Nervous Systems Handout

3 October, 2006

Introduction:

* insects have well-developed senses relative to many other invertebrates
* share our same *five senses*
  - their vision is thought to be rather modest; nowhere as good as a human's
  - other insect senses may be more acute than those of humans, e.g., smell, taste, hearing, touch
  - bonus senses:
* nerves organized into *ganglia*
* polarization and depolarization, works like ours, that is...action potentials generated in dendrite (input side of a neuron), depolarization travels along the length of the nerve, and output sent from axon
* depolarization causes neurotransmitters to be released into *synapse*
* common insect neurotransmitters include:
  - acetylcholine
  - glutamic acid (primarily in muscles)
  - GABA (inhibits further depolarization)
  - some pesticides act by inhibiting functioning of the nervous system, esp. neurotransmitters
  - organophosphates (malathion, and others) disrupt activity of acetylcholinesterase
* a fundamental difference between invertebrate and vertebrate nervous systems is the number of cells:
  - mollusks: few thousand neurons
  - insects: 500,000 neurons
  - vertebrate: 10 billion neurons
* insects provide remarkable examples of parsimony in nerve cell number: escape response of roaches may be generated by as few as three nerves.
  - *sensory nerve* attaches to cercus
  - *interneuron*, "giant axon," runs from circus to thorax
  - *motor nerve* runs from thorax to leg
  - 44 millisecs from detection to initiation of evasive response!

Four Types of Insect Neurons

1) *Sensory nerves*: pick up stimulus and generate an action potential
2) *Motor nerves*: effect a response, e.g., gland releases or muscle movement
3) *Interneurons*: nerve to nerve communication
   * comprise the body of the central nervous system
   * responsible for setting up endogenous rhythms (of activity, hormone release, etc.)
4) *Neuroendocrine cells*: secrete hormones

Nervous System Organization

* insects have so many nerve centers

1) **central nervous system**
   * one of four nerve systems, e.g., also the peripheral, visceral, and stomatogastric
   * *brain* (tripartate): first three body segments
     - ingestion, vision, olfaction, regulation of molting, most learning and integration of complex behaviors
   * *subesophageal ganglion*: innervates mouthparts (fusion of ganglia from segments 4-6 from the embryo, i.e., the mandible, maxilla, and labium)
   * *ventral nerve cord*, including

- *thoracic ganglia*: locomotion
- *abdominal ganglia*: genitalia, heart, excretion, etc.
- primitively there were are pair of ganglia for each segment

* these other nerve systems are capable of some regulatory control and some coordinated movement and even learning!!!
    - electroshock leg of headless cockroach and assoc. ganglion; roach will learn to keep leg raised
* headless insects can carry out many tasks and live for days

Insect Brain

Three parts

1) *Protocerebrum*:
    * innervates eyes, optic lobes, labrum, and median ocellus
    * coordination of complex behaviors and most learning
    * neuroendrocrine control of molting (PTTH secreted from protocerebrum)
    * *mushroom bodies* located dorsomedially between optic lobes
        - important in smell and may be involved in learning
2) *Deuterocerebrum*
    * innervates antenna, olfactory lobes, and lateral ocelli
3) *Tritocerebrum*
    * innervates control to ventral nerve cord
        - embryonically part of ventral nerve cord then fuse to lower part of brain

Sense Organs

Mechanoreception

Four major types of mechanoreceptors:

1. *trichoid sensilla* - seta like
    * a hair that provides sensory input based on its position
        - e.g., hairs (setae) on neck (neck plate) tell the insect the position of its head
2. *campaniform sensilla* - "bulge plates" that measure distortion
    * common on wings, halteres, and joints
3. s*tretch receptors*
    * many-branched dendrites that attach at several spots on integument
        - these may trigger molts
4. *chordotonal organs* - internal organs that detect vibrations and/or sound
    * like a submersed trichoid sensilla with multiple neurons
    * three important chordotonal organs

    a. *subgenual organ*
        * found in all legs of many insects [(but not beetles and flies)]
        * proximal part of tibia
        * extremely sensitive to substrate borne vibration
        * subgenual organ is involved in orthopteroids

    b. *Johnston's organ*
        * in antennal base (pedicel) of all insects
        * detects movement of flagellum (very important in orientation during flight)
        * most famous example is in antenna of mosquito (Culicidae)
            - males only respond to female's wing beat frequency (100 - 800 Hz)

    c. chordotonal organs associated with tympanic membranes (hearing structures)
        * metasternum of mantids
        * below HW base in noctuid moths

* protibia of many orthopterans
* abdomen of many Homoptera, Orthoptera, Lepidoptera, etc.
* prosternum of some flies, etc.

Roles of tympanal membranes
* involved in either mating and courtship (including male-male interactions related to reproduction such as territoriality)
* also detection of predators and especially bats, e.g., in moths:
  - detect bats at distances of 30-40 m response,
  - orient away from source by balancing signal to both ears
    - at 3 m go into erratic dive or drop out of air
  - ear evolved *independently* in three largest clades of Lepidoptera:
    Noctuidae (thoracic ear)
    Pyralidae (abdominal ear)
    Geometridae (abdominal ear)
    as well as several other moth taxa (all independently)
  - Mantidae:
  - other (nocturnally active) insects with bat detecting membranes: nocturnal flies, lacewings, some beetles (e.g., scarabs), locusts, katydids, & crickets
* detection of prey
  e.g., tympanum on prosternum of (*Ormia*) tachinid flies…cricket parasitoids

Photoreception: detection of light

Four photosensitive detection systems in insects
1. Photosensitive cells in body wall (dermal detection)
2. Ocelli
3. Stemmata
4. Compound eyes

1. Photosensitive cells in body wall = *dermal detection*

Insect Eyes: lens and photosensitive pigment
* resolving power is thought to be great
* clarity/acuity is believed to be modest
* sensitivity (to light intensity) is high
  - hawkmoths can "see" color in extremely low light intensities (lowest in animal kingdom)

2. O*celli*: dorsal, simple eyes; either 1, 2 or 3;
   * single lens
   * light sensitive, but *no image* is formed (focal point of lens falls behind "retina")
   * important in entraining daily rhythms; orientation during flight
   * typically present in adults, and some nymphs, but never larvae of Holometabola
3. *Stemmata* or lateral eyes
   * present on side of head in Holometabola (larvae)
   * single lens, a crude image is formed
4. *Compound Eyes*
   * each eye is made up of one to several thousands of *ommatidia* or facets
   * each ommatidium has its own lens, "retina," etc.
   * each plugged into optic lobe (of protocerebrum), thus each facet is thought to produce a distinct image

Night vision in insect is pretty interesting subject: apposition versus superposition eyes? (read in text). Good midterm question...

Color Vision in Insects:

* not all insects see colors
* among those that do see color, vision is often trichromatic (but a few lineages see more)
* some that are trichromatic have three types of color sensitive cells (cones)
  - green-yellow-orange receptors
  - blue-green receptors
  - UV receptors
* insects probably don't see across entire color spectrum like vertebrates
  - e.g., bees only can be trained to discriminate between about four colors
* many diurnal insects (e.g., bees) see ultraviolet wavelengths
* bees (and other insects) are often insensitive to reds, ca. 700 nm
* many insects don't see yellows well (this why bug lights work)
* one group of insects see reds quite well: the butterflies
  - butterflies may have broadest color sensitivity of any animal, i.e., 300 to 700 nm

Detection of polarized light

* sunlight get increasing polarized at greater angles from the sun, i.e., the more the light vibrates in some planes relative to others
* light most polarized at 90 degree angle to sun
* insects can detect polarized (UV) light
* a single patch of sky is enough for some insect to calculate the sun's position at any time of day
* polarized light very important in insect navigation, e.g., ants and social insects

Image Formation

* insects are very sensitive to movement but not still objects
  - with regard to movement; bugs can distinguish single degree of arc
* insects (e.g., bees) learn shapes and colors

Chemoreception: includes both smell and taste

* sensilla with pores that pick up certain molecules
* taste is usually aqueous reception (roughly equal to contact reception)
* smell is usually gaseous detection (roughly equal to remote detection)
* specialist (single molecules) or generalist nerves (classes of molecules) in receptor nerve in receiving setae/structure

Two common types of chemoreceptors

a. single pore at tip (commonly taste)
  * taste same kinds of things we do: water, salt, bitter, sour, and sweet
    - flies taste sugar solutions 1/250 as sweet as what we can detect
    - or according to Dethier
  * Location of taste receptors: tips of palpi, tarsi, antennae, and ovipositor

b. multiple pores (smell)
  * especially antennae
  * fewer on mouthparts and ovipositor
  * some very sensitive systems, e.g., male antennae in species that communicate with pheromones