LEARNING & MEMORY: *OCTOPUS VULGARIS*

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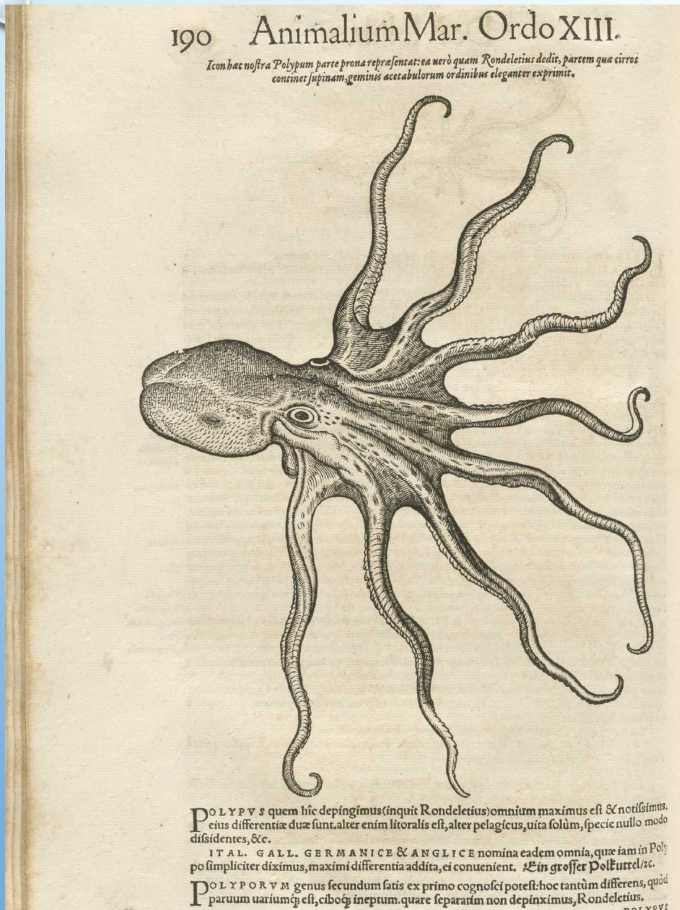
PSYC-149-601 2017C

HISTORY OF ANIMALS – ARISTOTLE, 350 BC



190 Animalium Mar. Ordo XIII.

Icon hæc nostra Polypum parte prona repræsentat: ea uerò quam Rondeletius dedit, partem quæ cirros continet supinam, geminis acetabulorum ordinibus eleganter exprimit.

POLYPVS quem hîc depingimus (inquit Rondeletius) omnium maximus est & notissimus. eius differentiæ duæ sunt. alter enim litoralis est, alter pelagicus, uita solùm, specie nullo modo dissidentes, &c.

ITAL. GALL. GERMANICE & ANGLICE nomina eadem omnia, quæ iam in Polypo simpliciter diximus, maximi differentia addita, ei conuenient. Ein grosser Polkuttel/ꝛc.

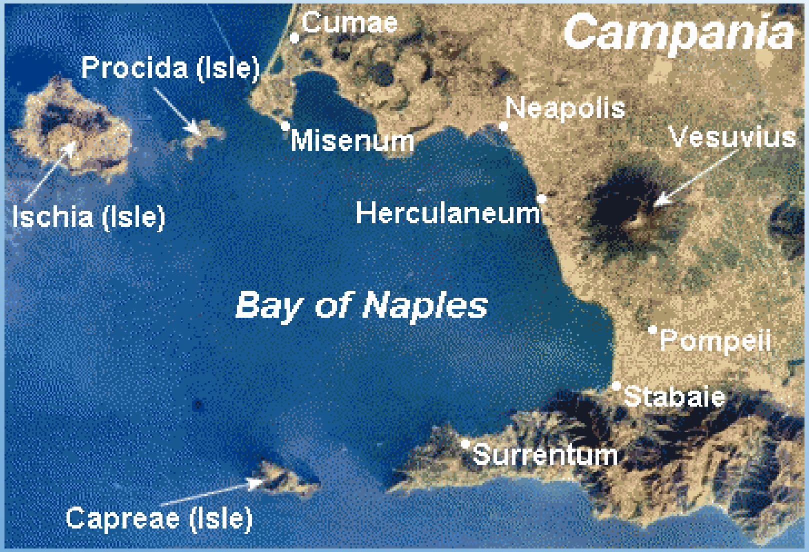
POLYPORVM genus secundum satis ex primo cognosci potest: hoc tantùm differens, quòd paruum uariumq; est, ciboq; ineptum. quare separatim non depinximus, Rondeletius.

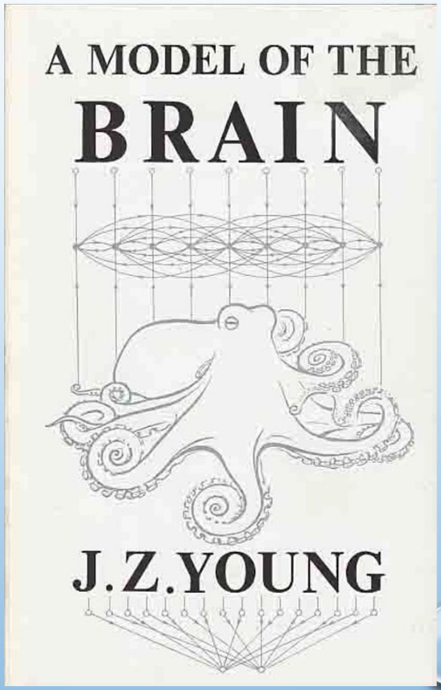
POLYPVS

- *"THE OCTOPUS IS A STUPID CREATURE, FOR IT WILL APPROACH A MAN'S HAND IF IT BE LOWERED IN THE WATER"*

BRIEF HISTORY OF RESEARCH ON OCTOPUS

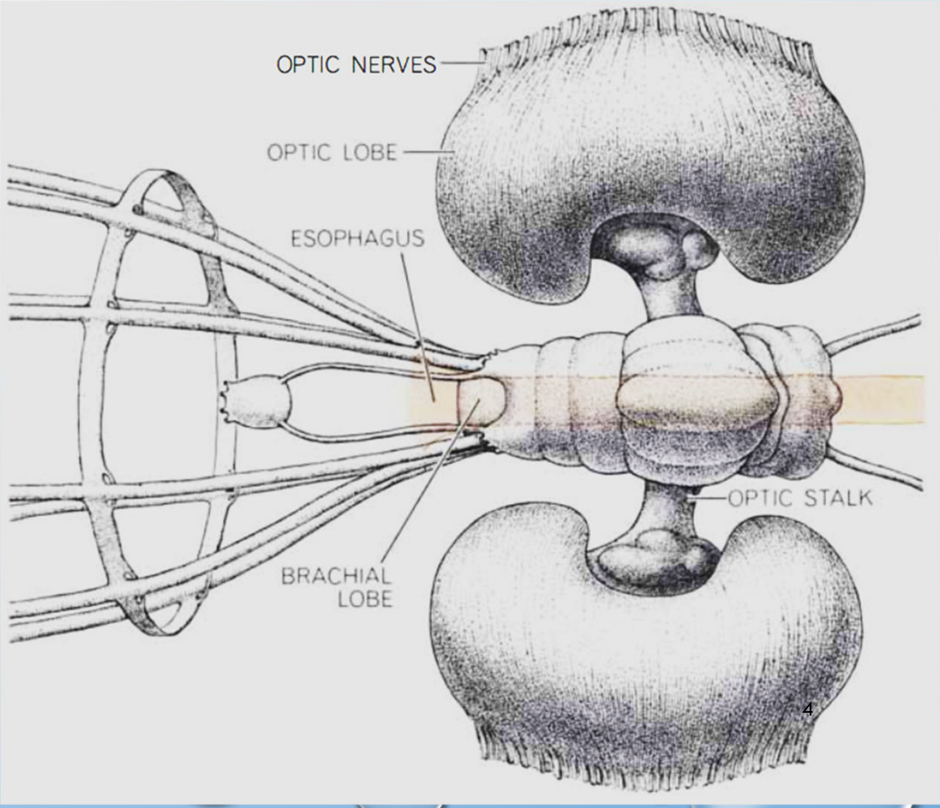
- *A MODEL OF THE BRAIN – J.Z. YOUNG 1964*





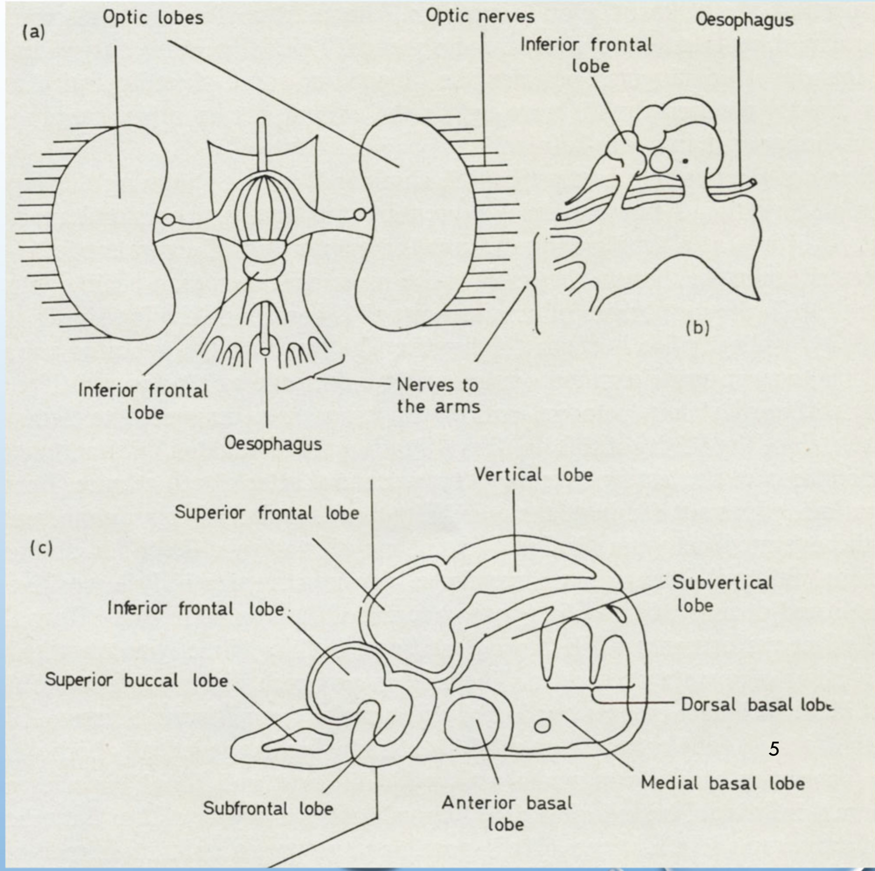
CENTRAL NERVOUS SYSTEM OF *OCTOPUS VULGARIS*

- CIRCUM-ESOPHAGEAL BRAIN
  - 40 TO 45 MILLION NEURONS
- TWO LARGE OPTIC LOBES
  - 120 TO 180 MILLION NEURONS
- AXIAL NERVE CORDS (ANC)
  - 280 TO 340 MILLION NEURONS
  - *ROUGHLY TWO THIRDS OF NEURONS ARE IN THE ARMS*



OCTOPUS BRAIN STRUCTURES INVOLVED IN LEARNING

- LEARNING AND MEMORY
  - VERTICAL LOBE (VL) & MEDIAN SUPERIOR FRONTAL (MSF) LOBE
- VISUAL LEARNING
  - OPTIC LOBES & SUPERIOR FRONTAL LOBE
- CHEMOTACTILE LEARNING
  - SUBFRONTAL (SBF) LOBE & INFERIOR LOBE (IF)



LEARNING AND MEMORY: *VL-MSF*

- VERTICAL LOBE (VL)
  - LONG TERM MEMORY
  - RECEIVES SIGNAL FROM MSF TRACT
- MEDIAN SUPERIOR FRONTAL LOBE (MSF)
  - INTEGRATES SENSORY INFORMATION
  - ALLOWS FOR SHORT TERM MEMORY
- INVERTEBRATE SIMILARITY OF THE HIPPOCAMPUS

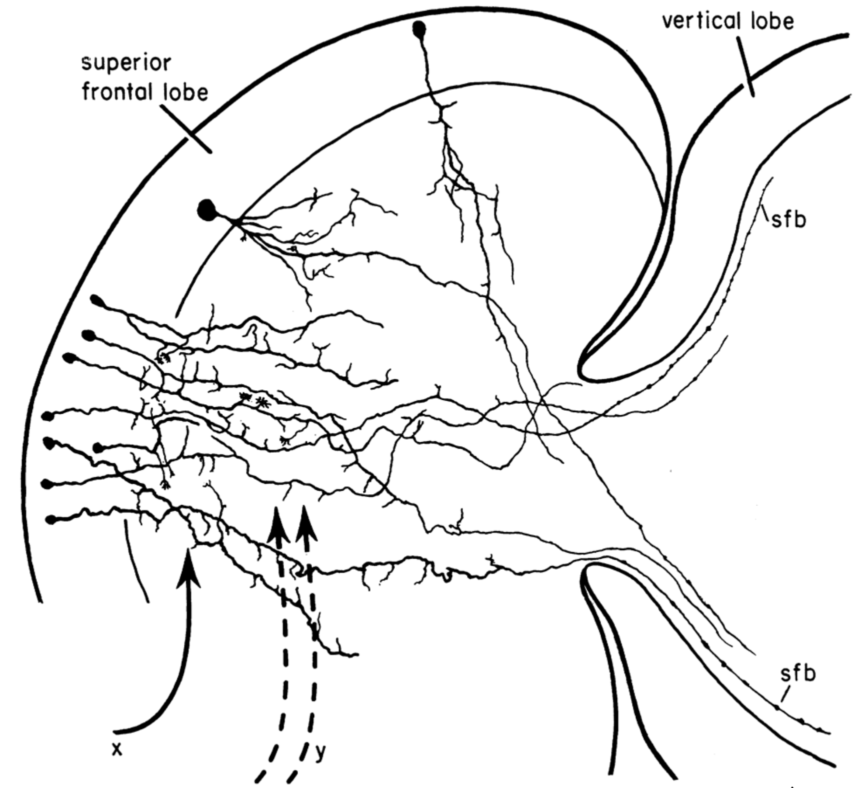
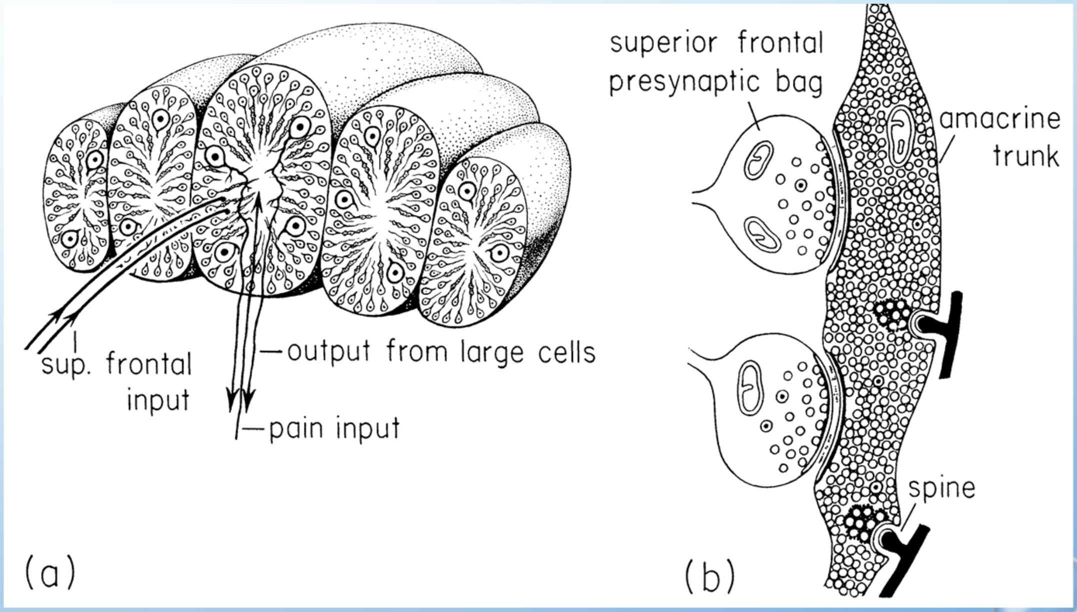
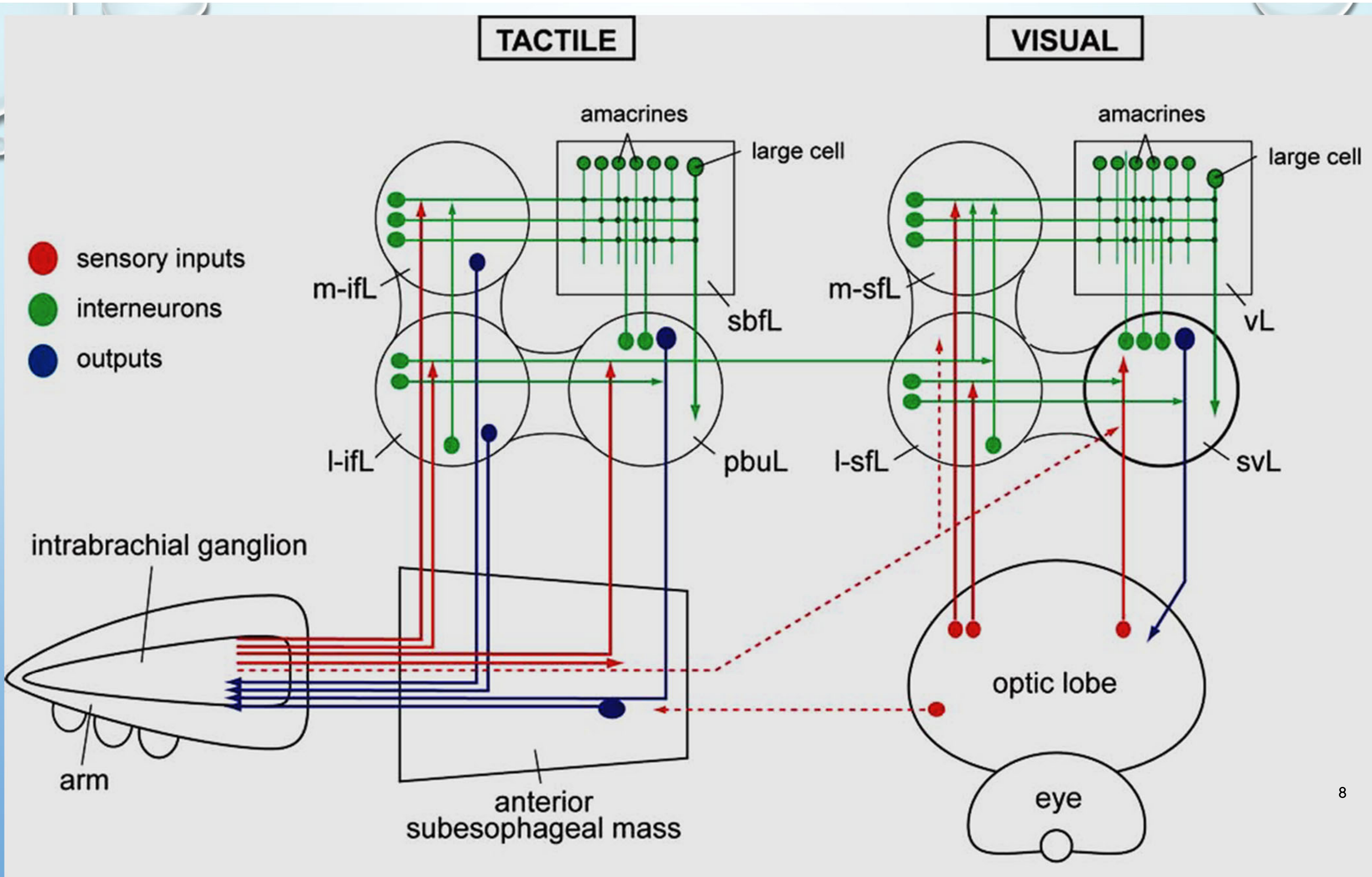


FIGURE 13 Superior frontal lobe. Diagram made from Golgi preparations. The input (chemotactile fibres *x*, and visual fibres *y*) is presumably directed to the numerous dendritic collaterals. The superior frontal cells send their fibres to the vertical lobe and become varicose. These are thought to be the presynaptic bags that contact the amacrine trunks.

VERTICAL LOBE & LONG TERM MEMORY

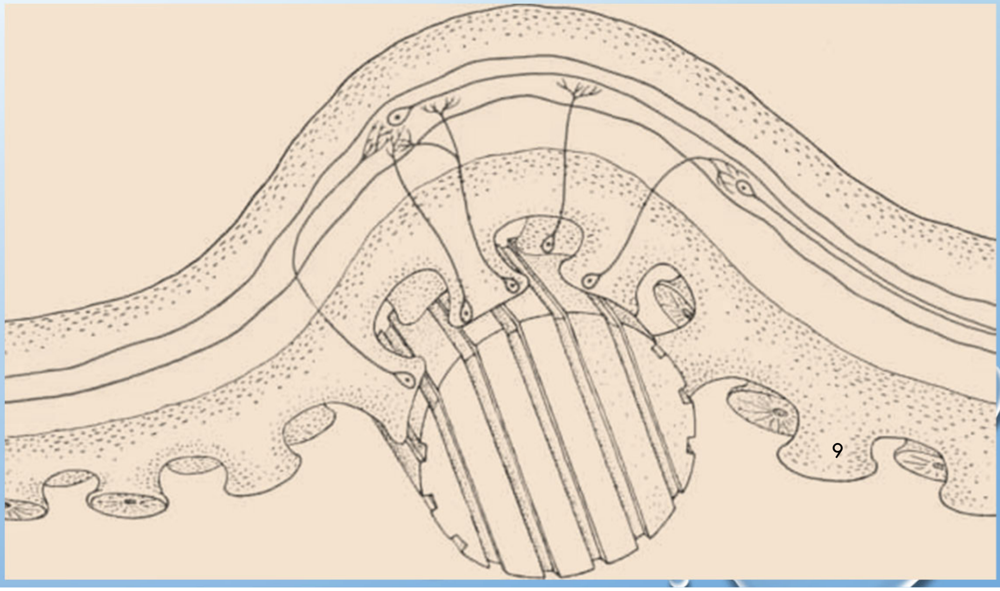
- FIVE GYRI WITH UNIQUE NEUROCHEMICAL TRACES FOR VISUAL & CHEMOTACTILE INPUT
- AMACRINE INTERNEURONS
  - SMALL AND DENSELY PACKED, 25 MILLION
  - PRESYNAPTIC *EN PASSANT* FROM MSF TRACT
  - NO AXONS, BUT SYNAPTIC VESICLES IN AMACRINE TRUNK… **SERIAL SYNAPSES**
- LARGE CELL NEURONS
  - LARGER CELLS, ONLY 65,000 PRESENT
  - AXONS OUTPUT TO SUBVERTICAL LOBE




TACTILE
VISUAL
amacrines
large cell
amacrines
large cell
sensory inputs
interneurons
outputs
m-ifL
sbfL
m-sfL
vL
l-ifL
pbuL
l-sfL
svL
intrabrachial ganglion
arm
anterior
subesophageal mass
optic lobe
eye

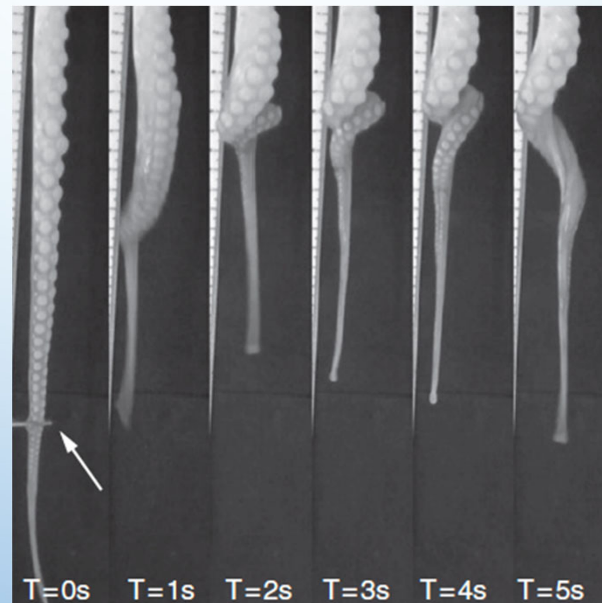
CHEMOTACTILE LEARNING

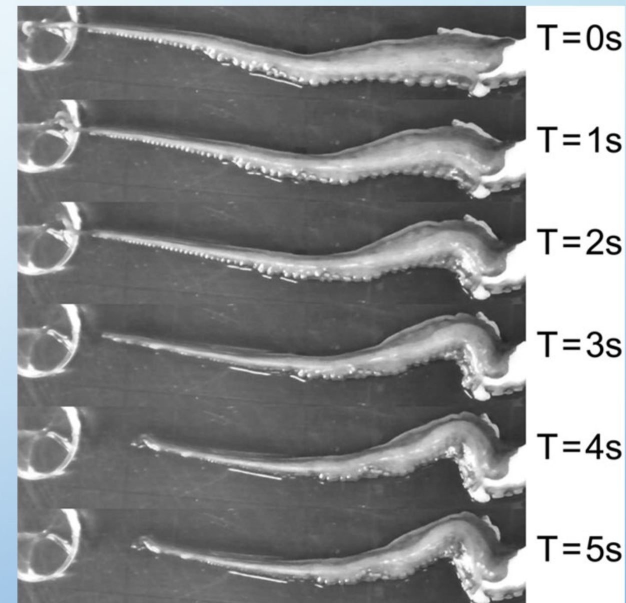
- SUBFRONTAL LOBE
  - DENSELY PACKED WITH NEURONS, SIMILAR TO VERTICAL LOBE
  - VITAL FOR CHEMOTACTILE LEARNING
  - SPLIT LESION WILL PREVENT CHEMOTACTILE LEARNING ON ONE SIDE OF OCTOPUS
- MEDIAN INFERIOR FRONTAL LOBE
  - AMPLIFIES SENSORY INFORMATION FROM AXIAL NERVE CORDS IN ARMS
- SUPERIOR & POSTERIOR BUCCAL LOBE
  - COORDINATING MOVEMENT
  - NOT REALLY INVOLVED IN LEARNING



STIMULUS RESPONSE IN ISOLATED ARMS

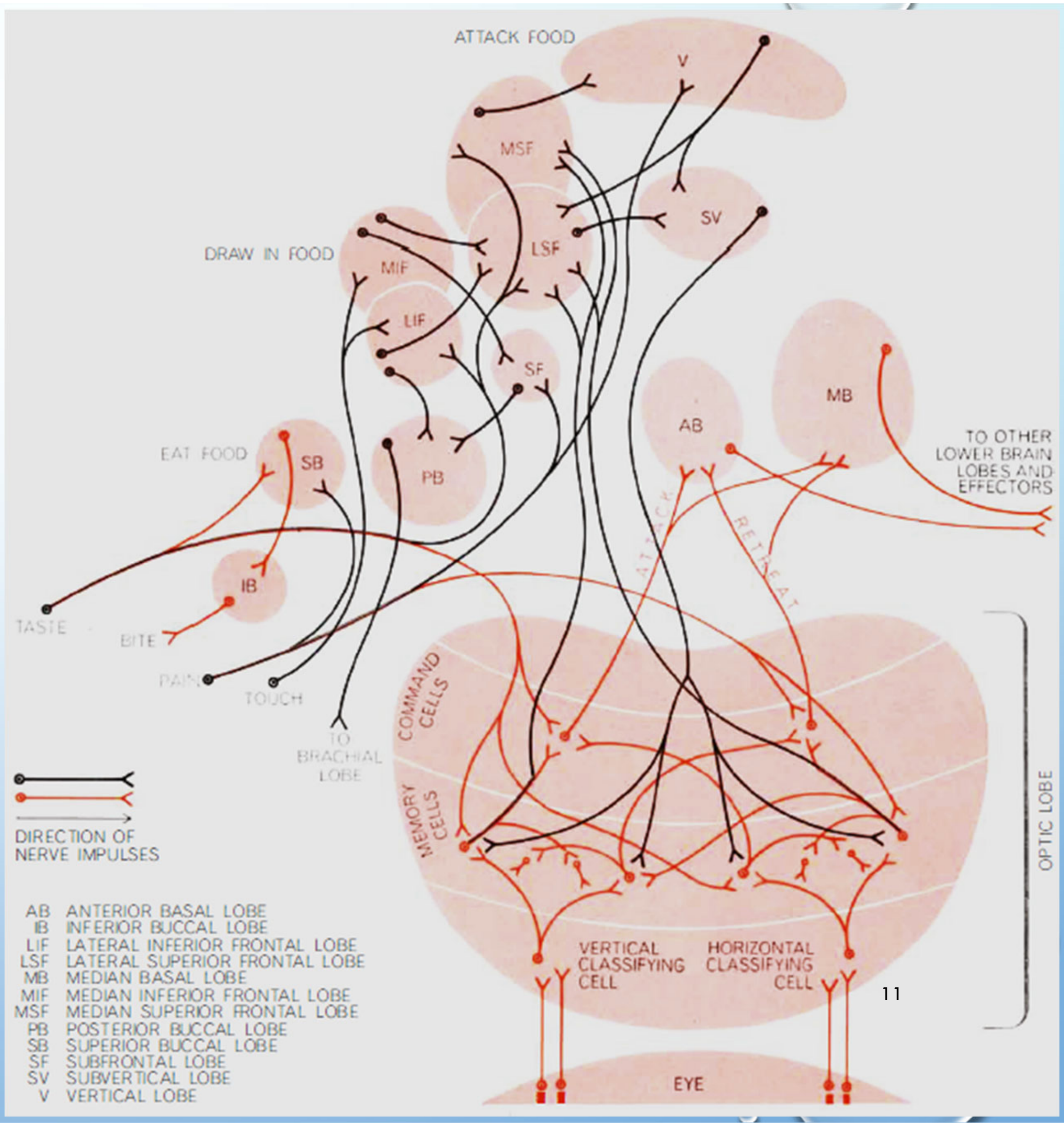
- ISOLATED ARMS RESPOND TO NOXIOUS STIMULUS WITHOUT REFERENCE TO CENTRAL BRAIN
- CAN DETECT ACIDITY, FRESH WATER, AND MECHANICAL PINCH
- STIMULUS APPLIED AT TIP CAUSES DISTANT MUSCLE CONTRACTION,
    - AXIAL NERVE CORD REMAINS IN TACT SO SIGNAL IS SENT UP THE ARM





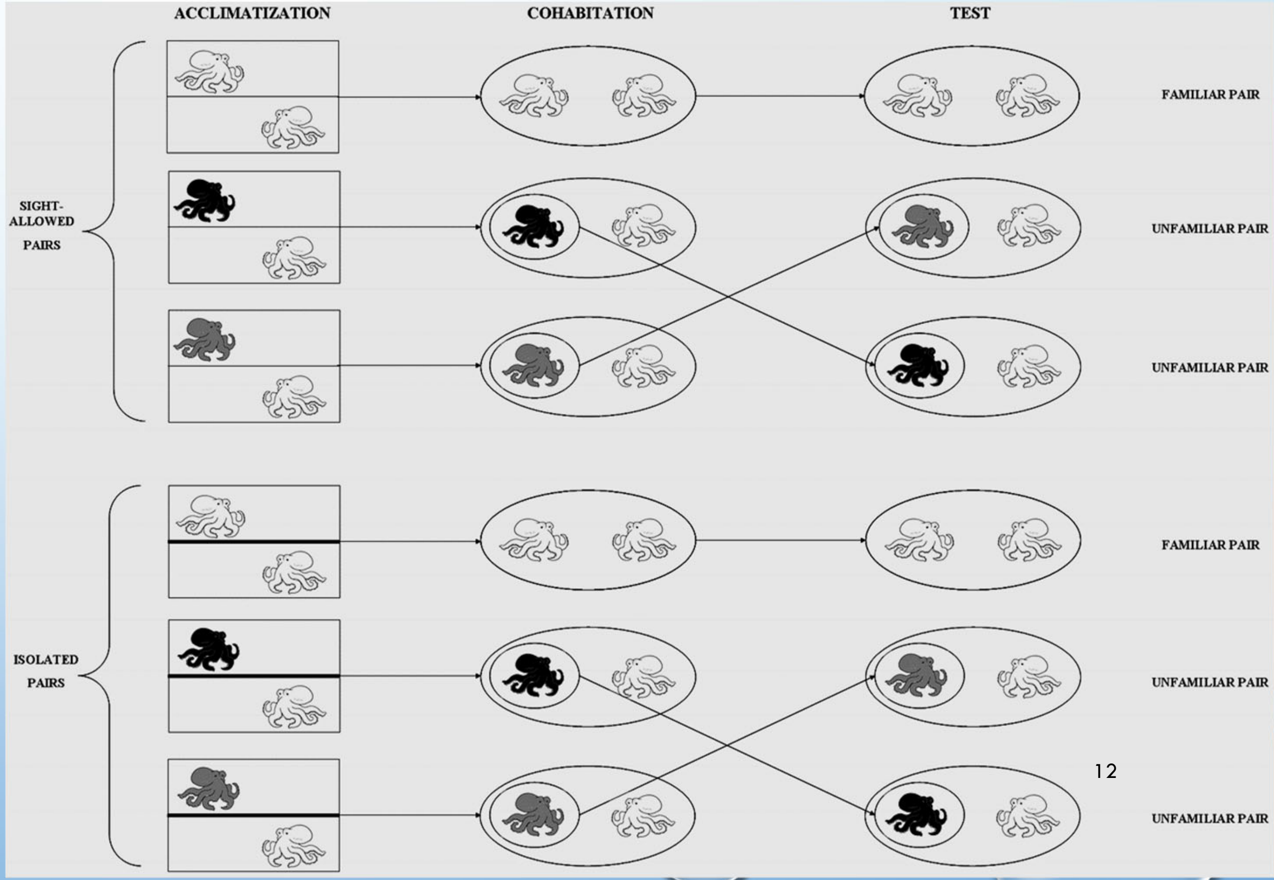
VISUAL LEARNING

- OPTIC LOBE
  - ”CLASSIFYING CELLS” & MEMORY CELLS (RED NERVE IMPULSE)
  - ATTACK & RETREAT PARADIGM
- SUPERIOR FRONTAL LOBE
  - INTEGRATES VISUAL SENSORY INFORMATION FOR LONG TERM MEMORY (BLACK NERVE IMPULSE)



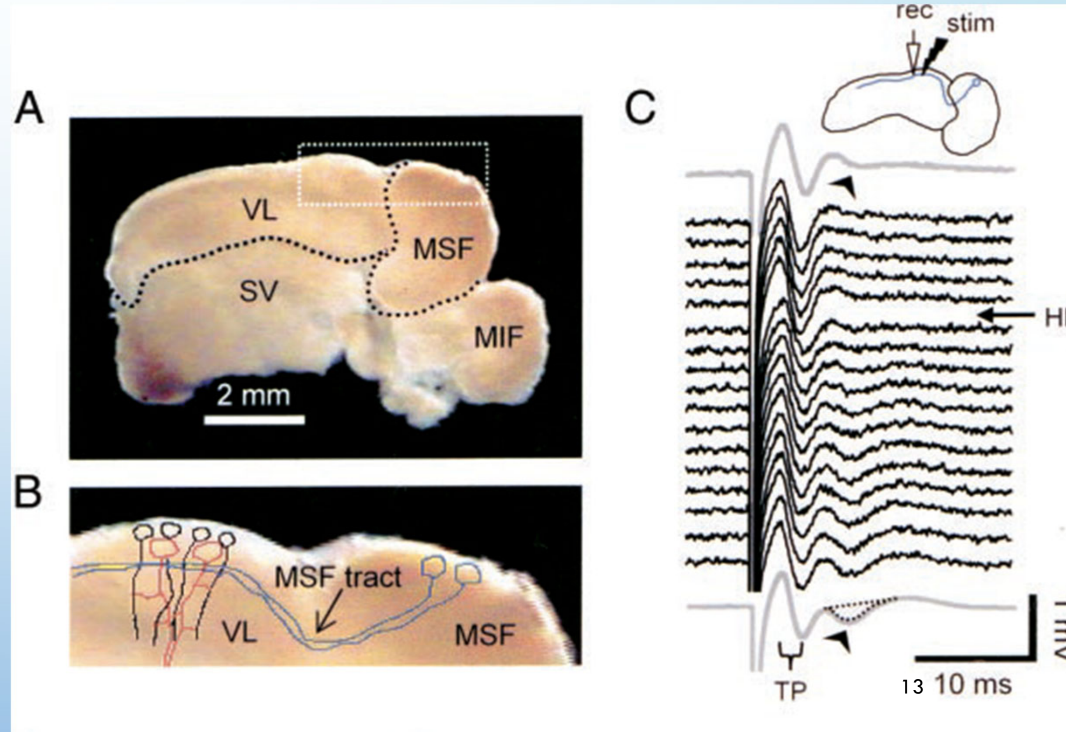
INDIVIDUAL RECOGNITION IN OCTOPUS

- TRUE OR BINARY RECOGNITION?
- VISUAL LEARNING THROUGH OBSERVATION (ALSO CHEMOTACTILE)
- ASOCIAL ANIMALS THAT QUICKLY ADAPT TO HIERARCHICAL SOCIAL STRUCTURES
  - REVERSAL OF ALPHA/BETA DOMINANCE ONLY OCCURRED IN UNFAMILIAR PAIRS, SUGGESTING INDIVIDUAL RECOGNITION



LONG TERM POTENTIATION AND SYNAPTIC PLASTICITY

- VL-MSF TRACT IS STIMULATED WITH HIGH FREQUENCY AND POSTSYNAPTIC POTENTIALS ARE RECORDED
- VERTICAL LOBE MANIFESTS SIMILARITIES TO LONG TERM POTENTIATION
- MEDIAN SUPERIOR FRONTAL LOBE HAS ELEMENTS OF HEBBIAN AND NON-HEBBIAN PLASTICITY



LEARNING & MEMORY: A CASE OF CONVERGENT EVOLUTION

- CONNECTIVITY VS STRUCTURE?
  - LEARNING AND MEMORY MECHANISMS OF THE OCTOPUS SUGGEST THAT **CONNECTIVITY** IS MORE IMPORTANT FOR INTELLIGENCE THAN STRUCTURE OF CELLS
- CAN WE COMPARE THE VERTICAL LOBE & MEDIAN SUPERIOR FRONTAL LOBE OF INVERTEBRATES TO THE HIPPOCAMPUS OF VERTEBRATES?
  - YES BUT NOT EXACTLY…
- LONG TERM POTENTIATION AND SYNAPTIC PLASTICTY AS REQUIREMENTS FOR EVOLUTION OF MEMORY & LEARNING OF COMPLEX BEHAVIOR

References

1. Ilaria Zarrella, Giovanna Ponte, Elena Baldascino, Graziano Fiorito, *"Learning and memory in Octopus vulgaris: a case of biological plasticity"*, In Current Opinion in Neurobiology, Volume 35, 2015, Pages 74-79, ISSN 0959-4388, https://doi.org/10.1016/j.conb.2015.06.012.
2. Tricarico E, Borrelli L, Gherardi F, Fiorito G (2011) *"I Know My Neighbour: Individual Recognition in Octopus vulgaris."* PLoS ONE 6(4): e18710. https://doi.org/10.1371/journal.pone.0018710
3. Shigeno, S. and Ragsdale, C. W. (2015), *"The gyri of the octopus vertical lobe have distinct neurochemical identities."* J. Comp. Neurol., 523: 1297–1317. https://doi.org/10.1002/cne.23755
4. Fiorito, Graziano, and Pietro Scotto. "*Observational learning in Octopus vulgaris*." Science 256, no. 5056 (1992): 545+. Health Reference Center Academic. http://link.galegroup.com/apps/doc/A12127254/HRCA?u=upenn_main&sid=HRCA&xid=a4e0ee34.
5. E. G. Gray, J. Z. Young, *"ELECTRON MICROSCOPY OF SYNAPTIC STRUCTURE OF OCTOPUS BRAIN"*, The Journal of Cell Biology Apr 1964, 21 (1) 87-103; https://doi.org/10.1083/jcb.21.1.87
6. Hochner, Binyamin, Tal Shomrat, and Graziano Fiorito. "*The octopus: a model for a comparative analysis of the evolution of learning and memory mechanisms.*" The Biological Bulletin 210, no. 3 (2006): 308+. Health Reference Center Academic. http://link.galegroup.com/apps/doc/A148675894/HRCA?u=upenn_main&sid=HRCA&xid=a3bb562b.
7. Wells, M. J. *"Split Brains and Octopuses."* Science Progress (1933-), vol. 54, no. 216, 1966, pp. 561–574. JSTOR, JSTOR, www.jstor.org/stable/43419591.
8. Theresa Hague, Michaela Florini, Paul L.R. Andrews, *"Preliminary in vitro functional evidence for reflex responses to noxious stimuli in the arms of Octopus vulgaris"*, In Journal of Experimental Marine Biology and Ecology, Volume 447, 2013, Pages 100-105, ISSN 0022-0981, https://doi.org/10.1016/j.jembe.2013.02.016.
9. David L. Glanzman, *"Octopus Conditioning: A Multi-Armed Approach to the LTP–Learning Question"*, In Current Biology, Volume 18, Issue 12, 2008, Pages R527-R530, ISSN 0960-9822, https://doi.org/10.1016/j.cub.2008.04.046.
10. Binyamin Hochner, Euan R. Brown, Marina Langella, Tal Shomrat, Graziano Fiorito, *"A Learning and Memory Area in the Octopus Brain Manifests a Vertebrate-Like Long-Term Potentiation"*, Journal of Neurophysiology Nov 2003, 90 (5) 3547-3554; https://doi.org/10.1152/jn.00645.2003
11. Boycott, Brian B. *"LEARNING IN THE OCTOPUS."*, Scientific American, vol. 212, no. 3, 1965, pp. 42–51., www.jstor.org/stable/24931810.