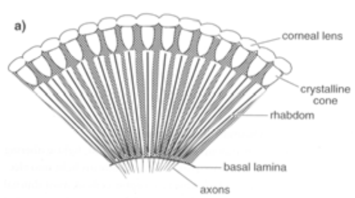
INSECT SENSES

- Vision
- Smell
- Hearing (+insect sounds)

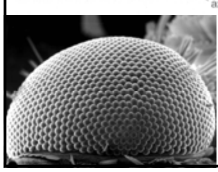
Vision

- General structure and function of eye
- Seeing polarized light
- Adjustments to light levels
- Limits to resolution
- Processing and image formation

ommatidial units in eye



- are separate from each other, similar
- hexagonal packing

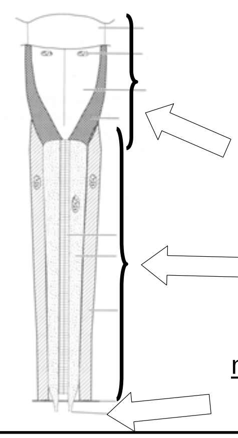


- dragonflies have about 10K ommatidia

Army ants

have very few ommatidia, sometime just 1

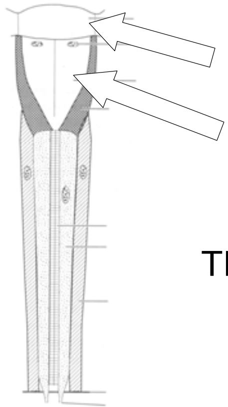
Ommatidial structure



light collector = lens unit

light detector = retinula cells

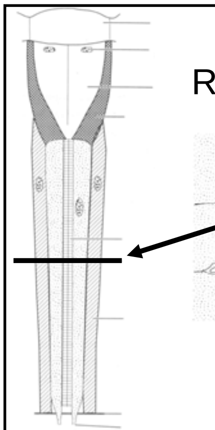
nerves synapse here



corneal lens
(transparent cuticle)

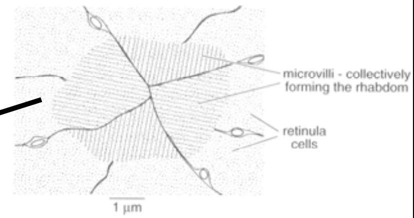
crystalline cone

THE LENS UNIT

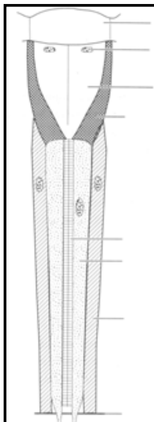


- usually <u>eight</u>

Retinula cells

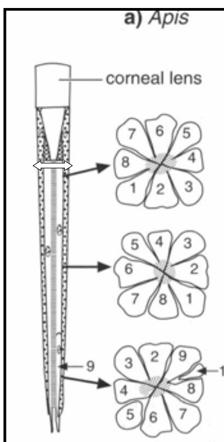


- microvilli extend centrally



retinula cells

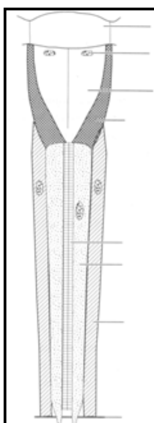
- most retinula cells are <u>very long</u>
- this increases chance that enough light will be detected to stimulate neurons

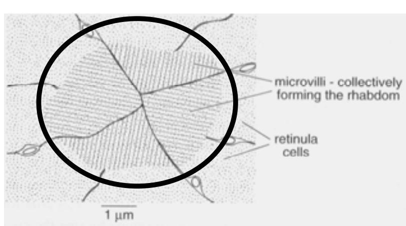


retinula cells

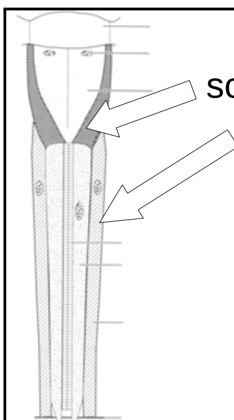
- retinula cells twist
- so all the cells are exposed

rhabdom





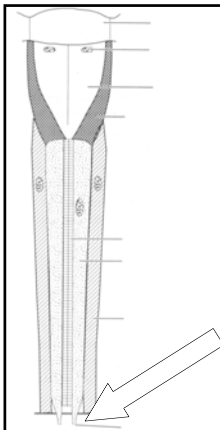
- composite structure made up of <u>microvilli in the retinula cells</u>
- location of <u>visual pigments</u>



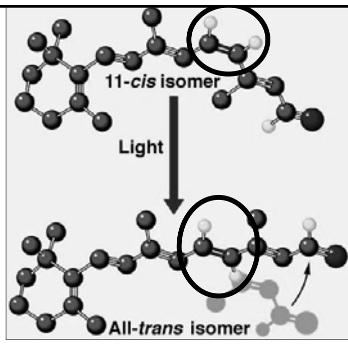
screening pigments

- along entire length of lens and retinula cells
- NOT a visual pigment

how does light get transduced into neural signal?

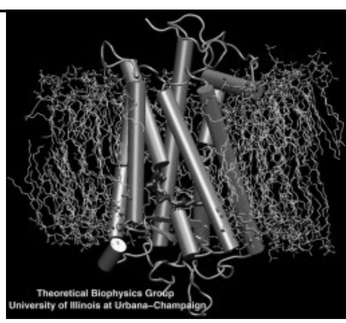


nerve synapse –
I see the light



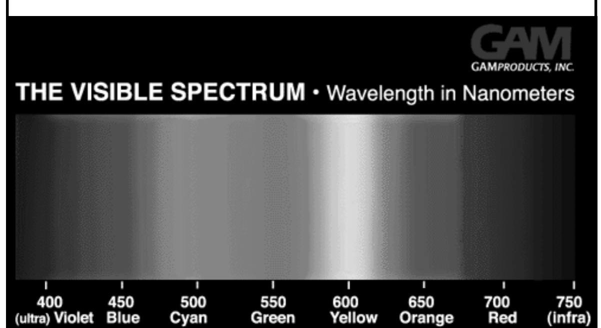
Transduction made possible by RETINAL which has two conformations – one is stable and the other is not.

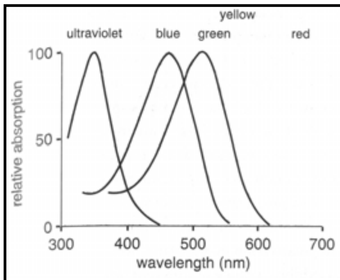
- light converts unstable form to stable trans-retinal
- change in conformation triggers depolarization of the nerve



- Retinal is linked to the visual pigment rhodopsin
- Different rhodopsins responds to different wavelengths

What colors can insects see?



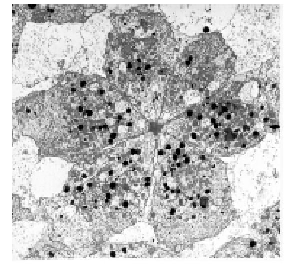


insects usually have 3 visual pigments

- with maximal sensitivity in green, blue and UV

different pigments in different cells

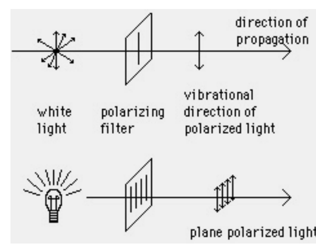
- it is important that different pigments be in different retinula cells
- why?

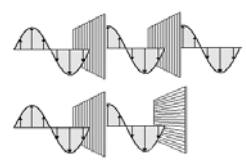


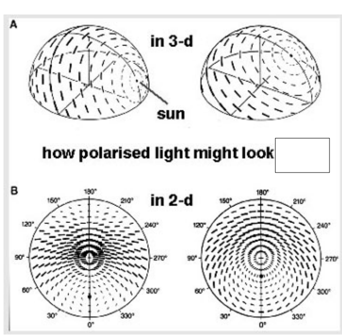
Many insects detect polarized light

- most studied in social insects which use it as a navigational aid

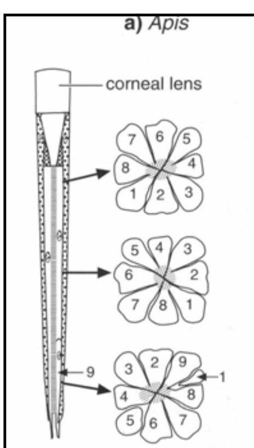
What is polarized light?







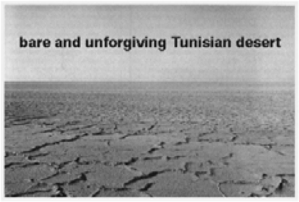
- planes of polarization different across sky
- position of sun can be determined, even if you can't see the sun



rhabdom

- most retinula cells twist
- but ommatidia for polarized light don't

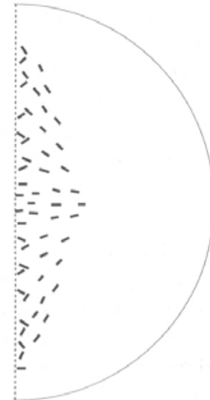
remember

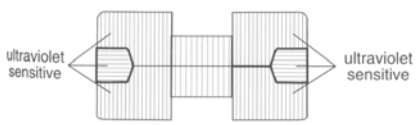


Cataglyphis

- navigates using polarized light
- few landmarks in environment
- it's @#$%& hot
- speed essential
- return home in straight line

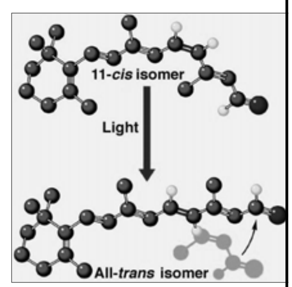
special ommatidia along top of eye



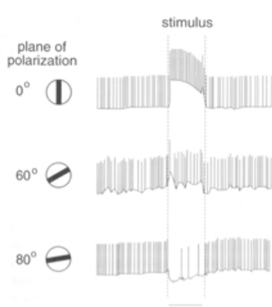


- X-section of retinula cells
- all are sensitive to plane of polarization
- microvilli are arrayed precisely

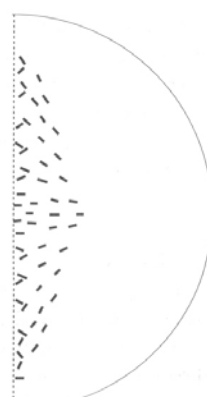
- orientation of microvilli important because molecules of retinal are oriented along their long axis AND
- pigment is stimulated only if struck by light vibrating in the plane of its long axis



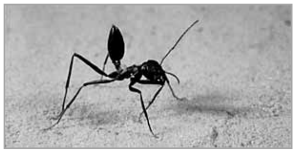
you can see this electrically

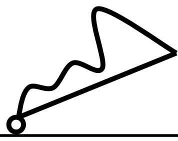


- ommatidia cover the range of possible planes
- so insect can detect a pattern of planes of polarization



Cataglyphis





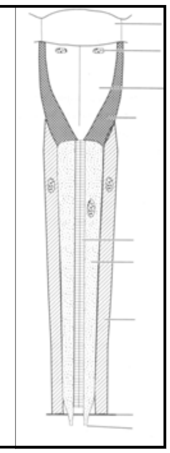
- somehow uses polarization map for navigation
- remembers it on way out
- goes straight home
- =path integration

Pedometer

Light Control

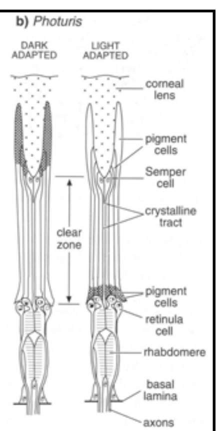
apposition eye

- found in day-flying insects
- best suited for high light levels
- light entering om. can only trigger its own nerves
- screening pigments prevent stray light



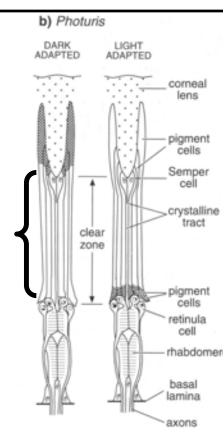
superposition eyes

- best for low light levels – nocturnal insects
- works in two modes
- light and dark adapted



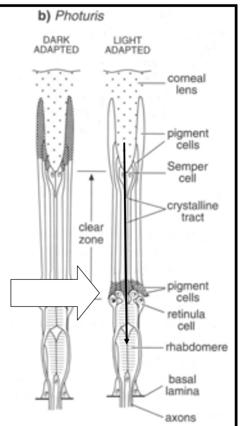
superposition eyes

- lens
- retinula cells
- screening pigment
- CLEAR ZONE



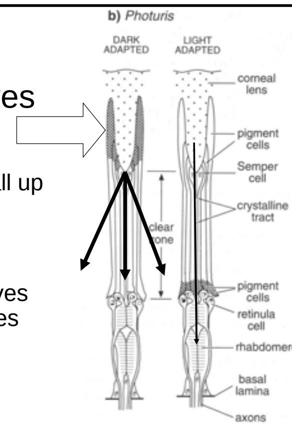
Light adapted superposition eyes

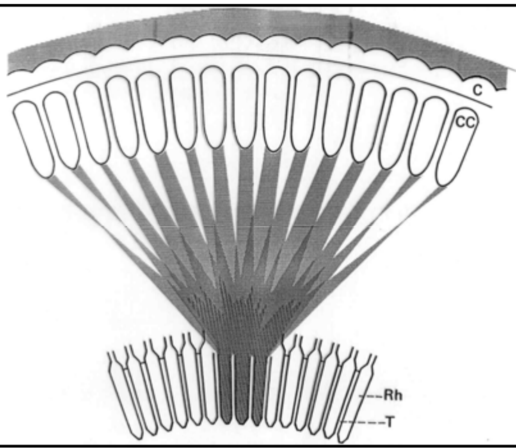
- In the day, pigment is near retinula cells
- light can pass only through lens to its own rhabdome

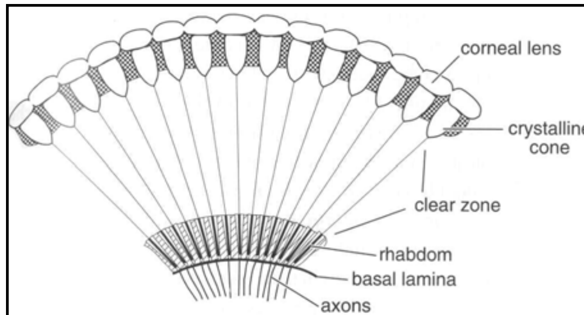


Dark adapted superposition eyes

- at night, pigment is all up around lens
- light is free to move throughout eye
- each rhabdom receives light from many lenses

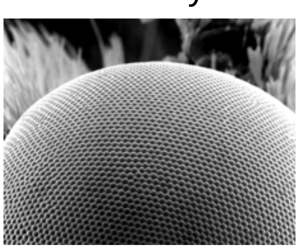






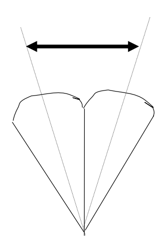
- better use of light (it's night!)
- BUT poor resolution of image

What determines the quality of the image formed by an insect's eye?



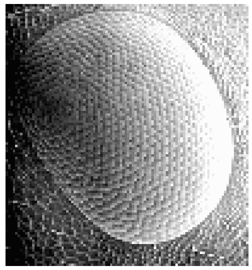
What determines resolution?

- interommatidial angle



for an eye of a particular curvature,

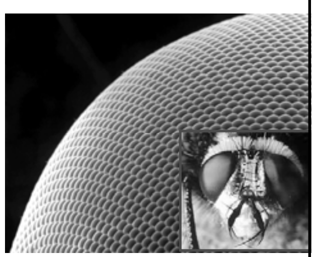
- smaller facets will result in smaller angle and more facets



10 (5k) 25 (33k) 50 (135k) pixels/inch

BUT, there is a lower limit to diameter

- increased diffraction causes loss of useful light



facet diameter varies

- between species
- between sexes
- on a single eye

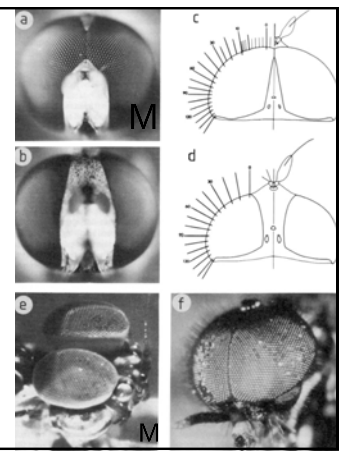
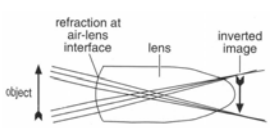
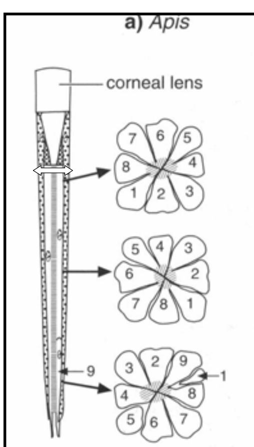


IMAGE PROCESSING How it all works



- inverted image forms just behind lens

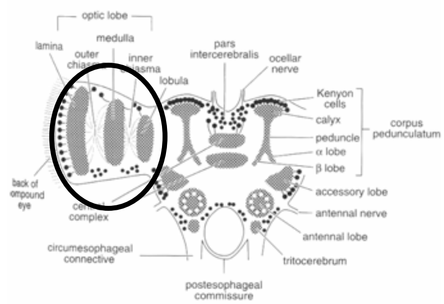


retinula cells

- retinula cells twist as they extend towards nerve
- so all the cells are exposed to the light and image is not preserved

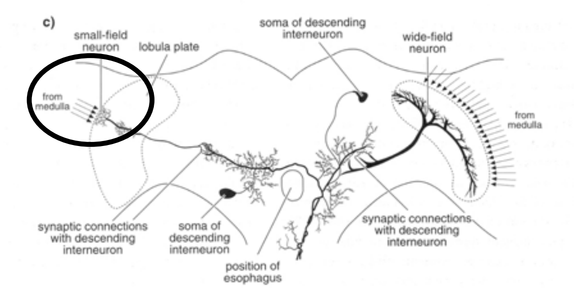
How is the image put together?

Processing, processing, processing

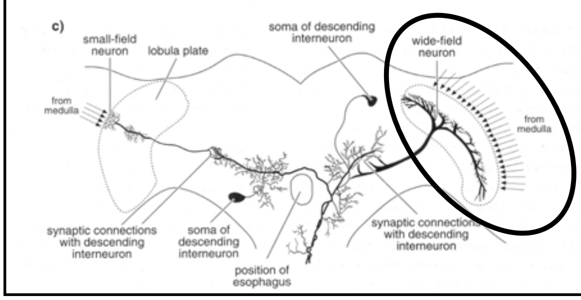


example in the fly lobula

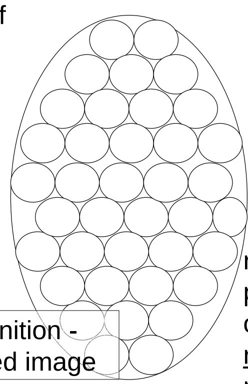
- small field neurons connect with relatively few columns (20-100)



- wide field neurons connect with many columns: 3 run one way, 9 the other

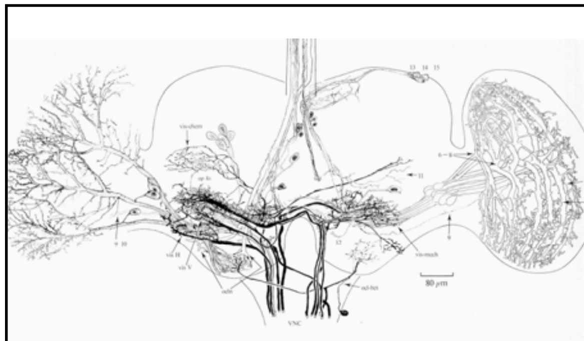


coverage of small field neurons in medulla



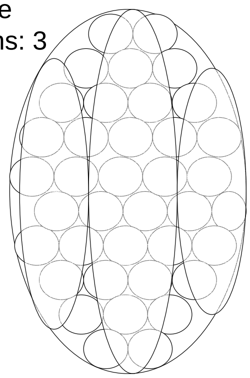
pattern recognition - coarse grained image

retains general patterns of ommatidia - <u>retinotopic mapping</u>

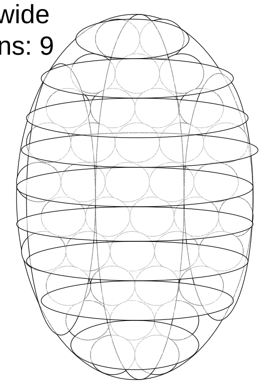


wide field neurons

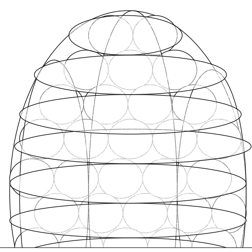
vertical wide
field neurons: 3



horizontal wide
field neurons: 9

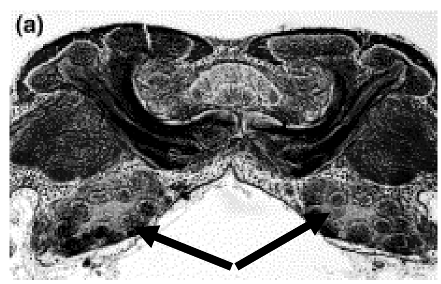


wide field
neurons: 9

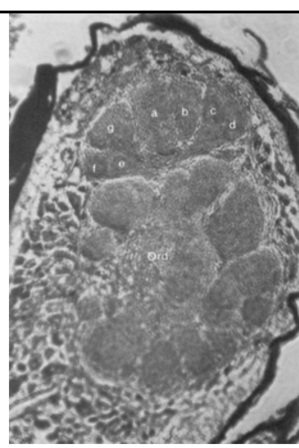


- horizontal cells sensitive to movement front to back - detect yaw
- vertical fields sensitive to roll
- IMPORTANT IN CONTROLLING FLIGHT

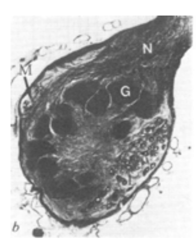
antennal lobes are for smells



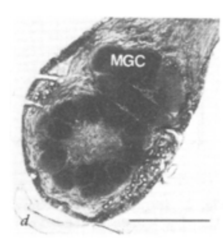
glomeruli



Sexual dimorphism of AL
Antennal nerves grow and contact brain – then MGC develops



female

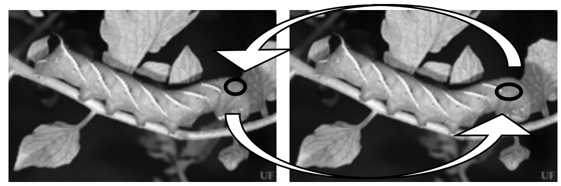


male

How does the AL know to develop the MGC?

- Because the brain tissue is male?
- Or because the developing antennae induces it?

transplant experiment with antennal imaginal discs

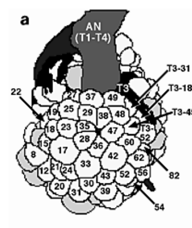


- female larva male larva

male antenna tissue induces male type brain development in AL

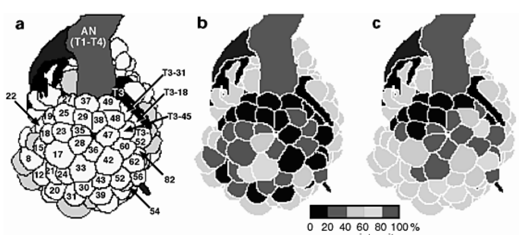
- female larva male larva

honey bee - odor specific code



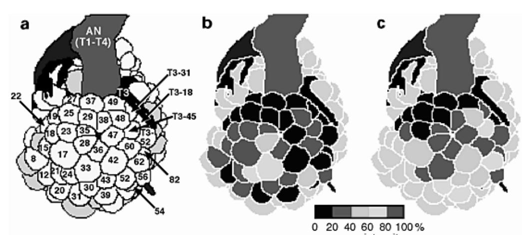
38 most active glomeruli

honey bee - odor specific code



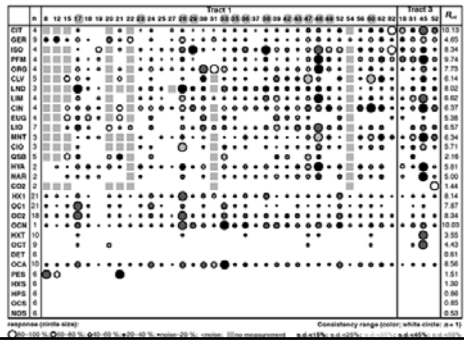
38 most active glomeruli | 1-octanol, 21 individuals | clove oil, 5 individuals

honey bee - odor specific code

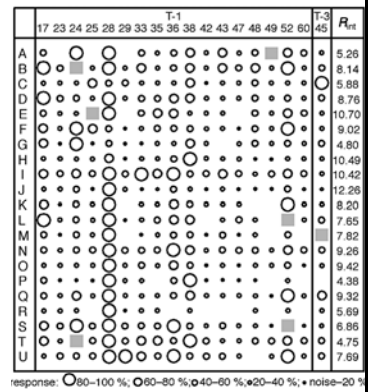


38 most active glomeruli | 1-octanol, 21 individuals | clove oil, 5 individuals

patterns produced by 30 compounds = avg. differences in brain response



individual variability



Points

- same glomerulus can respond to many odors in varying degrees
- combination of glomeruli responses yields an odor specific response
- individual variability in glomerular responses

Insect Hearing

I. Hearing

A. Chordotonal ears

B. Tympanal ear

Insect hearing is an extension of mechanoreception

- hearing is detecting vibrations - usually air or substrate
- sensory detector attached to something that amplifies vibration - cuticle

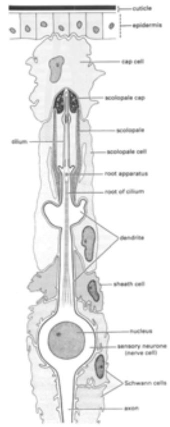
chordotonal organs

- made up of scolopidia
- one <u>scolopidium</u> = neuron, scolopale cell, attachment cell
- under the cuticle
- attached to cuticle on at least one end

scolopidium

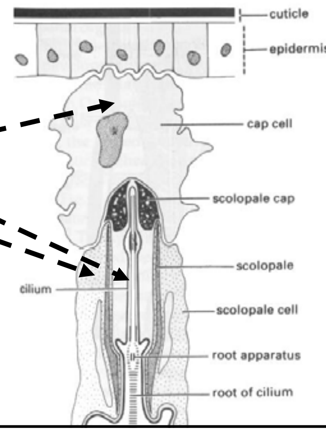
[mod.L., coined in Ger. (F. Eggers 1923, *Zool. Anzeiger* LVII. 239), f. Gr. skolop, skolof, **spike**, after OMMATIDIUM.]

- **1939** V. B. WIGGLESWORTH *Princ. Insect Physiol.* vii. 135 Chordotonal sensilla or scolopidia These sensilla are generally believed to be derived from sensilla becoming elongated and deeply sunk within the body.



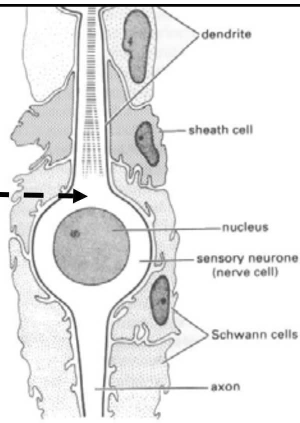
scolopidium

- attachment cell
- neuron
- scolopale cell



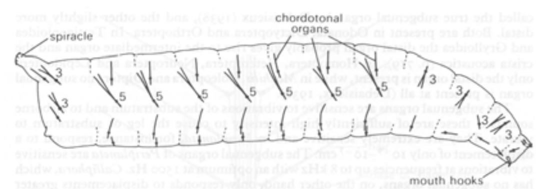
scolopidium

- neuron

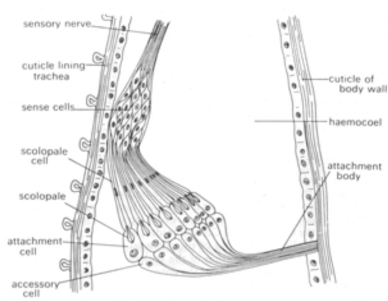


simple chordotonal organs in *Drosophila* larva

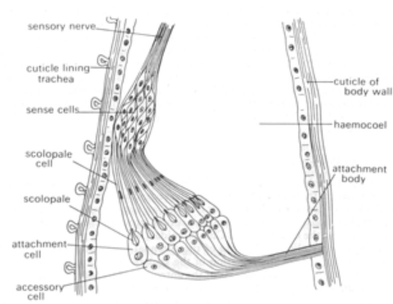
- group in clusters and give general sense of pressure, deformation of cuticle



larger groups of scolopidia placed in particular locations can detect air and subtrate vibration

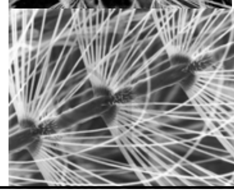


subgenual organ “below the knee”



chordotonal organ extraordinaire

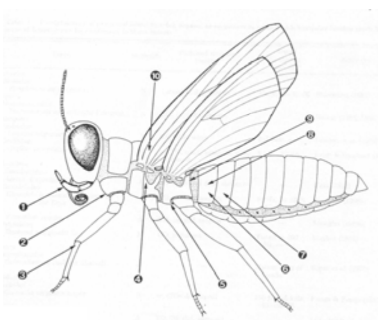
- Johnston's organ in mosquitoes
- second antennal segment
- the most complex mechanosensory organ known in insects
- what does it detect?



tympanal organs

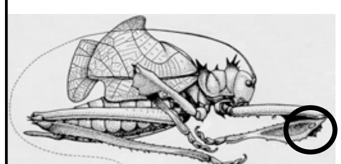
- use principle of a vibrating membrane - really thin cuticle
- usually backed by an air sac to allow free vibration
- to it are attached 1-1000 scolopidia

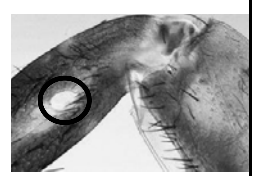
tympanal organs can be just about anywhere



tympanal organs can be just about anywhere

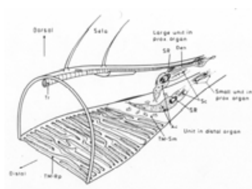
- prothoracic legs - crickets and katydids



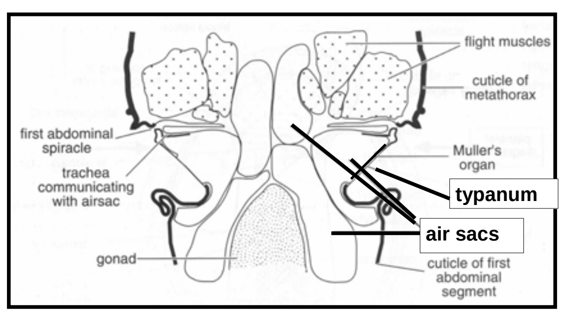


tympanal organs can be just about anywhere

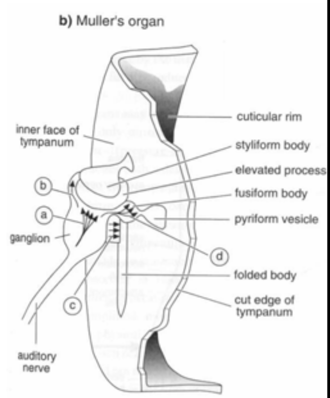
- wing vein - lace wing



grasshopper ear - abdomen

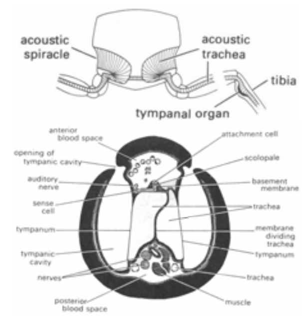


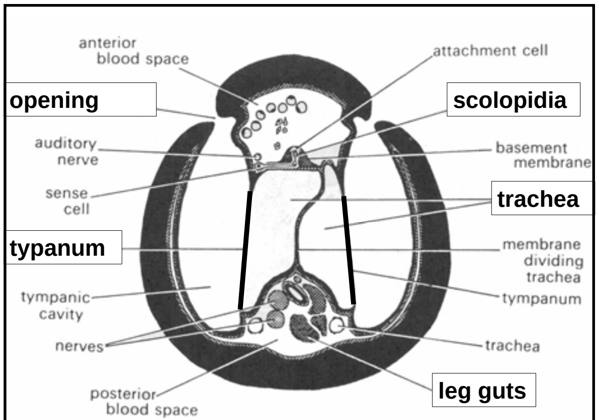
- ~80 scolopidia attached to tympanum
- different directions, attachment sites, shapes give different nerves different sensitivities
- remind you of anything?

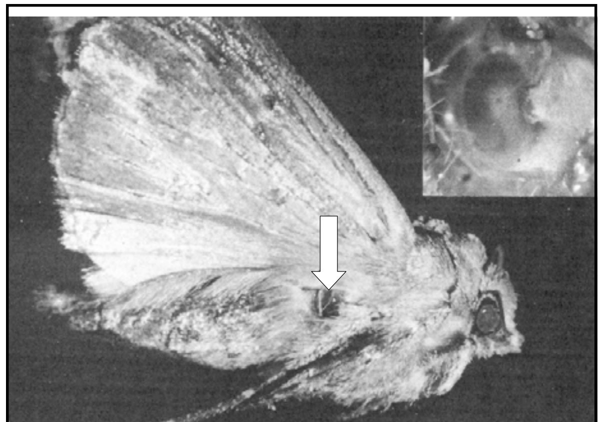


katydids and crickets

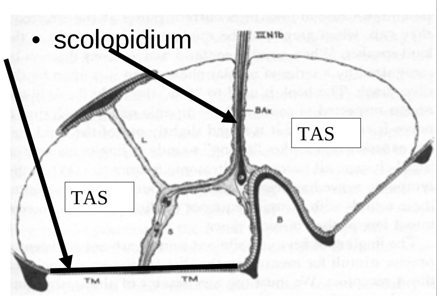
- acoustic spiracle stays open
- acoustic trachea
- directional hearing





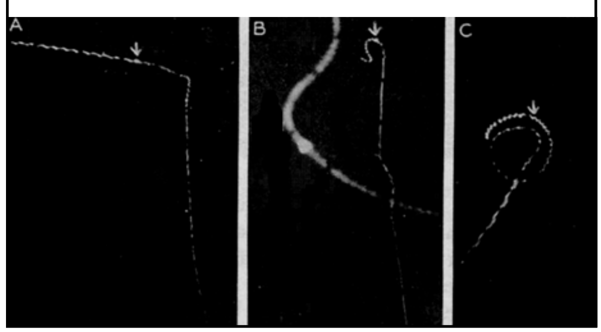


- tympanum
- scolopidium



simple moth ears

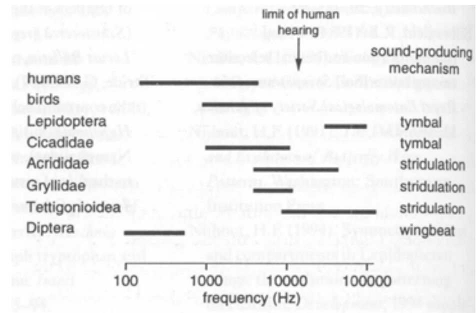
moth dives



Insect Sounds

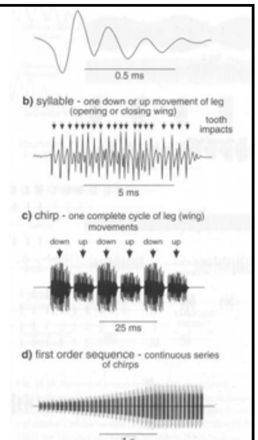
- stridulation (file and scraper)
- tymbal - vibrating membrane
- percussion (eg. striking head on substrate)
- vibrations produced by wing muscles
- air expulsion (eg. hissing cockroach)

frequencies

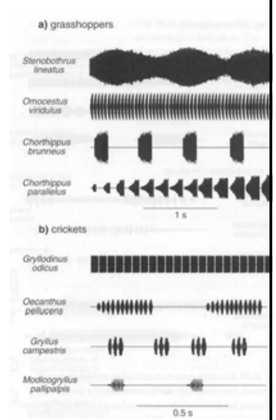


sonograms

- syllable - one stroke
- chirp - full cycle
- sequence - <100 ms between chirps

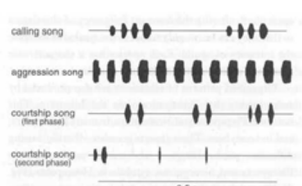


grasshopper (leg)
and cricket (wing) songs
-different songs for
different species

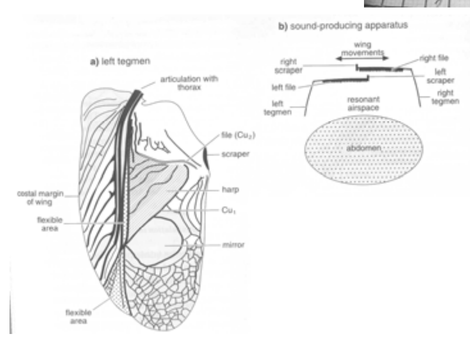


crickets

- different songs made by the same individual

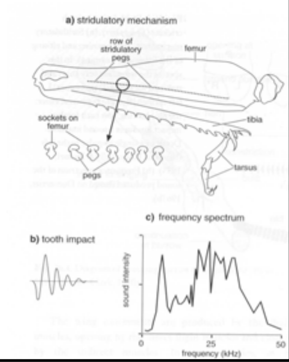


cricket stridulation

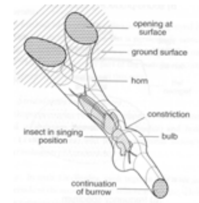


grasshopper stridulation

- pegs are pulled across wing vein



mole cricket

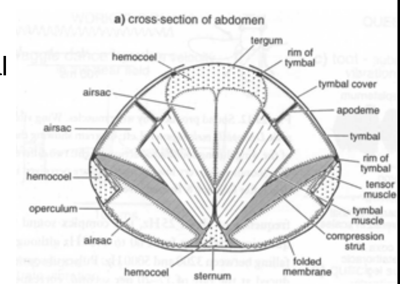


- burrow is an exponential horn
- wings of male form a diaphram across it
- sound travels 600m

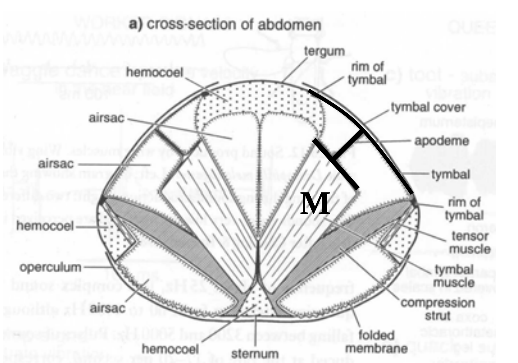
tymbal of a cicada with sclerotized ribs

cicada

- males only
- first abdominal segment
- resilin membrane
- protected by cover



cicada



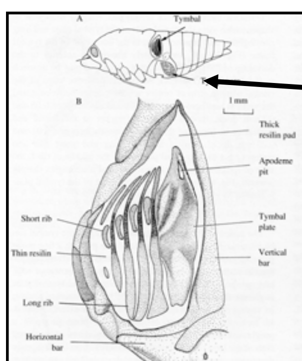


Fig. 4. (A) Outline of a male *Cyclochila australasiae* in lateral view, showing the locations of the tymbal and tympanum. (B) The tymbal in lateral view, drawn to show the distribution of the sclerotised elements (stippled) and of the unsclerotised membrane containing resilin (no stippling). The long ribs are numbered (1–4) in the order in which they buckle during sound production.

also has <u>tympanum</u>

- sound can radiate from both tymbal and typanum - volume of airsacs varies intensity

vibration of wings made by wing muscles

- sound is at the frequency of the wing beat

Tree and leaf hoppers

- produce vibrations through their tymbal organs (they think)
- abdominal vibrations have been observed during signal production.
- Vibrations are transmitted to the substrate through the legs.