3.3%)
Touch	0.030 (3.0%)
Loudness	0.050 (5%)

Image from J. Antonio Aznar Casanova, INTRODUCCION A LA PSICOFÍSICA

Weber's Law



Fechner's Law



Stevens Law

- The process of measuring how changes in **stimulus intensity relates to changes in perceived intensity**
- The relationship between perceived intensity of a stimulus (S), ist physical intensity (R), the perceptual constant (c), and the exponent n is different for each perceptual dimension is:
  - $S = cR^n$

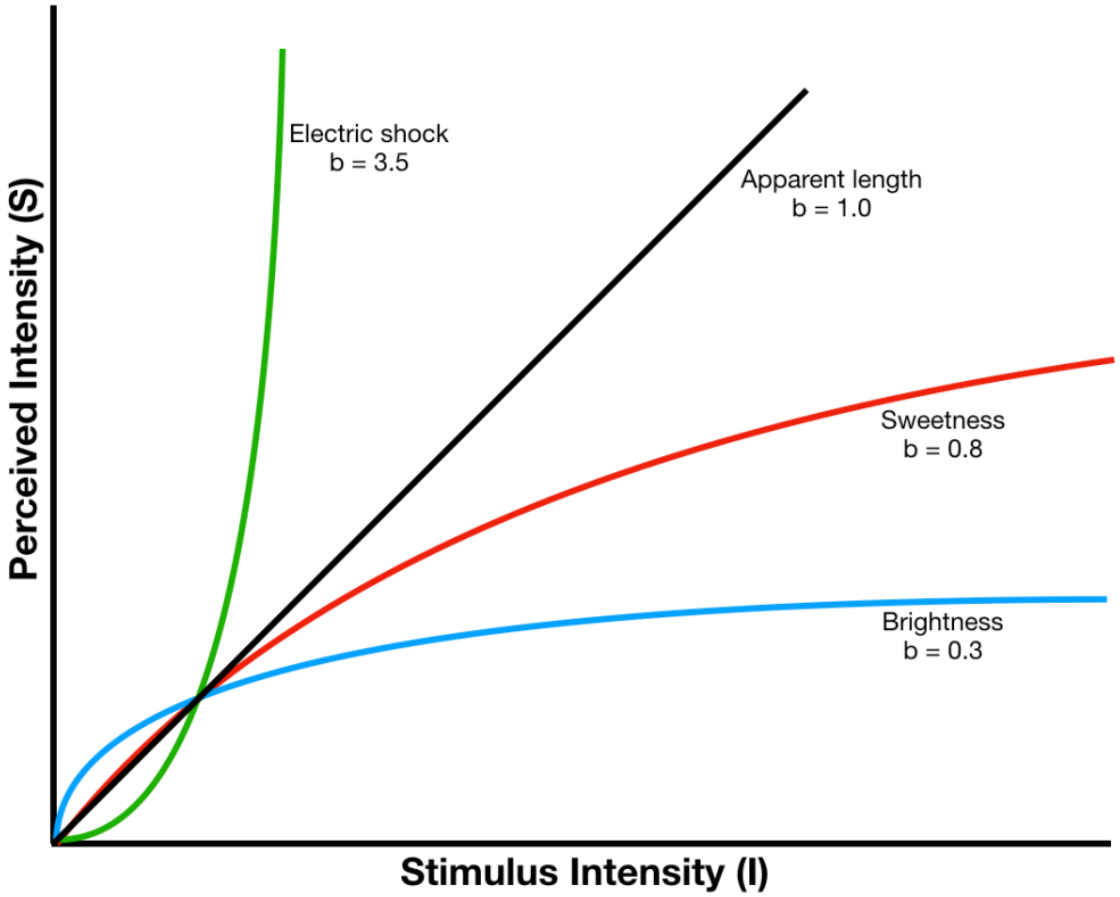
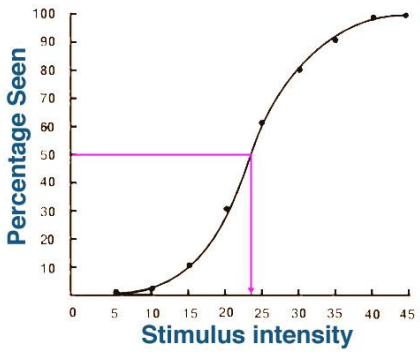


Image from: https://deephci.wordpress.com/

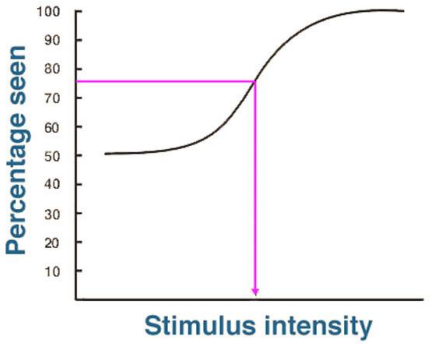
Measuring the JND

- In a **Yes-No Procedure** the presence or absence of the signal must be detected (yes or no response).
  - The correct response can range from 0% to 100%
- In a **Forced-Choice Procedure** a subject is forced to choose from alternative choices, one of which contains the stimulus
  - e.g., in a two-alternative forced choice (2AFC) describes a subject choosing between two alternative
  - As there is already a 50% chance of a correct response with 2AFC, threshold is commonly considered as 75%
- **Parameter Esimtation by Sequential Testing (PEST) or Staircaise Test** addresses the problem of step size and starting intensity
  - Begins the session with large steps with the intensity progressively halved until the smallest noticeable step has been found

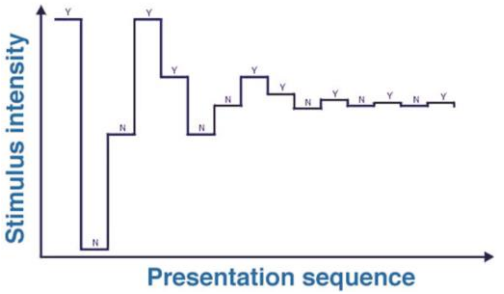
Yes-No



2AFC

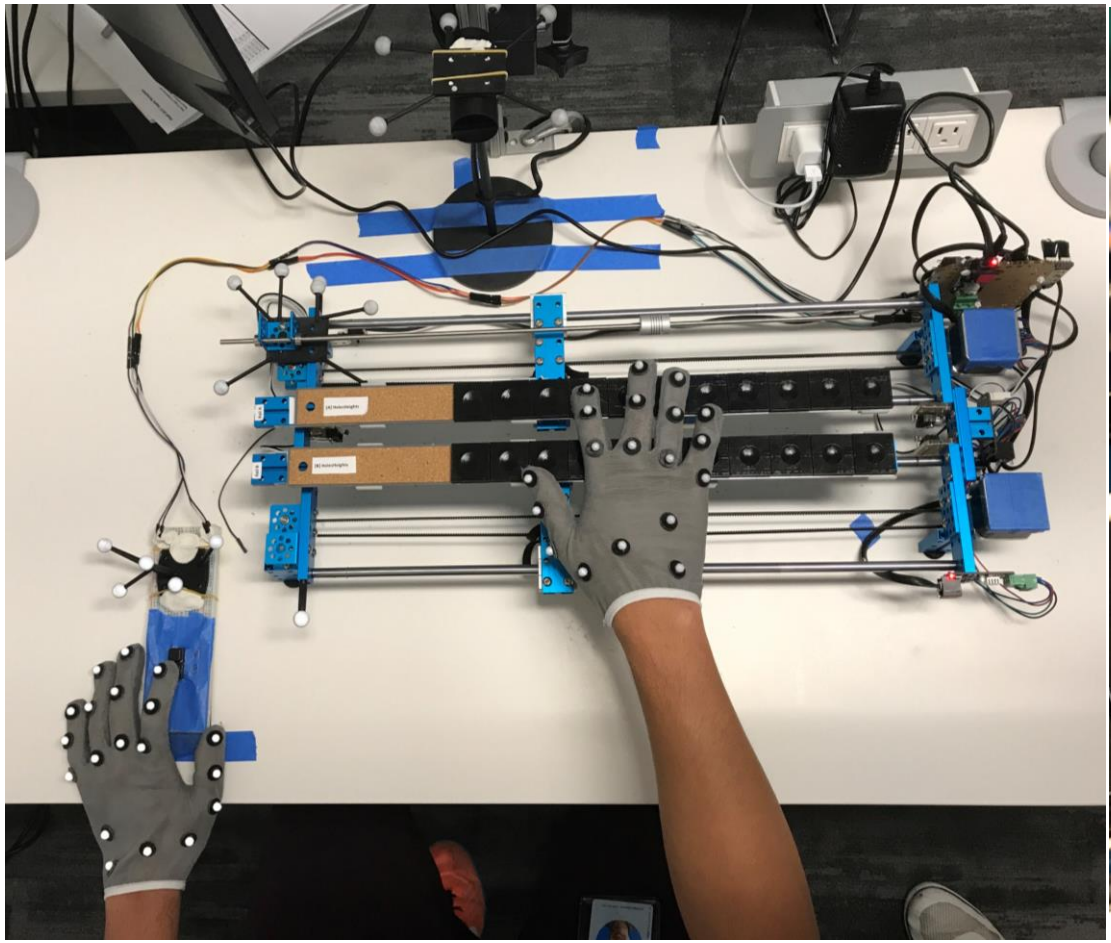


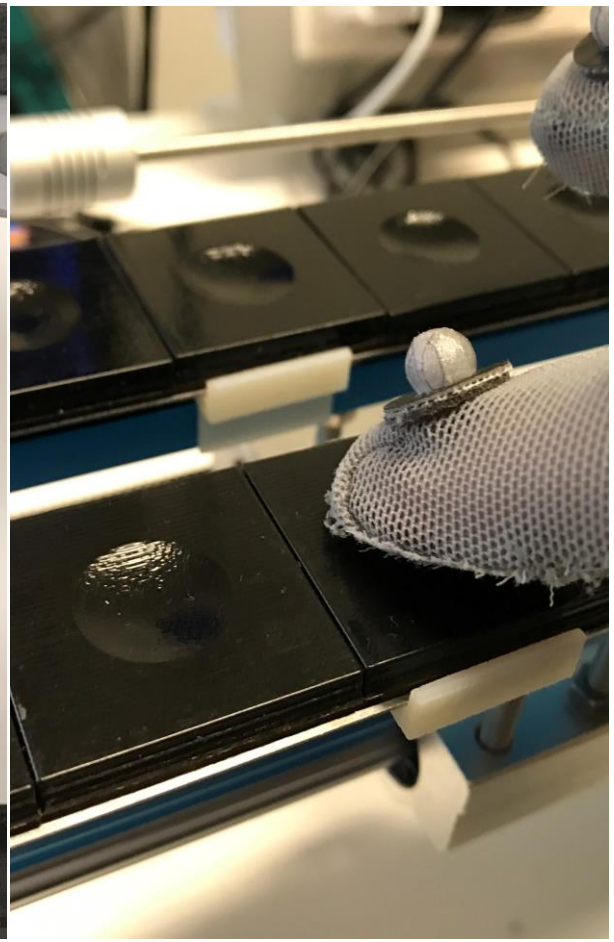
PEST

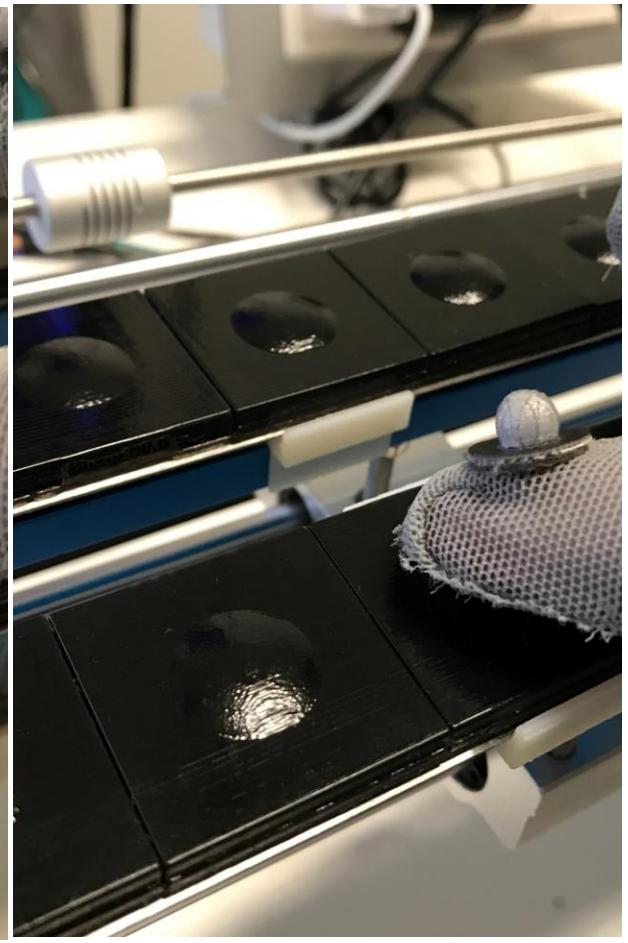


Images from: https://webvision.med.utah.edu/book/part-viii-psychophysics-of-vision/psychophysics-of-vision/

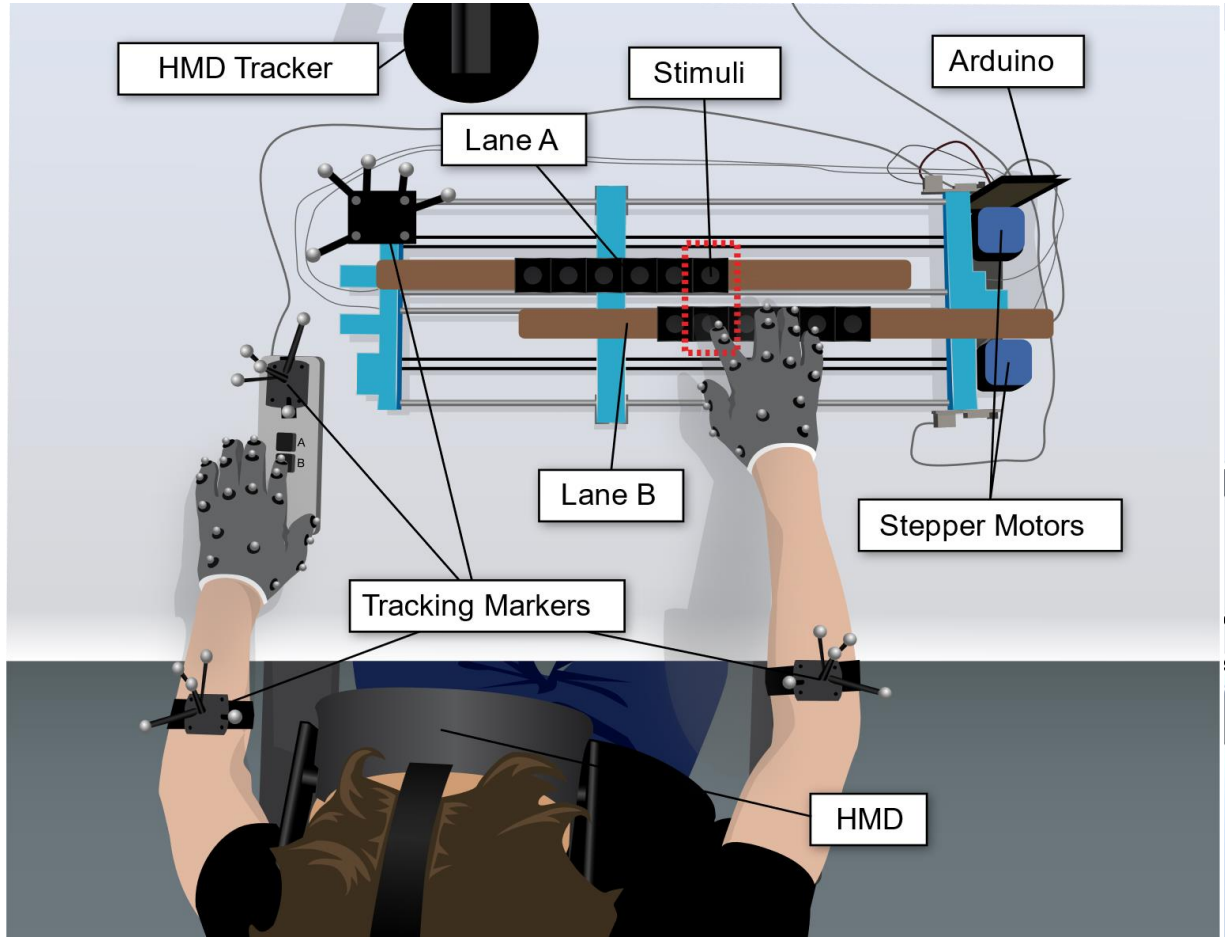
Example: Visual-Haptic Integration

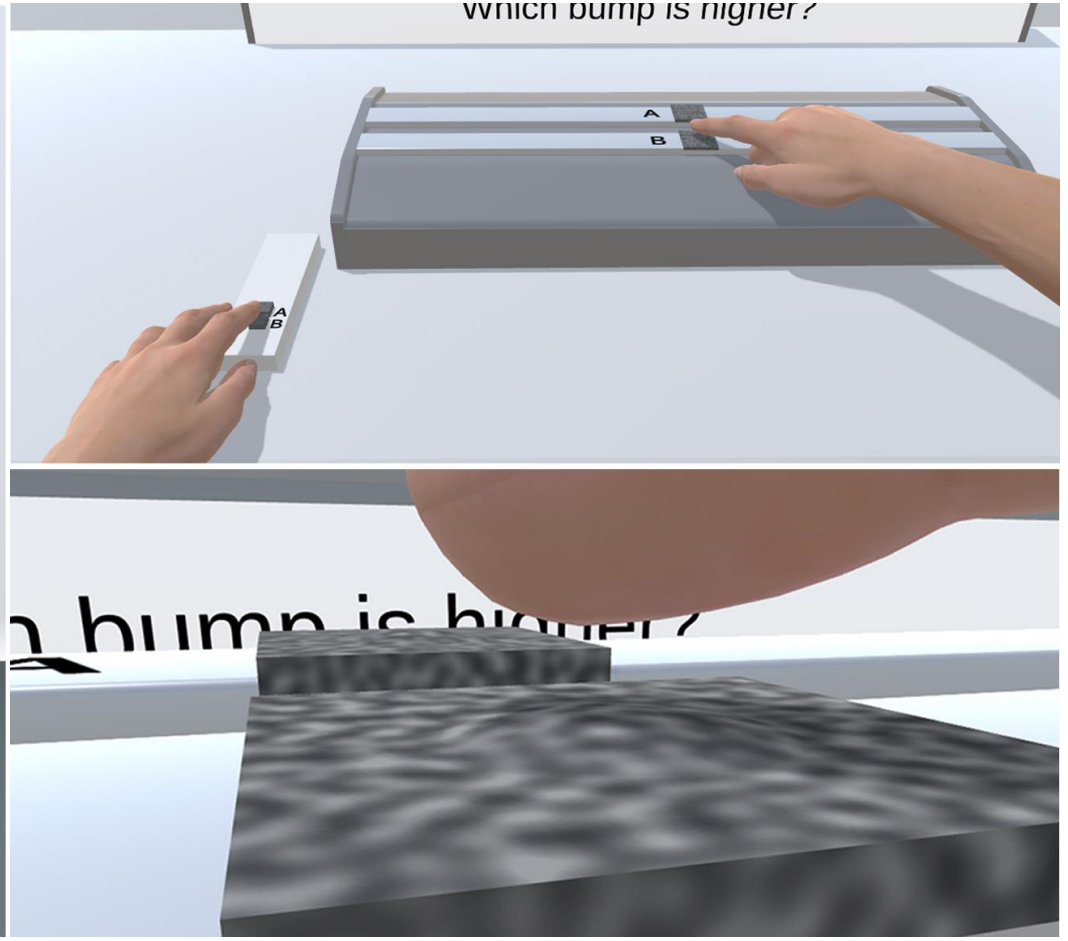






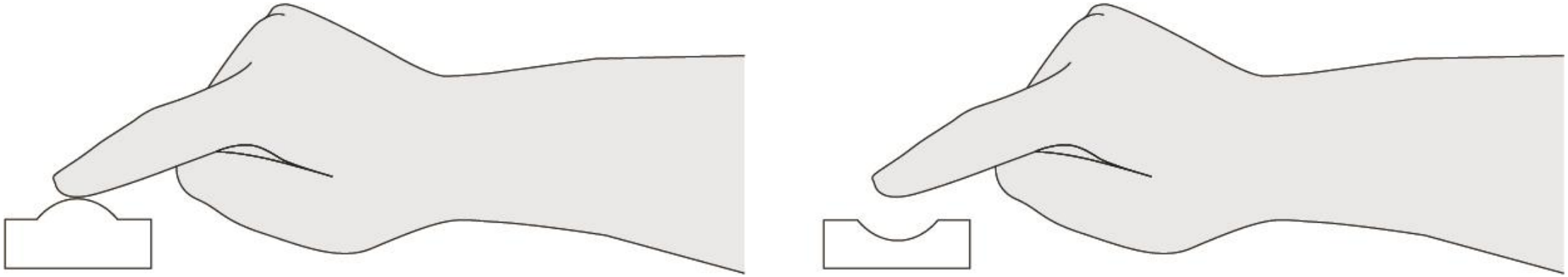
Measuring Tactile Sensitivity



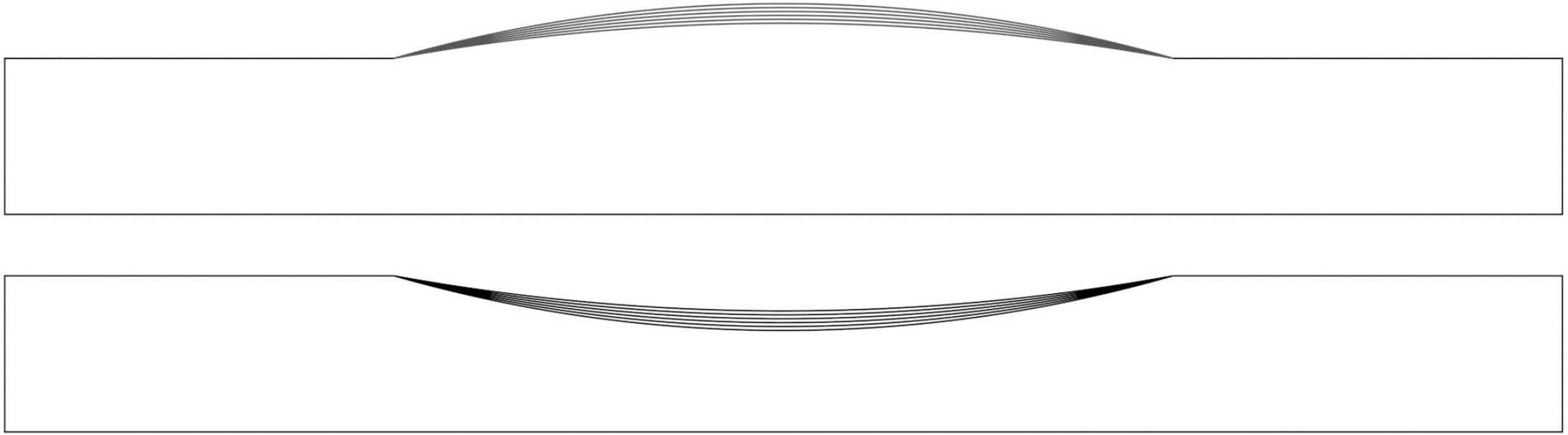


2AFC Task

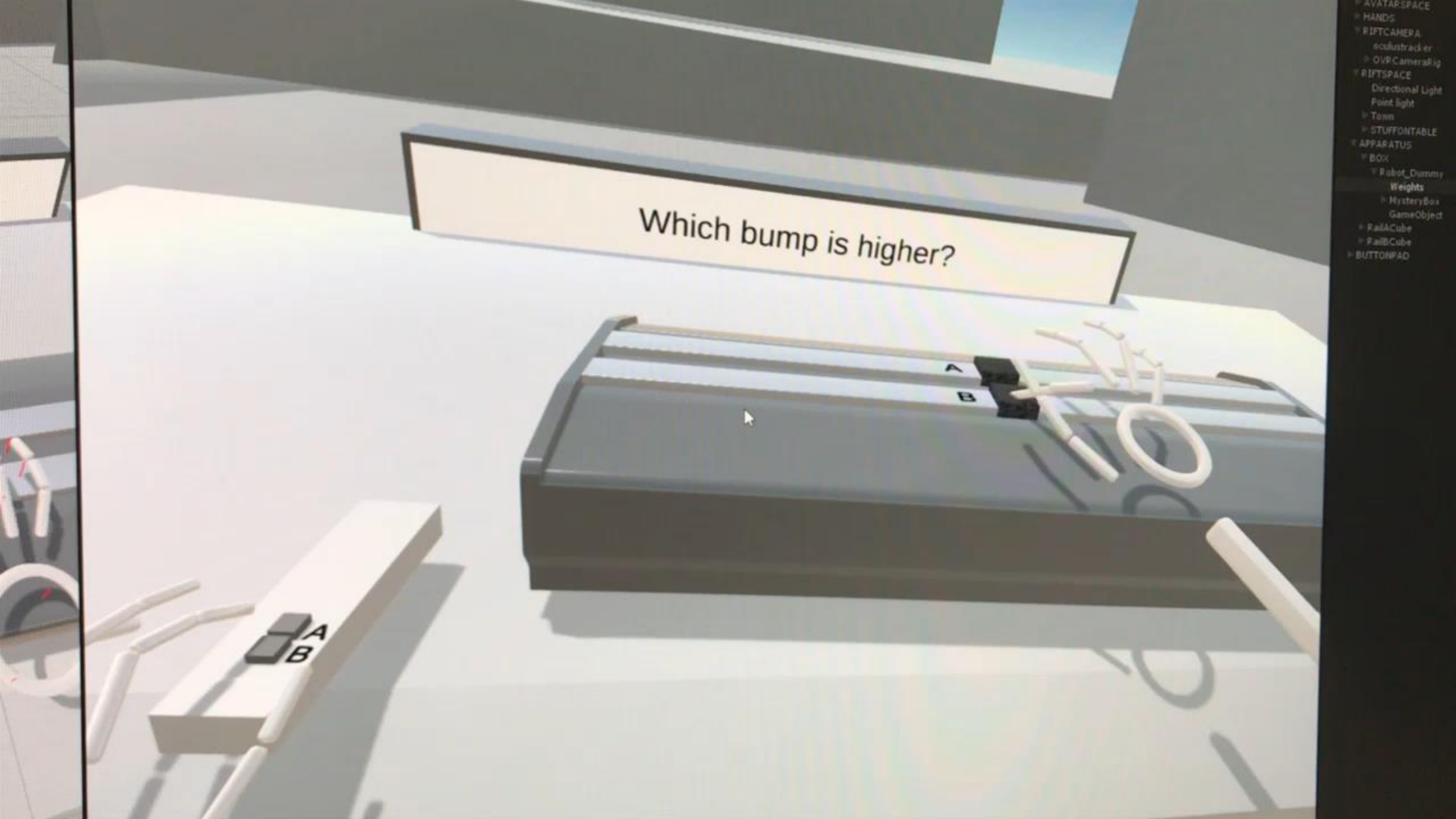
- A psychophysical experiment using a two-alternative forced choice (2AFC) task
- Discrimination of height / depth differences
  - Bumps: “is a bump higher?”
  - Holes: “is a hole deeper?”



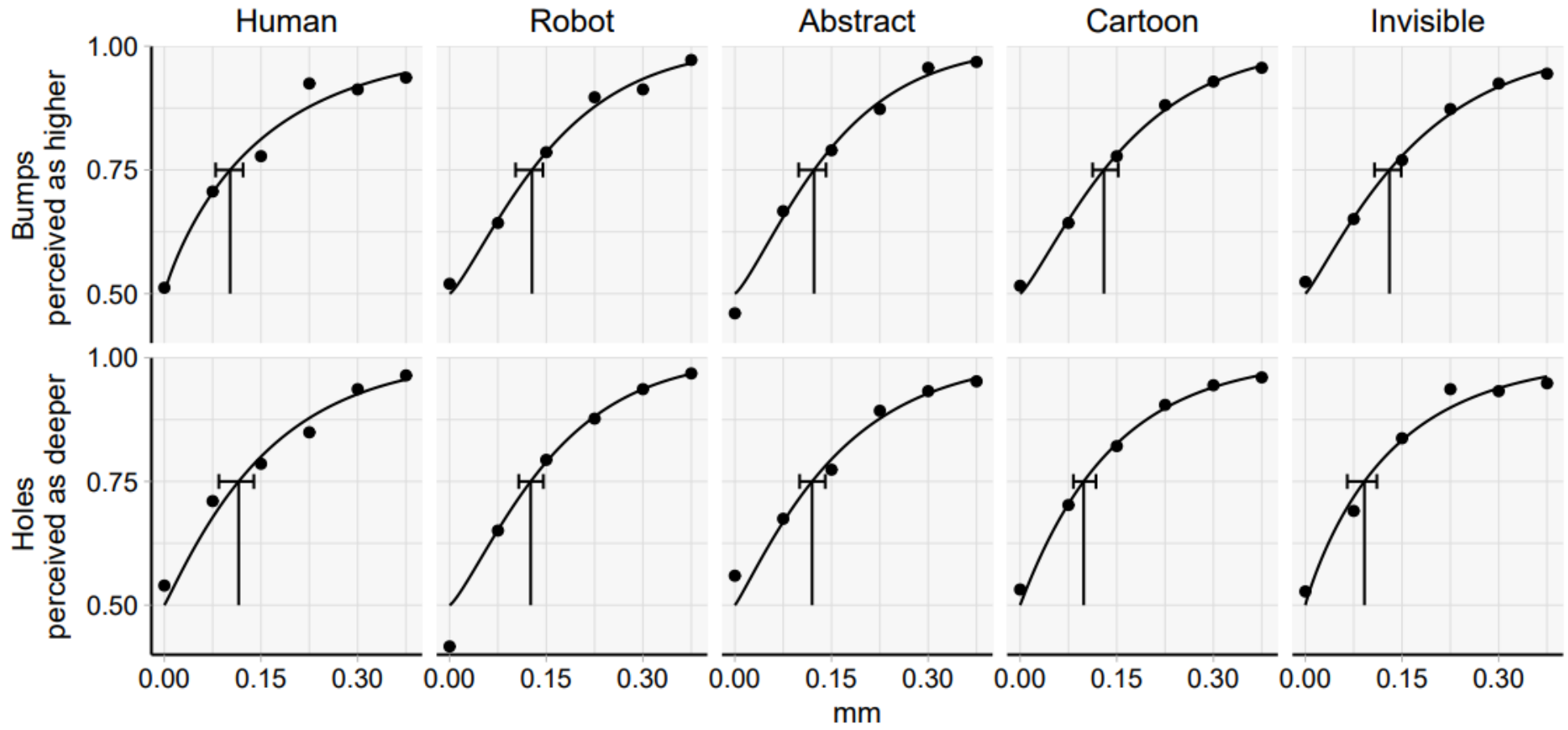
Just Noticable Differences (JNDs)



3d printed plates with bumps / holes from 0.675 to 1.05mm height / depth in
0.075mm steps


Which bump is higher?
A
B
A
B

Effect of Hands on Tactile Sensitivity



Vision

The Dominant Sense

Slides adapted from hci-lecture.org (A. Schmidt, N. Henze, K. Wolf, V. Schwind), Image from https://pxhere.com/de/photo/1007006

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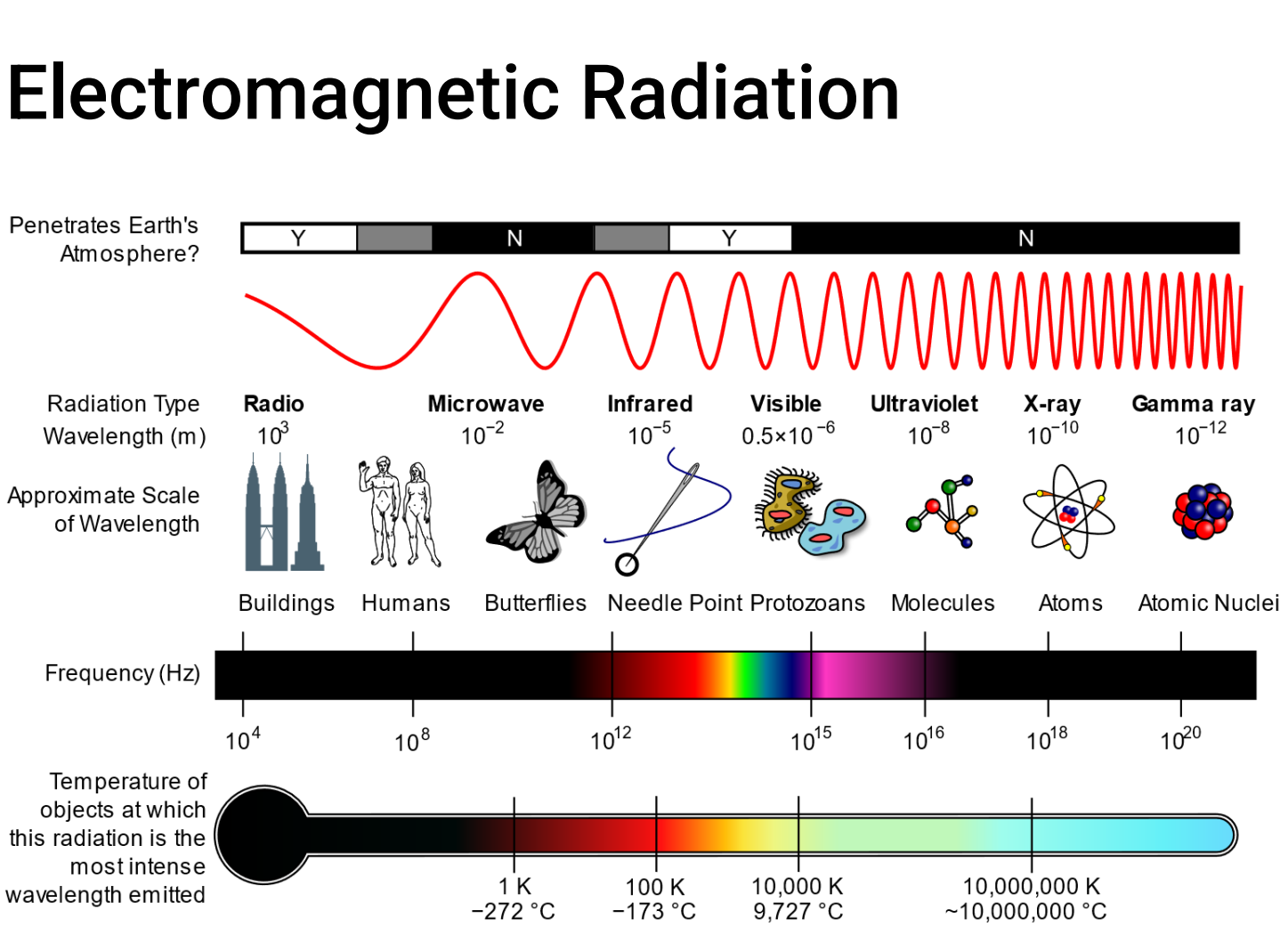
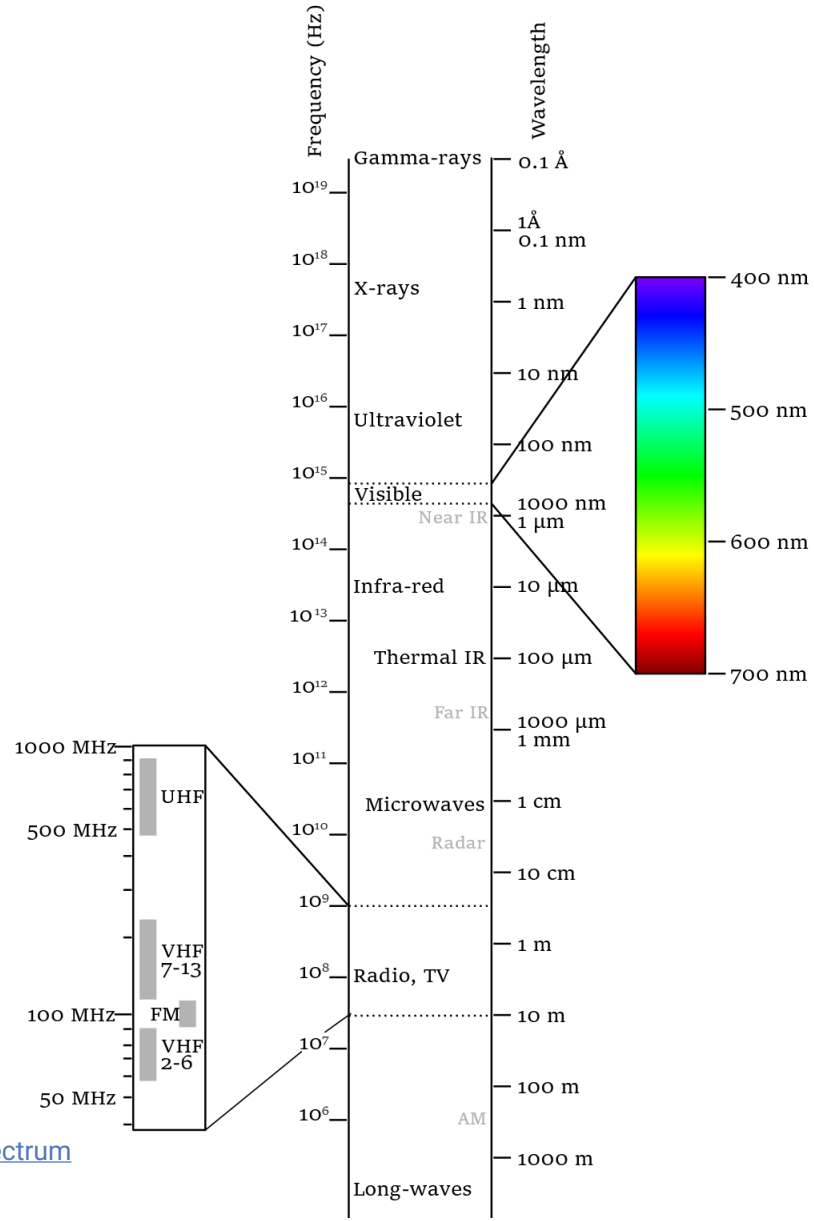
The Dominance of Vision

- **Information Processing**: provides a substantial amount of information about our environment. The rich set of data helps us to navigate our environment, recognize objects and people, and perform complex tasks
- **Evolutionary Significance**: spot predators and prey from a distance, navigate diverse environments, and identify edible plants and fruits has been essential for human ancestors.
- **Communication and Social Interaction**: facial expressions, body language, and eye contact convey a wealth of social information.
- **Learning and Memory**: human memory appears to be particularly adept at recalling visual information compared to other types of data.
- **Cultural and Technological Influences**: The human-made environment and cultural artifacts heavily rely on visual elements. From reading and writing to the use of screens in various devices, modern society is structured around the visual processing of information.

Electromagnetic Radiation

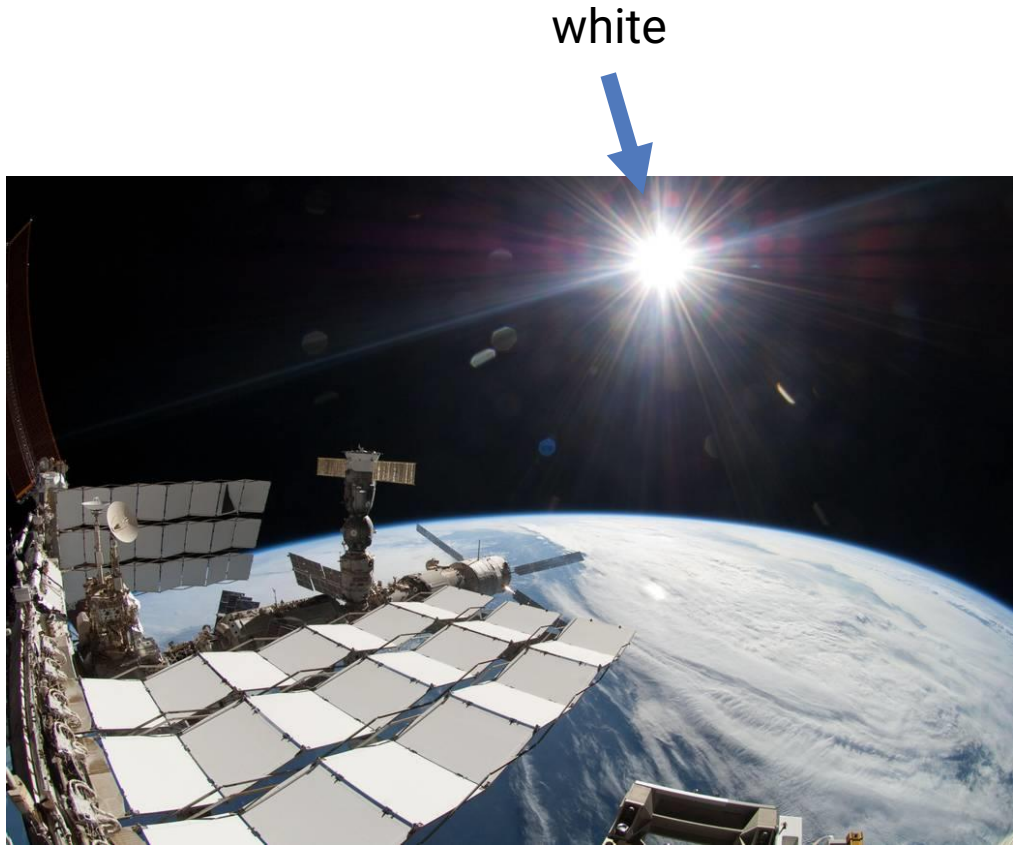




A diagram of the electromagnetic spectrum, showing various properties across the range of frequencies and wavelengths, Inductiveload, NASA - self-made, information by NASA, CC BY-SA 3.0, Source: https://en.wikipedia.org/wiki/Electromagnetic_spectrum
The electromagnetic spectrum, Victor Blacus, CC BY-SA 3.0, https://en.wikipedia.org/wiki/Electromagnetic_spectrum

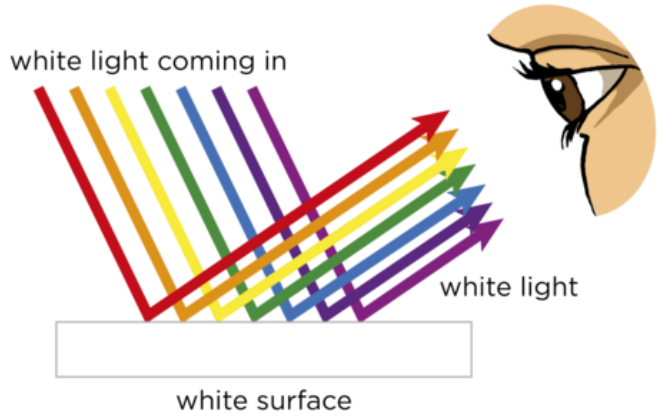
Facts about Visible Light

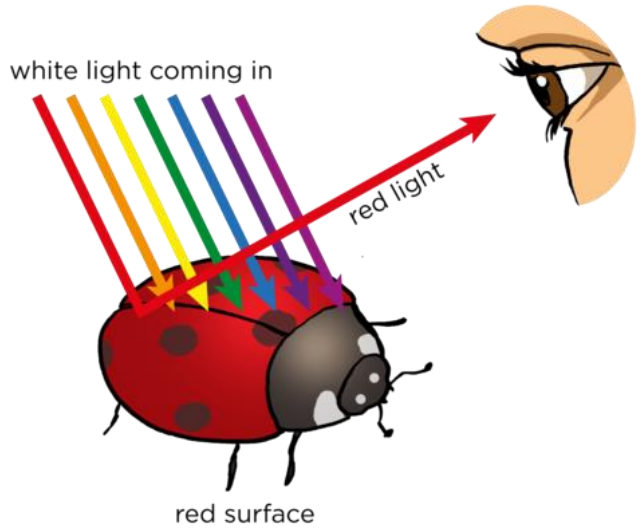
- The visible light for humans has a wavelength between 280 nm (violet) and 740 nm (red)
  - The sun emits a huge spectrum of electromagnetic radiation and includes all waveforms of visible light
- Colors containing only one wavelength are also called pure colors
  - Monochromatic light with high energy density is called laser
- It is not possible to mix wave with different lengths to create a new color

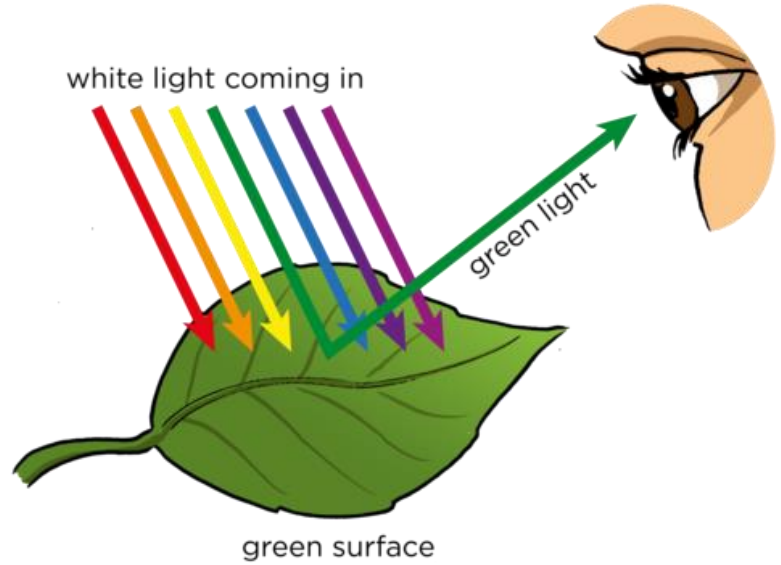


Light Absorption

- Not every surface reflects every color
- When light hits a surface, some of the light is absorbed and the rest is reflected
- Based on their structure/material, surfaces only reflect color(s) in specific wavelengths







Eye Anatomy

- The **cornea** (~43 dioptres) and **lens** (~18 dioptres) are responsible for the **refraction of light**
  - The lens can change its shape with a focal length ~17 - 22 mm
  - As the focal length is equal to the diagonal size the retina “sensor” the field of view is comparable with the focal length of a 50 mm lens
- The **iris** and **pupil** (2 - 8 mm) control the **brightness**
- The **retina** includes the **photoreceptor cells**
- **Each eye is controlled by seven extraocular muscles** (six the movement, one the eyelid)

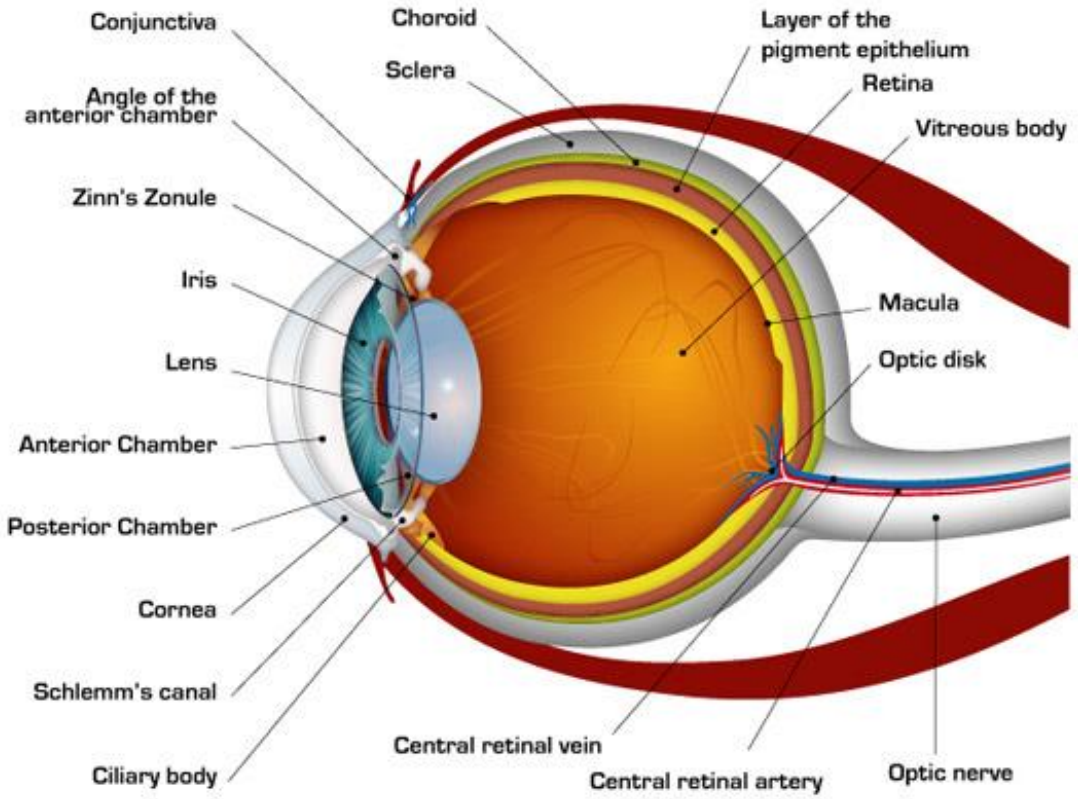


Image from: https://www.nkcf.org/about-keratoconus/how-the-human-eye-works/

Eyes and Cameras

- The f-number or f-stop describes the diameter of the aperture/iris
- ISO speed describes the sensitivity of the photoreceptor cells
- (Electrical) Shutter describes the time a camera needs to complete the cell charges of a complete image

Parameter	Nikon P1000	Human Eye
f-stops	15	21
ISO speed	100 - 1600	<1
El. Shutter	1/125 – 4	1/100 – 1/200
Frame per second	60 Hz	60 Hz
Color Depth	24 Bit	20 Bit
Resolution	16 MP	576 MP
Focal Length	24–3000 mm	50 mm

https://www.nikon.de/de_DE/product/digital-cameras/coolpix/super-zoom-share/coolpix-p1000

Photoreceptor Cells

- Convert light into neurological signals (and stimulate other biological processes)
- **Rod**, **cone**, and **ganglion cells** in the retina allow vision
  - **Rods** (ca. 120 million per eye) and are **responible for light intensity** perception (actually the absence of light)
  - **Cone cells** (ca. 6 million per eye) respond differently to light of different wavelengths, and are **responsible for color vision**
  - **Ganglion cells** (ca 0.7 to 1.5 million) are photosensitive but mainly **responsible for delegating and triggering signals**

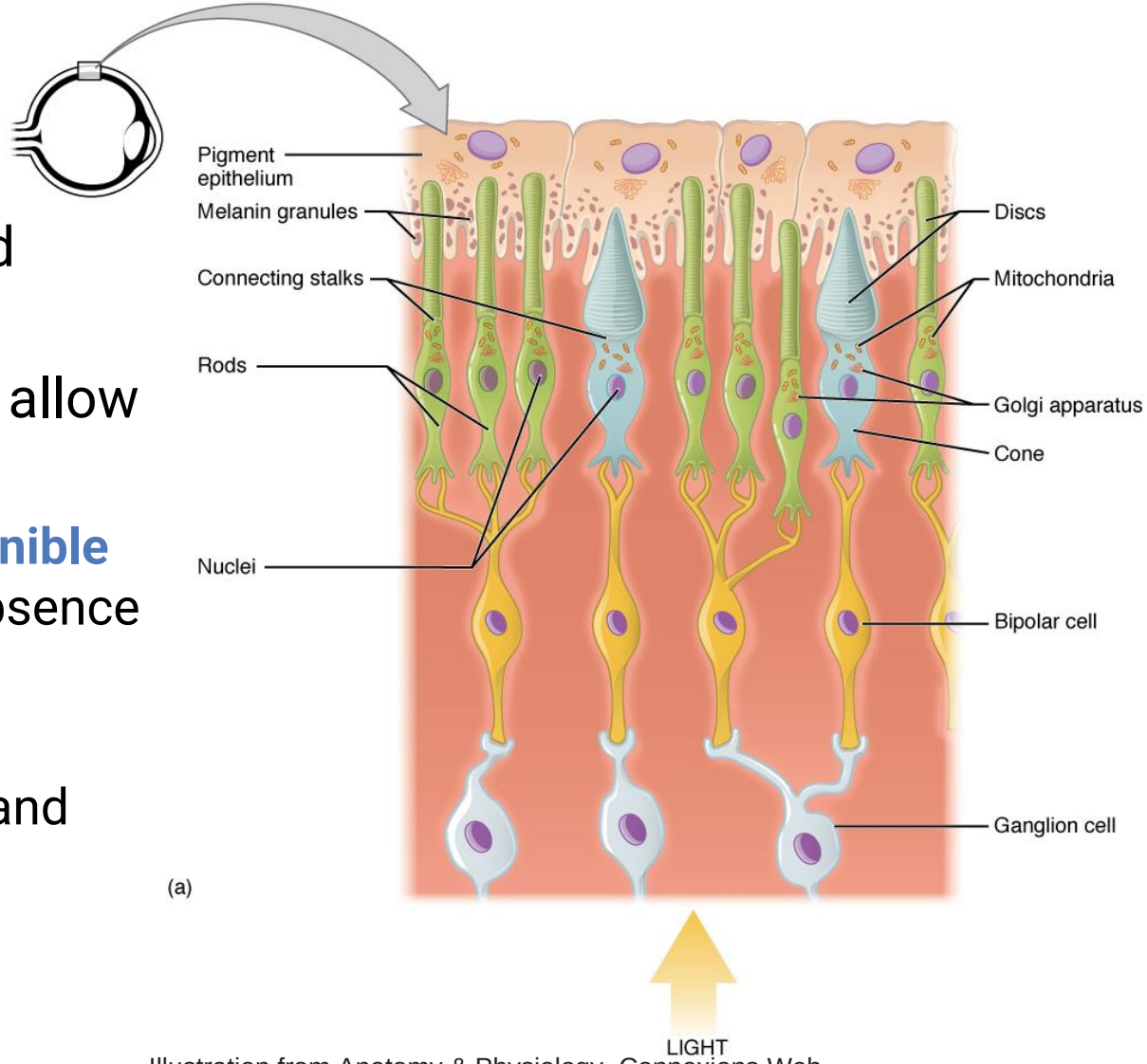
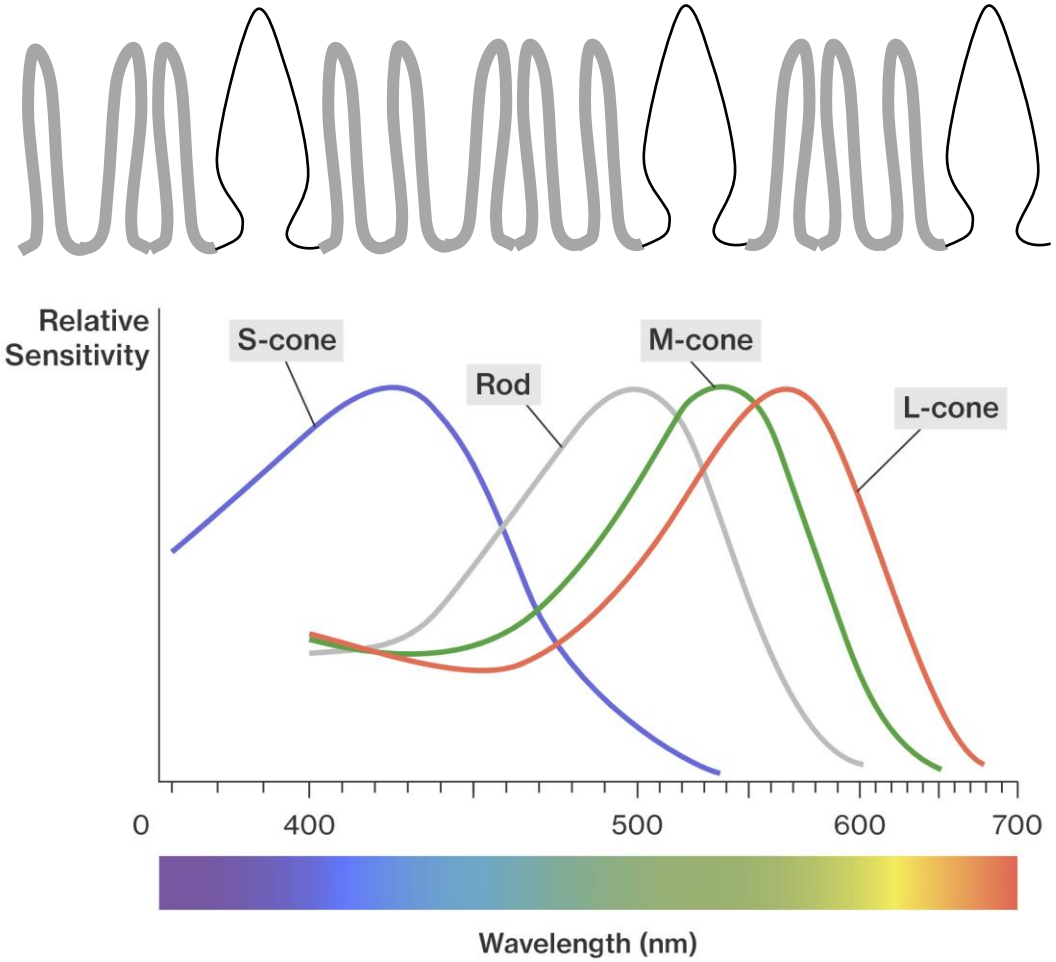


Illustration from Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/, Jun 19, 2013. https://commons.wikimedia.org/wiki/File:1414_Rods_and_Cones.jpg

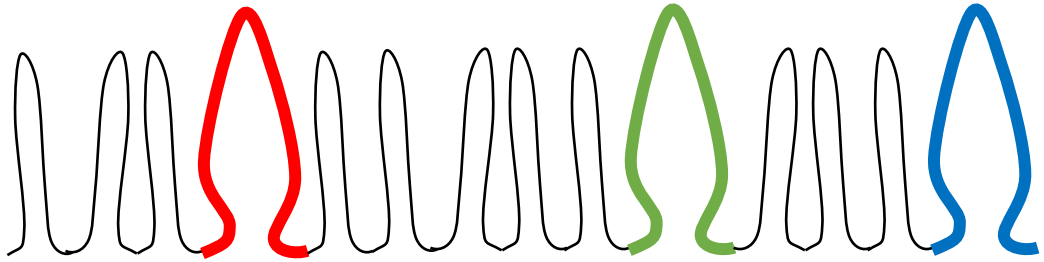
Rod Cells

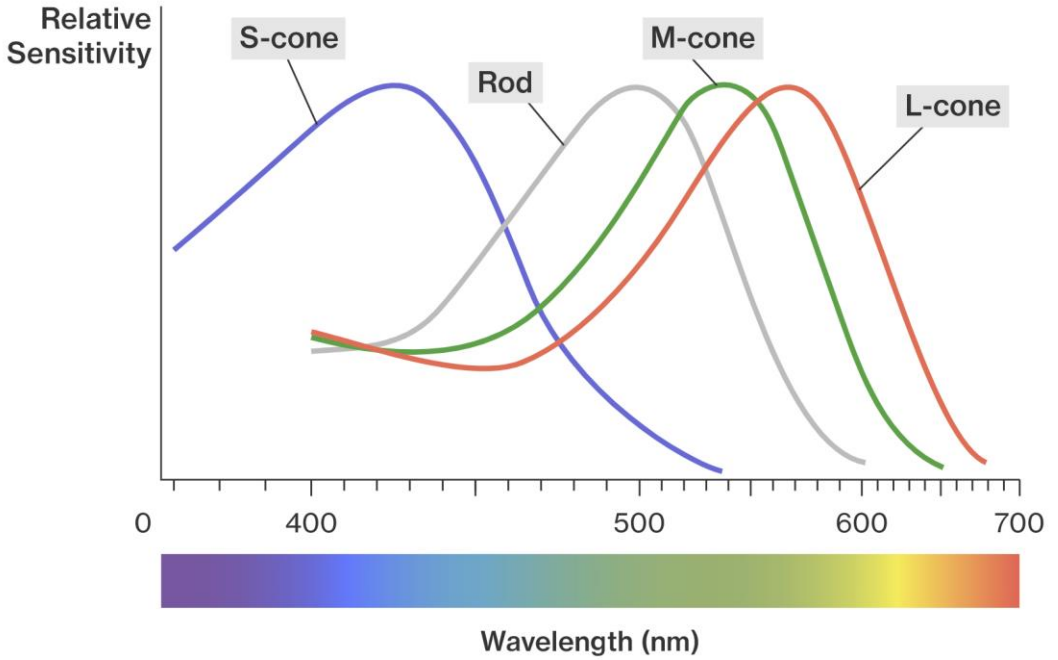
- Function well **in lower light** and have **little role in color vision**
  - Can respond to a single photon of light
  - Respond more slowly to light than cones
- Mainly located **at the outer edges** of the retina
  - Important for peripheral vision
- **Rod cells perceive**
  - Brightness
  - Contrast
  - Movements



Cone Cells

- **There are 3 types of cones**
  - Blue light cone receptors (S-cones, 420 nm)
  - Green light cone receptors (M-cones, 533 nm)
  - Red light cone receptors (L-cones, 564 nm)
  - 12% of the women in Europe have a 4th one (Tetrachromats)
- **Cone cells perceive**
  - Colors
  - Details
  - Movements
- **Humans can distinguish ~1 Mio color tones**





Color Blindness

Troxler‘s Fading

- The **sensitivity** of rod and cones **decreases** when they are exposed to **persistent stimuli** of similar intensity
  - **Unvarying stimuli disappear** from our awareness as neurons adapt and start to ignore the unimportant stimulus
- **Retinal photoreceptors** mainly respond to changes in lighting conditions

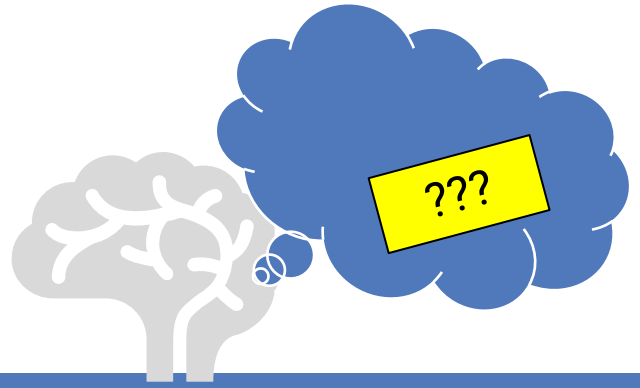
  → A fixated head and paralysis of the eye muscles lead to a temporary blindness
- **Micromotions**/**Microsaccades** of the eye constantly shifts the **light incident on the retina to stimulate receptors** and, thereby, enable vision
- **Microsaccades** prevent the blindness and usually occur 1 to 10 times per second

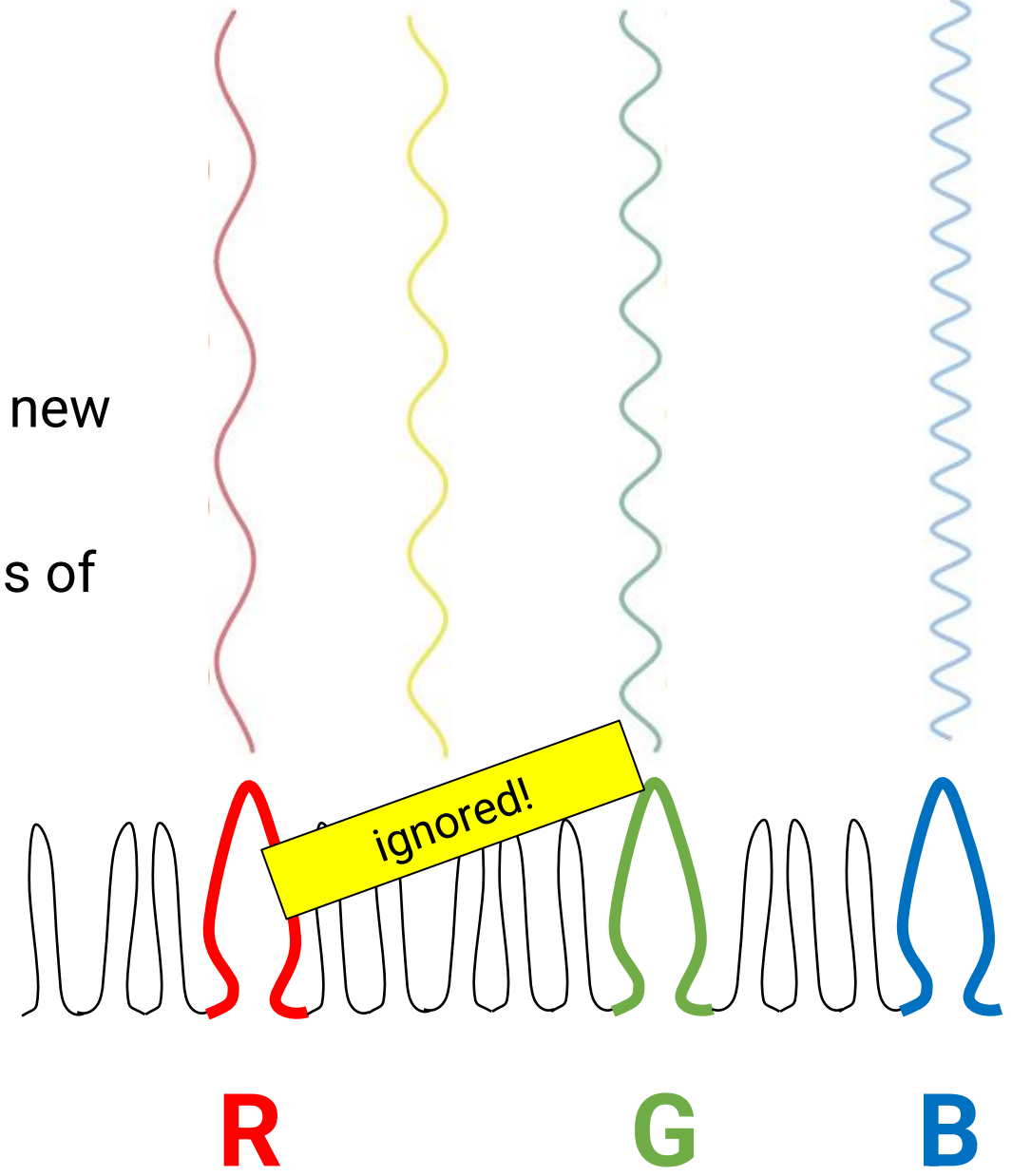
  → Depend on the task (e.g., while reading 3 per second)
- The amplitude typically <15 arcmin. This angle corresponds to about 80 µm or ≈ 40 photoreceptors shift on the retina

https://youtu.be/aQclvZpPWHQ

How we see colors…

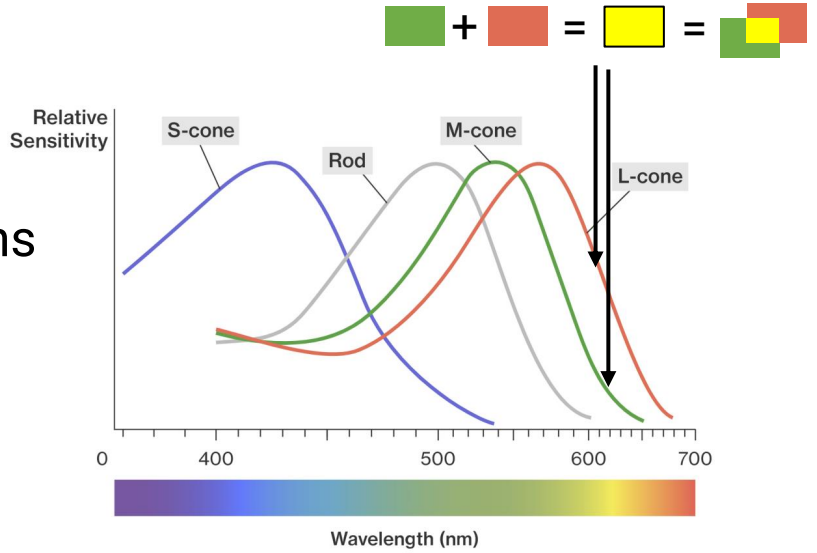
- We remember: it is not possible to mix waves with different lengths to create a new color (e.g., yellow)
- Cone receptors only receive wavelengths of the light they are able to perceive
- There are no receptors for yellow.
- But how can we see yellow?





Trichromatic and Opponent Processes

- **Trichromatic** (or Young–Helmholtz) **Process**
  - Ganglions interpret an overlap of light with different wavelengths
  - The system is not perfect and cannot distinguish yellow from a red-green mixture
- **Opponent Process**
  - The visual system codes pair differences instead of taking the raw signal
  - Activation of one pair member inhibits the activity in the other pair member
    - red blocks green
    - blue blocks yellow
    - black blocks white



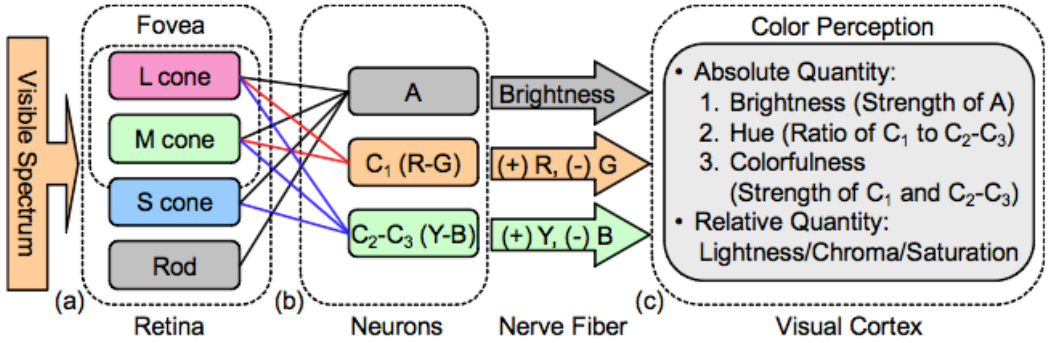
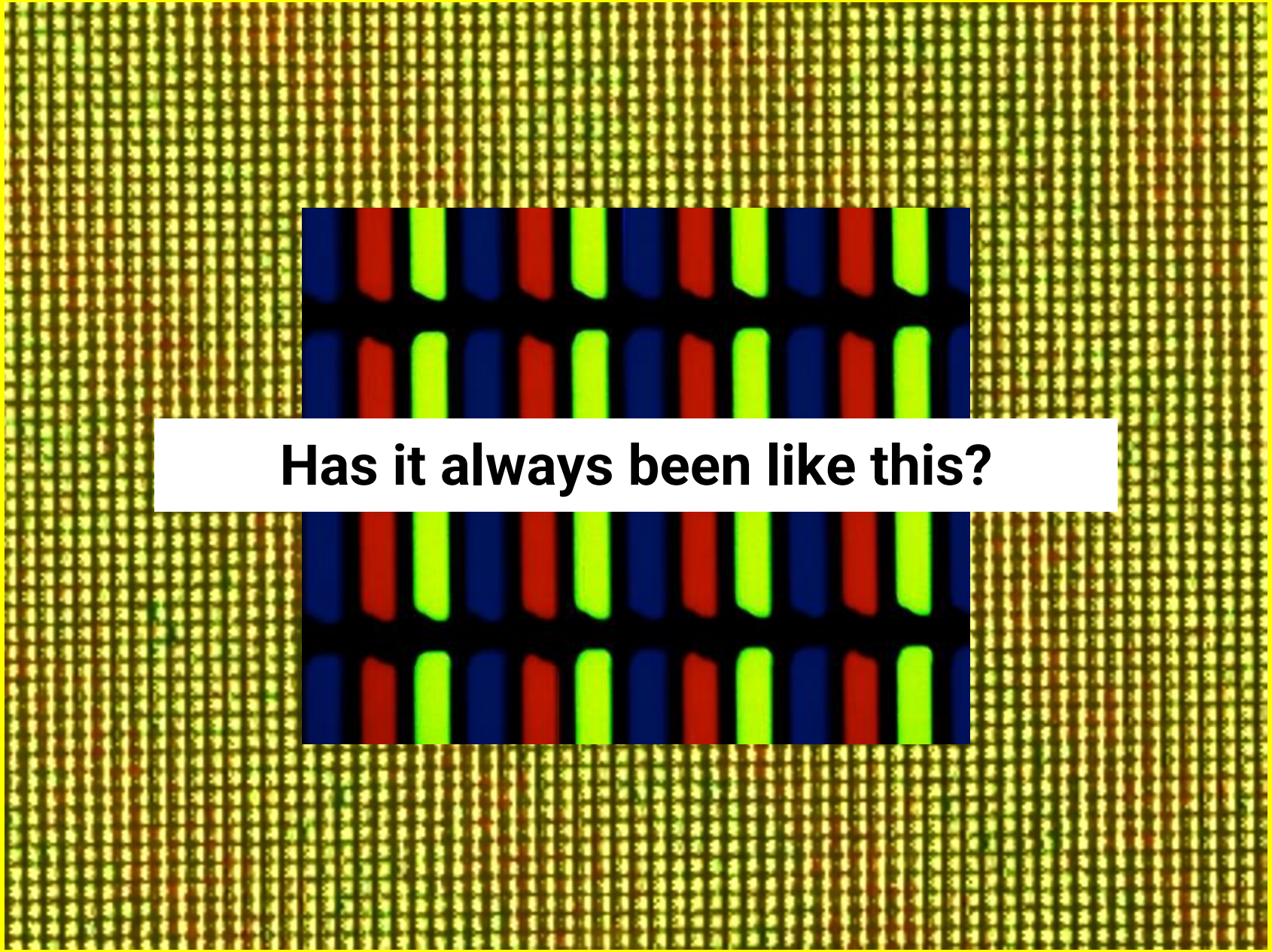


Diagram of the opponent process, CC BY-SA 3.0, https://en.wikipedia.org/wiki/Opponent_process


Has it always been like this?

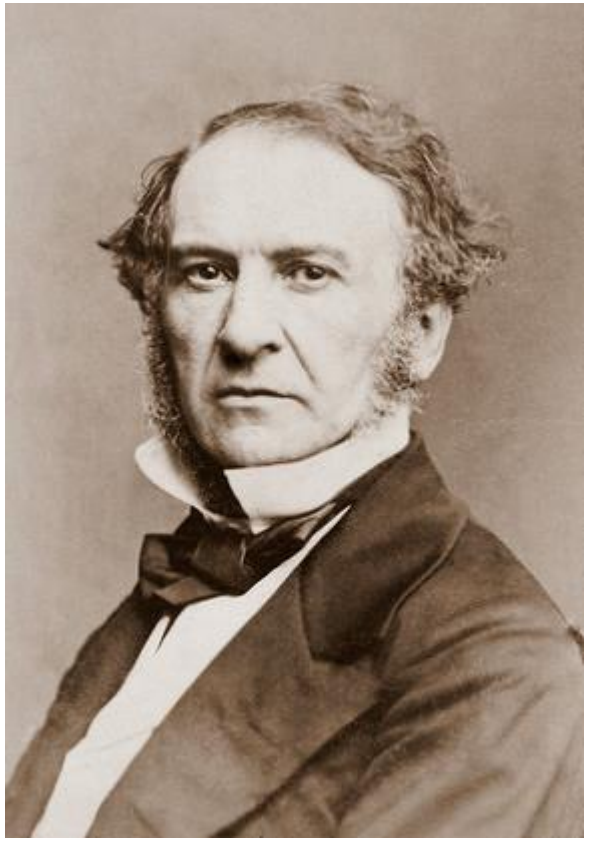
*“And jealous now of me, you gods, because I befriend a man, one I saved as he straddled the keel alone, when Zeus had blasted and shattered his swift ship with a bright lightning bolt, out on the **wine-dark sea**.”*

- Homer, The Odyssey, Book V

J. M. W. Turner - The Yorck Project (2002) 10.000 Meisterwerke der Malerei (DVD-ROM), distributed by DIRECTMEDIA Publishing GmbH. ISBN: 3936122202.
Image from https://www.goodreads.com/review/show/2163306189

History of Color Perception

- William E. Gladstone published a three-volume work on Homer around 1858
  - He noticed that **Homer had problems to describe colors**
    - 200x the word black
    - 100x the word white
    - 15x the word red
    - 10x the word yellow
    - 10x the word red
    - honey → green
    - sky → bronze
  - **not a single word with the colors “blue” or “orange”**
- The color “blue” appears not even once in the New Testament



William Ewart Gladstone, Prime Minister of the United Kingdom, 1861

The Problem with Blue

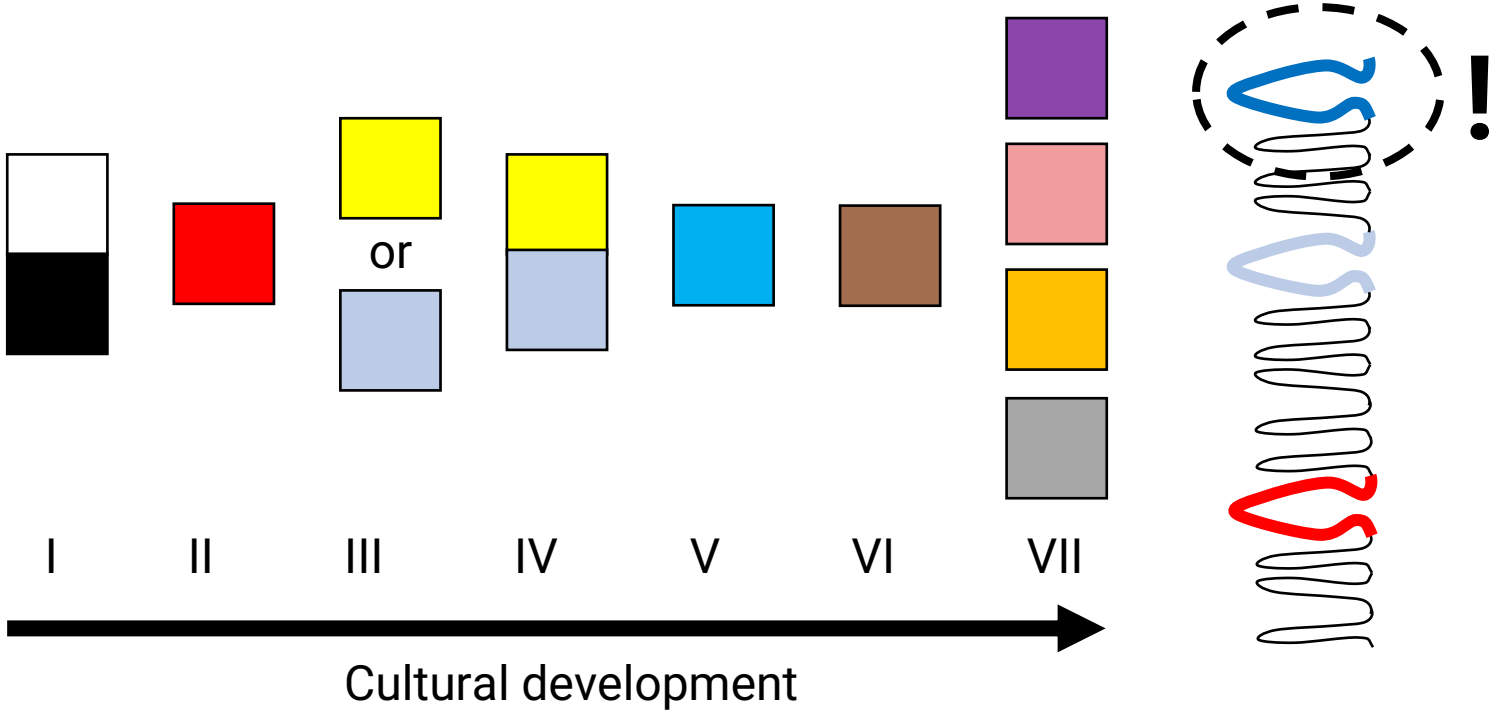
- Blue pigments cannot be found in nature

Do not absorb blue light, cancel out other colors

„hyacinthine purple„
„tyrian purple“
King James Bible (1611) translated both as “blue.” (because they were talking about the sky)

Linguistic Relativity

- **Color terms in a language are predictable by the number of color terms**
- All human cultures have terms for black/dark and white/bright. If a culture has three color terms, the third is red. If a culture has four, it has yellow or green, and so on…

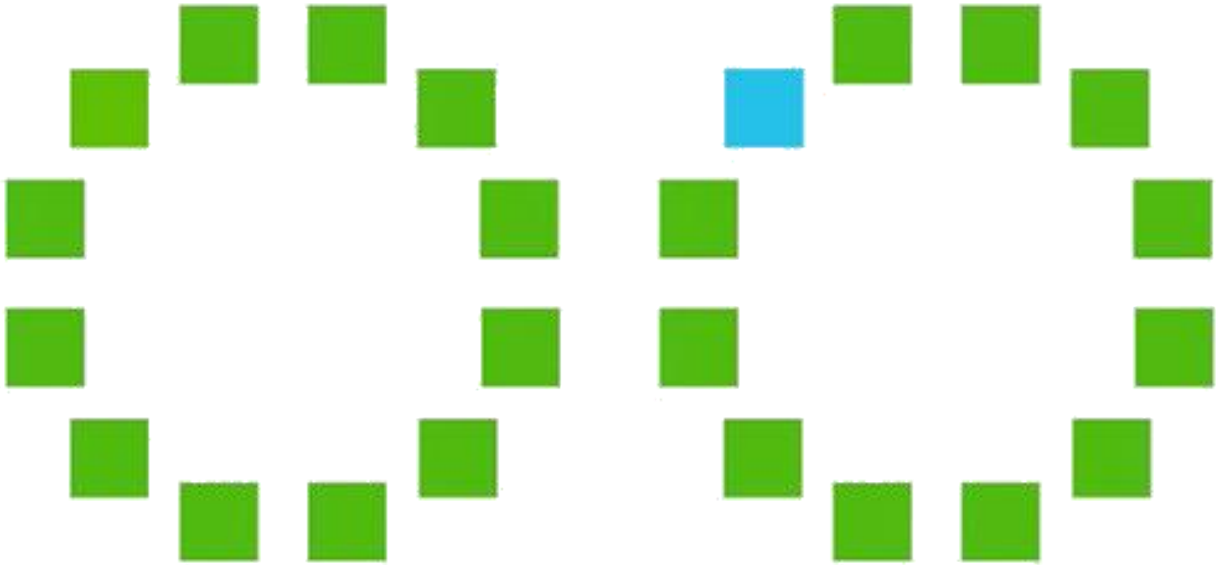


Basic Color Terms: Their Universality and Evolution, (1969) Brent Berlin and Paul Kay, (ISBN 1-57586-162-3)

Sapir-Whorf-Hypothesis

- The **structure of a language affects** world view and **perception** of a person
- The human **perception is relative** to the spoken **language**
- There is a **strong** and **weak** version in **linguistic relativity**
  - strong: *“language determines thought and that linguistic categories limit and determine cognitive categories”*
  - weak: *„linguistic categories and usage only influence thought and decisions”*
- Racists often use the number of words for categories as a measure of intellectual superiority over others (which is wrong)
- Perception does not only emerge with experience but also from the cultural need to distinguish it

The Himba Tribe Example

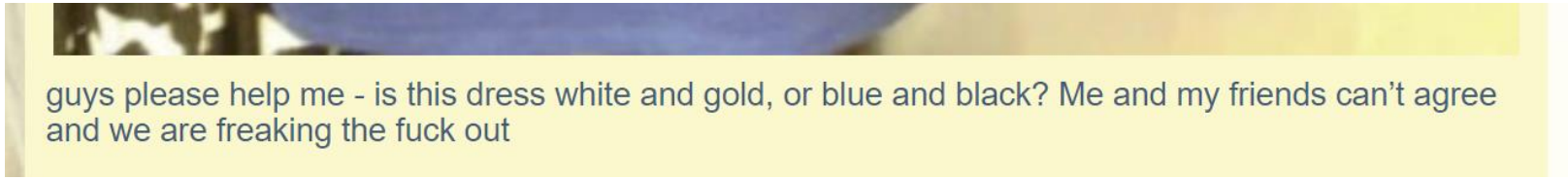


Distinguishable by Himba tribe

Distinguishable by English speakers

The Dress

- A Tumblr user named “Swiked” posted a picture of a dress on the Internet on February 25, 2015



- The dress was the subject of 4.4 million tweets within 24 hours
- The actual colors were black and blue
- However, many people do not agree and see white and gold
- The image prompted many discussions on the colour and how they perceived the dress

The original dress picture, Roman Originals, https://en.wikipedia.org/wiki/The_dress

The Dress

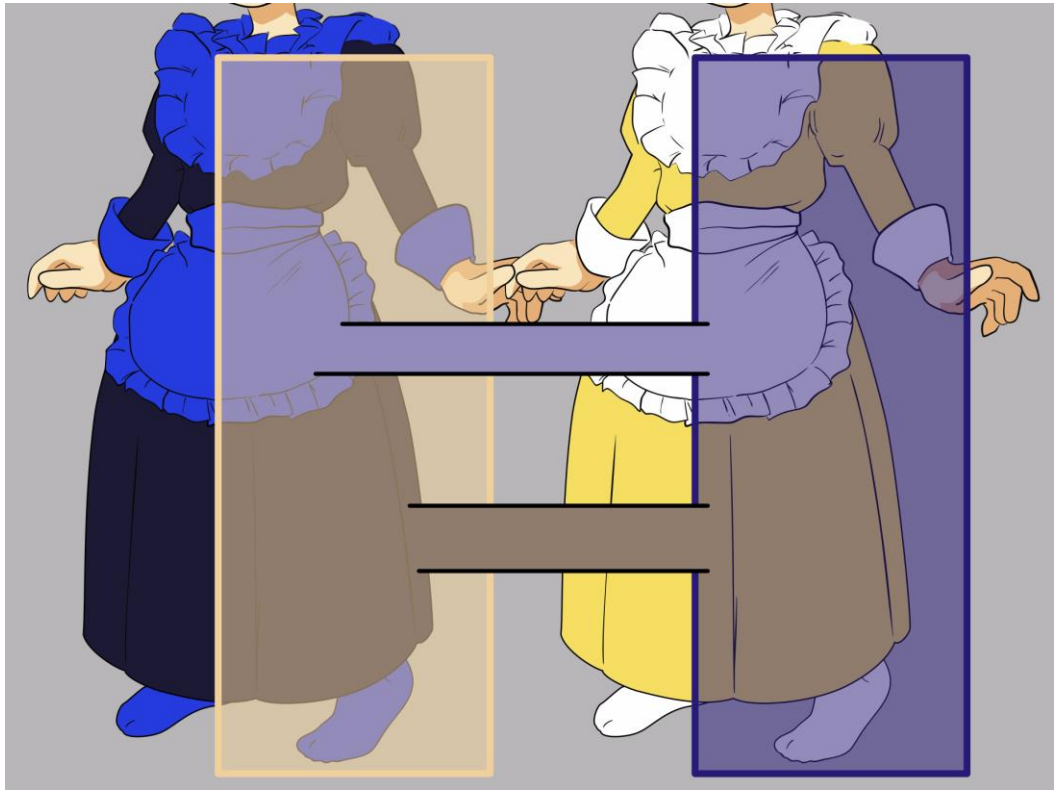
- **57%** see the dress as **blue and black**
- **30%** see it as **white and gold**
- **11%** see it as **blue and brown**
- **10%** can **switch** between any of the color combinations
- People either discount
  - the blue side, in which case they end up seeing **white and gold**
  - the gold side, in which case they end up with **blue and black**
- Women and older people disproportionately see the dress as white and gold

The original dress picture, Roman Originals, https://en.wikipedia.org/wiki/The_dress

Chromatic Adaption

- The **biggest known individual difference** in vision **after the red-green blindness**
- The effect **was unknown until „the dress“**
  - Mainly occurs with blue colors
- The phenomenon has a connection to **how the brain processes the various hues of a daylight sky and depends if someone is regularly exposed to the blue sky**
  - Vision is trying to discount the chromatic bias of the daylight axis
  - People who see white and gold show increased activity in the frontal and parietal regions of the brain

  → Areas critical in higher cognition activities



Wikipe-tan wearing The Dress https://en.wikipedia.org/wiki/The_dress

Color Depth

- 1 Bit: 2 colors (Binary images, LCDs)
- 4 Bit: 16 colors (EGA-GPUs)
- 6 Bit: 64 colors (Amiga 64)
- 16 Bit: 65.536 colors (High Color Mode, Windows 95)
- **20 Bit: 1.048.576 colors (number of colors humans can distinguish)**
- 24 Bit: 16.777.216 colors (True Color Mode, Windows 2000)
- 30 Bit: 1.073.741.824 colors (Deep Color, HDR)
- 36 Bit: 68.719.476.736 colors (Deep Color, HDR10+, Dolby Vision)

BRAVIA
SONY

?

Dynamic Range

- Human **vision** is capable of **adapting to light conditions** that range over nearly ten orders (10^1-10^{10})
- Humans **cannot perform these feats of perception at both extremes** of the scale at the same time
  - **Up to about 1:1,000,000 are simultaneously visible** (daylight conditions).
  - Humans **continually "record" images with different color ranges** and combine them into one complete **mental high dynamic range image** of the scene
  - A in a moonless night, humans perceive stars with 1:1,000,000,000 (90 dB) of the illumination they would have on a bright sunny day
    - No camera has this dynamic range
    - However, the eyes don't see more detail after staring at something > 10-15 seconds.

Dynamic Range & Tone Mapping

- **Digital Cinema Cameras** (e.g., Red Weapon 8k) are able to **capture** multiple stops to capture a **dynamic range**
- Some displays are able to map the dynamic range (15 stops) of the human eye (21 stops)
- Images or videos need a downsampling of the dynamic range to fit the dynamic range of the display
- Tone mapping uses a combination of multiple exposures of the same scene
- Retains details in light and dark areas

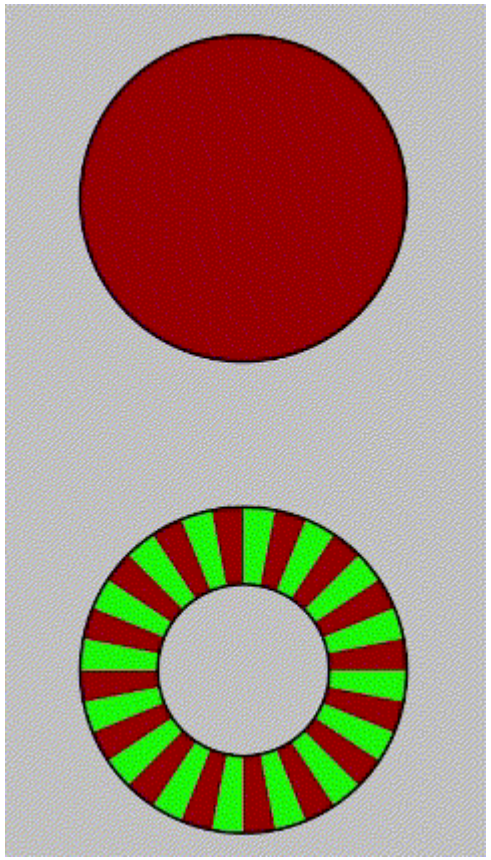
© Bartłomiej Okonek https://www.easyhdr.com/examples/

Motion Perception

1. **Detecting dangers**: animals/humans recognize when an attacker moves
2. **Create attention**: attention is focused on motion. If you are in a large group, you can draw attention to yourself by waving
3. **Detecting objects**: an object can stand out from its background or helps to make its shape more recognizable
4. **Information about environment**: gestures, for example, can give hints about the intensity of a conversation
5. **Spatial perception**: our brain also uses the movement information for spatial perception (e.g. motion parallax)

Flicker Fusion Threshold

- The **frequency** at which an intermittent light stimulus **appears to be steady**
- Cathode ray tube (CRT) displays are usually operated at a vertical scan rate of 60 Hz, which often resulted in noticeable flicker
  - Many systems allowed increasing the rate to higher values such as 72, 75 or 100 Hz to avoid this problem
  - Most people do not detect flicker above 400 Hz
  - Depends on the wavelength and photoreceptor cells
- Other display technologies do not flicker noticeably, so the frame rate is less important
  - negligible for LEDs or TFT Displays



Motion Perception

- **Perception of movement distinguish between short-range and long-range distances** of the movement jumps
- **Short-range distance** (small viewing angles)
  - first-order: movement derived directly from luminance changes
  - second-order: movement derived from structural or contrast changes
- **Long-range distance** (large viewing angles)
  - third-order: The movement is derived from the change of any object features and do not depend on low but on a high-leveled order cognitive mechanism in the human brain
- The exact causes and thresholds between short- and long-range distance are still unclear!
  - There are two known motion percepts: **the beta movement** and the **phi phenomenon**

Beta Movement

- Describes **an apparent movement** of an object, whose physical properties (shape, size, color) are identical to the properties of stationary targets
- **Two stimuli** a + b appear in succession, but are perceived as the **motion of a single object**
  - A series of static images on a screen **creates the optical illusion of movement**
- Occurs when the frame rate is about **10 to 12 images per second**
  - **Value must be above the number of microsaccades** that can occur in 1 second
- Does not fully explain the apparent motion in film

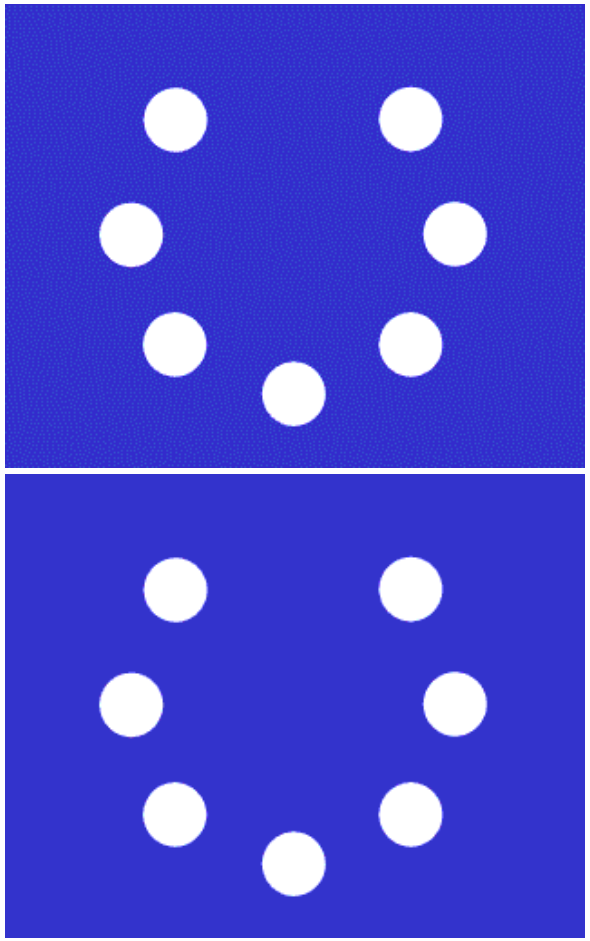


Image source: visual-memory.co.uk Beta movement

Phi Phenomenon

- **Occurs at faster frame rates**, and if the distance between the stimuli is in a certain limit (with high individual differences)
- **Two stimuli** a + b appear in succession, but are **perceived as the motion of a vague shadowy something** passing (a over b)
  - **An illusory ”object” with the same colour as the background is seen moving** between the two stimuli
  - Perceived as **“pure” motion** uncontaminated (as in beta movement) by form cues
- The whole process is **not well understood**
- Does not fully explain the apparent motion in film

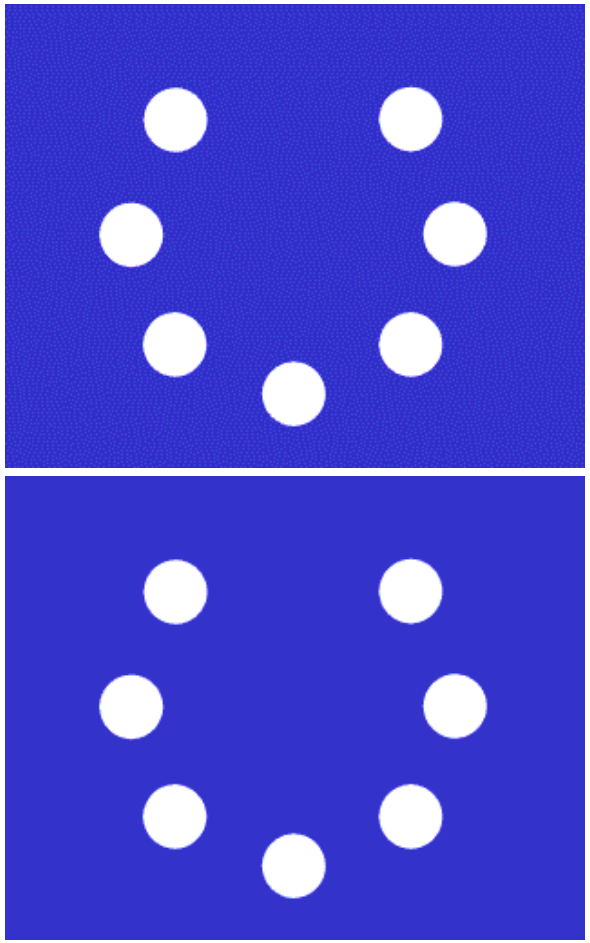


Image source: visual-memory.co.uk Beta movement

Eye and Head Movement Correction

- **Two motion cues**: The difference of an object location on an image seen by the left and right eye
  - **Retinal movement**: when the image shifts on the retina and receptors are stimulated

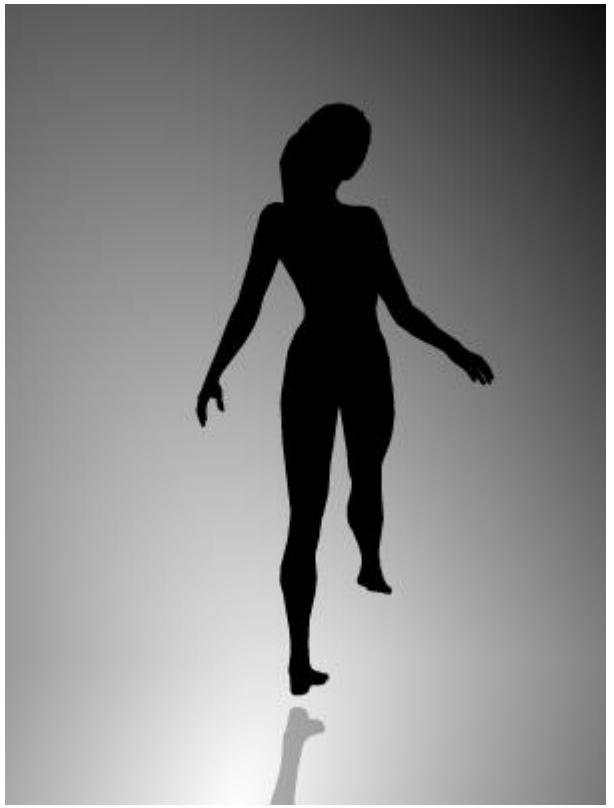
    → the further the object is moving, the lower the retinal shift
  - **Eye Movement**: retinal image remains the same retina because the object is being tracked with the eyes or even the entire head

    → inferring the speed and direction of objects based on vestibular and proprioceptive inputs
- **Efference copy**: a copy of the motor signal sent to other areas of the brain instead of the eye muscles to differentiate between the movement of the own body (especially the eye movement) and an object's movement

  → important for all movement-producing signals generated by the motor system

Motion and Depth Cues

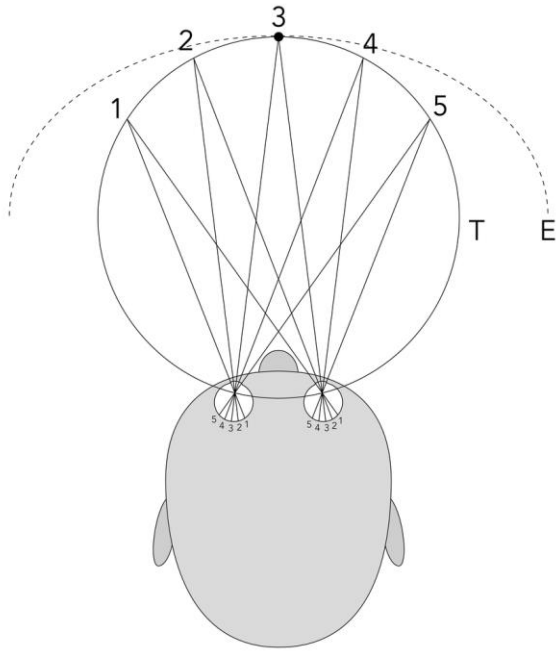
- **Motion parallax**: When an observer moves, the apparent relative motion of several stationary objects against a background gives hints about their relative distance
- **Depth from motion**: When an object moves toward the observer, the retinal projection of an object expands over a period of time, which leads to the perception of movement in a line toward the observer
- **Kinetic depth effect**: refers to the phenomenon whereby the three-dimensional structural form of an object can be perceived when the object is moving

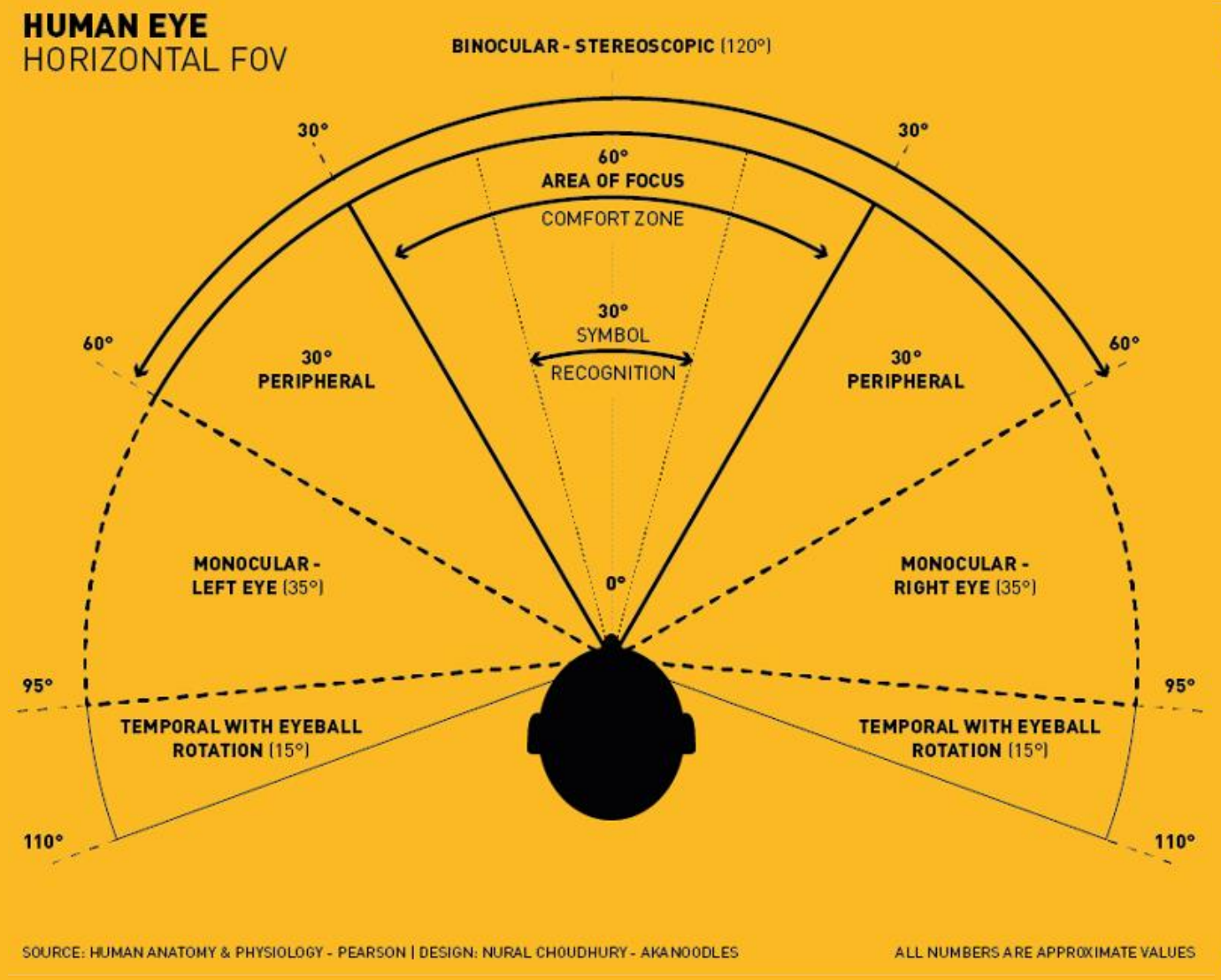


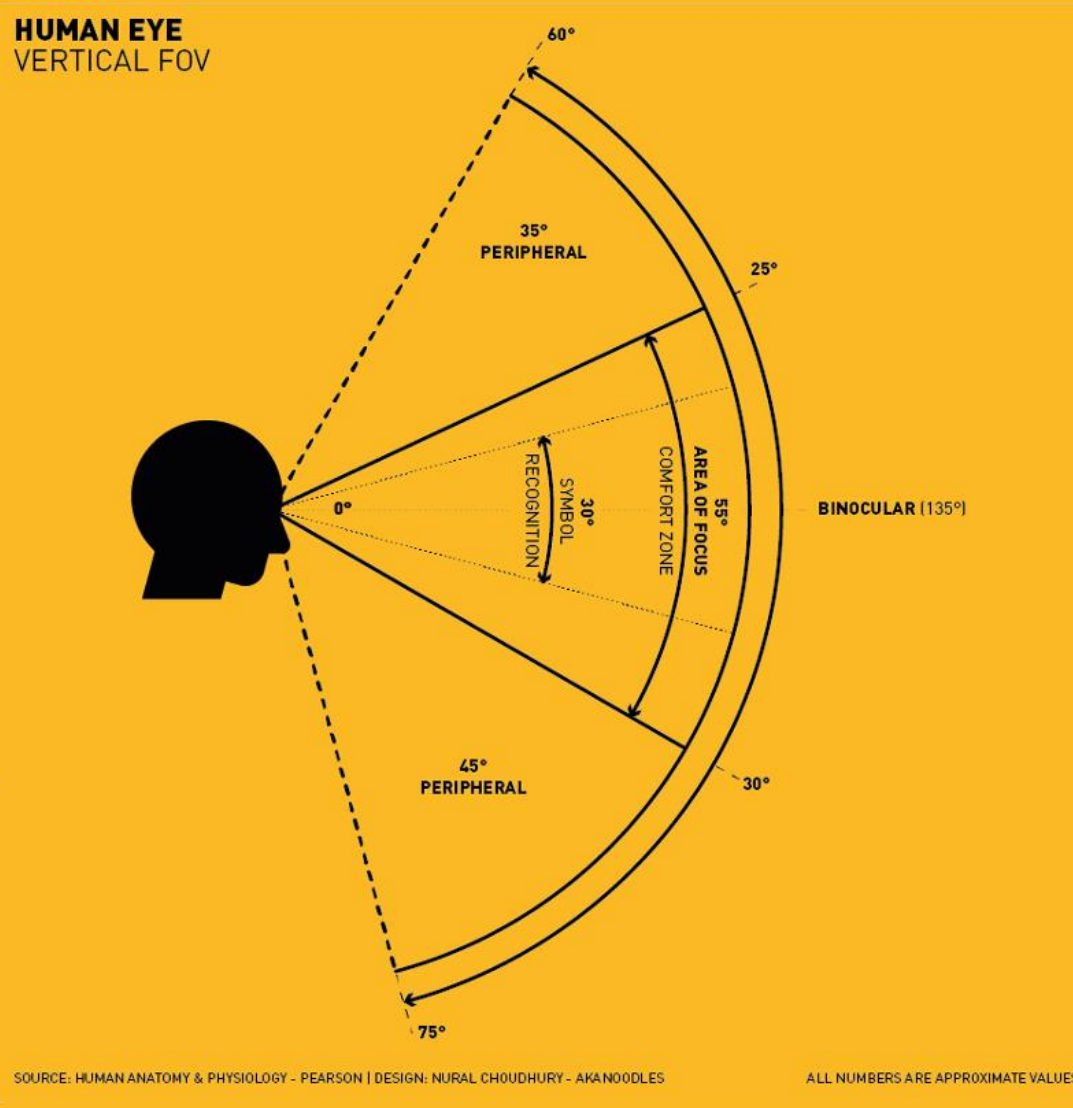
The Spinning Dancer, CC BY-SA 3.0, https://en.wikipedia.org/wiki/Kinetic_depth_effect

Stereo Vision

- **Binocular disparity (or parallax):** different positions of the eyes provide precise depth perception
- Binocular vision enables a maximum **horizontal field of view of ~190°**
  - ~120° horizontal monocular
  - the vertical range of the visual field in humans is around 150 degrees)
- **Determines the line of sight**, relative to each other (vergence) and relative to a particular object (angle)
- **Allows to see more of an object behind an obstacle**

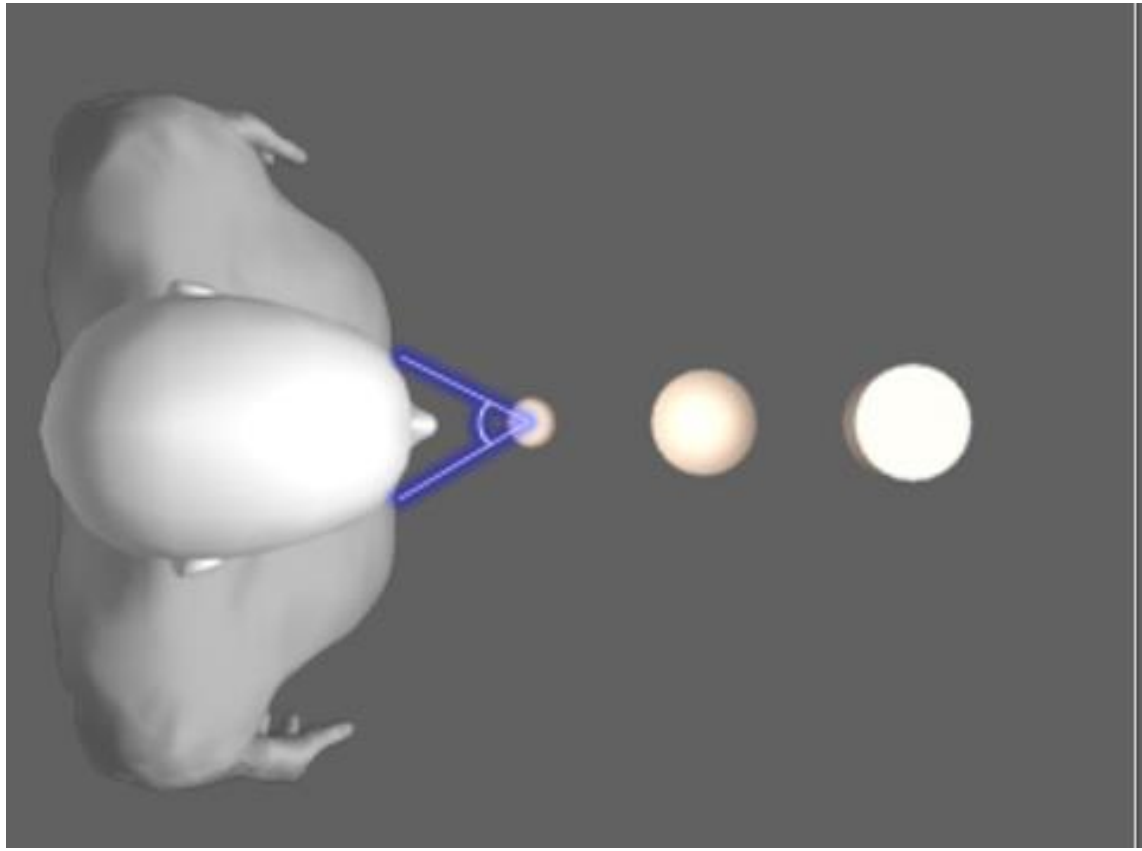



HUMAN EYE
HORIZONTAL FOV
BINOCULAR - STEREOSCOPIC (120°)
30°
30°
60°
AREA OF FOCUS
COMFORT ZONE
30°
SYMBOL
RECOGNITION
60°
60°
30°
PERIPHERAL
30°
PERIPHERAL
MONOCULAR -
LEFT EYE (35°)
MONOCULAR -
RIGHT EYE (35°)
0°
95°
95°
TEMPORAL WITH EYEBALL
ROTATION (15°)
TEMPORAL WITH EYEBALL
ROTATION (15°)
110°
110°
SOURCE: HUMAN ANATOMY & PHYSIOLOGY - PEARSON | DESIGN: NURAL CHOUDHURY - AKANOODLES
ALL NUMBERS ARE APPROXIMATE VALUES

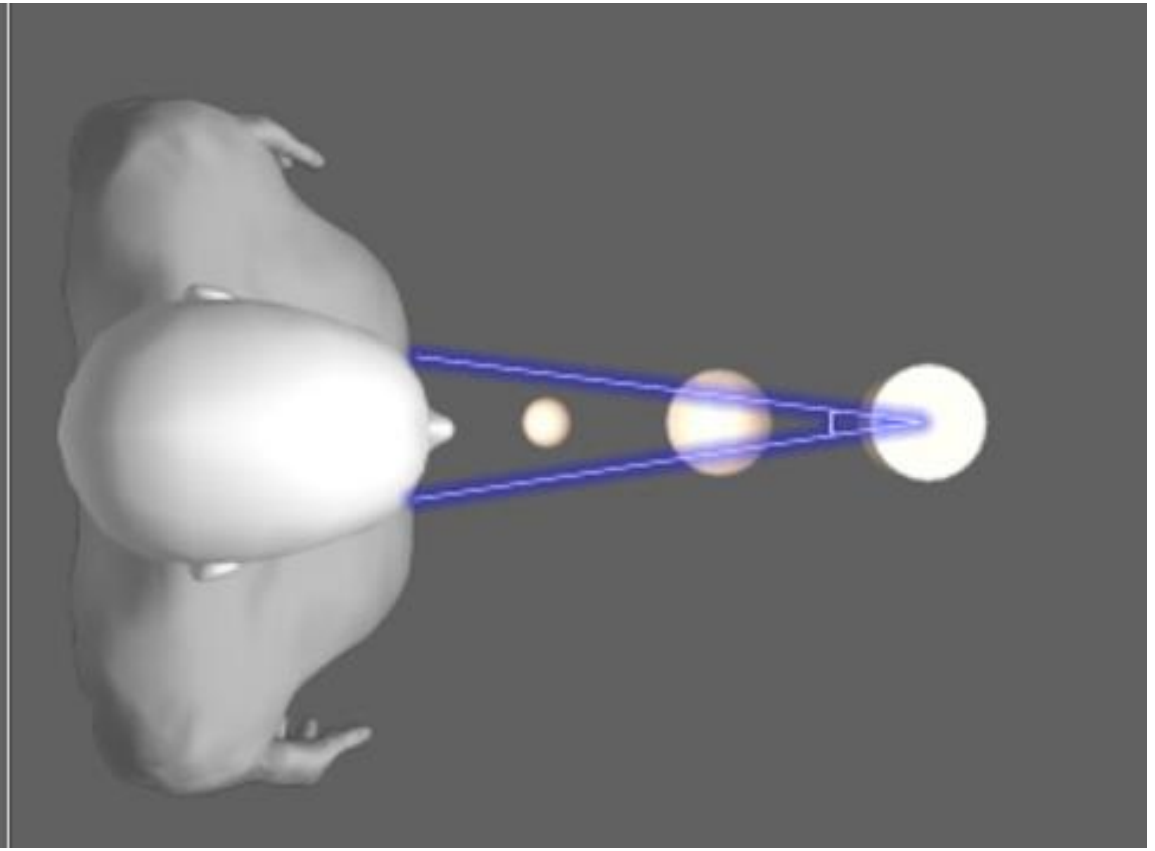

HUMAN EYE
VERTICAL FOV
60°
35°
PERIPHERAL
25°
0°
30°
SYMBOL
RECOGNITION
55°
AREA OF FOCUS
COMFORT ZONE
BINOCULAR (135°)
45°
PERIPHERAL
30°
75°
SOURCE: HUMAN ANATOMY & PHYSIOLOGY - PEARSON | DESIGN: NURAL CHOUDHURY - AKANOODLES
ALL NUMBERS ARE APPROXIMATE VALUES

Wide Field Displays

Parallax in Stereo Vision



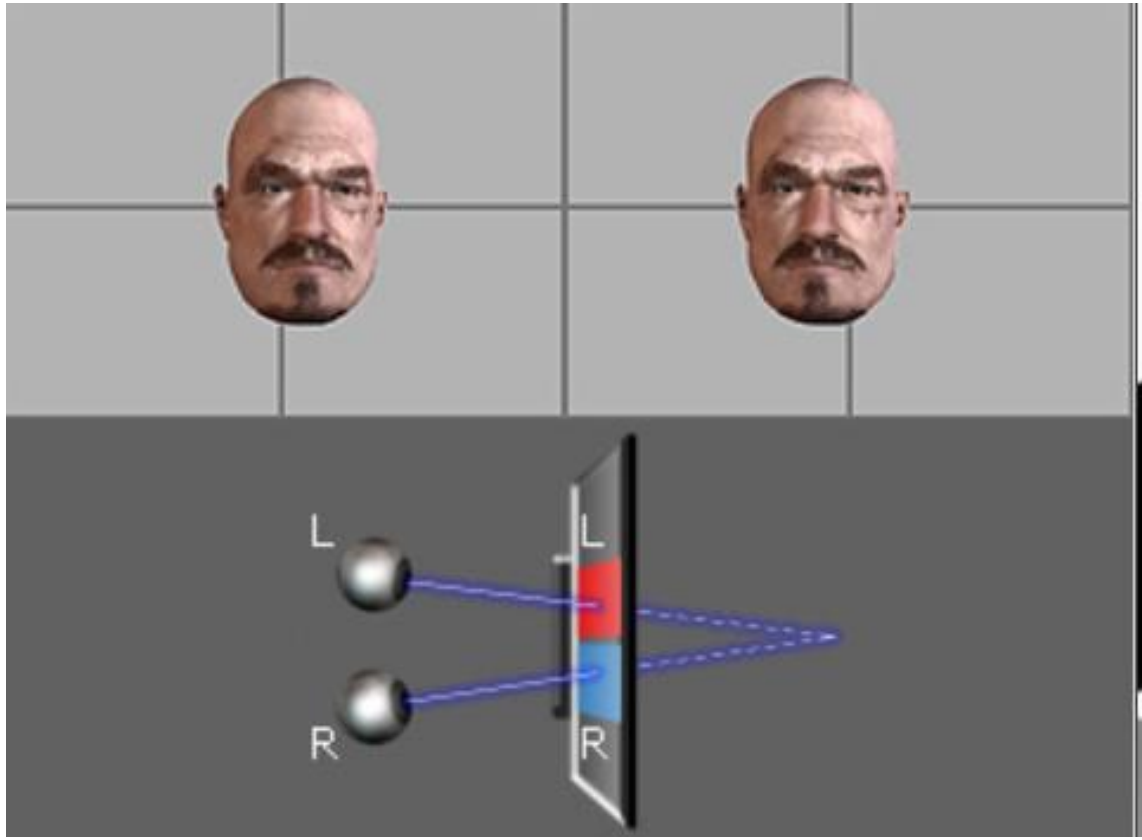
High Convergence (near object)



Low Convergence (far object)

Positive Parallax

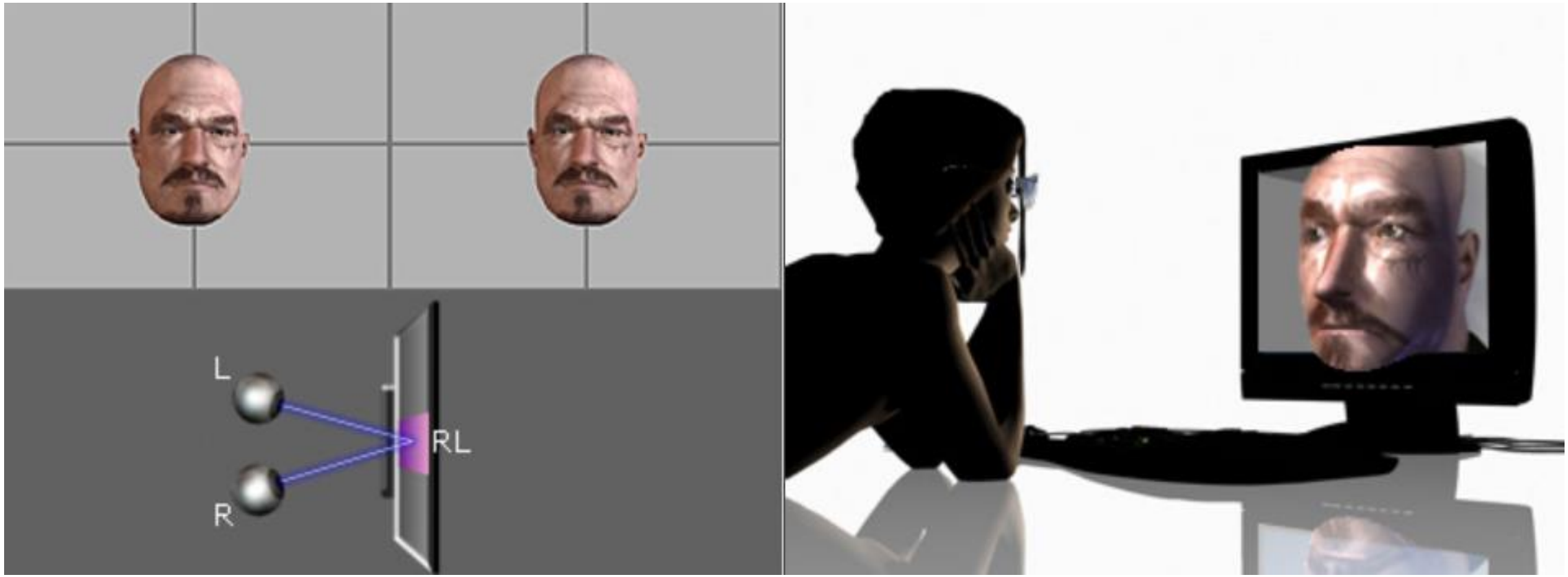
- Convergence falls behind the display



All images from : http://www.reallusion.com/crazytalk/help/CrazyTalk6/09_3D_Vision/The_Concepts_of_Stereo_Vision.htm

Zero Parallax

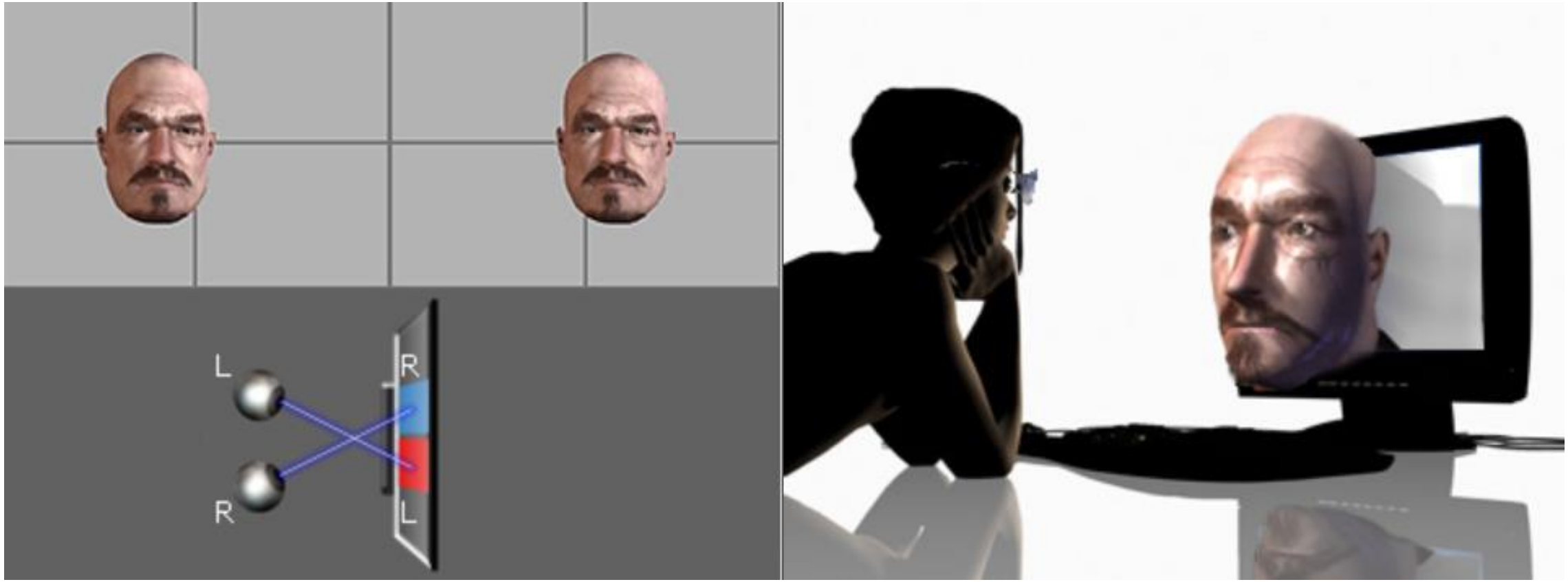
- Convergence falls on the display



All images from : http://www.reallusion.com/crazytalk/help/CrazyTalk6/09_3D_Vision/The_Concepts_of_Stereo_Vision.htm

Negative Parallax

- Convergence falls in front of the display

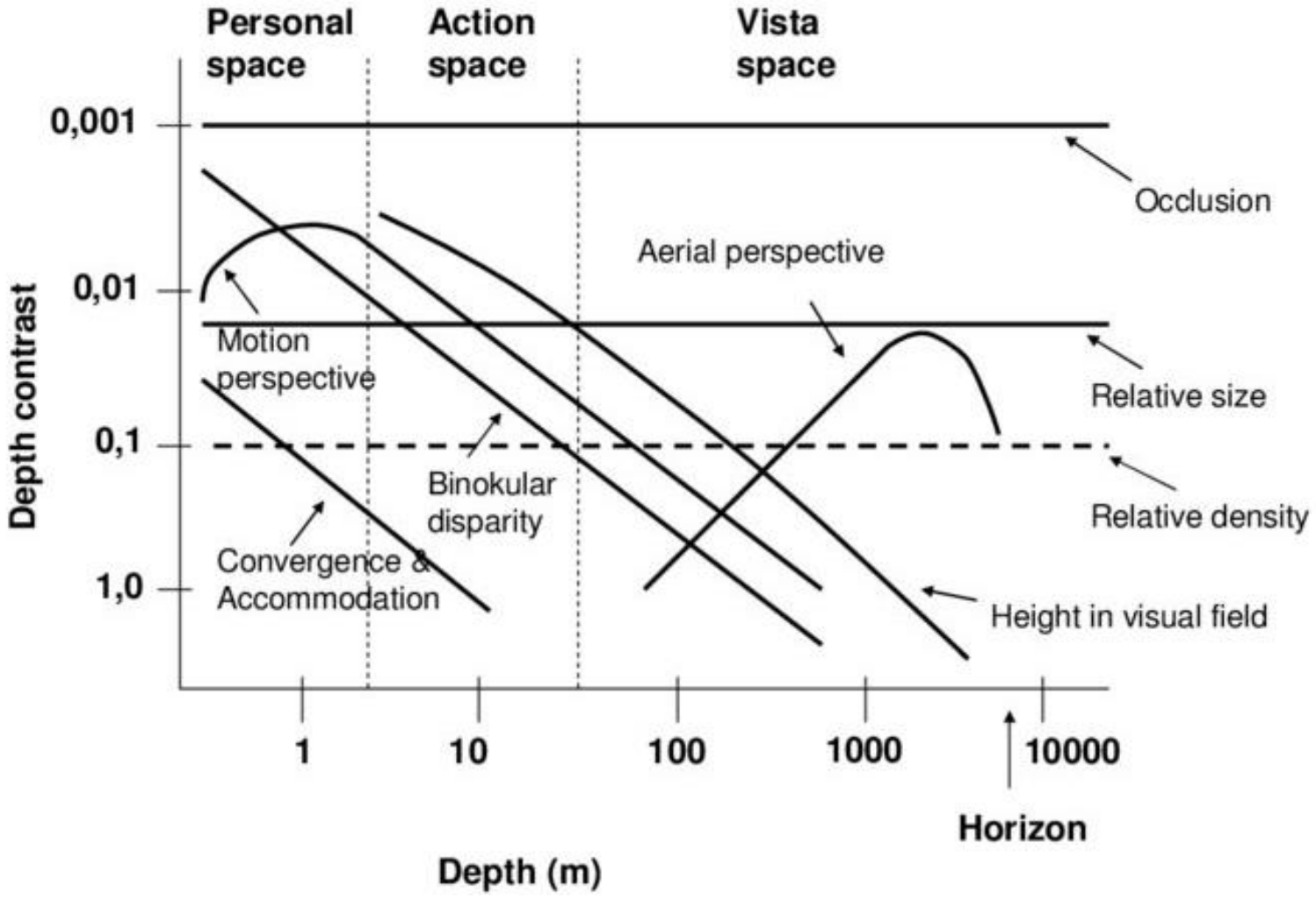


All images from : http://www.reallusion.com/crazytalk/help/CrazyTalk6/09_3D_Vision/The_Concepts_of_Stereo_Vision.htm

Depth Perception

- **Absolute and relative size**: the known size of objects provide information about their distance
- **Convergence**: parallel lines in a three-dimensional space appear to converge
- **Accomodation**: perceived change in the thickness of the lens of the eyes
- **Light and shadow**: patterns of light and shadow result in a 3D appearance
- **Occlusion**: when one object blocks another, it appears to be closer
- **Defocus blur**: depth of focus of the eye
- **Aerial**: contrast and saturation of objects decreases due to smog, fog, dust, and fine particles in the atmosphere

Importance of Depth Cues



Negative Parallax

- Depth Perception using stereoscopic glasses

Stereoscopic image by coloring the two pictures, Tamar Hayardeni תמר הירדני - Own workCC BY-SA 4.0 Wikipedia.org

Pocket Stereoscope, Joaquim Alves Gaspar - Own work (own photo) CC BY 2.5

Hearing

Sounds and the vestibular system

Image https://pxhere.com/en/photo/1428401 by mbpogue

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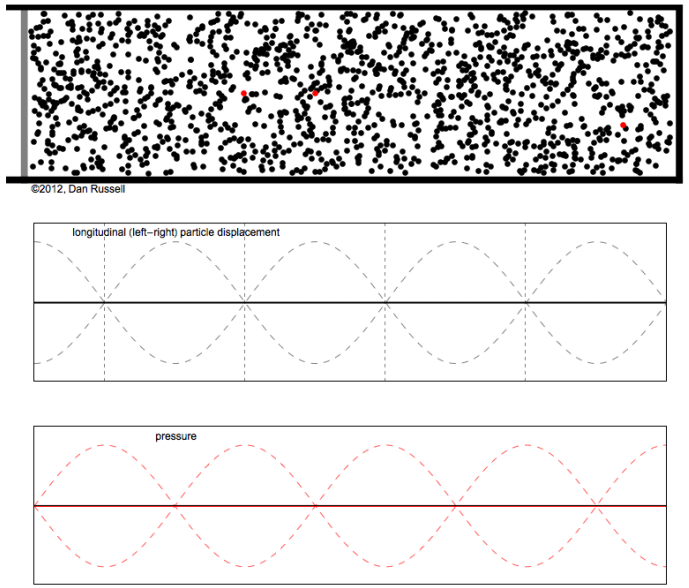
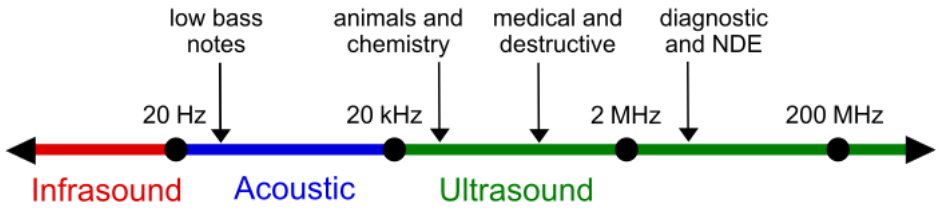
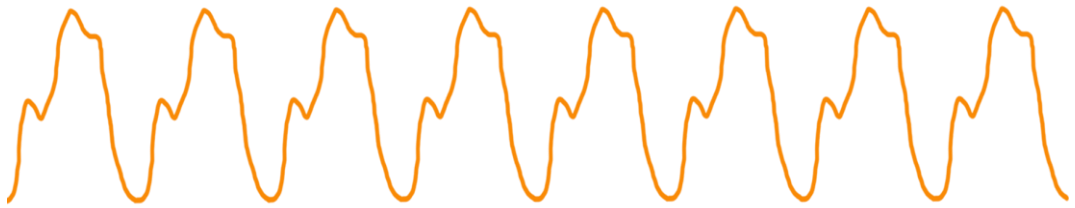
Propagation of Sound Waves

- Sound: changes of air pressure in the perceivable frequency range
- Hearing: sensory perception of sound





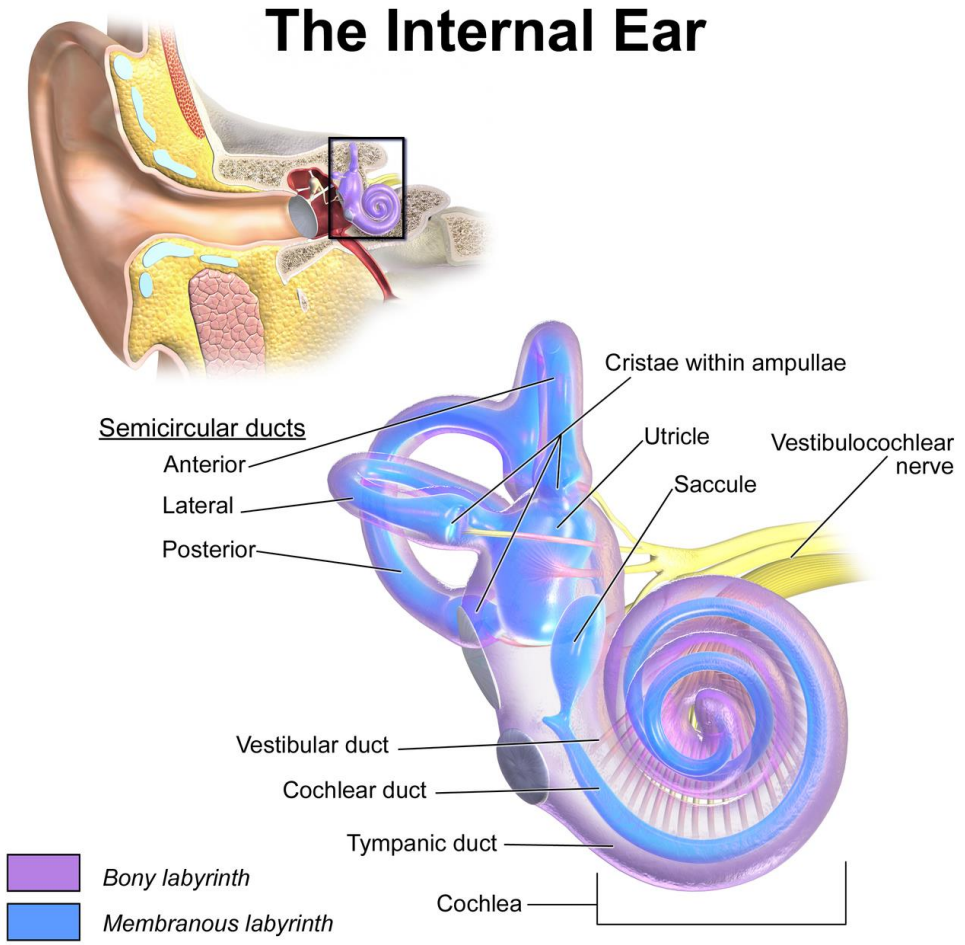


C note 220Hz

Image Source https://commons.wikimedia.org/wiki/File:Standing.gif by Daniel A. Russell & https://commons.wikimedia.org/wiki/File:Ultrasound_range_diagram.svg by Mikhail Ryazanov

Auditory Perception

- Ears detect **changes of pressure** in the surrounding medium (not necessarily air)
- The auditory system consists of
  - **the outer ear (the visible part)**
    - The asymmetry filters sound depending on the vertical location (enables vertical sound localization)
  - **the middle ear (known as hammer, anvil, stirrup)**
    - Transmission of vibrations and impedance matching from the eardrum to the inner ear
  - **the inner ear (cochlea and vestibular system)**
    - A fluid-filled spiral with a membrane in which frequencies are transformed into location-based signals

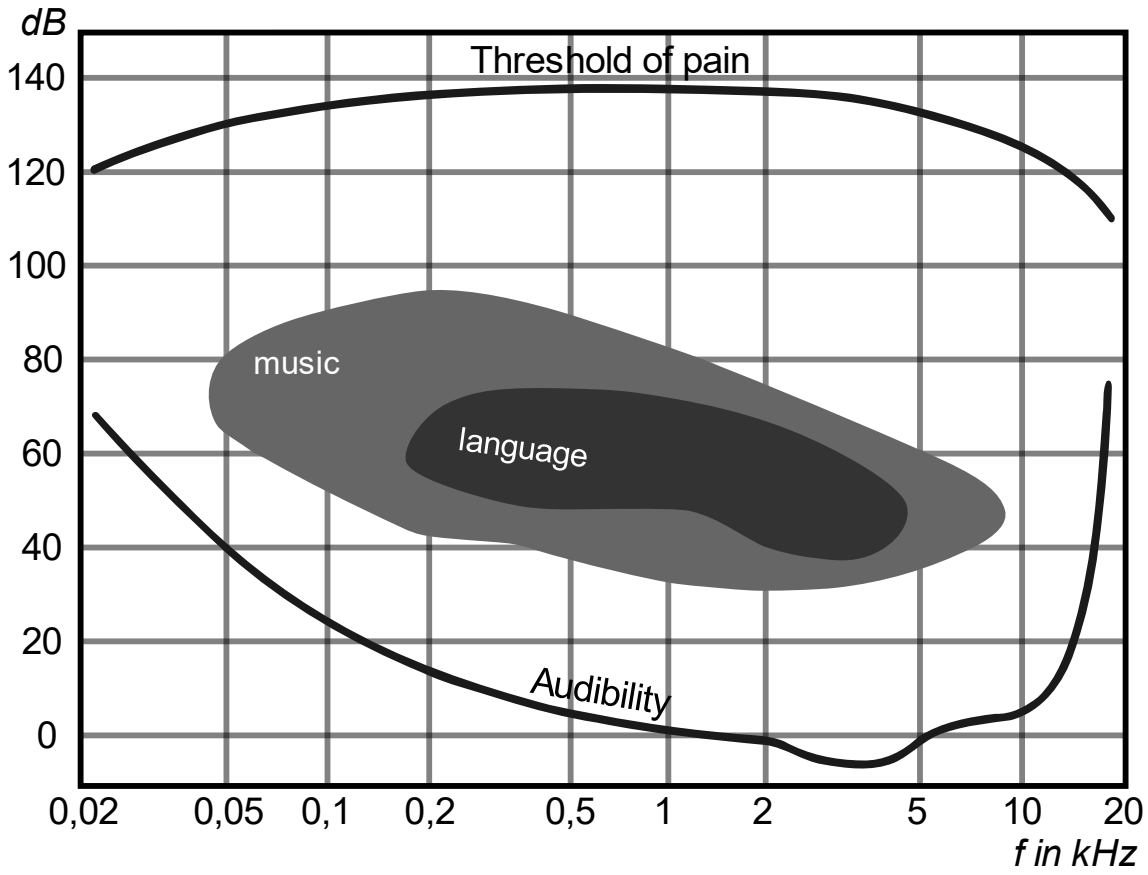


Sound Localization

- **Inter-aural time differences** are calculated in the brainstem (some cells are more directly connected to one ear than the other)
  - Does not explain the **precedence effect** – sound followed by another sound is being separated after a short time delay (below a listener's echo threshold)
  - There are also neurons sensitive to inter-aural time differences inhibiting the stimulation of the other ear
- Cues for **sound source localization**
  - Time- and level-differences (or intensity-difference) between both ears
  - Spectral information
  - Timing
  - Correlation analysis
  - Pattern matching

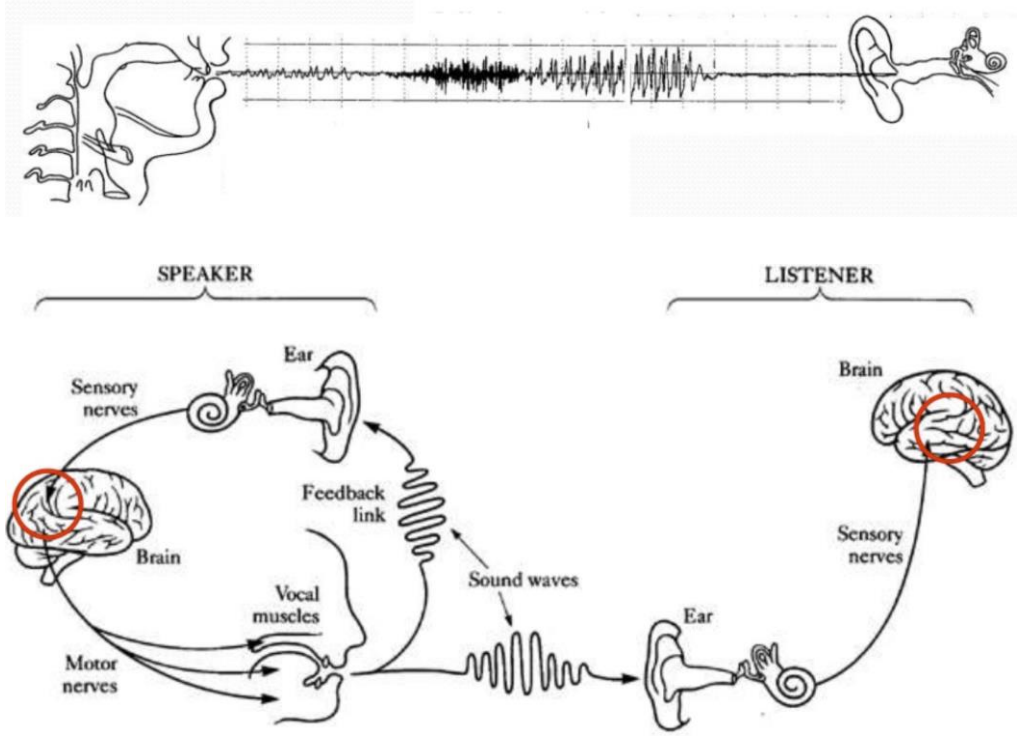
Hearing Range

- **From ~20 to ~20.000 Hz** (laboratory conditions: 12 Hz and 28.000 Hz)
- Humans are most sensitive in a range between 2.000 and 5.000 Hz
  - Language
  - Music
  - Sound
- **Shrinks during life** (men to a higher degree than women)



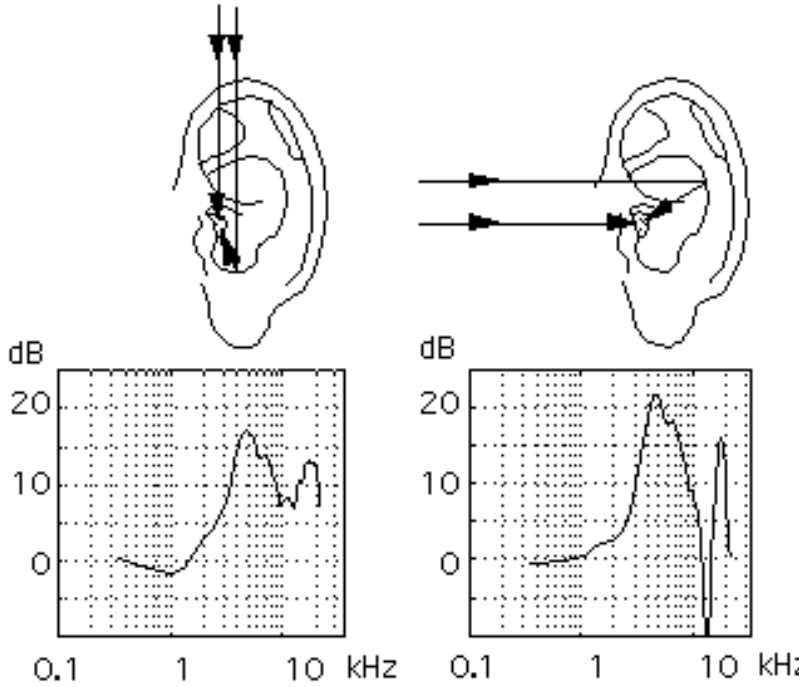
Speech Perception

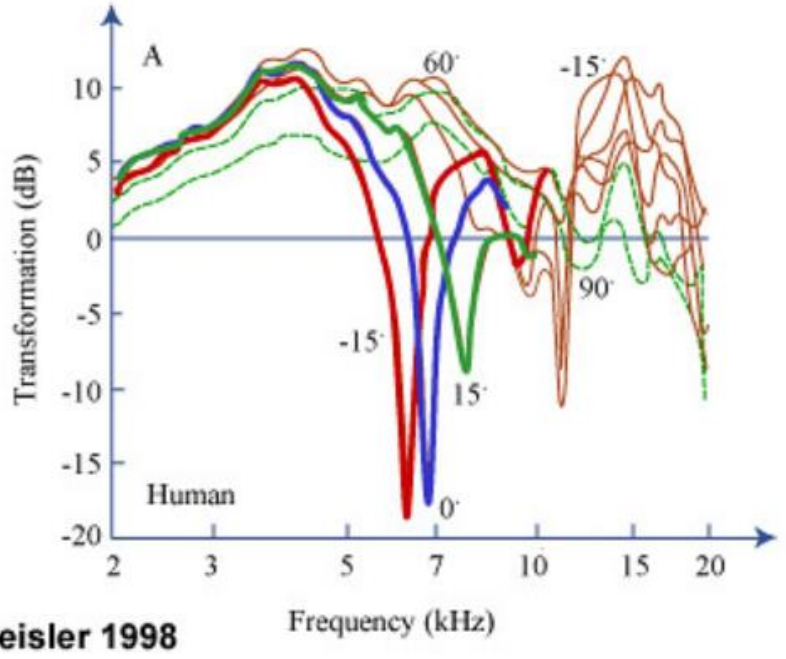
- **Acoustic cues are extracted** and stored in sensory memory and then mapped onto **linguistic information**
- Includes multiples processes
  - Filtering (Cocktail party effect)
  - Abstraction (ignoring individual differences)
  - Identification (who is speaking?)
  - Analysis (Context “I scream” = “ice cream”)
  - Semantics (words, word combinations)
- The average person can speak 125-150 words per minute



McGurk Effect

Head-Related Transfer Function (HRTF)





Geisler 1998

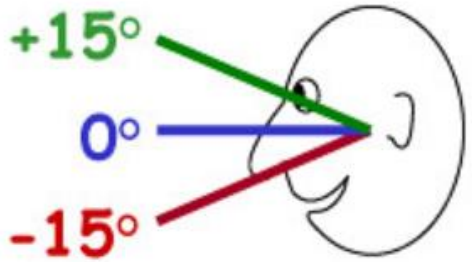


Image Source https://upload.wikimedia.org/wikipedia/commons/1/19/Binaural.gif by T.A.V. Multimedia. Andreu & Vila & https://www.flickr.com/photos/mitopencourseware/4809307652 by MIT OpenCourseWare

Bone Conduction

- **Bones** (mainly the skull) **convey lower-frequency sounds** to the inner ear
  - Hard to locate
- Reason **why the own voice sounds different** when it is recorded any played back
  - people perceive their own voices to be lower and fuller than others
- **Bone conduction speaker** work e.g. underwater and can consume audio content while maintaining situational awareness

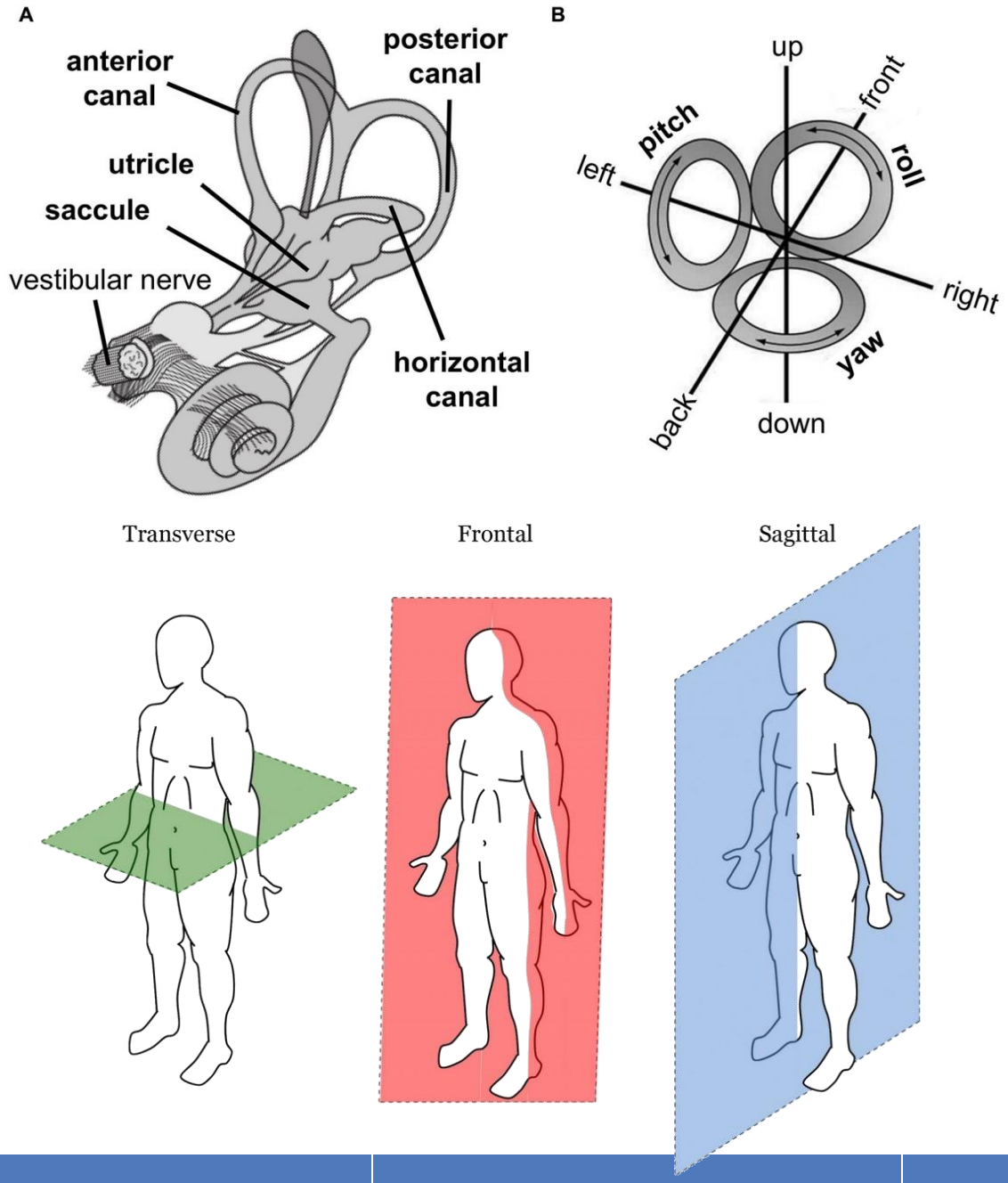
Image Source https://upload.wikimedia.org/wikipedia/commons/1/19/Binaural.gif by T.A.V. Multimedia. Andreu & Vila & https://www.flickr.com/photos/mitopencourseware/4809307652 by MIT OpenCourseWare

Audio and Video Quality

- **Video quality contribute** significantly to the **subjectively perceived audio quality**
  - The effect is about 1.2 x on a media quality scale
  - The reversed effect is much smaller: 0.2 x on a media quality scale
- A mapping from the audio and video quality to the overall audiovisual quality shows that the **video quality dominates the overall perceived audiovisual quality**
  - Only applicable to non-conversational footage

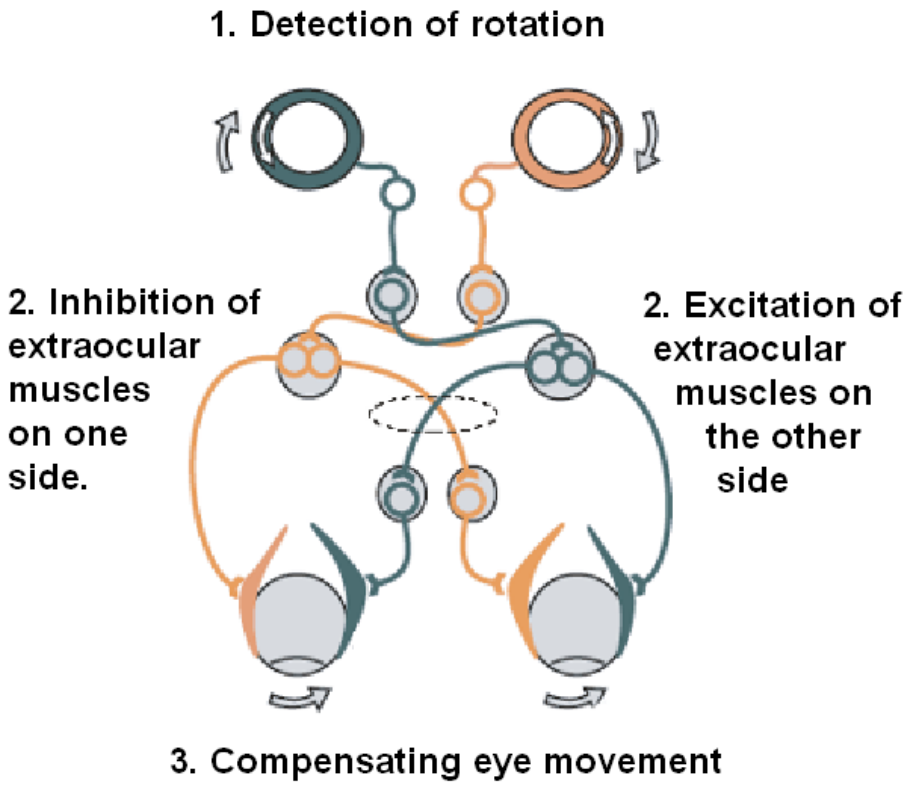
The Inner Ear

- The **horizontal semicircular canal** corresponds to rotation of the head (rotations in the transverse plane)
- The **anterior** and **posterior semi-circular canals** detect rotations in the sagittal plane (nodding) and in the frontal plane (cartwheeling)
  - Working together and orientated at approximately 45° between frontal and sagittal planes

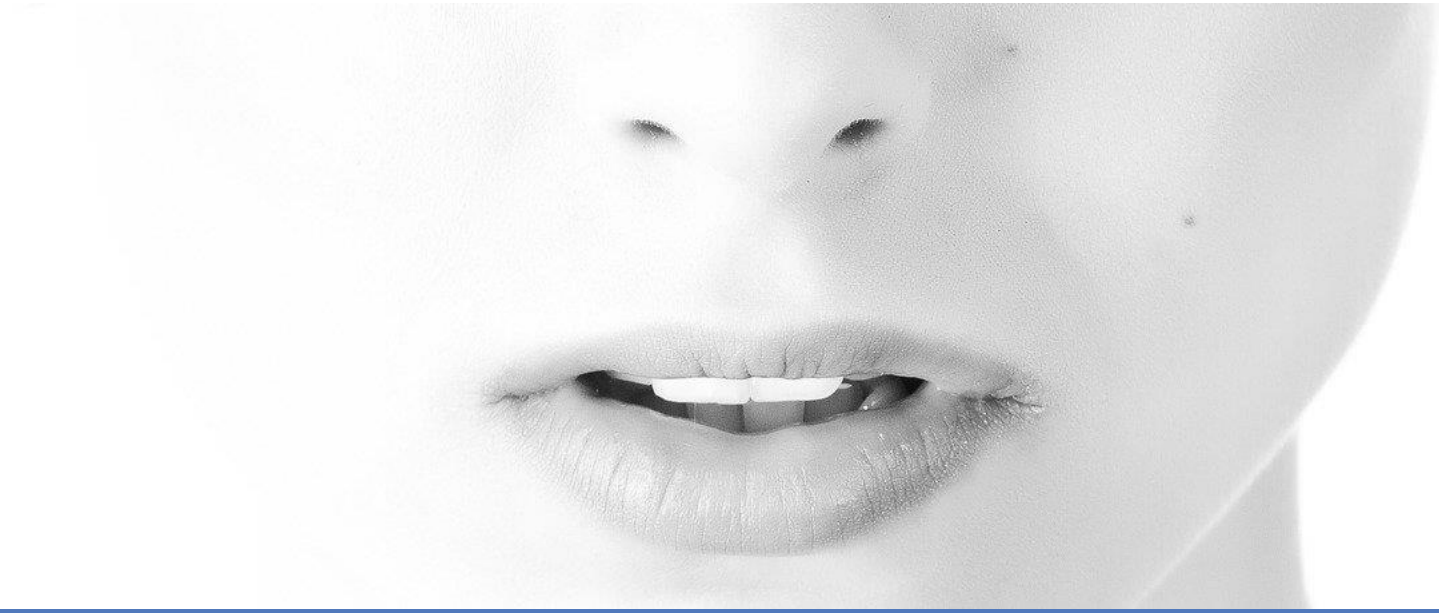


The Vestibular System

- **Balance** is the result of a number of systems working together:
  - the eyes (visual system),
  - ears (vestibular system)
  - the body's sense of where it is in space (proprioception)
- **The vestibulo-ocular reflex (VOR)** of the vestibular system in the inner ear causes eye movement
  - Stabilize images on the retinas
  - Gaze is held steady on a location in the direction opposite to head movement



https://en.wikipedia.org/wiki/Vestibulo%E2%80%93ocular_reflex#/media/File:Simple_vestibulo-ocular_reflex.PNG



Taste & Smell

Gustatory and Olfactory Sensations

Image https://pxhere.com/en/photo/1428401 by mbpogue

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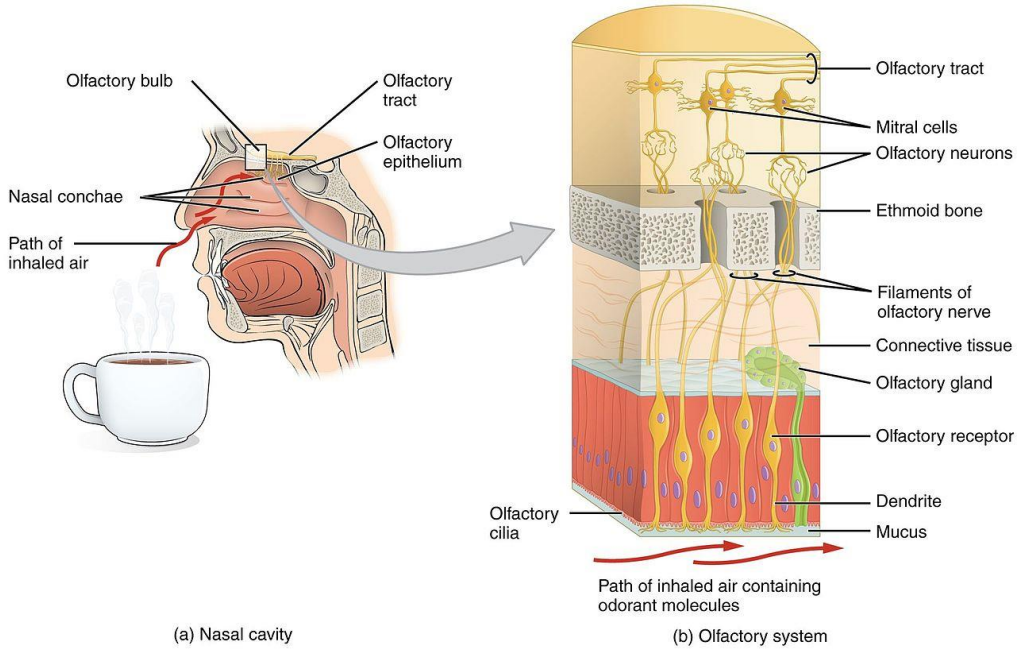
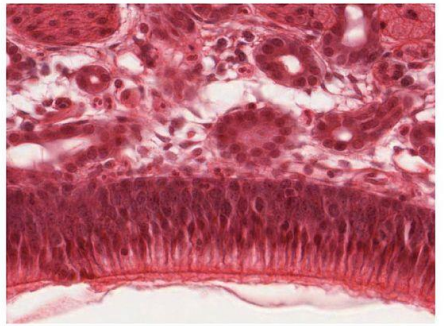
Olfactory Perception

- **Olfactory perception** is mediated by specialized sensory cells called **olfactory receptor cells**, which are **located in the olfactory epithelium**, a small patch of tissue at the top of the nasal cavity
  - These cells have **tiny hair-like structures** (cilia), on their surface that are sensitive to specific chemical compounds (odorants)
  - When an odorant binds to a receptor, it triggers a cascade of chemical reactions that ultimately generates **an electrical signal**.
- Odors are detected through **two pathways**:
  - **Orthonasal pathway** (nose): Odors sniffed in through the nose
  - **Retronasal pathway** (top of the throat): Aromas contained in food





(c) Olfactory epithelium

Olfactory Perception

- The olfactory bulbs are directly **connected to the amygdala in the human brian and the limbic system**
  - The system is involved in the **processing of** our **emotions**, **reinforcement**, **survival** instincts, and **memory** formation
  - Olfaction also has an important role in **food selection** and in detecting and avoiding spoiled or dangerous food.
- **Humans have between 10 and 20 million olfactory receptor neurons**
- Olfaction plays an important role in many aspects of behavior, including **mating**, **foraging**, and **avoiding predators**.
- Humans can discriminate more than **1 trillion olfactory stimuli**
- Hundreds of different **olfactory receptors outperform other senses** in the number of physically different stimuli it can discriminate.

Gustatory Perception

- **Gustatory perception**, also known as the sense of taste is the ability to perceive the basic taste qualities of **sweet**, **sour**, **salty**, and **bitter** (there is a fifth taste called **Umami**, which is the taste of Monosodium Glutamate (MSG) and is related to the taste of proteins).
  - These tastes are detected by specialized **taste receptors**, called **taste buds**, which are **located on the tongue**, as well as in the **roof of the mouth** and the **back of the throat**
  - The **primary gustatory cortex**, located **in the brainstem**, is responsible for processing taste information
    - From there, the signals are sent to other brain regions such as the insular cortex, the amygdala, and the hypothalamus (involved in the perception and recognition of taste, as well as in the regulation of appetite and hunger)
- **Gustatory perception and olfactory perception** are closely related.
  - Together, they are responsible for **the sense of flavor**, which is the combination of taste and smell.

Touch

Proprioception, Haptics, and Tactile Perception

Image https://pxhere.com/en/photo/1428401 by mbpogue

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The Sense of Touch

- The sense of touch refers to: **tactition, haptics**, and **proprioception**
- **Tactition:** the **sense of touch in general**, including the ability to perceive physical sensations such as **pressure**, **temperature**, and **pain**.
- **Haptics** refers to the study of the **sense of touch with the skin** as it relates to the sense of touch in interaction with objects, specifically in the field of human-computer interaction and robotics.
- **Proprioception** refers to the **sense of the position and movement of the body** and its parts. Proprioceptors are specialized receptors located in muscles, tendons, and joints that detect changes in muscle length and tension, as well as joint position and movement.

Tactition

- **Tactition**, is the ability to perceive physical sensations such as **pressure**, **temperature**, and **pain**
- It is mediated by specialized sensory receptors called **mechanoreceptors**, **thermoreceptors** and **nociceptors**, located in the skin and other tissues
  - **Mechanoreceptors** are sensitive to **mechanical pressure** and **vibrations**. They are located in the skin, muscles, tendons, and joints, and are responsible for the sense of pressure, vibration, and texture
  - **Thermoreceptors** are sensitive to **temperature changes**. They are located in the skin and are responsible for the sense of hot and cold. They send signals to the brain that help us to sense changes in temperature, such as the warmth of a hug or the chill of an ice cube.
  - **Nociceptors** are specialized receptors that are sensitive to potentially **damaging stimuli** such as extreme heat, extreme cold, pressure, and chemicals. They send signals to the brain that help us to **sense pain**

Haptics

Modality	Sub Modality	Sub-sub Modality
Pain	sharp cutting pain	
	dull burning pain	
	deep aching pain	
Temperature	warm/hot	
	cool/cold	
Touch	itch/tickle & crude touch	
Haptics	discriminative touch	touch
		pressure
		flutter
		vibration
	Proprioception	position: static forces	muscle length
			muscle tension
			joint pressure
		movement: dynamic forces (kinesthetic)	muscle length
			muscle tension
			joint pressure
			joint angle

Cutaneous (Haptic) Receptors

- **Merkel discs**: shearing forces and Skin deformation (slow)
- **Meissner corpuscles**: touch discrimination
- **Ruffini endings**: xontinous pressure
- **Pacinian corpuscles**: pressure
- **Free nerve endings**: pain and temperature

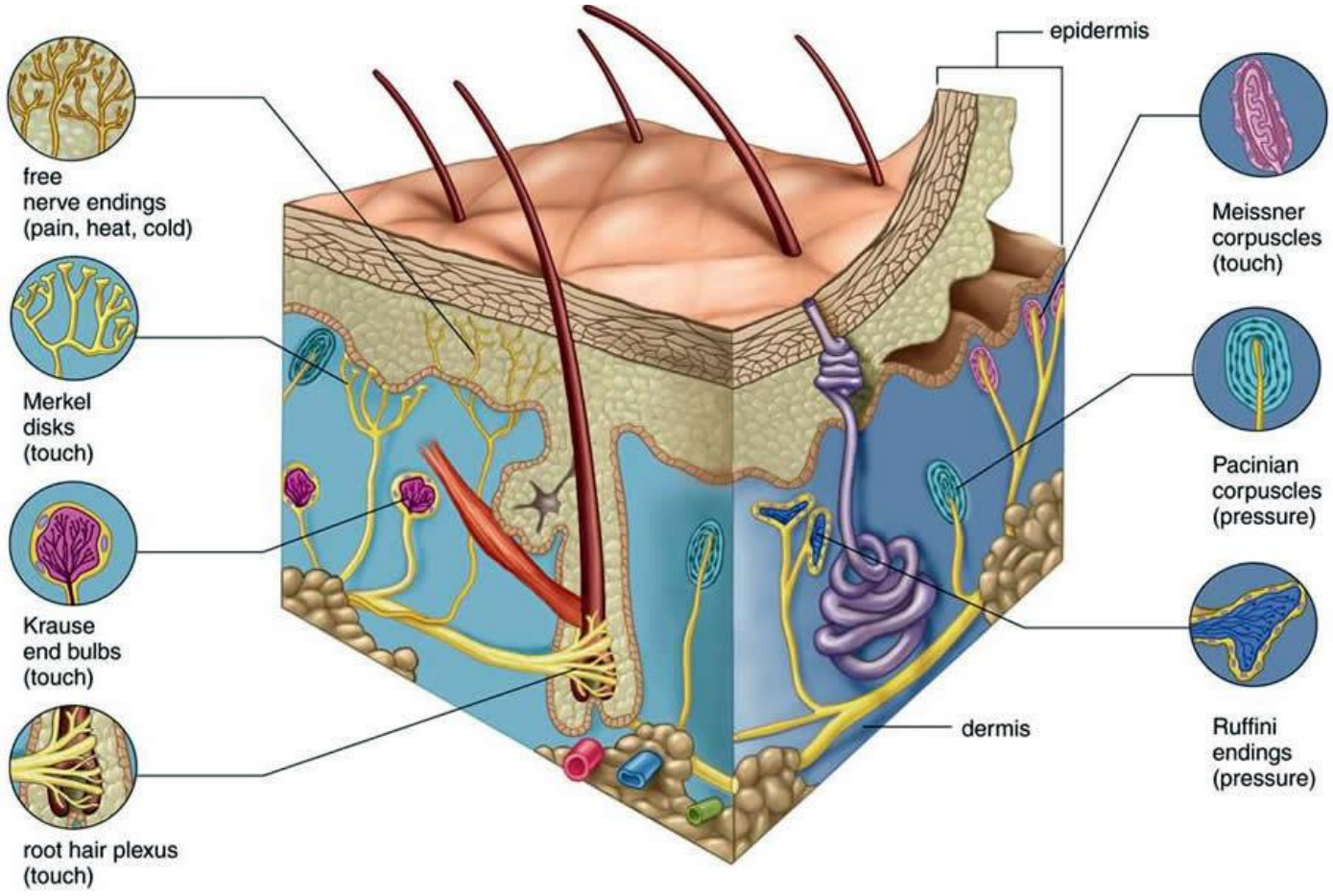
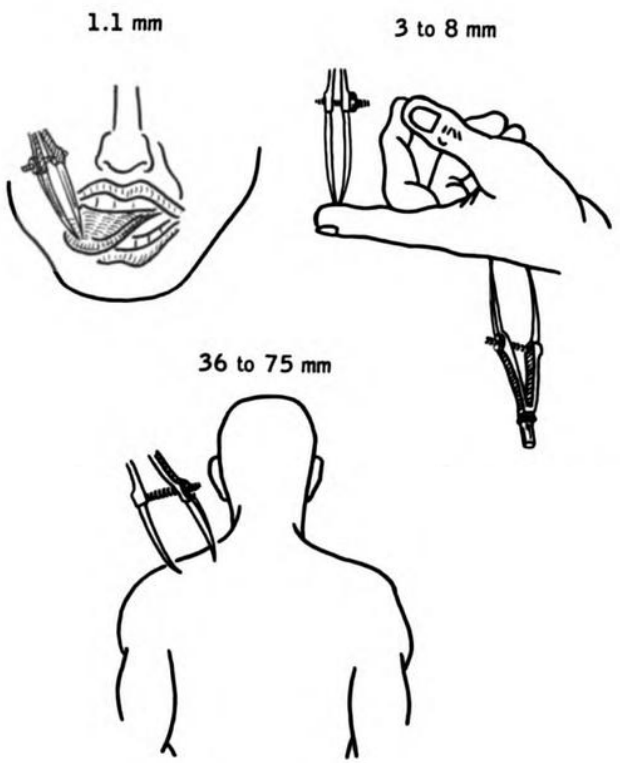
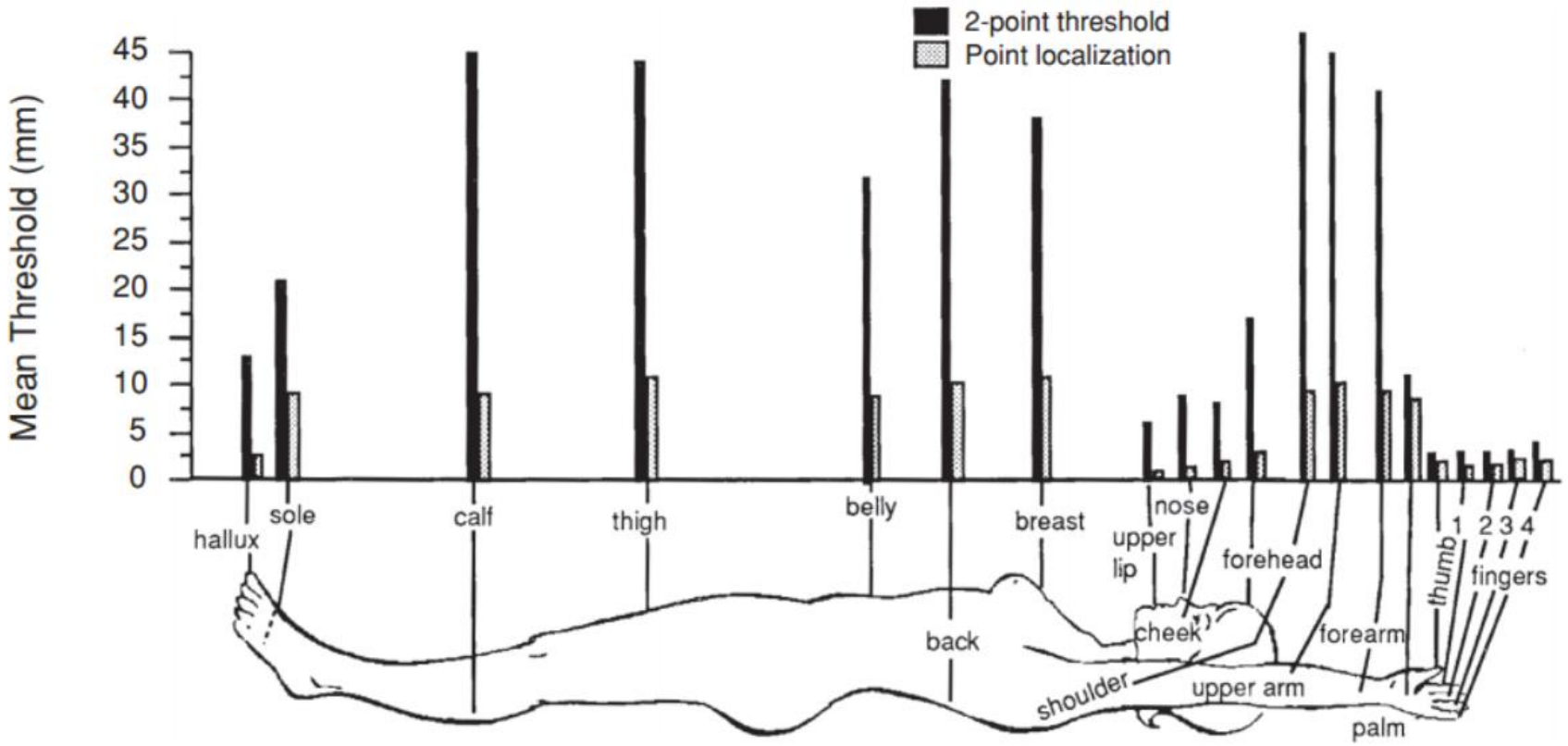


Image from: https://quizlet.com/385317734/general-senses-diagram/

Tactile Sensation Resolution





Proprioception

- **Activated during distinct behaviors** and encode types of information related to
  - Limb velocity and **movement**
  - Limb **load** on a limb
  - Limb **constraints** (limits)
- **Integrated into vision and the vestibular system** and important for the **body schema** e.g.:
  - Upright walking (monitoring postures and balancing)
  - Reaching and grooming

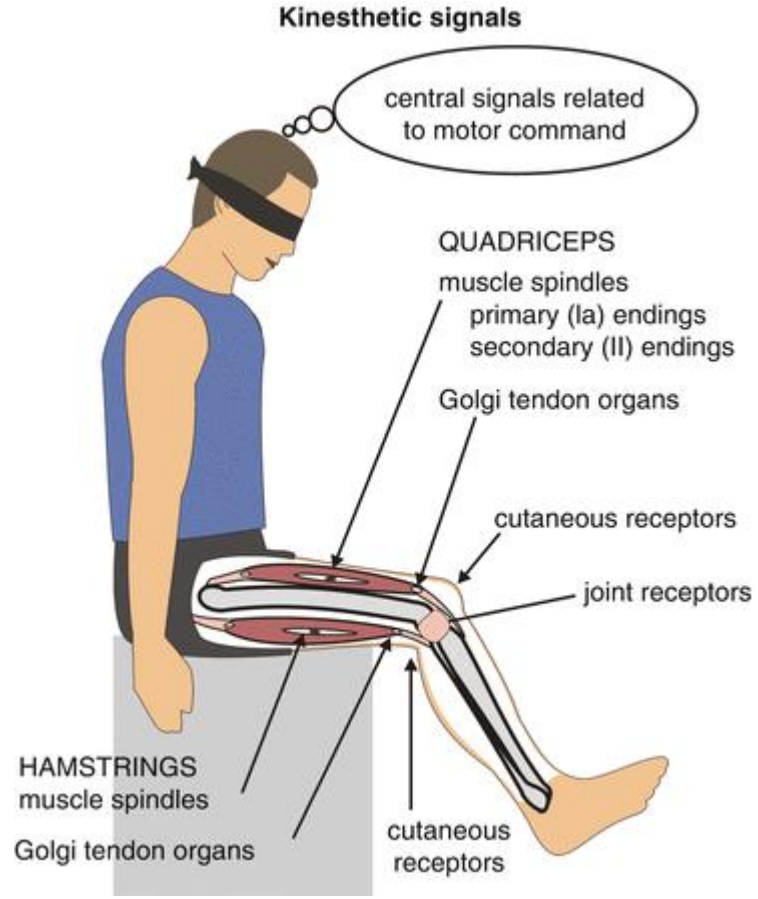
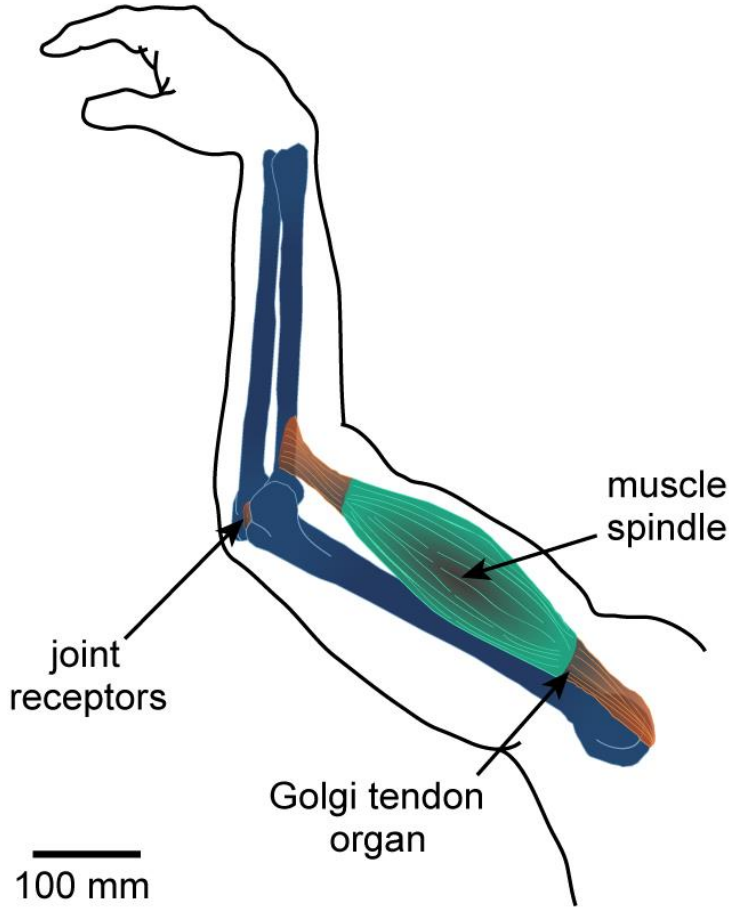


Image from https://link.springer.com/referenceworkentry/10.1007/978-1-4939-3474-4_3 1

Proprioceptive Receptors

- **Muscle spindles** are located within the muscles that detect changes in muscle length.
  - They are responsible for sensing the stretch of a muscle
- **Golgi tendon organs** are located in tendons, where they detect changes in muscle tension.
  - They are responsible for sensing the force of a muscle contraction
- **Joint receptors** are located in the joints and detect changes in joint position and movement.
  - They are responsible for sensing the position and movement of the bones that form the joint
- **All these proprioceptors work together** to allow us to sense the position and movement of our body parts in space, and to coordinate our movements.



Schematics and images of limb proprioceptors in mammals and insects John Tuthill - wikimedia.org CC BY-SA 4.0

The Sense of Gravity

- **The perception of gravity** through the sense of touch is mediated by the mechanoreceptors, which detect changes in pressure and force of the body (weight)
- Send signals to the brain that determines the **center of gravity**
- The center of gravity is mediated to the sense of balance (the vestibular system)

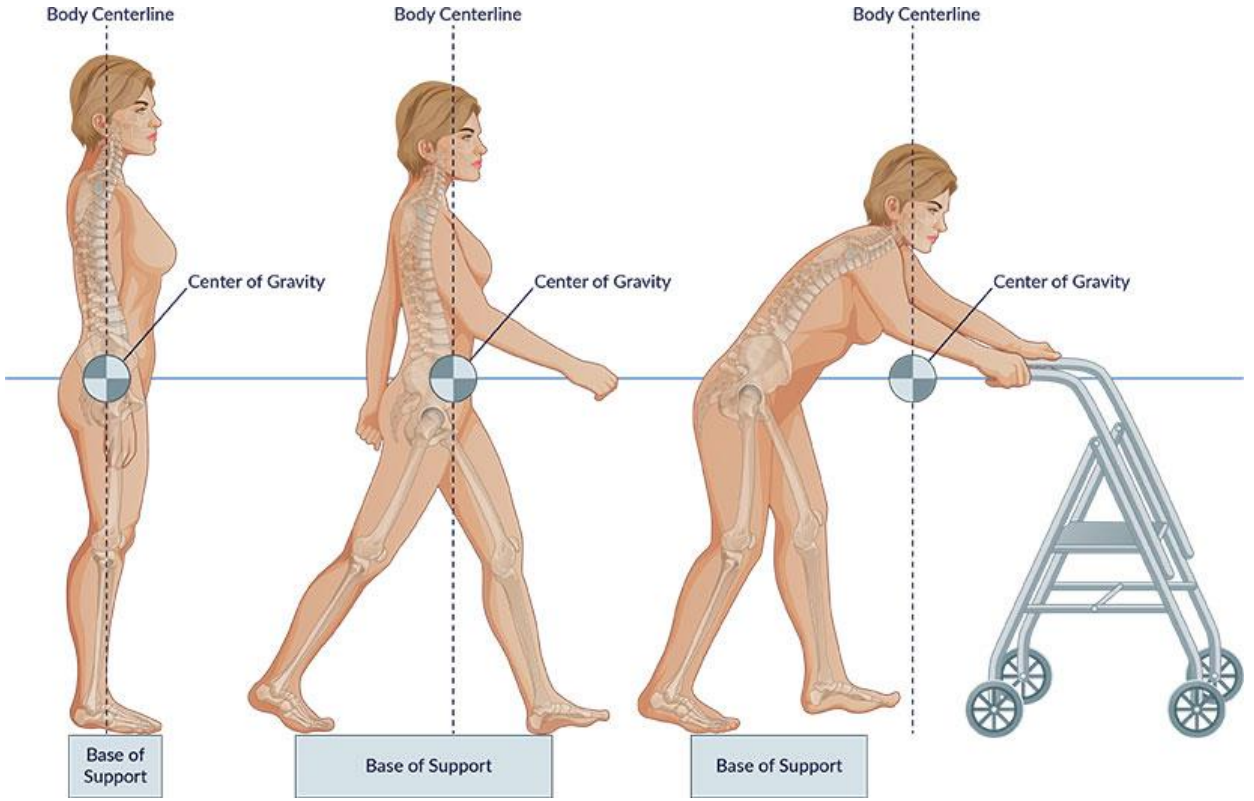
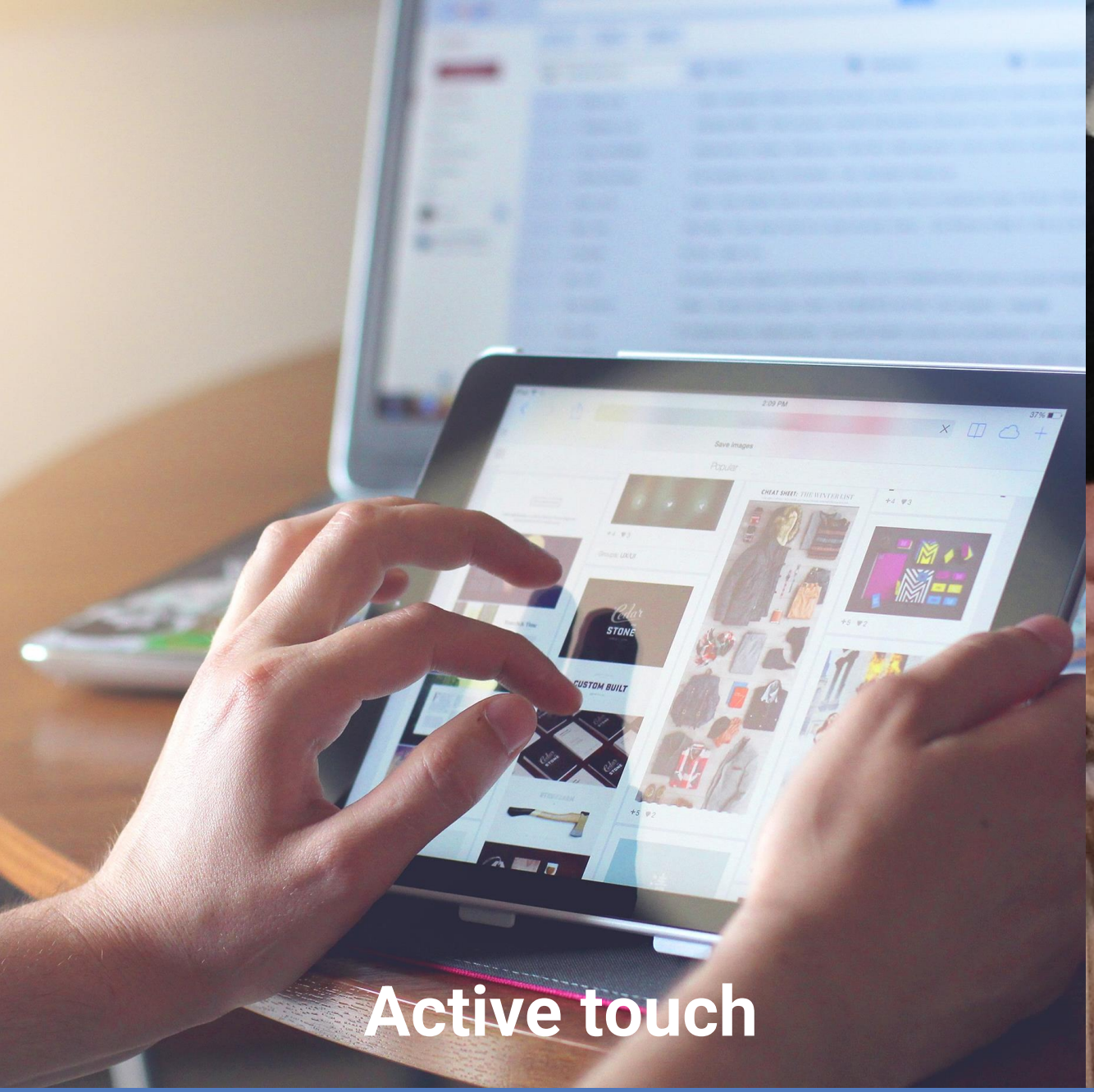
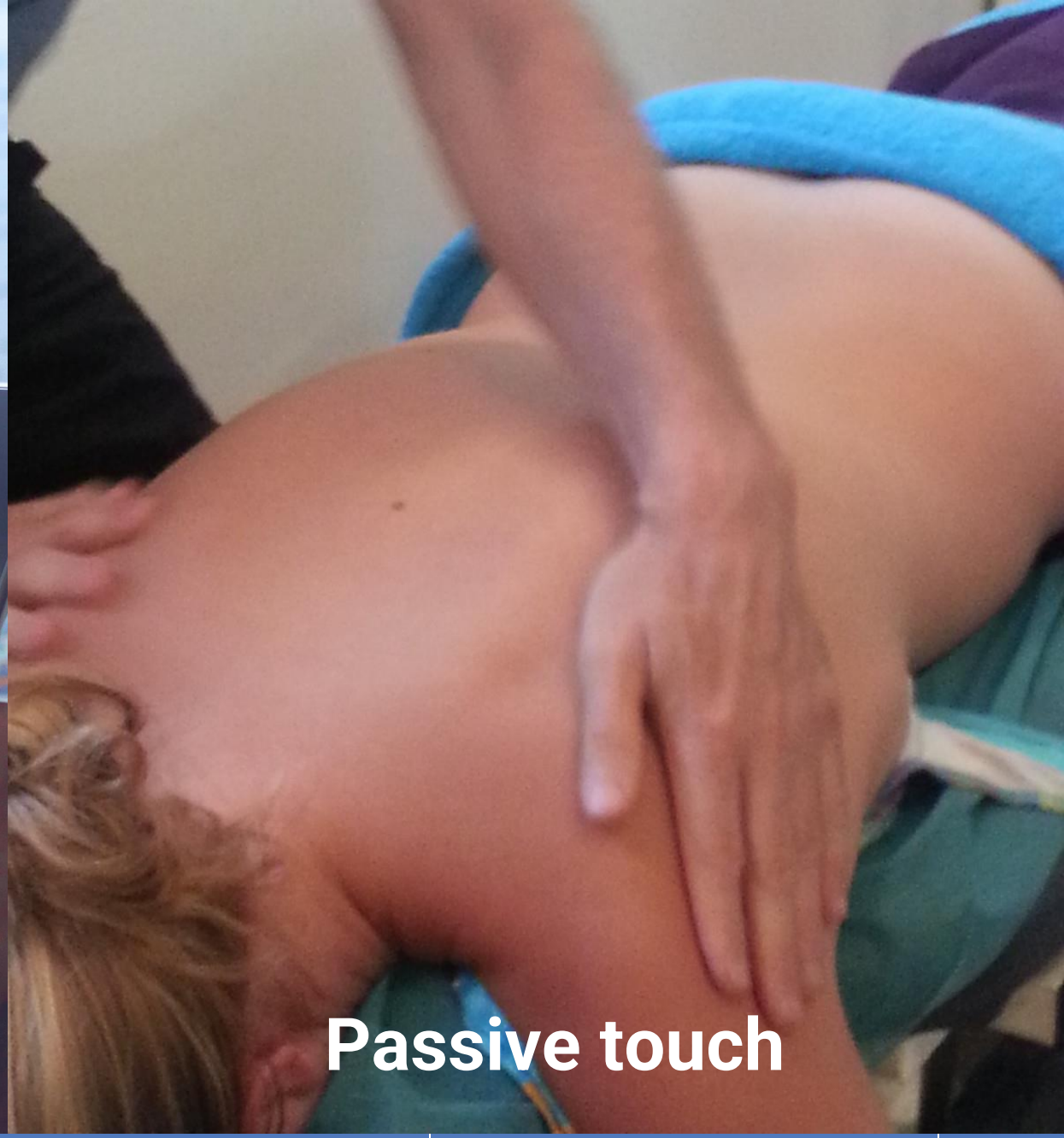


Image from: https://rehabshop.com.sg/why-understanding-your-center-of-gravity-is-key-to-fall-prevention

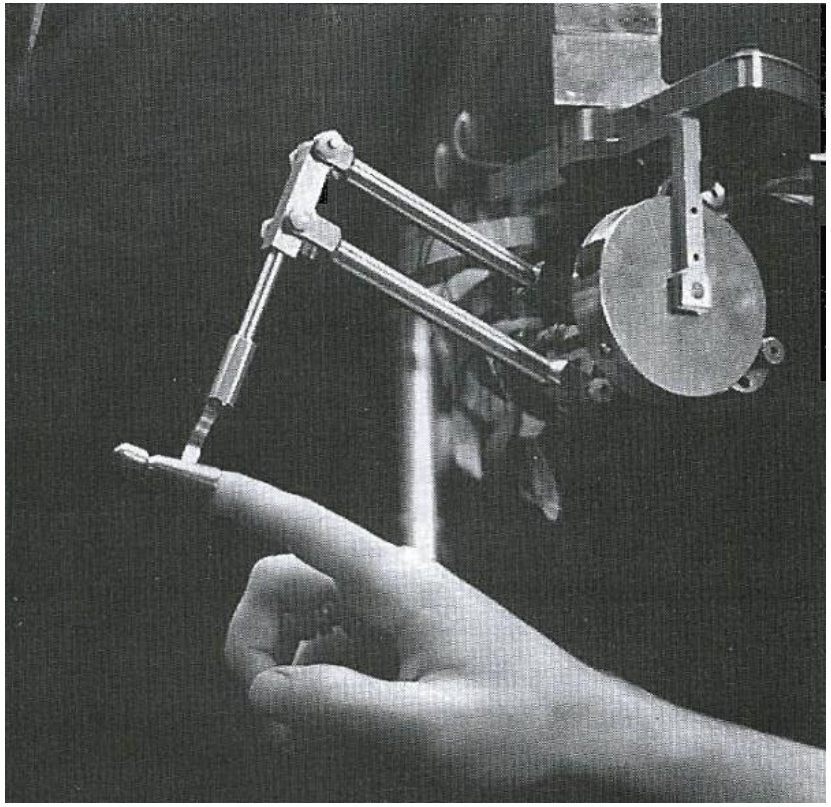
Somatosensory System and Touch

- **Somatosensory system**: informs us about objects in our external environment through touch and about the position and movement of our body parts through the stimulation of muscle and joints. The somatosensory system differentiates between active and passive touch
  - **Active touch** is mediated by both **mechanoreceptors** and **proprioceptors** and refers to **the process of actively exploring an object** (e.g., with the fingers). Active touch allows us to gather more detailed information about an object and to make more precise judgments about its properties (e.g., texture).
  - **Passive touch** is mainly mediated by **mechanoreceptors** and **thermoreceptors** and refers to the perception of touch that **occurs without being engaged in the process of touch**. For example, feeling the pressure of another hand on the skin or sensing the temperature of a bath


Active touch


Passive touch

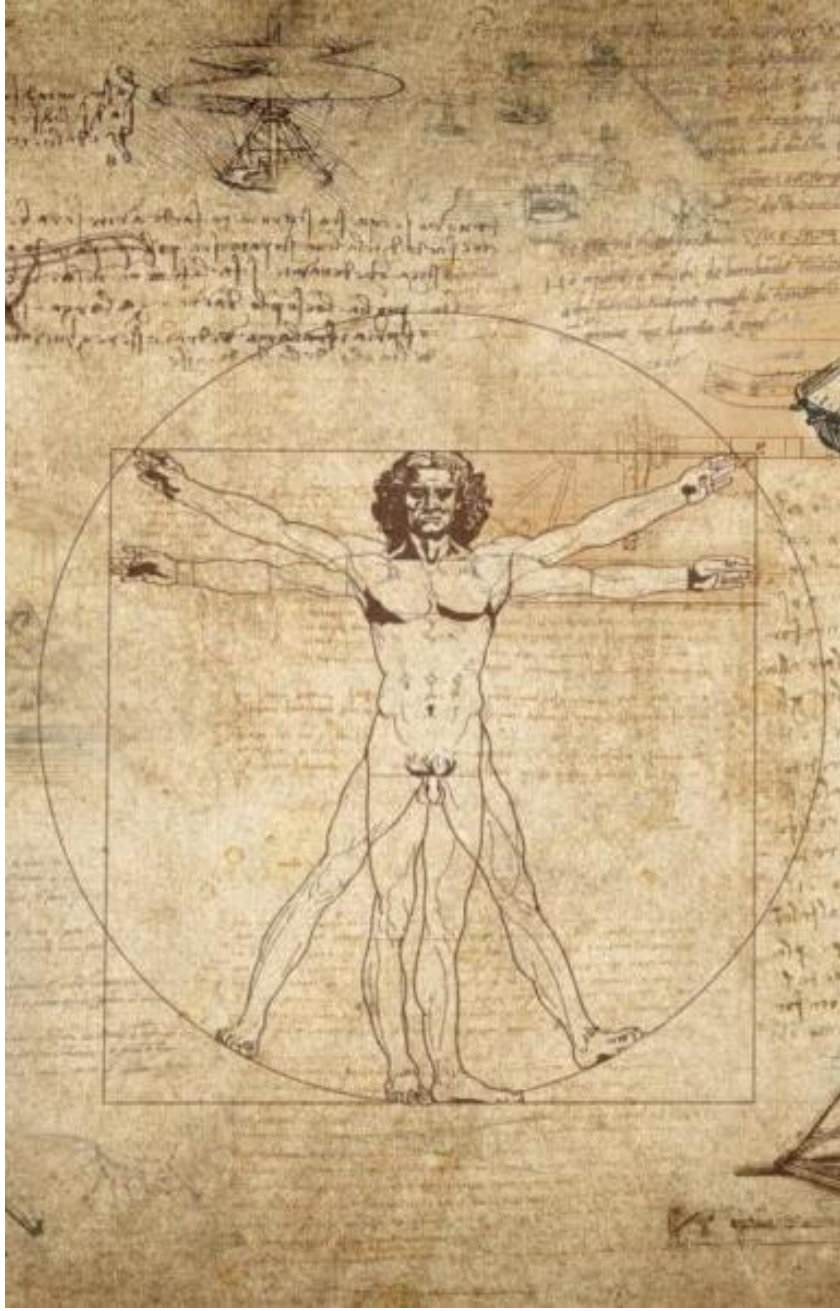
Passive and Active Touch in HCI



Massie, T. H., & Salisbury, J. K. (1994, November). The phantom haptic interface: A device for probing virtual objects. In *Proceedings of the ASME winter annual meeting, symposium on haptic interfaces for virtual environment and teleoperator systems* (Vol. 55, No. 1, pp. 295-300).

Body Schema

- The collection of processes that registers the posture of one's body parts in space rising **into consciousness**
- **Sensorimotor representation of the body morphology** used for planning and executing body movements
- **Updated during body movement** and used for spatial organization of action
- A representation of **the body's spatial properties** including
  - the length of limbs and limb segments
  - their arrangement
  - the configuration of the segments in space
  - the shape of the body surface
- The body schema is **highly plastic**, which means not necessarily limited to true morpholopgy of the body



Extended Body Schema (EBS)

- **Incorporates external objects into** the mental conception of **one's body**
- The experience of **controlling external events** through one’s own actions is crucial for determining an extended body schema
  - Not necessary to be physically connected
  - Needs at least one sensory experience (vision, haptics)
  - Supported by multiple sensory experiences e.g. vision and haptics

Summary

- **Humans can see, hear, smell & taste, and feel touch**
- **Human senses are limited**
- In human-computer interaction, we use address, use, and support perception to enable interaction
- Supporting individual senses must be in the range of perception and must have the least possible effect on mental workload