Sensory Systems

- Vision
- Chemoreception
  1. Olfaction
  2. Gustation
- Mechanoreception
  1. Hearing
  2. Lateral Line
- Electrical Senses

Properties of water that affect sensory systems

1) Dense: 800x more dense than air
2) Incompressible: any particle that moves, moves a particle next to it
   - motion sensors: lateral line - senses water movement
   - sound sensors: inner ear (and swim bladder in some)
3) Conducts electricity well
   - ampullary receptors in elasmobranchs: Ampullae of Lorenzini
   - ampullary receptors + tuberous receptors in bony fishes
4) Barrier to light, turbid, absorbing and scattering light rays
   - light is selectively filtered out with depth: red & orange first, green & blue last
5) Chemicals in solution
   - chemoreception (taste & smell) can occur all over body

Effectiveness of Senses in Air vs Water

<table>
<thead>
<tr>
<th>Sense</th>
<th>Air</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smell</td>
<td>good</td>
<td>good, but slow</td>
</tr>
<tr>
<td>Taste</td>
<td>good, needs contact w/ liquids</td>
<td>good</td>
</tr>
<tr>
<td>Vision</td>
<td>very good</td>
<td>good to not possible: depends on light absorption</td>
</tr>
<tr>
<td>Hearing</td>
<td>fair</td>
<td>excellent, faster &amp; farther</td>
</tr>
<tr>
<td>Distant touch</td>
<td>not possible</td>
<td>good: water incompressible</td>
</tr>
<tr>
<td>Electrocception</td>
<td>not possible</td>
<td>good: water conducts electricity</td>
</tr>
</tbody>
</table>

Fish Brain in relation to sensory abilities

- forebrain (telencephalon + olfactory bulbs) = olfaction
- "between-brain" (diencephalon + pineal gland) = homeostasis, endocrine, circadian rhythm
- midbrain (mesencephalon + optic lobes) = vision
- hindbrain (metencephalon, including cerebellum) = hearing, balance, & lateral line (acoustico-lateralis system)
- brainstem (myelencephalon) = relay station for all sensory systems except smell

Size of portion of brain reflects importance of corresponding sense

- e.g., Catfish: large olfactory lobes
- e.g., Minnow: large optic lobes

Vision

- glass sphere
- fish lens (Cichlid)
Vision (photoreception): How?

- parts of eye: cornea, lens, iris, retina
- lens has highest refractive index of all vertebrates
  - focusing does not require cornea
  - lens moves towards or away from retina to focus
- iris controls the amount of light entering eye in elasmobranchs – but not in teleosts (cannot change the size of the pupil)
- retina
  - rods: sensitive, low light
  - cones: high resolution, high light, color

Vision: For what?

- most activities, if living in at least somewhat clear water
  - feeding: prey location & selection
  - reproduction: courtship displays and coloration
  - predator avoidance
  - schooling

Vision: unique characteristics of light in water

- water absorbs light
  - longer wave lengths drop out rapidly with depth
    - red 600 nm
    - green 530 nm
    - blue 460 nm
    - UV 380 nm
- many deepwater & nocturnal fishes are red

Why?

Vision: diversity of eyes in fishes

- eye shape and size give clues to habits...
  - big eyes = nocturnal or low light environment
  - bulging, upturned eyes = deep water predators
  - small or no eyes = areas with little or no light
  - split lens = water’s surface (Anableps)

blind fishes

Anableps, four-eyed fish

Figure 31. Rhinella fishes. Above: pygmy cichlid fish (P. peckii, sp.-new) from the Río Rio, South America. Middle: anableps (A. crenipinnis) from limestone caves in the north-eastern United States. Below: the blind, Cynopsphotus goyuel, seen in the Congo. (Top figure after G. S. Weitzman.)
Many fishes can see ultraviolet (UV) wavelengths and have UV color patterns.

Chemoreception

1. Olfaction (smell)
   - olfactory receptors in pits
   - can be extremely sensitive
2. Gustation (taste)
   - similar to humans, except...
   - more acute (one molecule per receptor)
   - sensory cells (“taste buds”) not confined to mouth
     - barbels
     - fins
     - flanks

Olfaction (smell): How?

- receptors in olfactory pits: incurrent and excurrent channels = nares
- receptors arranged on lamellae in rosettes
- water contains molecular cues
- when chemical contacts olfactory rosette = smell
- passive entry when swimming
- active intake by cilia or pumping of branchial cavity

Olfaction (smell): Why?

- find and discriminate food
  - klinotaxis = gradient searching behavior (“getting warmer”)
- recognition of opposite sex: pheromones
- recognition of young
- homing behavior: salmon imprint on natal streams
- defense against predators: Schreckstoff

Gustation (taste):

How?

- receptors – taste buds found in the mouth, lips, skin, fins, barbels (e.g., catfish)

Why?

- procurement and discrimination of food
Mechanoreception – the Acoustico-Lateralis system

- **inner ear**
  - hearing
  - balance
- **lateral line system**
  - common theme – sensory hair cells

Inner Ear – Structure

- 3 semicircular canals (fluid-filled)
- 3 fluid-filled sacs - utriculus, sacculus, and lagena
  - lined with sensory hair cells
  - contain otoliths
    - sagitta – from sacculus
    - lapillus – utriculus
    - asteriscus – lagena

Hearing: How?

- **Pars inferior**
  - sound vibrations in the near field impinge on fish:
    - whole fish moves to and fro from particle displacement of water
    - otoliths are 3x more dense than the fish, so lag behind in their sacs
  - otoliths suspended in fluid and surrounded by hair cells:
    - different phase and amplitudes of motion cause otoliths to bend cilia which stimulate neural transmission to auditory center
  - no external ears because tissues are virtually transparent to sound
  - fishes have excellent hearing
  - sound travels 4.8x faster in water than air

Otoliths

- three pairs
  - **sagittae** (sagitta)
  - **lapilli** (lapillus)
  - **asterisci** (asteriscus)
- made of calcium carbonate imbedded in a protein matrix
- used to sense:
  - high frequency sound
  - body rotation/orientation
  - acceleration
  - gravity

Sound amplification by swimbladder in many species, especially

- clupeomorphs
- elopomorphs
- ostariophysans (Weberian apparatus)
- Gadids
- Holocentrids
Hearing: Why?
- important if vision is not an option
  e.g., catfish
- reproduction: courtship, locating a mate, spawning
  e.g., croakers
- predator avoidance
  e.g., many reef fishes
- prey detection
  e.g., sharks, catfish, goatfish
- territorial defense
  e.g., damselfishes
- alarm sounds
  e.g., squirrelfishes

Sounds are generated by:
- grinding bones together
- drumming swim bladder

Red Drum (Sciaenops ocellatus)
Atlantic Croaker, Micropogonias undulatus

Balance & Equilibrium (inner ear): How?
- three semicircular canals filled with endolymph fluid, each with a chamber (ampulla) with a gelatinous cupula surrounding the hair cells
- canals in three planes
- cupula partially block the flow of endolymph; fish moves, endolymph lags, cupula bends, hairs bend, nerves fire
- utriculus, otoliths also involved with balance
- vision also involved

Dorsal light reaction

Lateral line system
- “distant touch” - used to detect movement in water
  (works because water is incompressible)
- unique to fishes (but neuromasts also present in some amphibians & ascidians)
Lateral line system: How?

- receptors are neuromasts, groups of hair cells with cupula
- neuromasts can be free or protected in shallow tubes (= canal organs)
- cupula responds in same way as in balance
- all fish have at least some free neuromasts as well - most common in sedentary fish
- lateral line - canal with neuromasts
  - cephalic lateral line: above and below eye, along mandible, below dermal bones
  - trunk lateral line: along body with modified scales - mostly in swimming, active fish
  - continuous line provides integration over time and space

Lateral line: Why?

- prey location: lateral lines often tuned to prey frequencies
- navigation (e.g., eyeless fish)
- schooling
- parental care
- predator avoidance
- communication

Electroreception

- many different fishes can detect very weak electrical fields
- found in fishes (elasmobranchs & bony fishes), some amphibians, & the platypus
- ampullary organs - derived from neuromasts

Electroreception: How?

- receptors are specialized neuromasts: usually no cilia
- on head, ventral and dorsal area, not usually on sides or caudal peduncle
- 2 types of organs
  - Ampullary organs sensitive to weak low freq (0.1-50 Hz)
    - passive electrolocation
      - elasmobranchs, sturgeons, paddlefish, lungfish, some teleosts
  - Tuberous organs sensitive to Electric Organ Discharge (EOD) of own electric organ, high frequency (50-2000 Hz)
    - active electrolocation
      - Gymnarchidae, Gymnotidae, Mormyridae (also have ampullary organs)
Electroreceptor (tubercular) organs like hair cells except no cilia
- change in flux of Ca²⁺ ions cause nerve reaction

Electroreception: how are electrical fields made?
- can detect fields made by:
  - wounds
  - flexing muscles
  - swimming through earth’s magnetic field
  - bioelectric activity

Active electrolocation:
- using electric organ and tubercular receptors
- electric organs are modified striated muscles

Aggressive electroproducers:
- Torpedo ray
- Electric Eel

Non-aggressive electroproducers (with one exception):
- Gymnotiformes

Non-aggressive electroproducers: Mormyridae

**Figure 10.7:** Ampullary electroreceptors. Upper left: groups of ampullae (all) on head of a shark. Middle left: distribution of ampullary organs on the cuttlefish _Sepia officinalis_. Bottom left: groups of ampullary organs from shark ventral. Upper right, upper and anterior of our organ shown. Lower right, lower and anterior of organ shown. Anterior (left) and posterior (right) results are indicated. Bottom right: Ampullary organs from skates show the sensor cells are innervated. After Murray (1987) in _Cambridge C. Mar. Fish._ London: lo Proc. Zool. Soc. London, 49, 87, and Bennett (1971) _J. Physiol._ 237.
Electric perception/production: Why?

- Locate prey (e.g., sharks & rays)
- Stun prey or defense
  - electric eel (500 volts)
  - torpedo ray (50 volts)
  - electric catfishes (300 volts)
- Detect and avoid predators
- Navigate
- Communicate
  - e.g. species-, sex-, and dominance-specific discharges
    by Gymnotiforms (S. America), Mormyrids (Africa)

Species-specific electroproduction

Figure 5. Electromagnetic discharges from the venom apparatus of the electric eel, Electrophorus electricus, and the electric catfish, Malapterurus electricus. The left column shows the general pattern of the discharges, while the right column shows the detailed pattern of the discharges. The discharges are induced by the electric field generated by the fish, which is used for communication and defense.