SENSORY SYSTEMS AND OTOLITHS

There are five forms of sensory systems in fishes: mechanoreception, vision, chemoreception, electroreception, and magnetic reception. In today's lab, we will focus on the first four of these. It is important to note that although these systems are comprised of different structures, these systems may work in tandem (e.g., orientation).

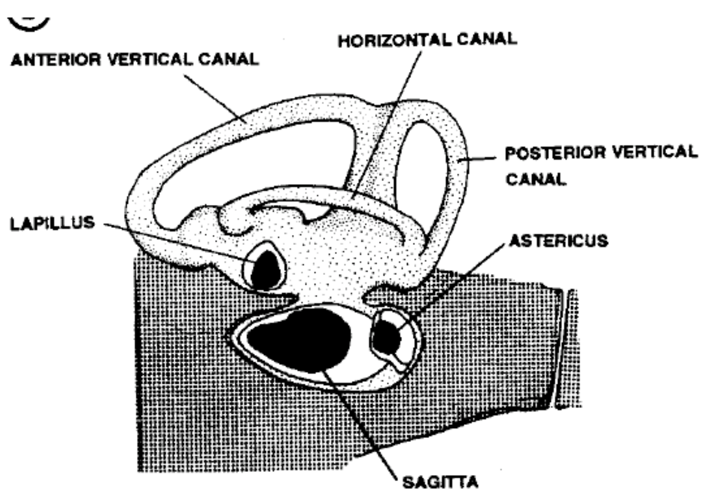
MECHANORECEPTION

Mechanoreception may be broken down into three forms: equilibrium and balance, hearing, and the lateral line system.

Equilibrium and balance and hearing, are largely achieved through the inner ear of the fish.

Equilibrium and balance.–Equilibrium and balance are achieved, in jawed fishes (lampreys and hagfish differ), by the **pars superior** of the inner ear. This consists of **three semicircular canals** and a chamber, the **utricle** (see Fig. 1). The semicircular canals are filed with a jelly-like substance called endolymph, which, when set in motion by changes in acceleration or orientation, displace the cupula that encloses the neuromasts lining the canals. The utricle contains the **lapillus**, the first of the three otoliths we'll discuss in today's lab. The lapillus is the largest of the otoliths (and the one used in aging fish), and works by providing the fish with information regarding its **vertical orientation** in the water.

Hearing.–Hearing is primarily achieved by the **pars superior** and **pars inferior** of the inner ear. The **utricle** of the pars superior is also used for hearing in addition to vertical orientation. Two chambers similar to the utricle make up the pars inferior: the **sacculae** and the **lagena**. Each contains an otolith, the **sagitta** and **astericus**, respectively, which function much the same way as the lapillus.



The auditory capabilities of some fishes are enhanced several by the cooption of the **gas bladder**, or structures associated with it. Gas bladders act to increase the sensitivity to sound as sound waves cause minor increases or decreases in their volume, which can then be detected.

Lateral line system

Fish can detect vibrations/disturbances in the water that originate from prey, predators, other fishes (especially in schooling species), and environmental obstacles. This is achieved through **lateral line system**, a series of pores containing neuromasts along the body of the fish, and in many cases on the head as well. As fish have diversified, so, too, have the lateral line systems.

1. Look at the fishes laid out. How does the number of lateral lines differ between fish? The presence of cephalic pores? The size of the lateral line pores? How might these tell you something about the fishes' basic biology?

VISION

2. Examine the eyes of the fishes at the vision station. How does the size of the eye relative to that of the body, compare across the suite of fishes. Where would you expect each fish to inhabit, based upon the size of its eyes?

CHEMORECEPTION

Because fishes live in water (where all chemical stimuli are in solution), there is less distinction between olfaction and gustation. Nonetheless, the structures that associate with each differ.

Olfaction

The olfactory organs of fishes are contained in **nasal sacs** on the anterior portion of the head. Jawed fishes have paired organs, while hagfish and lampreys have single organs. Contained within each nasal sac are folded olfactory epithelium arranged in **rosettes**.

3. Examine the dissected rosettes of the eel (*Anguilla* sp.) and the perch (*Perca flavicens*). Given that the eel has much greater olfactory capabilities, describe how nasal rosette size (i.e., the number of folds) is correlated with olfactory capabilities. Why do these differences in size exist?

Gustation

As is the case in humans, **taste buds** are the gustatory receptor organs. Taste buds consist of a foundation of basal cells supporting a bed of gustatory receptor cells. Taste buds may be found on the mouth, phyarnx, gill rakers, gill arches, the barbels, fins, and in special cases, all over the body.

4. Look at the locations (pinned) of taste buds on the specimens. Hypothesize why the fish have them where they do.

ELECTRORECEPTION

A variety of fishes utilize electroreception to detect prey and/or for inner-specific communication. Fish detect electric fields using receptor organs similar to the hair cells of the lateral line and inner ear. They differ in that they lack cilia (hairs). Electrical fields in the environment lead to changes in the flux of calcium ions across the membranes of **electroreceptive cells**. There are two kinds of electroreceptive cells:

(1) **Ampullary receptor cells–**These consist of receptor cells lying at the base of of a canal or pit that is filled with a conductive gel. They are involved in detecting **low frequency** AC or DC electrical stimuli. Sharks have only this type of receptor cell, known as the **Ampullae of Lorenzini**.

(2) **Tuberous receptor cells**–These consist of recpetor cells lying at the base of depressions in the epidermis filled with loosely packed epithelial cells. They are involved in detecting **high frequency** AC stimuli. These are found exclusively in **electric fish** (i.e., those that produce electrical stimuli beyond the weak electrical field all organisms generate). This is important as electrogenic fish can generate and detect an electric field, thus allowing the fish to detect disturbances within the field.

5. Look at the locations of the different receptor cells. How are they similar? How are they different?

ELECTRIC ORGANS

While electric organs are not a sensory system, they work in tandem with electroreceptive cells. Electric organs have evolved in several distantly related groups of fishes including the batiomorphs, osteoglossimorphs, otophysi, and percomorphs. Electric cells (most likely derived from muscle cells), called **electrocytes**, use the ion flux across the cell membranes to create a small electrical current. Cells are arranged in columns, so to produce an additive effect, like batteries in a series.

6. Locate the electrogenic organs in the fishes laid out. What might their location tell you about how they are used?

OTOLITHS

Fisheries biologists use otoliths and scales to study age and growth of fishes. Sagittae viewed on a dark background by reflected light exhibit a series of dark and light rings. There is evidence that the variation in the amount of and thickness of the shell are responsible for ring formation. With some exceptions, opaque zones are laid down during summer, and translucent hyaline zones are formed during winter. Translucent rings appear dark and opaque rings light when viewed by reflected light against a black background. These zones are referred to as **annuli.**

For otoliths, sophisticated chemical and radiometric techniques have been developed to validate age determinations and examine other life history patterns. Every body of water or layer of the water column has an isotopic or chemical signature that is incorporated into the sagittal rings as the fish deposits them. This provides data on where an individual fish has been at a certain age.

Some scientists also use scales instead of otoliths to study age and life history of fishes. Here are some contrasting characters of the two:

*Scales***:**

- May not be present until late larval or early juvenile stages
- Grow by accretion of bone
- Only show yearly growth
- Susceptible to degradation/alteration from environmental and health factors (e.g., mechanical damage, pollution, disease)
- Vulnerable to breaking off

*Otoliths***:**

- Often appear in embryonic stages before hatching.
- Grow by accretion of calcium carbonate and protein which incorporate chemical information about the environment at the time of deposition (e.g., isotopes, radioactive materials)
- Daily deposition, especially in larvae and juveniles
- Relatively independent of environmental conditions
- Less susceptible to degradation; useful in prey identification and archaeology through stomach content analysis and paleozoology.

Preparation and viewing: The simplest way to view otoliths is to place the whole sagitta in water on a dark-backed dish illuminated from above. This technique is very effective with the clear sagitta of young fish. When reading otoliths, compare the estimated age from both otoliths. Often one of the two has more distinct markings. Otoliths may have surface bands that are not annual (checks), particularly if the first few rings grew rapidly. Because these bands usually appear when viewed from a different perspective, be sure to tilt the otolith in various ways to verify that the rings are spatially consistent.

Improving ring resolution and the break-and-burn technique: Otoliths may be sectioned in several ways. One simple technique involves breaking the otoliths by placing your thumbs on either side of the coleus and snapping it. Although it sounds harsh, many researchers do it just this way. The sections are then mounted—broken end up and horizontal—and then examined under a microscope. More typically, a sagitta is broken by scoring it with a scalpel and then breaking it with forceps. In some species, rings are indistinct or invisible at first. **Sagittae of these species are often lightly burned over an ethanol flame to improve the contrast of the rings**. By burning the broken surface, the rings are darkened and are made more apparent.

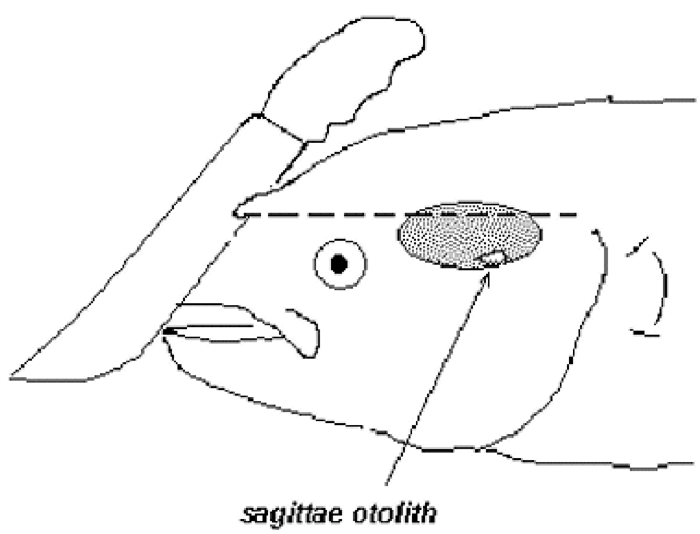
Otolith Removal

Fresh or frozen specimens, as opposed to preserved specimens, are best for otolith studies, as non-neutralized formalin decalcifies otoliths, making them unfit for study. The way in which otoliths are removed depends on the types of fish, the permissible amount of allowable damage, and the personality of the dissector.

For the least damage to the specimen, cut away the gill arches and remove the sagitta via the capsular otic bulla at the base of the skull (see images at http://tagotoweb.adfg.state.ak.us/ADU/OtolithRemoval.asp). The bones of the bulla are relatively thin and may be cut or broken with blunt forceps or a scalpel.

It is also possible to cleave the head with a cleaver or strong knife in a sagittal (longitudinal) direction or to lift off the top of the skull, exposing the otoliths (see drawing below). These methods involve greater chance of damaging the otoliths, but once learned they are a rapid technique, particularly useful when large numbers of specimens need to be processed. Similarly, for flatfish, a cut above the upper eye into the skull will expose the otoliths.

Generalized Fish Otolith Dissection



drawing by K.Munk