Virtual Reality:
Perception & Physiology Overview

Paul MacNeilage, Psychology
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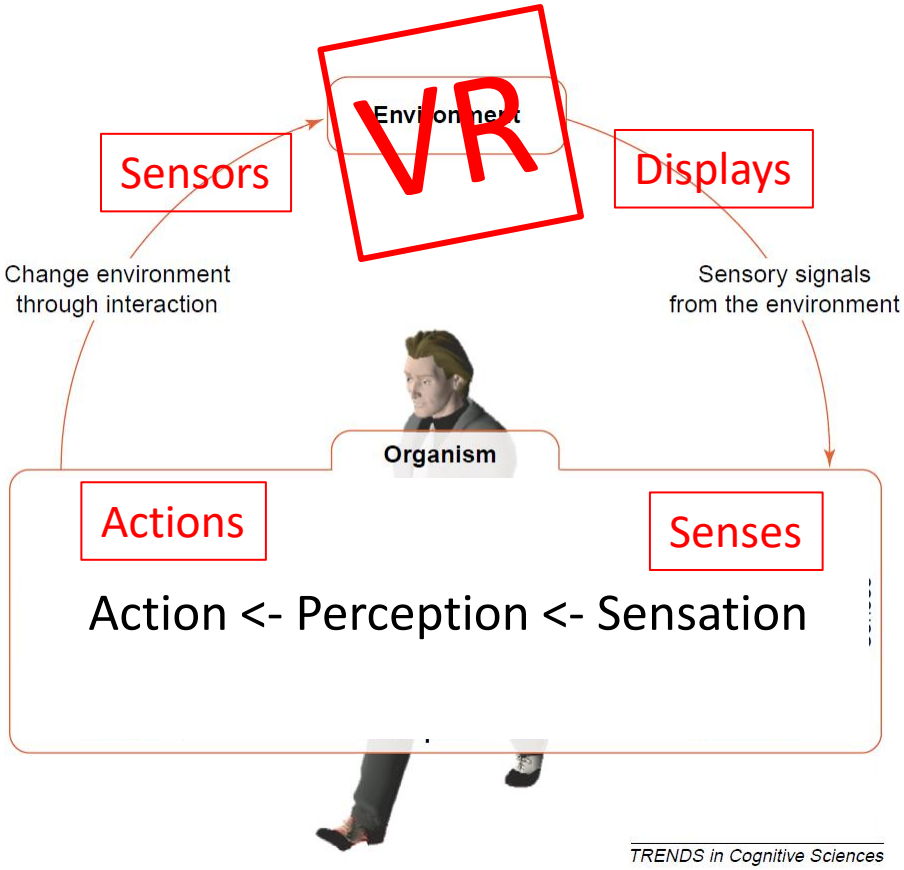
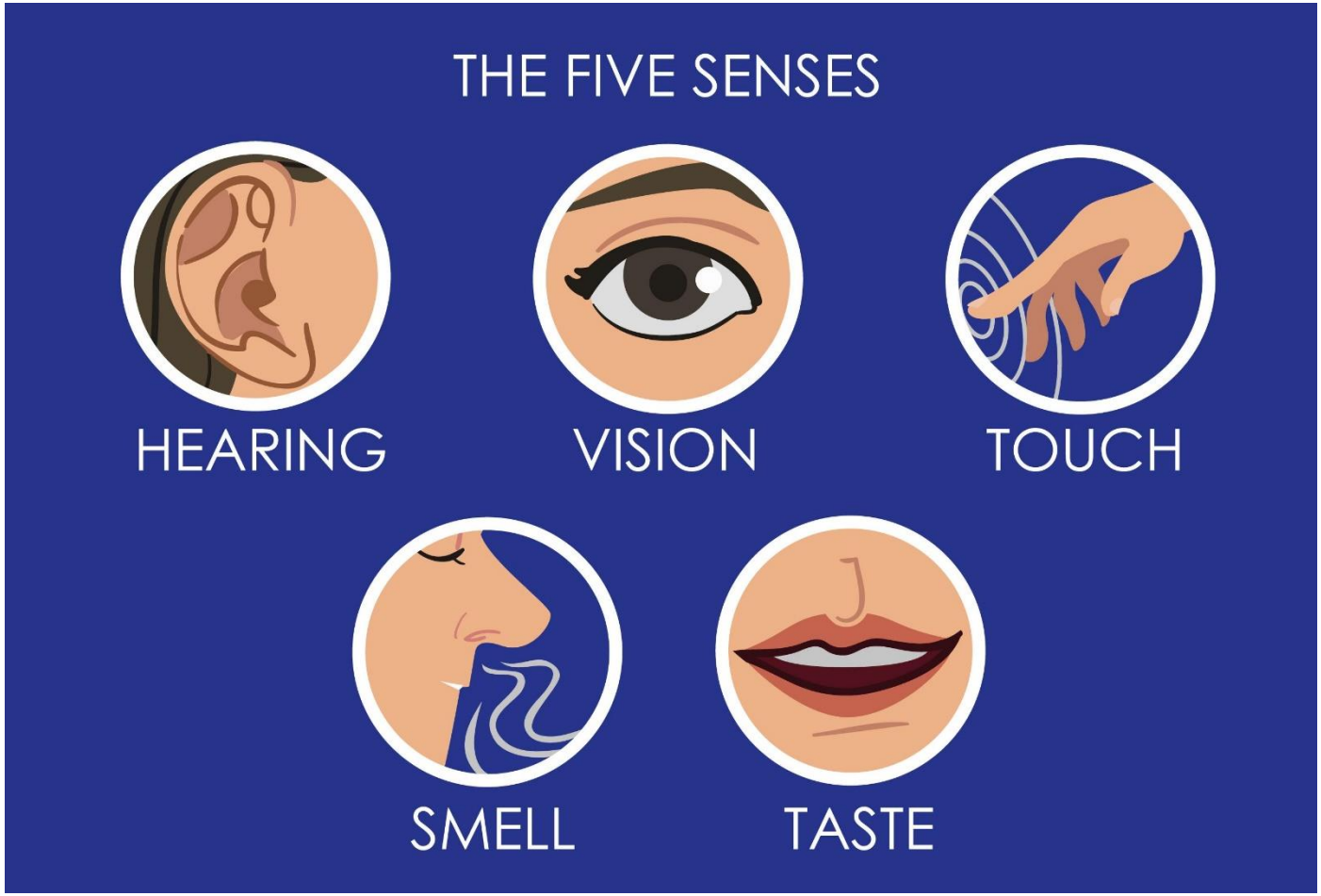
Some applied VR questions:

- How far away does that object appear to be?
- How much video resolution is needed to avoid seeing pixels?
- How many frames per second are enough to perceive motion as continuous?
- Is the user's head appearing at the proper height in the virtual world?
- Where is that virtual sound coming from?
- Why am I feeling nauseated?
- Why is one experience more tiring than another?
- What is presence?

Human-in-the-loop



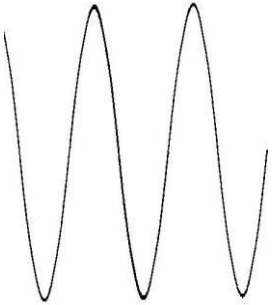
The five senses

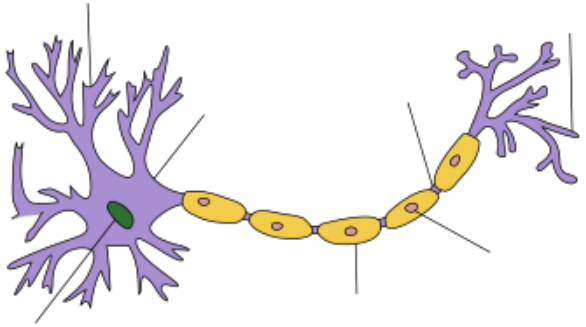


How do they work?

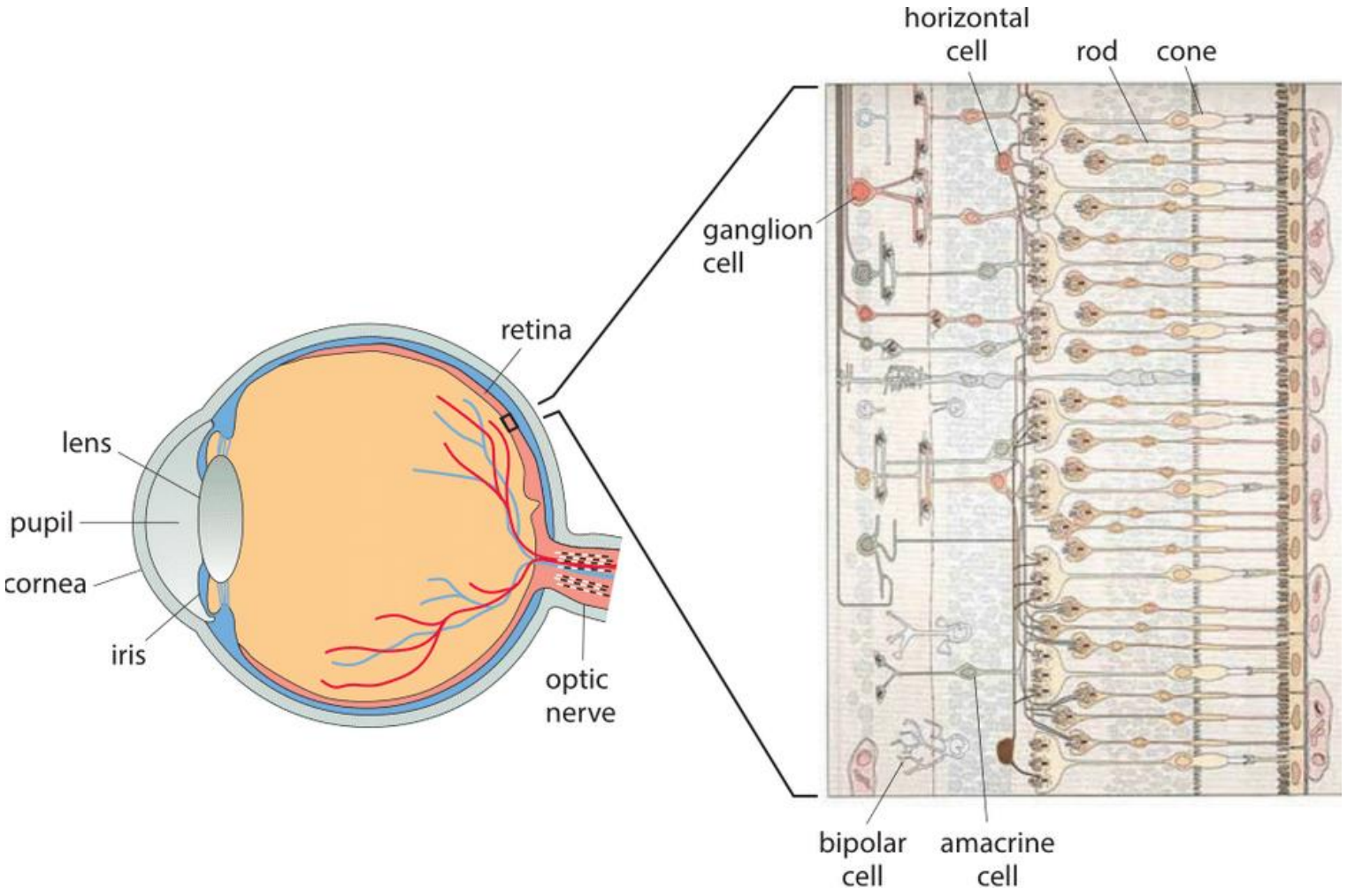
Physiology of Sensation

Physical energy → Neural impulses

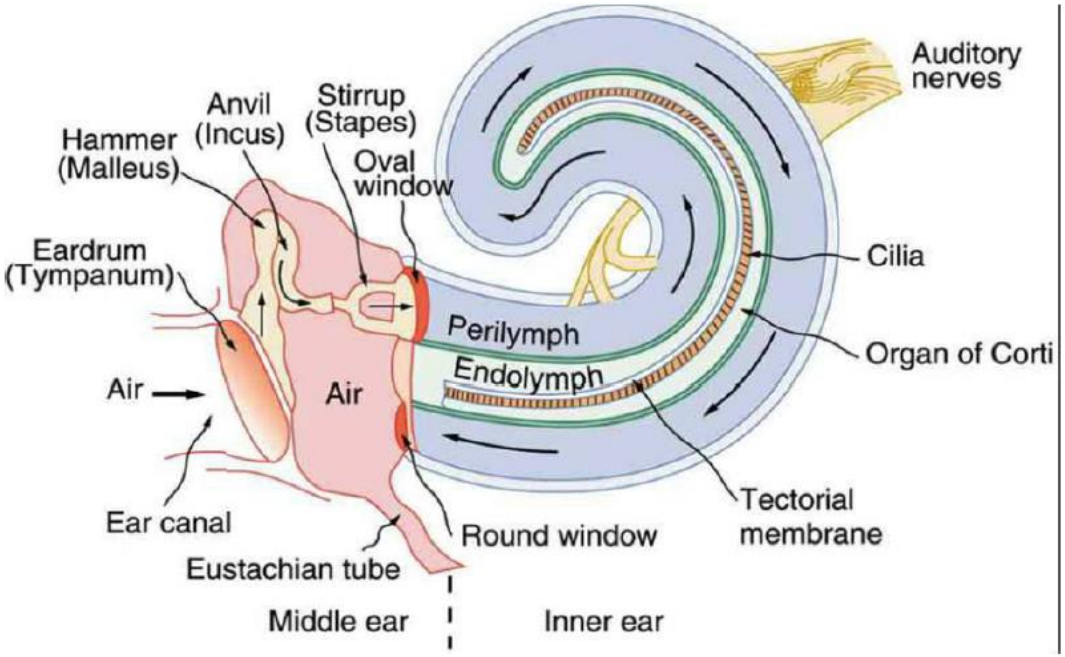


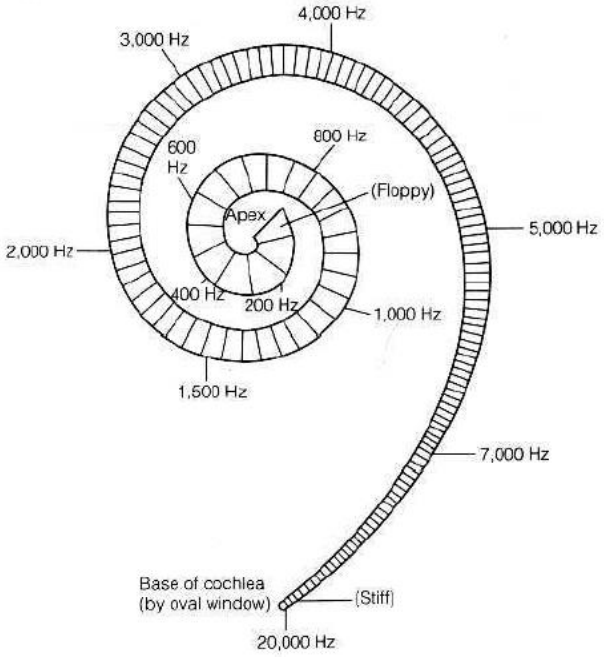


Vision

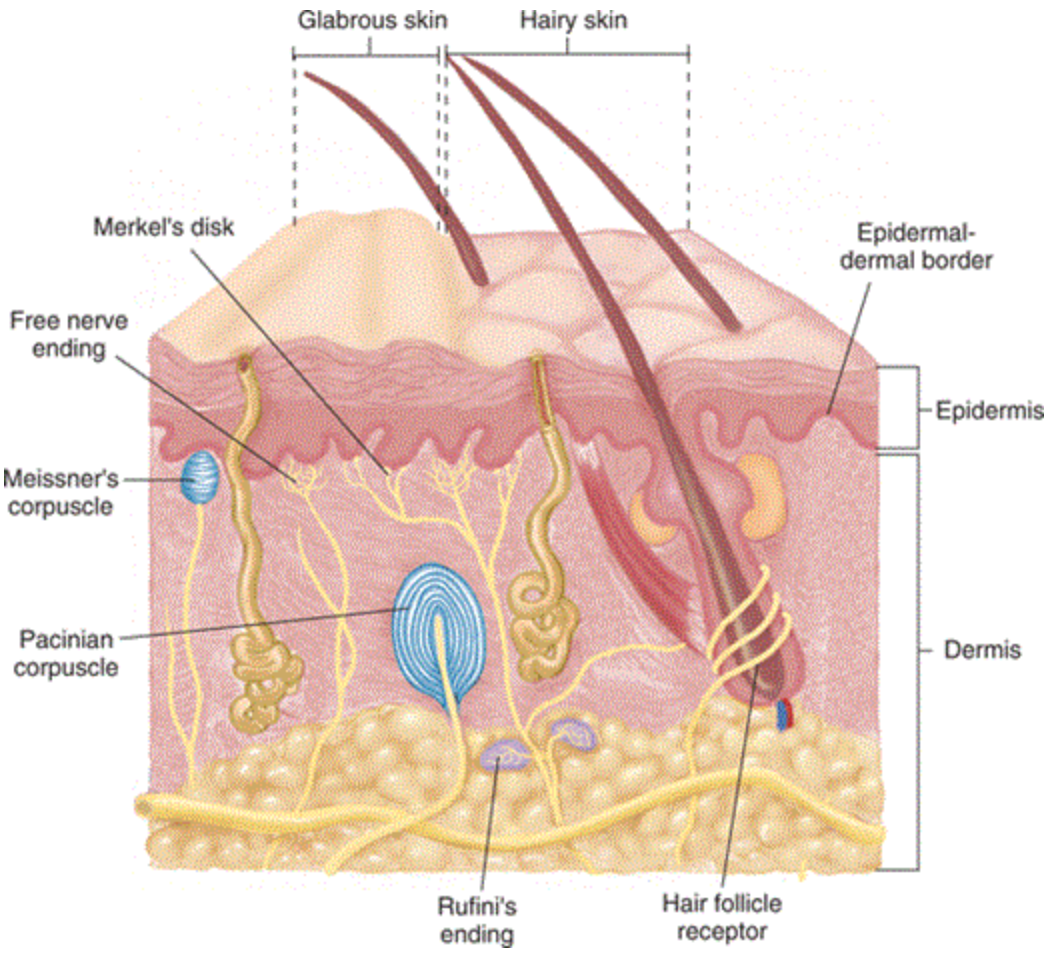

horizontal cell
rod
cone
ganglion cell
retina
lens
pupil
cornea
iris
optic nerve
bipolar cell
amacrine cell

Audition


Auditory nerves
Anvil (Incus)
Stirrup (Stapes)
Hammer (Malleus)
Oval window
Eardrum (Tympanum)
Cilia
Perilymph
Organ of Corti
Endolymph
Air
Air
Tectorial membrane
Ear canal
Round window
Eustachian tube
Middle ear
Inner ear

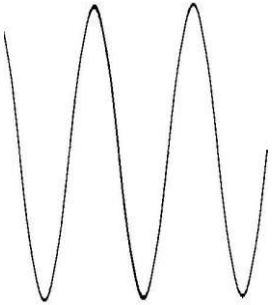

4,000 Hz
3,000 Hz
800 Hz
600 Hz
(Floppy)
Apex
5,000 Hz
2,000 Hz
400 Hz
200 Hz
1,000 Hz
1,500 Hz
7,000 Hz
Base of cochlea (by oval window)
(Stiff)
20,000 Hz

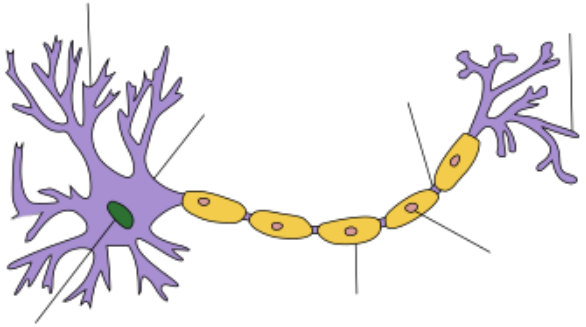
Touch


Glabrous skin
Hairy skin
Merkel's disk
Epidermal-
dermal border
Free nerve
ending
Epidermis
Meissner's
corpuscle
Pacinian
corpuscle
Dermis
Rufini's
ending
Hair follicle
receptor

Physiology of Sensation

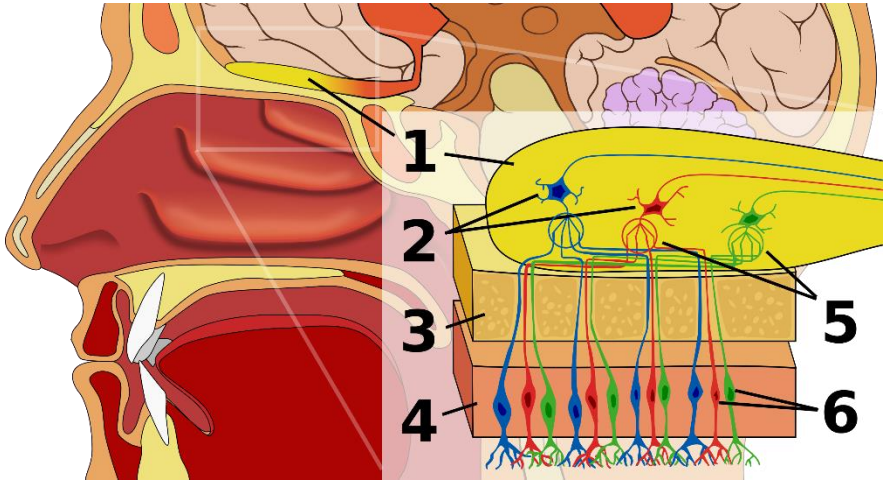
Physical energy → Neural impulses



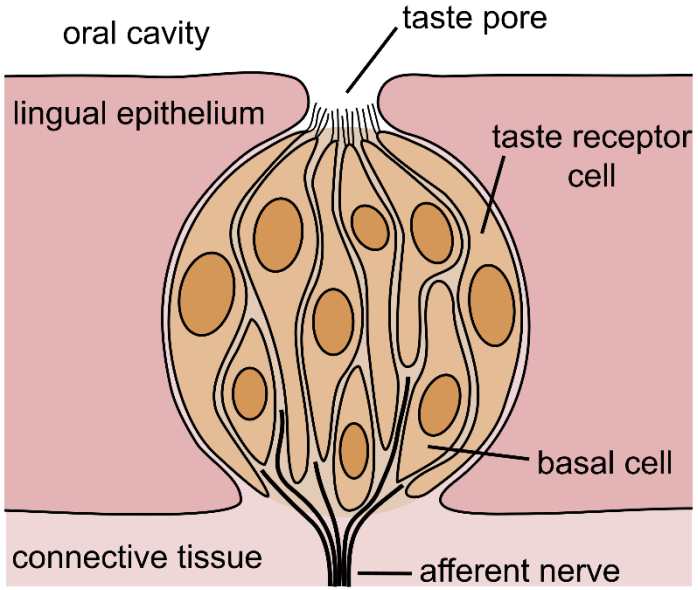


Chemical reaction

Smell and Taste

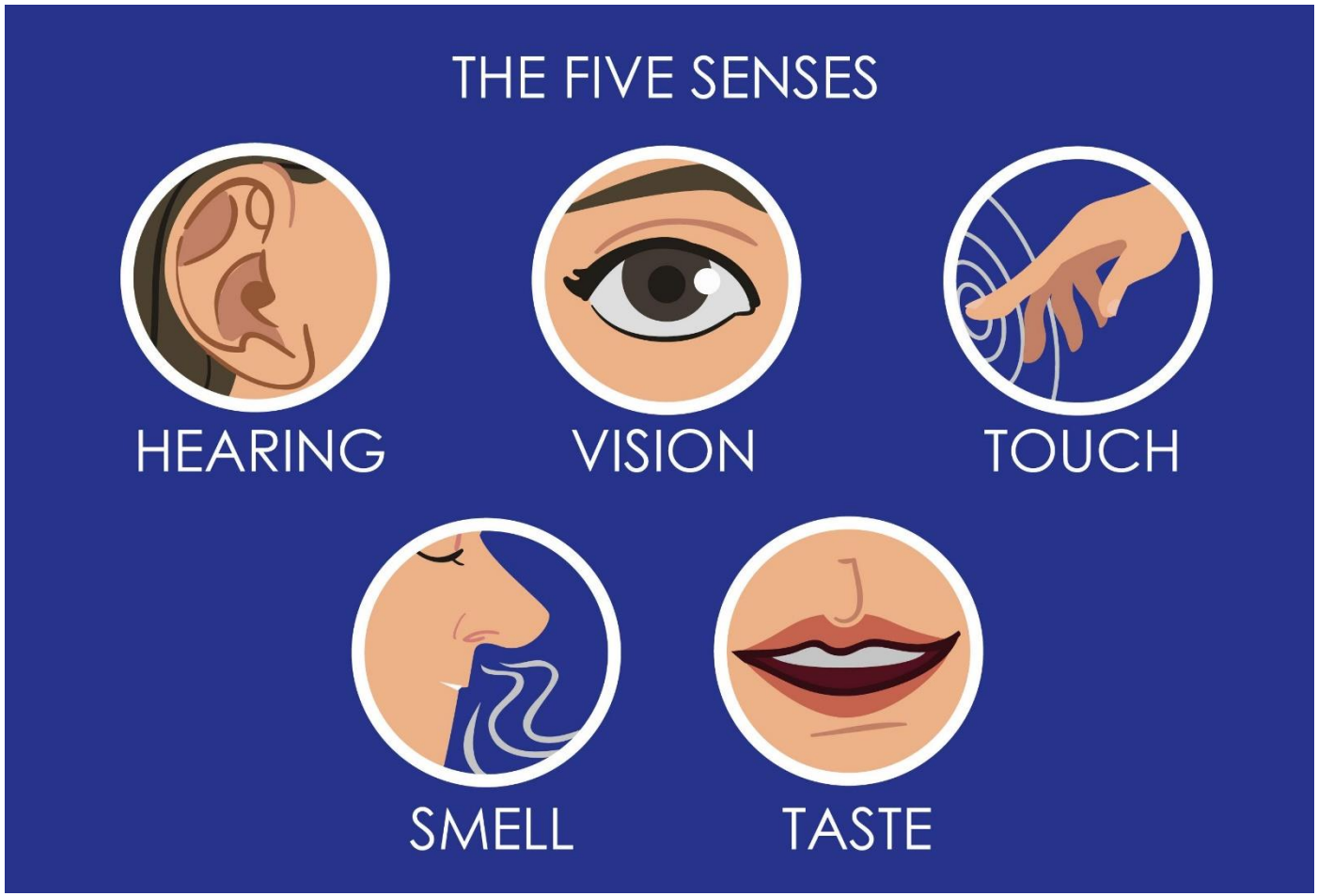


Olfaction



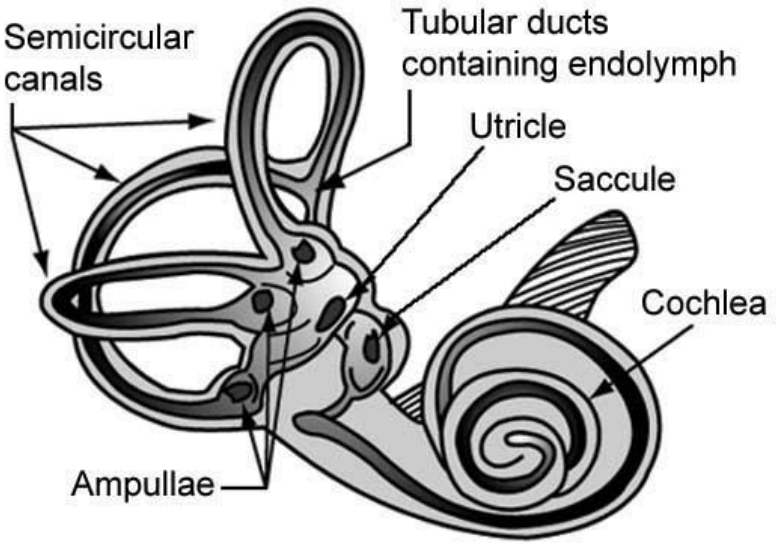
Gustation

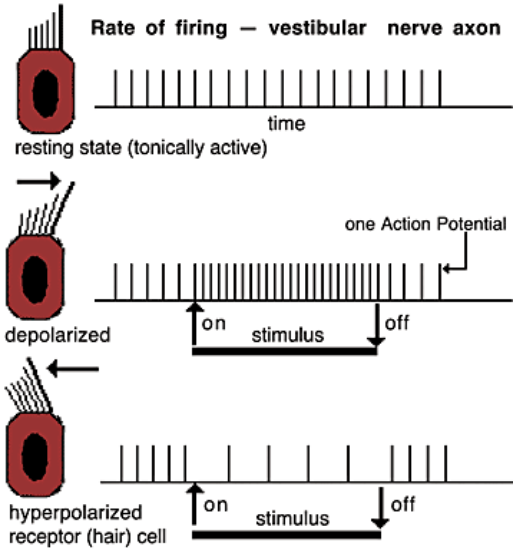
The five senses



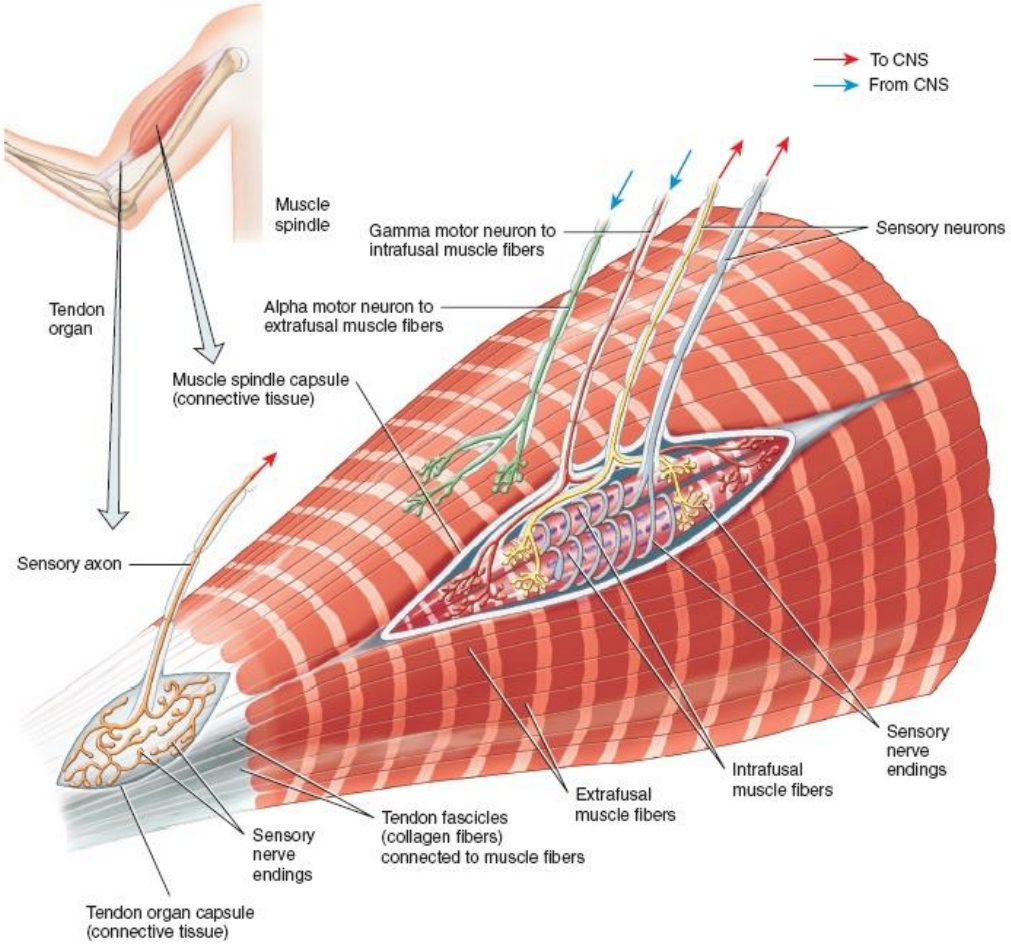
Are there more?

Vestibular (Balance) Sense





Proprioception



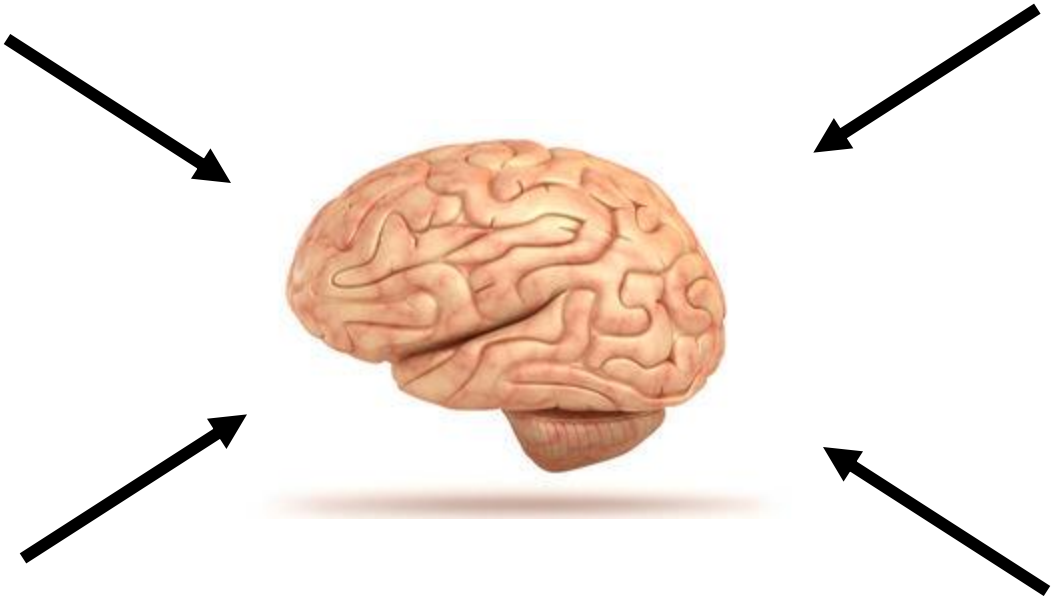
Sensory Transduction

Sense	Stimulus	Receptor	Sense Organ
Vision	Electromagnetic energy	Photoreceptors	Eye
Auditory	Air pressure waves	Mechanoreceptors	Ear
Touch	Tissue distortion	Mechanoreceptors	Skin, muscles
		Thermoreceptors	Skin
Balance	Gravity, acceleration	Mechanoreceptors	Vestibular organs
Taste/smell	Chemical composition	Chemoreceptors	Mouth, nose

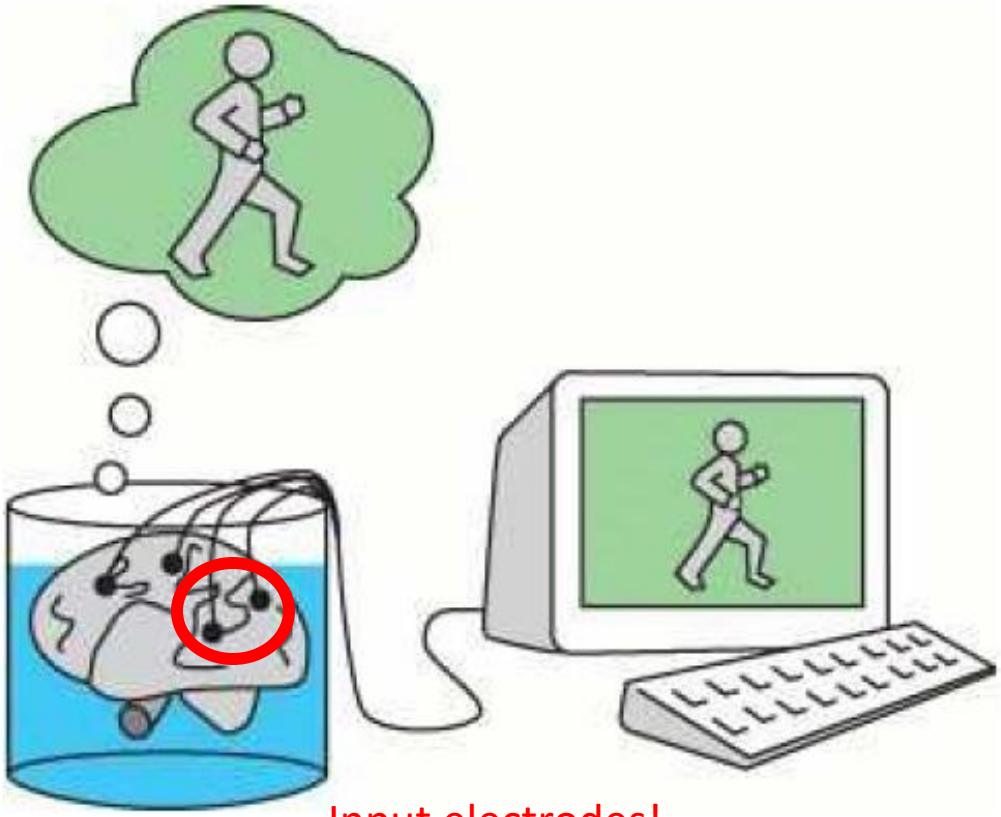
Figure 2.17: A classification of the human body senses.

Sensory Signals

- Only “input channels” to the brain!



The brain in a vat



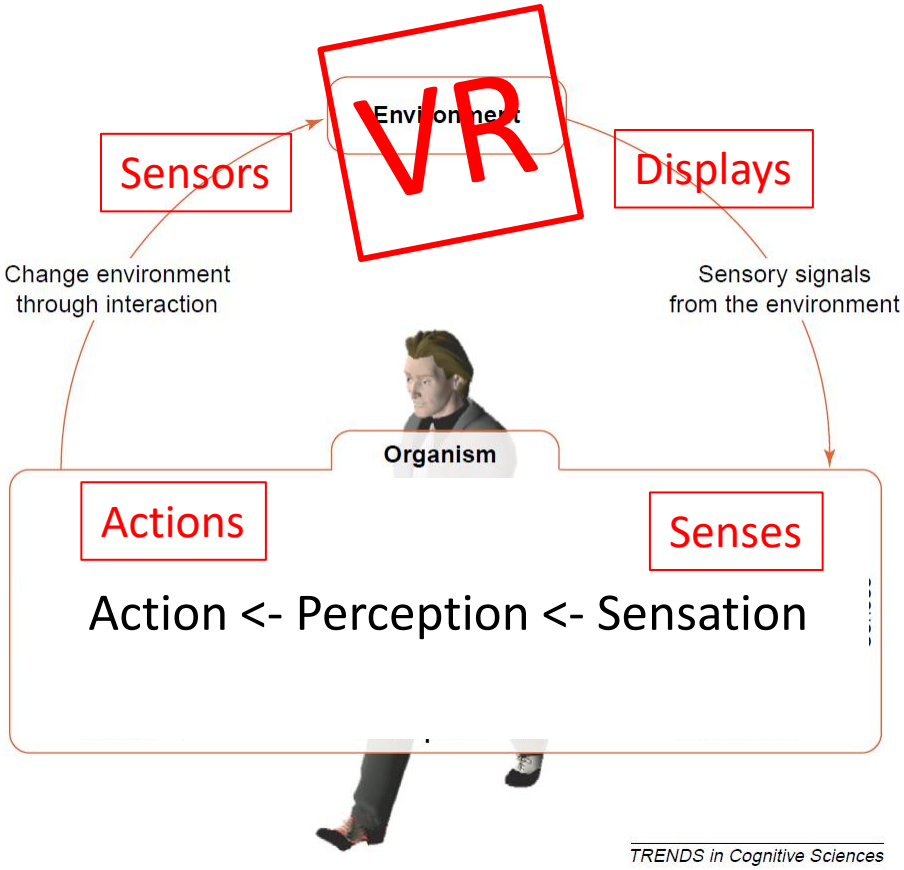
Input electrodes!

Sensory processing

- After sensory signals enter the brain…

- Neuroscience
- Perceptual psychology
- Cognitive psychology

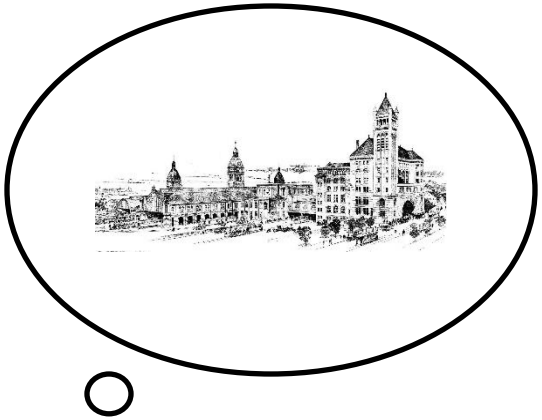
Human-in-the-loop



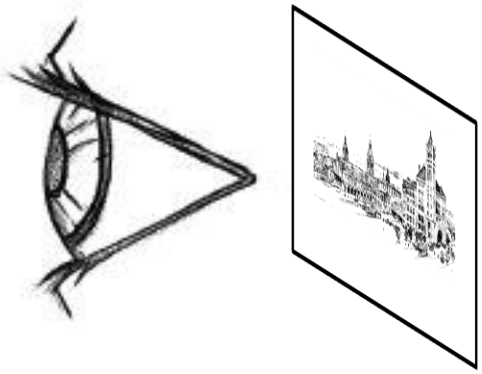
Extract Critical Features

- Depth
- Color
- Motion
- Etc.

Perceptual Reconstruction

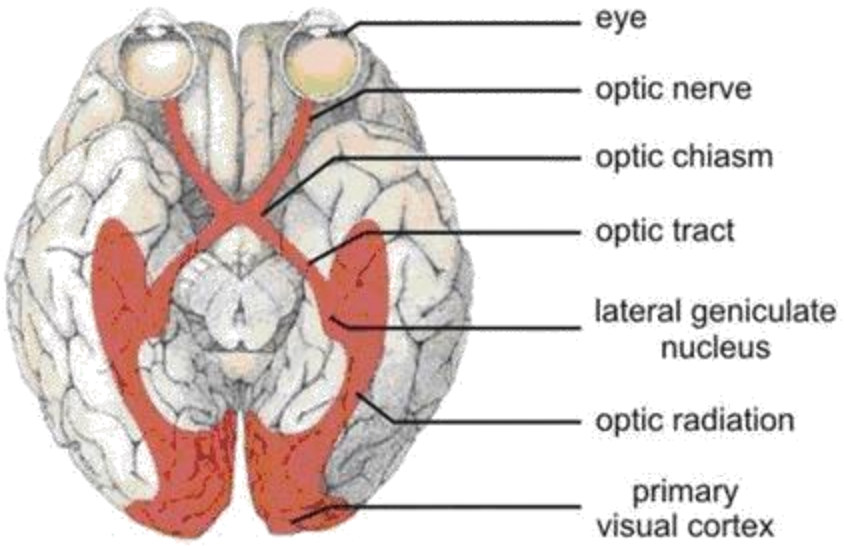


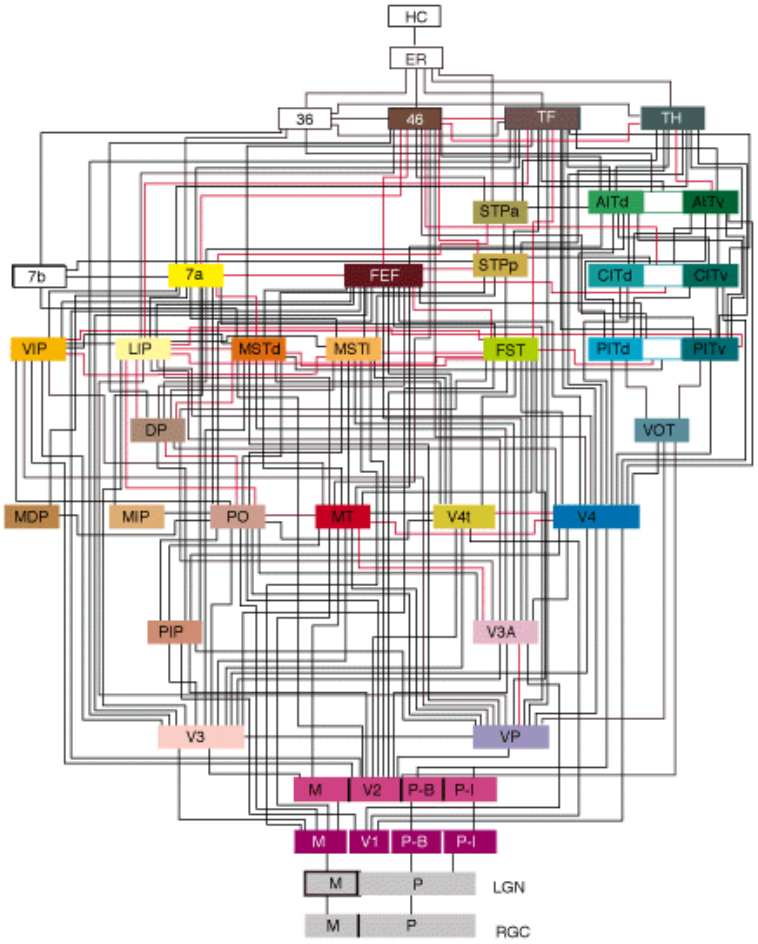
3D Real world



2D Image

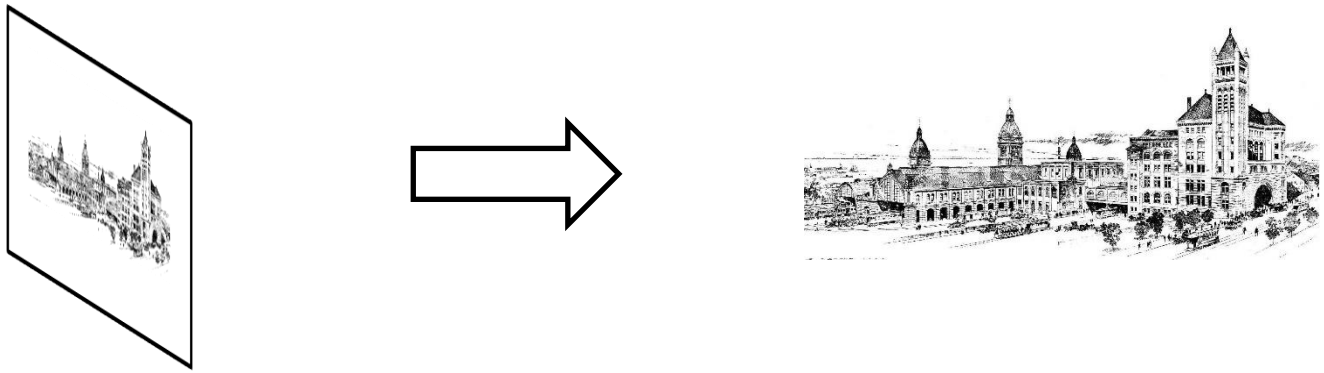
Anatomy of the Visual System





Inverse Problem

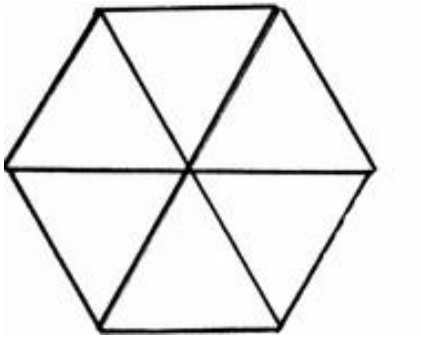
- Solution is underconstrained



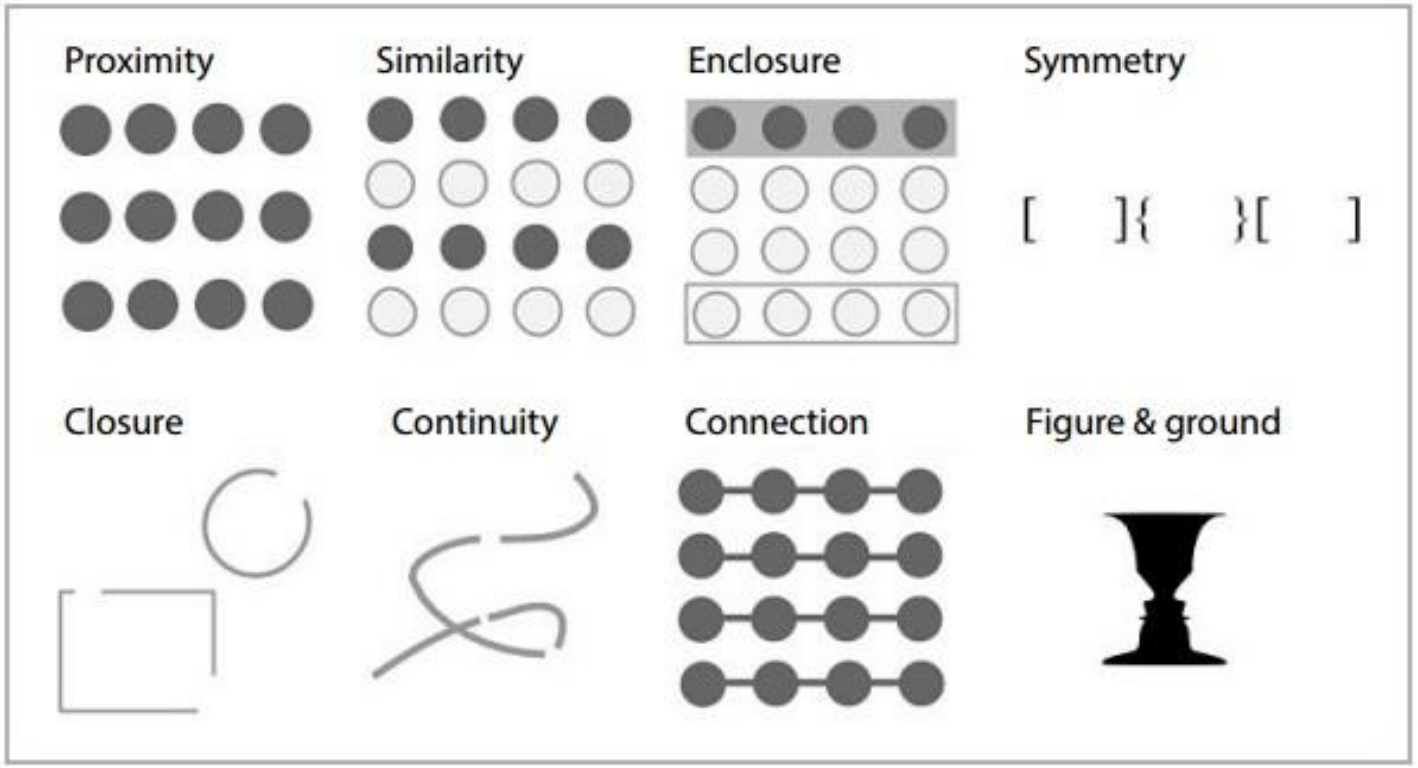
- Must infer solution; choose most likely
- Perception as probabilistic inference

Illusions Illustrate Inference

- Illustrate assumptions in inference…



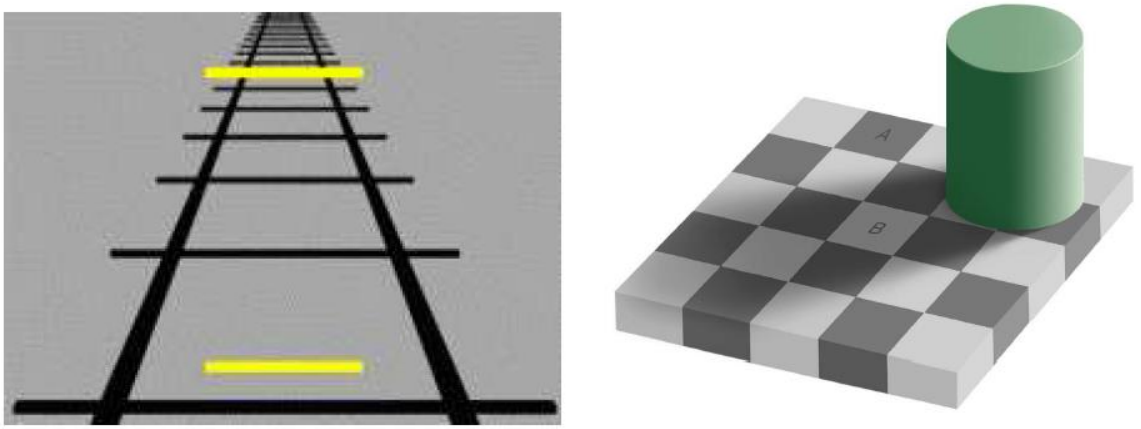
Gestalt Principles



Germany Psychology movement of early 1900's

Illusions Illustrate Inference

- From textbook:



(a) (b)

Figure 2.16: Optical illusions present an unusual stimulus that highlights limitations of our vision system. (a) The *Ponzo illusion* causes the upper line segment to appear larger than the lower one, even though they are the same length. (b) The *checker shadow illusion* causes the B tile to appear lighter than the A tile, even though they are the exactly the same shade of gray (figure by Adrian Pingstone).

Cue Integration

- Multiple sources of information:

Perspective

Depth from
Disparity /
Stereopsis

Familiar size

- How are they integrated?

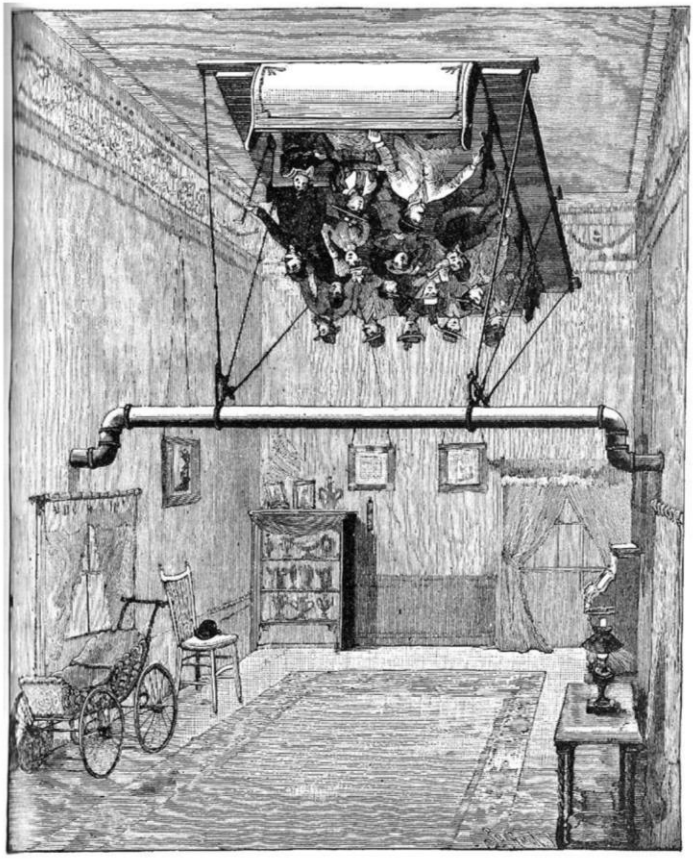
Crossmodal integration: McGurk Effect

- You tube link:

https://www.youtube.com/watch?v=aFPtc8BVdJk

- What do you see?
- What do you hear?
- Combined?

Cue integration across modalities



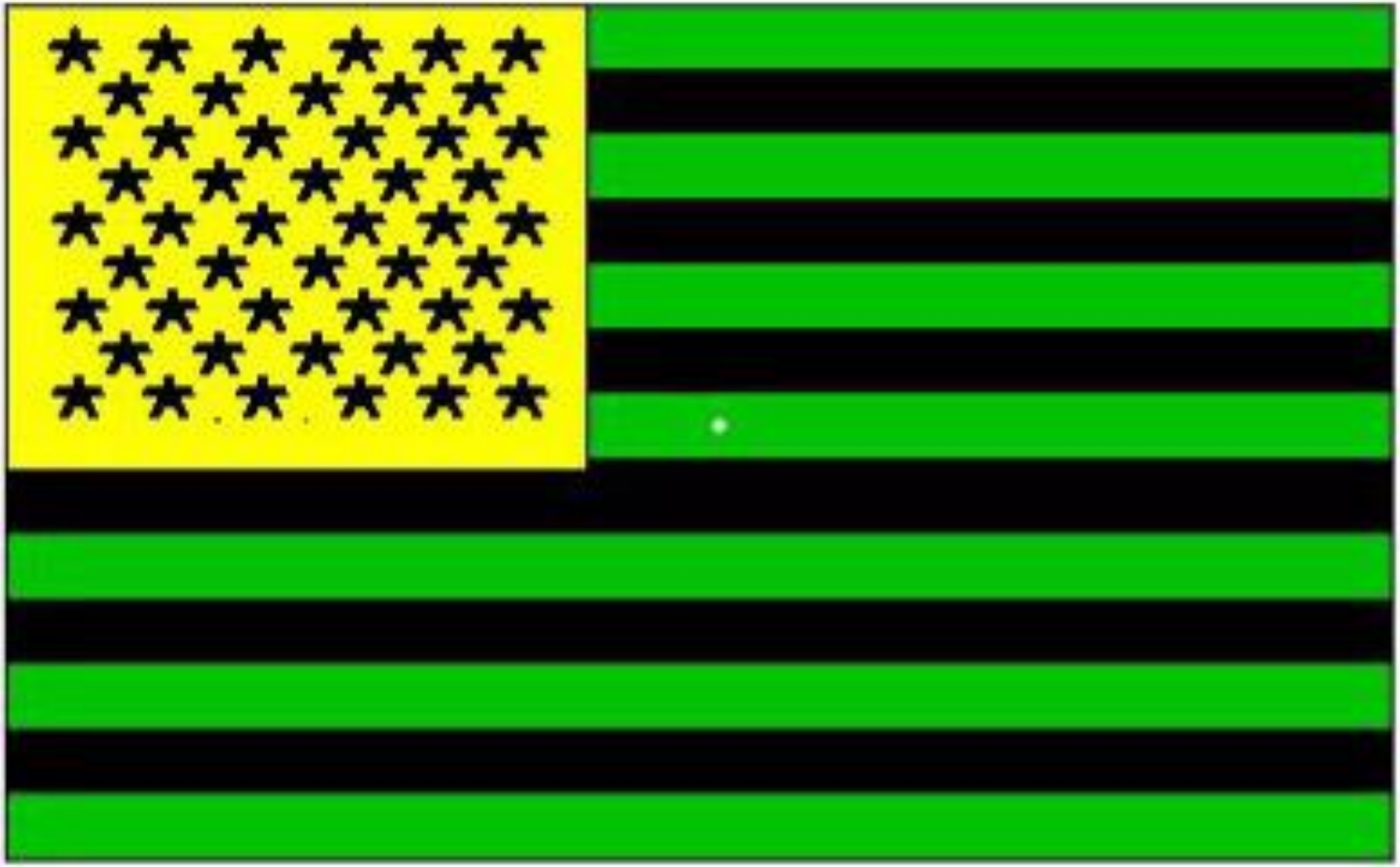
ILLUSION PRODUCED BY A RIDE IN THE SWING.

Figure 2.20: In the 1890s, a virtual swinging experience was made by spinning the surrounding room instead of the swing. This is known as the *haunted swing illusion*. People who tried it were entertained, but they became nauseated from an extreme version of vection.

Cue Integration across modalities

- Why does this matter for VR?

Adaptation



Adaptation

- Chromatic adaptation

Adaptation

- Waterfall illusion

Adaptation

- Nervous system changes its response based on recent stimulus history…
- This influences perception

- What is the relevance for VR?

Measuring perception

- Psychophysics – quantifying the perceptual response to a physical stimulus

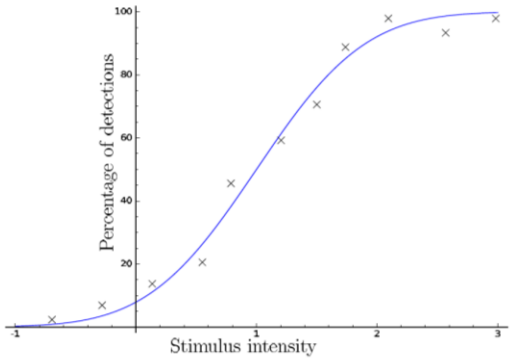
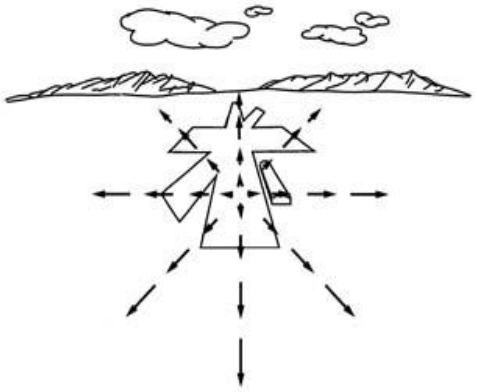


Figure 2.21: The most basic *psychometric function*. For this example, as the stimulus intensity is increased, the percentage of people detecting the phenomenon increases. The point along the curve that corresponds to 50 percent indicates a critical threshold or boundary in the stimulus intensity. The curve above corresponds to the cumulative distribution function of the error model (often assumed to be Gaussian).

- What is the relevance for VR?

Visual-vestibular Conflict

Visual



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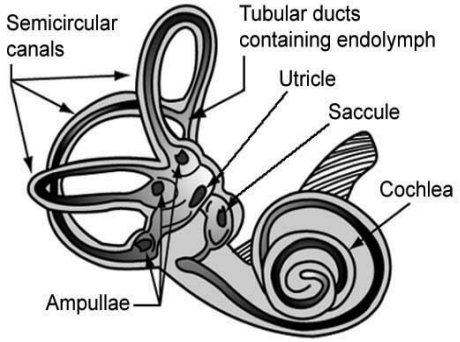
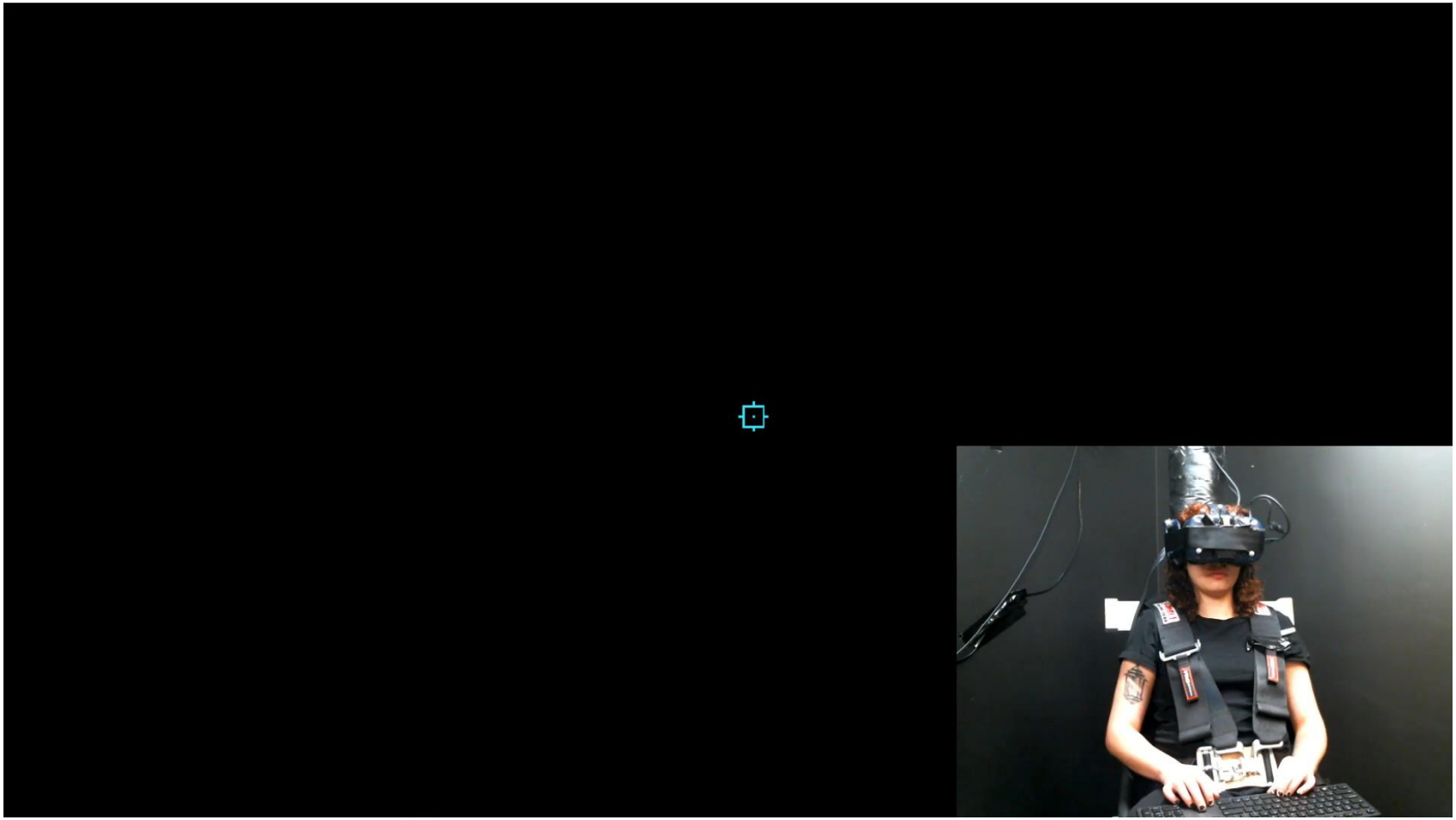
Vestibular



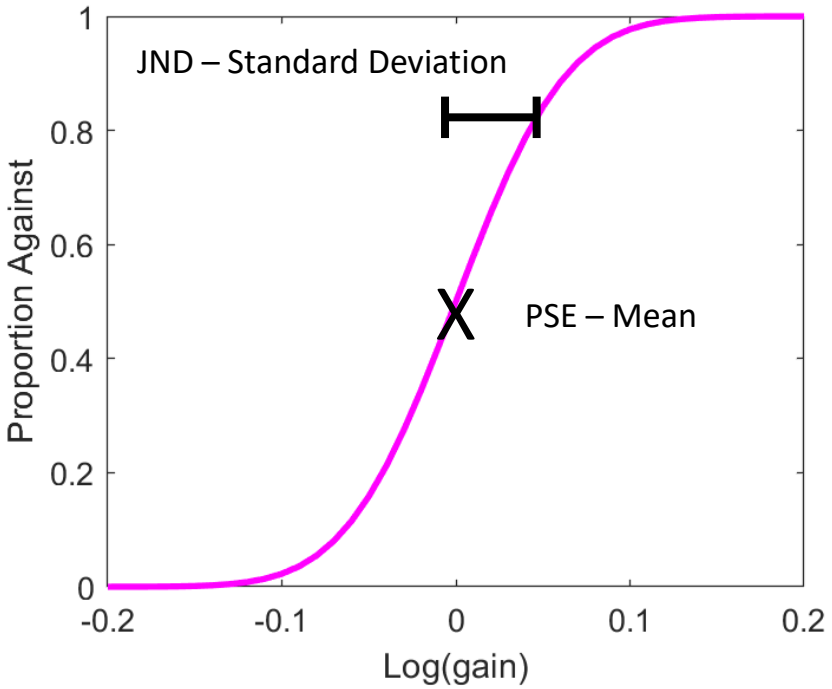
- Causes
  - Vehicular travel
  - Visual displays
  - Vestibular dysfunction
- Consequences
  - Dizziness / vertigo
  - Nausea
  - Other physiological responses

Visual-vestibular Conflict



Accuracy and Precision of Stationarity Judgments

- Accuracy
  - PSE – point of subjective equality
  - Visual gain perceived stationary
- Precision
  - JND – just-noticeable difference
  - Range of immobility/stationarity

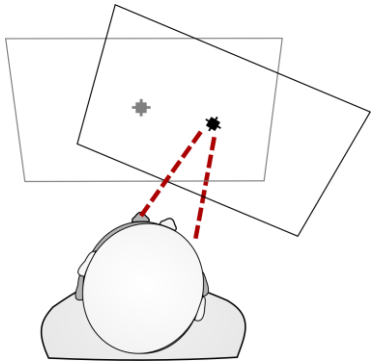


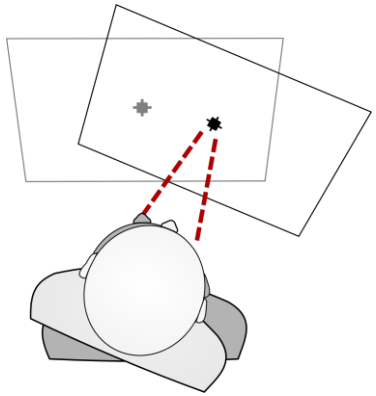
Impact of Motor Signals

Active Movement

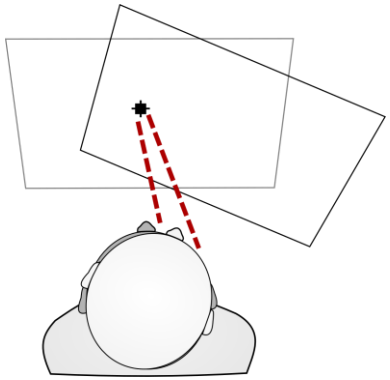
Passive Movement

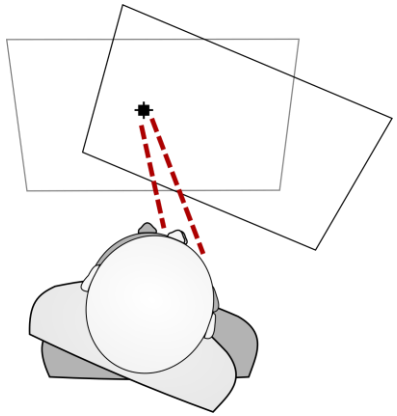
Head-Fixed





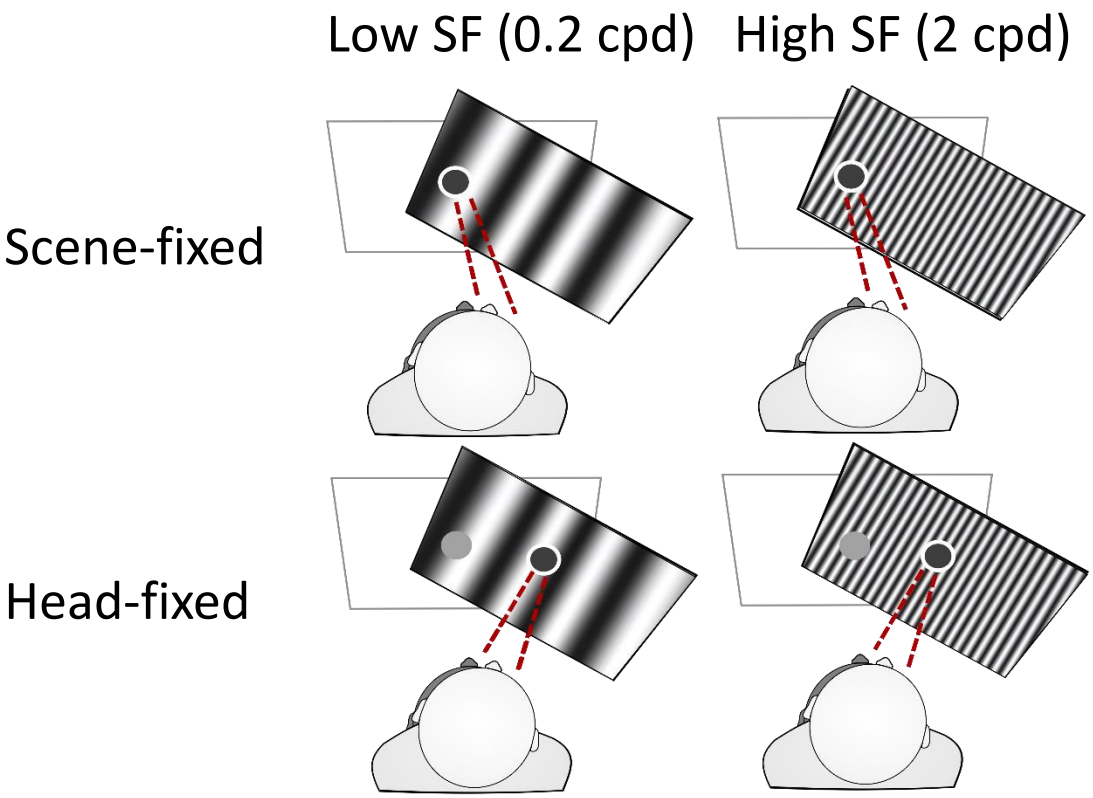
Scene-Fixed





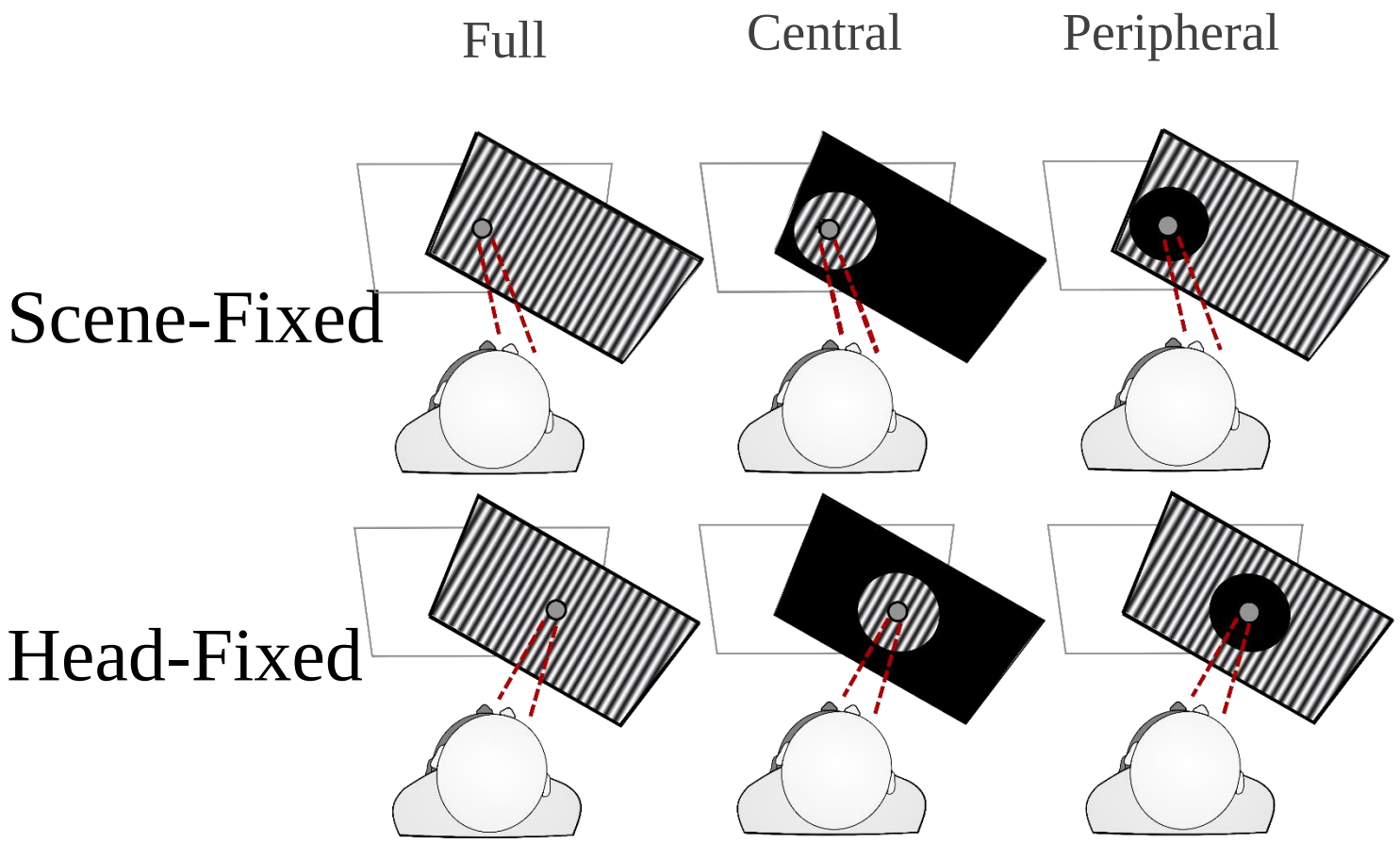
Halow et al 2023.

Influence of Spatial Frequency



Halow et al. in press

Influence of Retinal Stimulus Location



Halow et al. in press

Conflict and Sickness

Journal of Vision (2023) 23(14):7, 1–15

Impaired stationarity perception is associated with increased virtual reality sickness

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Some applied VR questions:

- How far away does that object appear to be?
- How much video resolution is needed to avoid seeing pixels?
- How many frames per second are enough to perceive motion as continuous?
- Is the user's head appearing at the proper height in the virtual world?
- Where is that virtual sound coming from?
- Why am I feeling nauseated?
- Why is one experience more tiring than another?
- What is presence?

Human-in-the-loop