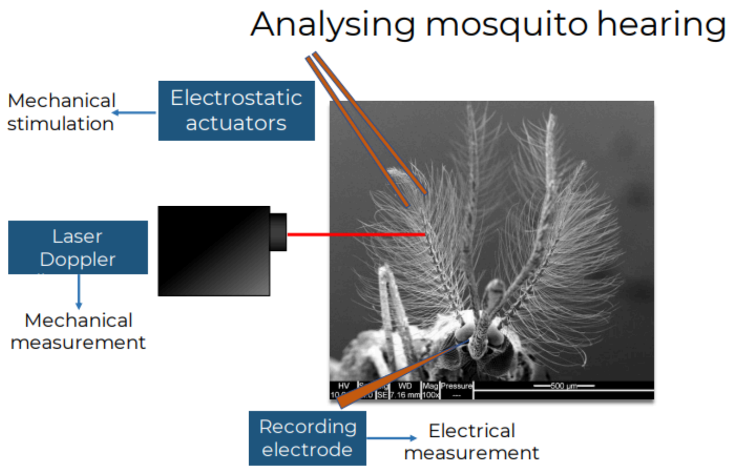
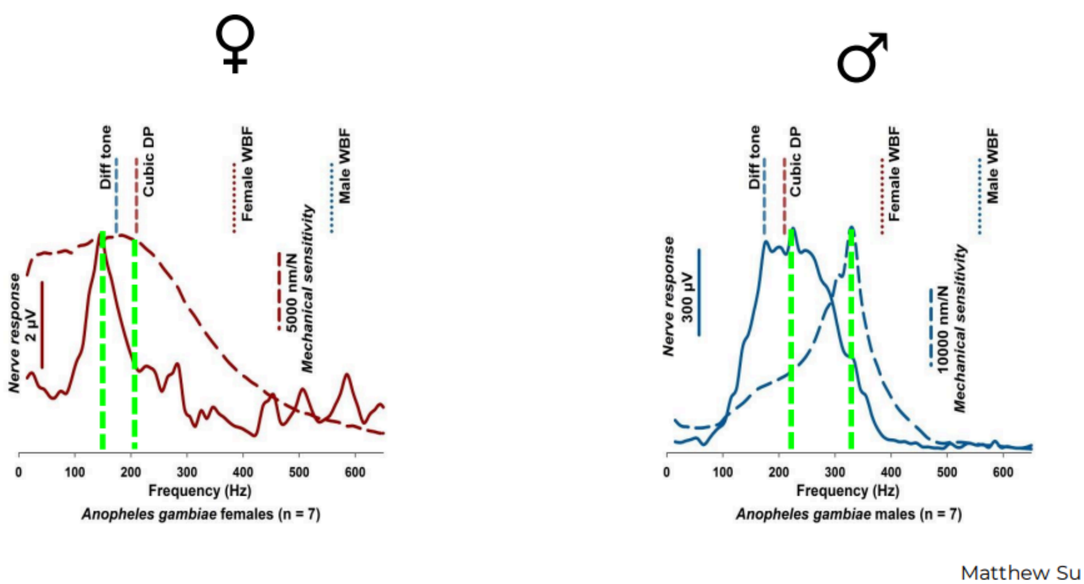
Male ears are used to detect females
Not sure what female ears are for, no auditory behaviours in response to sound

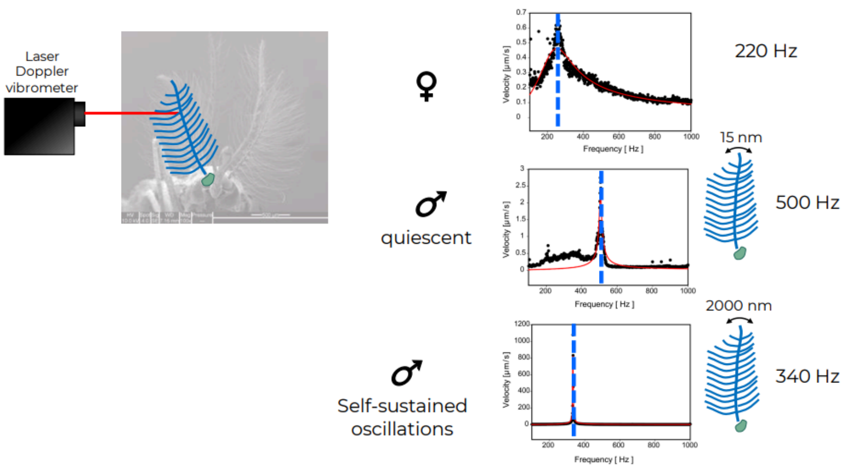


Electrostatic actuators, we can control exactly what the mosquito is receiving



Auditory tuning are different
Dash lines corresponds to flagellum frequency tuning
Normal lines reflects frequency tuning of nerve

- For males, the frequencies that the flagellum is “interested in” is different from the nerve’s

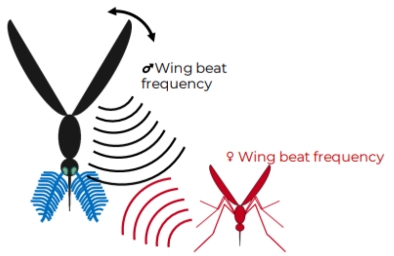


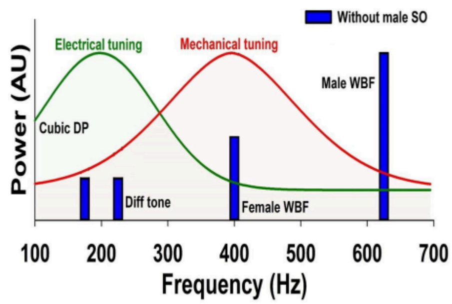
These two properties are important for male mosquito mating behaviours

1. Swarming behaviour
    a. Everyday at same location, probability the same mosquitoes go
2. Acoustic detection in the swarm
    a. Swarm is a noisy environment
    b. Mostly males
    c. Females occasionally enter swarm
    d. Different wing beat frequencies emitted by males and females, and also species
        i. Phonotaxis → attracted by sounds

- Particle velocity movement decreases with distance
    - Wing beat frequencies decrease with distance
- Flagellum tuning curve falls in line with female wing beat frequency
    - Flagellum is more interesting in female
- Nerve is interested in something else → male and female wing beat frequencies mix will create low frequency distortion product which falls in line with nerve tuning curve
    - Male uses their own sound emissions to detect females, thus males need to be flying to detect females

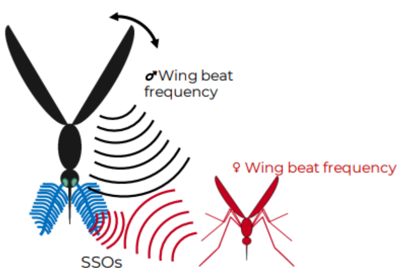
- Self-sustained oscillations creates sound in their own antennae
    - Self-sustained oscillation (SSO) are spontaneous activation of the ears
- The SSO has a similar frequency to female wing beat tones, this amplifies female wing beat frequency → more audible

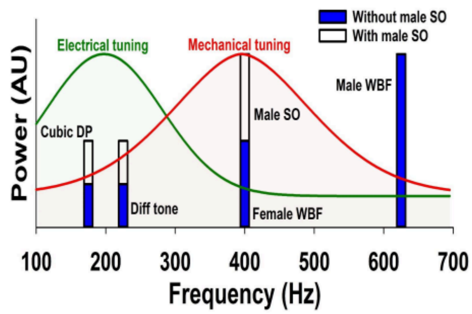




Su et al, Nat Comm, 2018;
Warren et al, Curr Biol, 2018;
Warren et al, Curr Biol, 2009;
Simões et al, J Exp Biol, 2016.

Su et al, 2018





Su et al, Nat Comm, 2018;
Warren et al, Curr Biol, 2018;
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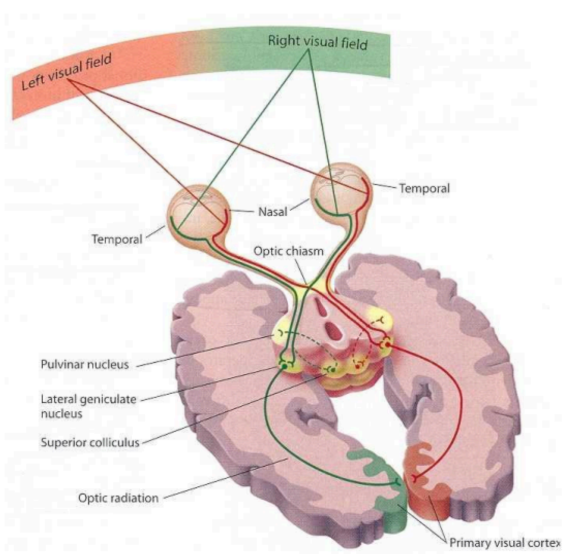
Su et al, 2018

Visual System

<u>Basic</u>

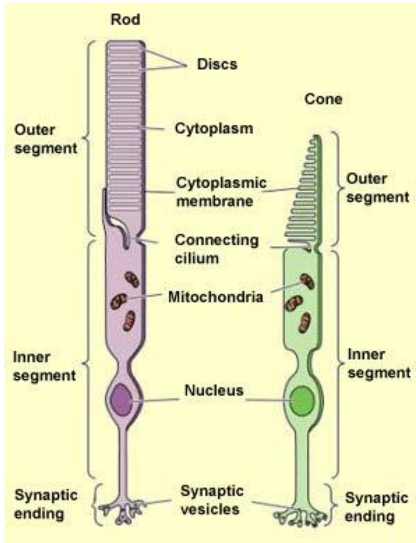


1. Light passes through transparent cornea, then through the lens of the eyes
2. Focused onto photoreceptors in retina
    - Light is refracted as it enters the vitreous space
    - Refraction permites formation of a focus image on retina
    - Lens contributes only about ¼ of refractive power, the rest is by the cornea
    - Accomodation → shape of lens can be actively adjusted to allow objects at various distances to be brought into focus
3. Photoreceptors transduce the light into electrical signals
4. Axons of retinal ganglion cells project away from eyes through optic nerve
5. Some axons cross over at the optic chiasm to the opposite hemisphere
    - Right visual field → left hemisphere
    - Left visual field → right hemisphere
6. Retinal ganglion cell axons project to lateral geniculate nucleus (LGN) of the thalamus and superior colliculus (in midbrain)
    - LGN relay cells project to primary visual cortex (V1)
    - Superior colliculus projects to pulvinar nucleus in the thalamus, which projects to specialised regions beyond V1
        i. In primates, superior collicus is involved in eye movements and receives fewer ganglion cell axons than LGN
        ii. In other mammals, they receive a larger % of afferents, so a bigger role in vision

Retina

Pigment epithelium + Photoreceptor + Bipolar cell + Ganglion cells (neurons)

- Photoreceptors transduce light into electrical signals which travels along local neurons of retina
    - Structure:
        - Inner segment which contains the cell body
        - Outer segment which contains memrbanous disks specialised in phototransduction (aka converting light to electrical signals)

-
        - 

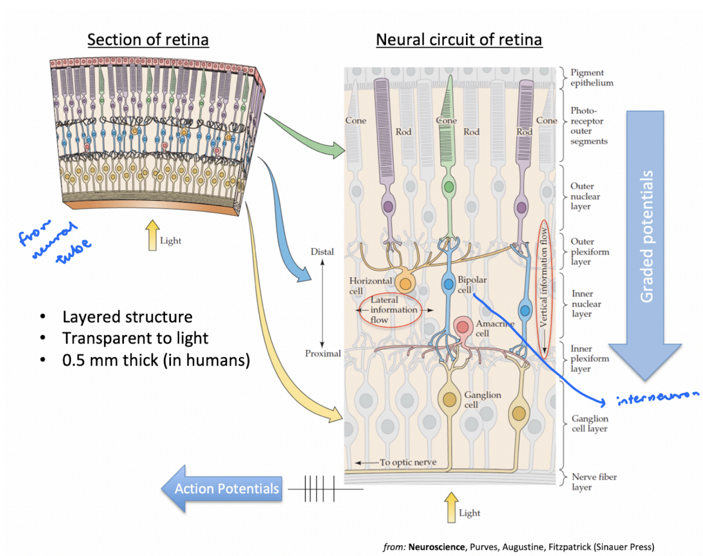
    - Types
        - Cones
            - Specialised for vision in light
                - Detection of higher intensity light (photopic)
                - Colour vision ⇒ comparisons of level of response from different cones contributes to colour vision
            - 3 types of cones
                - Short (blue)
                - Medium (green)
                - Long (red)
            - Each / very few cones transmit signals to a single ganglion cell (low convergence) → high vision acuity
                - Vision acuity is proportional to concentration of cones
            - High density of cones in fovea, density decrease with increasing distance from the fovea (less cones in the periphery of the retina)
        - Rods
            - Specialised for vision in the dark
                - Detection of low intensity light (scotopic)
            - Elongated outer segment
            - Only 1 type of rod
            - Rods are absent in the fovea, but present in rest of retina
            - Many rods converge on the same RGC
    - Photoreceptors are depolarised at rest, hyperpolarised when excited
        - More intense lights leads to greater hyperpolarsation
        - Without light
            - Photoreceptors depolarised (-40mV) and releases glutamate continuously
        - With light
            - Photoreceptors hyperpolarised and reduces release of glutamate (reduction amount proportional to received light)
- Retinal ganglion cells are the only output cells of the retina
    - Must convey form, colour and motion

            - Achieved by combining various local circuits
    - Type:
        - Midget
            - Static images
            - Luminance and colour sensitive
            - Sustained stimulus = sustained firing
        - Parasol
            - Motion and change
            - Luminance sensitive only
            - Fire to changing stimulus not to sustained stimulus
        - Koniocellular Ganglion Cells

Layered structure

Visual system emphasizes the centre of the visual field

- Fovea → centre of retina
    - Contains only cone cells → high vision acuity
    - High density of retinal ganglion cells
    - Contributes to high vision acuity (creates images with high accuracy and great details)
    - Fovea is represented by a large number of cells in the LGN and cortex, almost half of V1 represents fovea due to high conc of cones



- Saccade movement → compensation for absence of resolution outside of fovea by scanning the environment

Phototransduction

1. Light stimulation of rhopsin leads to activation of G-protein (transducin)

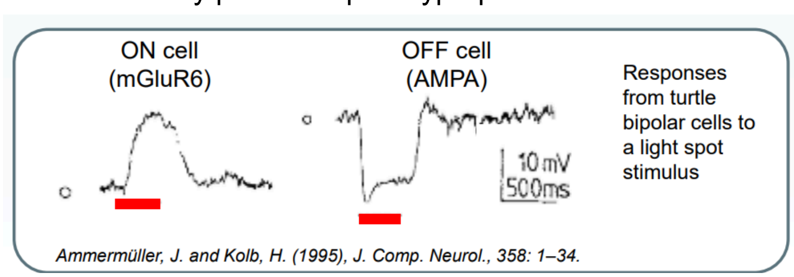
2. Activated transducin activates cGMP phosphodiesterase (PDE)
3. PDE hydrolyses cGMP, reducing its concentration
4. Hydrolysation causes calcium and sodium cation channels to close
5. Hyperpolarisation
6. Less release of glutamate

Signal is amplified:

1 photon → 1 photopigment → 800 transducin → 800 PDE → 4,800 hydrolysed cGMP → 200 sodium cation channels closed

Amplification is smaller in cones than rods

Receptive fields

- Each cell responds to a small part of the visual field
    - Receptive field: part of the visual field to which a cell responds
- Receptive field properties: Relationship between image properties of a receptive field and the level of response of the cell
- Cone bipolar cell
    - ON cells → excited by photoreceptor hyperpolarisation
    - OFF cell → inhibited by photoreceptor hyperpolarisation
        - 

Ammermüller, J. and Kolb, H. (1995), J. Comp. Neurol., 358: 1–34.
- Horizontal Cells
    - Responsible for lateral inhibition
    - Release GABA (inhibitory) onto photoreceptors
- Opposing centre-surround receptive field
    - On-centre, Off-surround
        - Light hits centre, not surround
            - Centre cones hyperpolarise → reduce release of glutamate → ON bipolar cells depolarise and excite retinal ganglion cells
            - No activity in surround cone cells → No change in activation of horizontal cells
        - Light hits surround, not centre
            - Surround cones hyperpolarise → horizontal cells hyperpolarise by decreased glutamate from cones → reduced GABA release from horizontal cells → central photoreceptors depolarisation and increase

            glutamate release → ON bipolar cells hyperpolarise → Inhibit retinal ganglion cell
    - Off-centre, On-surround
- Rod bipolar cells do not directly synapse with RGC
    - Rod bipolar synapse with amacrine cell
    - Amacrine cell synapses with cone bipolar cells

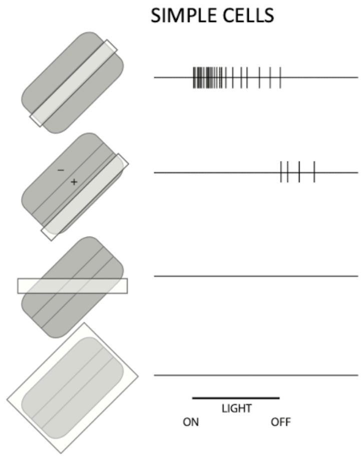
Imaging Retina

Optical coherence tomography (OCT)

Phototransduction changes optical path length of outer layer of the retina → detected by OCT

<u>LGN and Visual Cortex</u>

- LGN
    - Located in the thalamus
    - Relay to cortex
    - Layered structure
    - Each layer organised topographically
        - Target neurons have similar receptive field properties as ganglion cells they receive input from
        - Adjacent cells have adjacent receptive field locations
    - LGN projects to cortical layer 4 of V1
        - Specific LGN layers project to specific cortical layers but there is also information from other layers → oculodominant columns
- V1 Layer 4
    - Receptive field of layer 4 neurons is similar to LGN layer they receive input from
    - Consists of simple and complex cells which detect bars and edges
        - Important feature for nervous system to detect bars and edges because it defines boundaries of objects
        - Simple cells:
            - Receptive fields have separate regions that respond to light increments or decrements
            - Respond to bars/edges at one particular orientation and position in space with a maintained response
            - Inputs from centre-surround cells with linearly organised receptive fields



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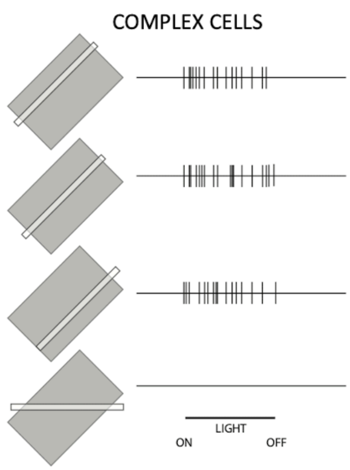
    - Complex cells:
        - Respond to the presence of static or moving bars/edges with a particular orientation located anywhere within their receptive fields
        - Input from multiple adjacent simple cells with similar orientation preferences
            - Lower spatial resolution



Organisation of V1

- V1 has a topographic representation of the visual space
    - Inherited from LGN
    - Each position of the V1 sheet of cells corresponds to a particular point in visual space
    - Segregation of input from two eyes are in alternating fashion in layer 4 → very defined
        - Columns of ocular dominance → each cell strictly responds to input from 1 of 2 eyes
        - Layers II, III, V and VI, cell inputs mixed
- V1 has organisastion of neurons responding to preferential direction of a bar

    - Same column of neurons have the same preference for orientation
    - Nearby neurons tend to have same orientation preference which changes slowly as one moves tangentially (laterally, horizontally) through the cortex
        - Pinwheel shape

Colour vision

- 3 types of cones that detect different wavelengths
    - Short (blue)
    - Medium (green)
    - Long (red)

Separate light intensity from light wavelengths (luminance contrast vs colour contrast)

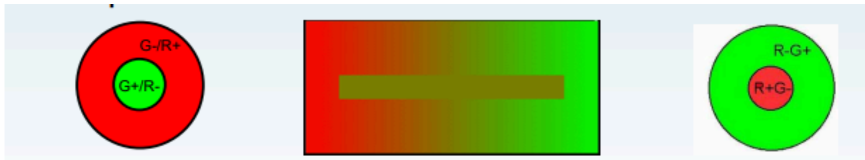
- Number of photons absorbed by a single photoreceptor depends on light intensity and wavelength
    - Once a photon is absorbed produces same effect on photoreceptor output
        - Wavelength of photon only affecting which type of cone absorbs it, not going to affect the signal from the photoreceptor (signal will be the same, release of glutamate)
    - Photoreceptor cannot discriminate between whether a photon absorbed is at which wavelength
    - Need comparison of of the responses from at least 2 photoreceptors with different wavelength sensitivity

Achromatic: Different colours are perceived as different intensities NOT as different colours (in the dark, a green object will be perceived as brighter than a red one but not greener)

- Looking at the output, we cannot tell colours apart because photoreceptors only able to count photons

Colour vision (Trivariant, able to detect 3 wavelength): Colour encoded by relative cone outputs

- Colour phenomenology
    - Colour opponency → some colours can coexist in a uniform patch, some colours will cancel each other out
        - There are colour opponent channels (exicted by red and inhibited by green, so if both activity are balanced, then are inactive)
        - Output from 3 cones are combined in opponent fashion
            - Red and green cannot coexist
            - Yellow (red+green cells) and blue cannot coexist
    - Simultaneous colour contrast → the same colour appears to be different when put against different backgrounds

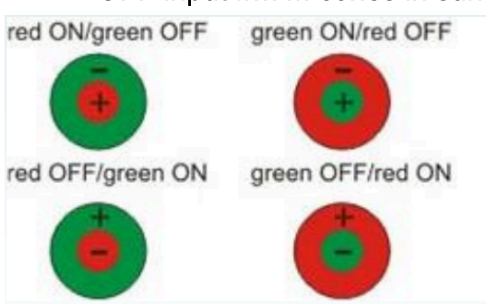


- The grey against the red background appears to be green because the surround R+/G- receives red light, thus the surround will be excited and enhance response of centre G+/R- bipolar cells, so the grey appears green
- The grey against the green backgroun appears more reddish because the surround R-/G+ receives green light, enahcing centre response

- Color constancy → colour remains constant despite being in different environments with different light intensity

  Shift caused by changes in ambient light is th same for centre and surround → contrast is the same

Midget Ganglion Cells

- Single colour-opponent cells
  - 4 types:
    - Red-Green (L-M), Green-Red (M-L)
    - Blue-Yellow (S-LM), Yellow-Blue (LM-S)
      - Inputs from short cones antagonise **combined** inputs from medium and long cones
  - Arrange in centre/surround
    - For example:
      - ON input from L cones in centre of receptive field
      - OFF input frm M cones in surround
    - 

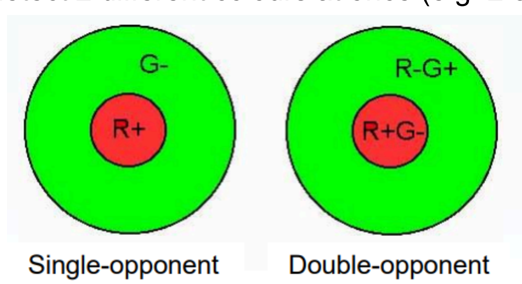
      from: **Webvision**. Kolb et al. 2005.
  - Do not respond to colour contrast → shining two different coloured lights do nothing for now
    - Mechanism of red ON/green OFF
      - When green light is shone onto the surround, horizontal cells are depolarised
      - Horizontal cells stimualted → increase in GABA release onto photoreceptor

            - ON centre bipolar cells depolarised due to less inhibition from photoreceptor
            - Increase in firing rate
        - If we shine a red light on centre and green light on surround, effects cancel out for a red-centre green-surround
        - Same for shining white light (because it contains all the wavelengths)
        - Can only detect 1 colour
- Coextensive single-opponent cells
    - Uniform receptive field
    - Inputs from short cones antagonist combined input from medium and long cones

Spatial resolution of chromatic vision → chromatic vision has innate lower spatial resolution

Primary visual cortex

- Colour sensitive cells concentrated in blobs
    - Organisation is not as good
- Centered in the ocular dominance columns
- Not selective for orientation
- Chromatic and achromatic information are segregated
- In layer 2-3 of V1, inputs from single-opponent cells are combined
    - Not only 1 type of wavelength for the centre or the surround
    - Each type of cone operates in all parts of the receptive with different effects in centre or surround
        - Double opponent cells
            - Combine info from simple opponent cells
            - Receptive fields are coarser than single oppoenent
            - Can detect colour contrast of an object → shining 2 different colours = can detect 2 different colours at once (e.g. 2 colours side by side)



- This double opponent cell can detect red and green next to each other

Vestibular System

Vestibular organ located in inner ear (both sides)