Mechanoreception

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Introduction

A mechanoreceptor is a sensory receptor that responds to mechanical pressure or distortion.

In fishes mechanoreception concerns the inner ear and the lateral line system.

Hair cells are the UNIVERSAL MECHANOSENSORY TRANSDUCERS in both the lateral line and hearing systems.

The INNER EAR is responsible for fish EQUILIBRIUM, BALANCE and HEARING

LATERAL LINE SYSTEM detects DISTURBANCES in the water.

Hair cell structure

EACH HAIR CELL CONSISTS OF TWO TYPES OF "HAIRS" OR RECEPTOR PROCESSES:

Many microvillar processes called STEREOCILIA.

One true cilium called the KINOCILLIUM.

COLLECTIVELY, the cluster is called a CILIARY BUNDLE.

The NUMBER OF STEREOCILIA PER BUNDLE IS VARIABLE, and ranges from a 10s of stereocilia to more than a 100.

The STEREOCILIA PROJECT into a GELATINOUS CUPULA ON THE APICAL (exposed) SURFACE of the cell.

The cilium and villi are ARRANGED IN A STEPWISE GRADATION - the longest hair is the kinocillium, and next to it, the stereocilia are arranged in order of decreasing length.

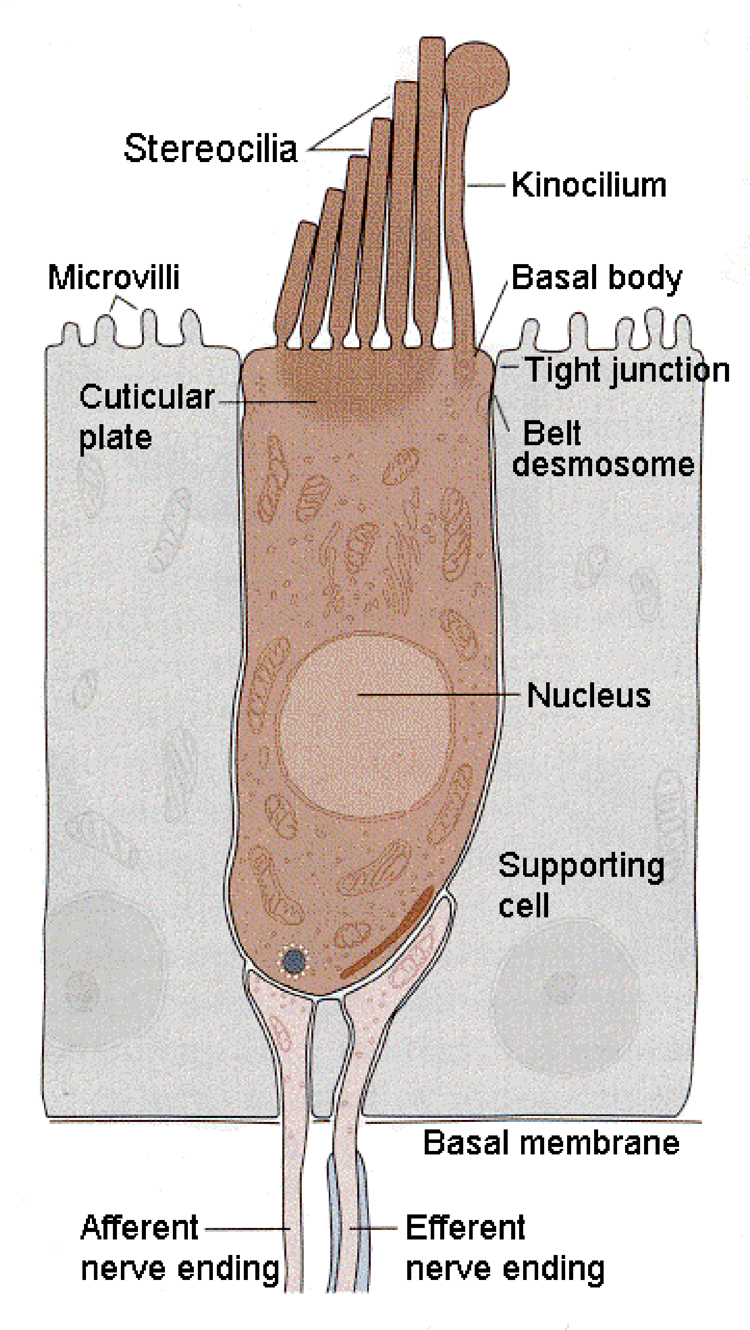
These cells SYNAPSE WITH GANGLION CELLS.

They have DIRECTIONAL PROPERTIES - response to a stimulus depends on the direction in which the hairs are bent.

So, if the displacement causes the stereocilia to bend towards the kinocilium, the cell becomes DEPOLARIZED = EXCITATION.

If the stereocilia bend in the opposite direction, the cell becomes HYPERPOLARIZED = INHIBITION of the cell.

If the hair bundles are bent at a 90^{o} angle to the axis of the kinocilium and stereocilia there will be no response.



The sensory hair cells are GROUPED TOGETHER TO FORM NEUROMAST ORGANS. These are situated on:

1. the body surface,
2. in the LATERAL LINE and HEAD. Here they are buried in pits, canals and grooves,
3. in the inner organs of the ear and on the pouches of otolith organs where they form LARGE FIELDS CALLED THE CRISTA AMPULLARIS

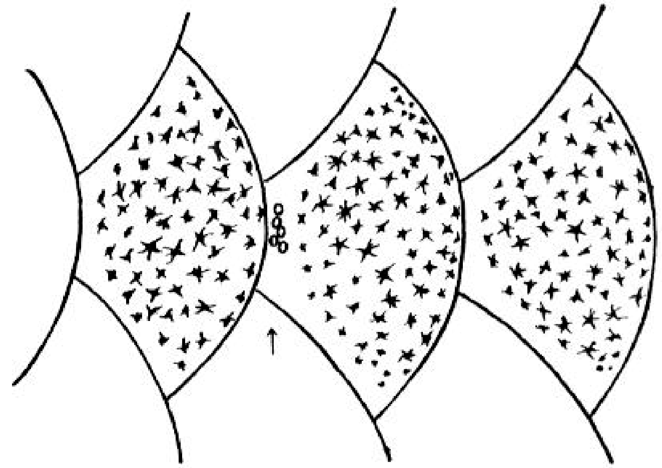


Fig. 10-1. A group of small 'pit organs' on a scale of the medaka. Original.

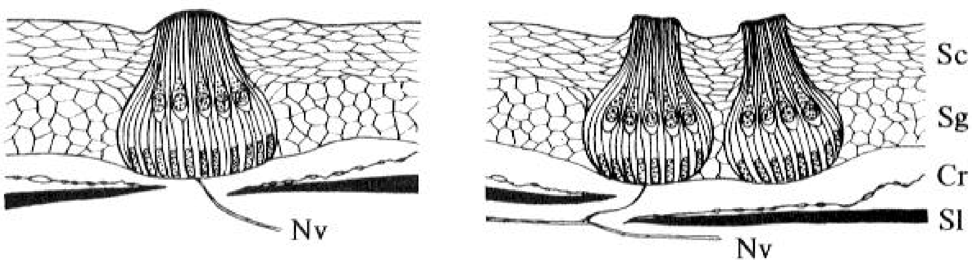


Fig. 10-3. Sections of 'pit organ' in head (left) and trunk (right) in the medaka. Sc, stratum corneum; Sg, stratum germinativum of epidermis; Cr, corium; Sl, scale; Nv, nerve. Original.

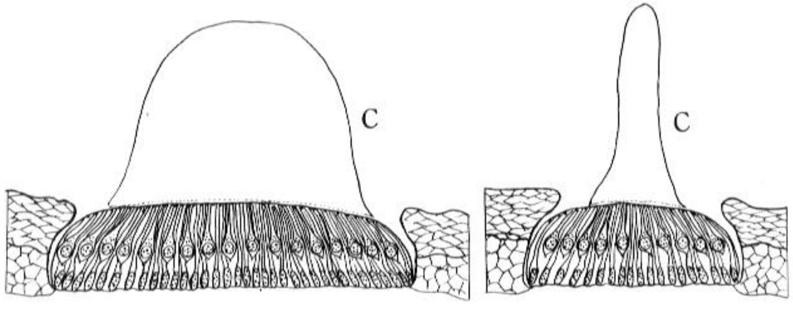


Fig. 10-4. Longitudinal (left) and transverse (right) sections of a groove organ in the head of the medaka. c, cupula. Original.

Inner ear and accessory organ structures

The INNER EAR IS MADE UP OF 3 SEMI-CIRCULAR CANALS (the vestibule) and 3 otolith organs.

The otoliths are found in the UTRICLE, SACCULE AND LAGENA.

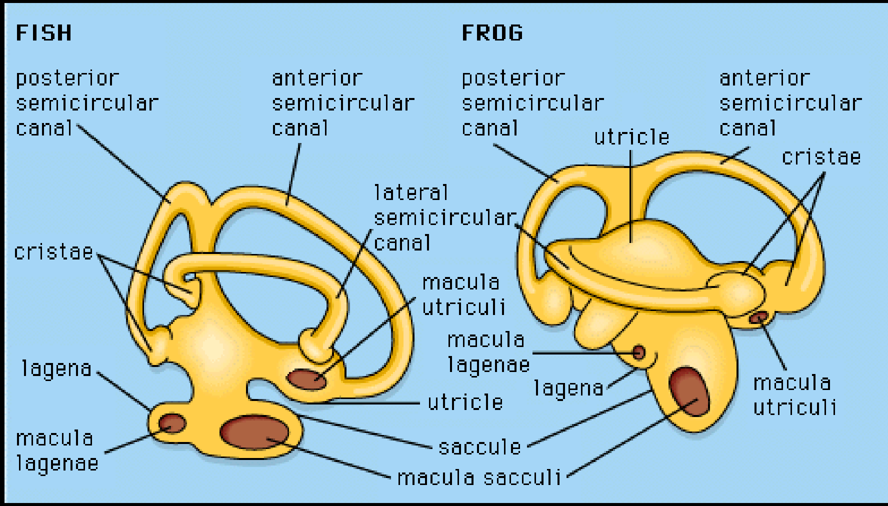
The inner ear is divided into the PARS SUPERIOR and the PARS INFERIOR.

The PARS SUPERIOR IS MADE UP OF THE SEMICIRCULAR CANALS AND THE UTRICLE in bony and cartilaginous fishes. The utricle contains the lapillus (=diminutive of stone)

The PARS INFERIOR IS MADE UP OF THE SACCULE AND THE LAGENA.

Many fishes have an additional organ, the MACULA NEGLECTA, a sensory structure located in Teleostomi in the utriculus of the inner ear near the opening of the ampulla of the posterior vertical semicircular canal, in selachians within a duct (posterior canal duct) through which the posterior vertical semicircular canal connects with the sacculus, while in the batoids it lies in the wall of the sacculus adjacent to the opening of the duct. It may have a neuromast associated with its sensory tissue. This structure has been demonstrated to be a sensitive vibration receptor in Raja. Also called crista neglecta, crista quarta, or papilla neglecta.

All these organs are INNERVATED BY BRANCHES OF CRANIAL NERVES.

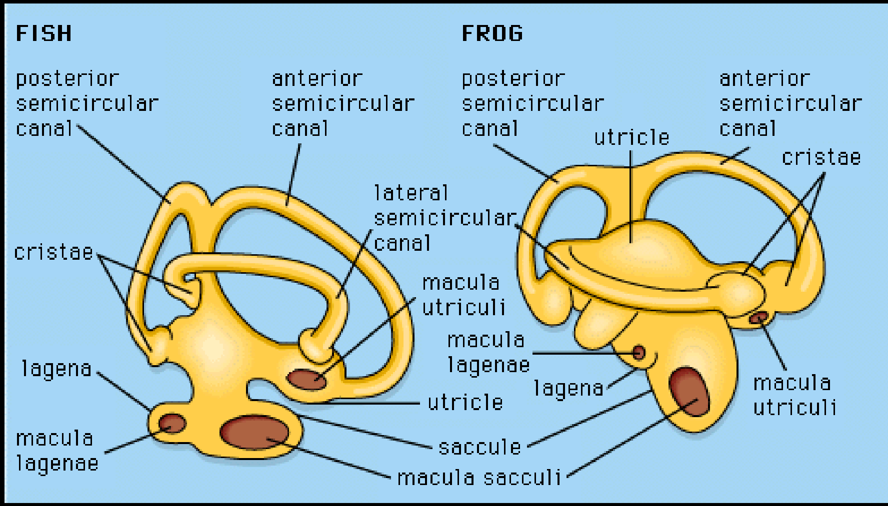


Vestibule

The three semi-circular canal ducts are called the ANTERIOR, POSTERIOR AND HORIZONTAL (or lateral) canals. They all extend from the utricle, and are FILLED WITH ENDOLYMPH. The anterior and posterior canals share a vertical section, called the crus commune.

At the BASE OF EACH CANAL, is a DOME-LIKE ENLARGEMENT CALLED THE AMPULLAE.

WITHIN EACH AMPULLA, is the CRISTA AMPULLARIS. The crista ampullaris forms a high, narrow ridge lying transversely across the ducts, and are covered with sensory hair cells.



Otolith organs

The THREE OTOLITH ORGANS (utricle, saccule and lagena) are FLUID-FILLED POUCHES each CONTAINING AN OTOLITH called the LAPILLUS, SAGITTA AND ASTERICUS.

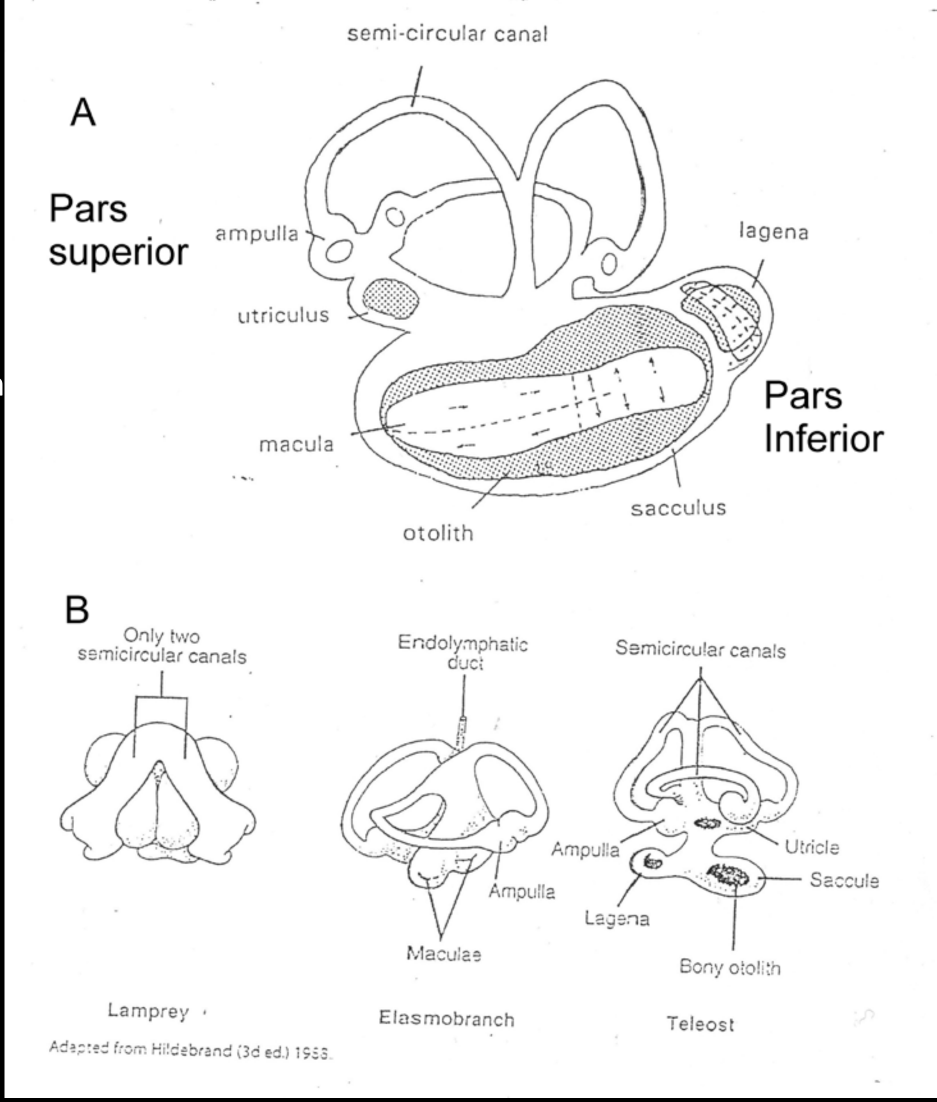
Comprised of calcium carbonate called ARAGONITE and protein called OTOLIN. Both are laid down periodically and under magnification look like a bar-code. Large seasonal differences gives the appearance of banding.

These often have defined elaborate grooves and protrusions that arc.

In ELASMOBRANCHS, the calcifications are more diffuse, forming the OTOCONIA.

Each OTOLITH CHAMBER IS LINED with patches of tissue composed of sensory hair cells called the MACULA. The otolith lies close to the sensory epithelium, and are coupled together by a gelatinous sheet or plate called the otolithic membrane.

The MACULA NEGLECTA is another endorgan of the ear, but it is not found in all fishes. The NEGLECTA CAN BE LARGE IN ELASMOBRANCH SPP, but is generally small in bony fishes.



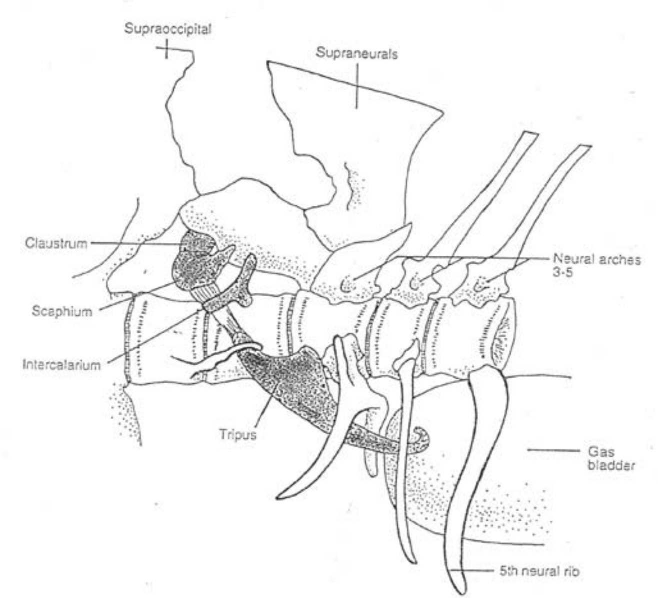
Weberian ossicles

The OSTARIOPHYSIN fish (Characidae, Cyprinidae and Siluriformes) have ACUTE HEARING AND PITCH DISCRIMINATION.

This is due to a SERIES OF SMALL BONES, called the WEBERIAN OSSICLES.

These bones physically CONNECT THE ANTERIOR END OF THE SWIM BLADDER WITH THE FLUID SYSTEM OF THE INNER EAR AT THE MIDLINE, BETWEEN THE SACCULES.

DEFLATION OF THE GAS BLADDER OR DISCONNECTION BETWEEN THE OSSICLES and the bladder causes DECREASED HEARING sensitivity in the fish.



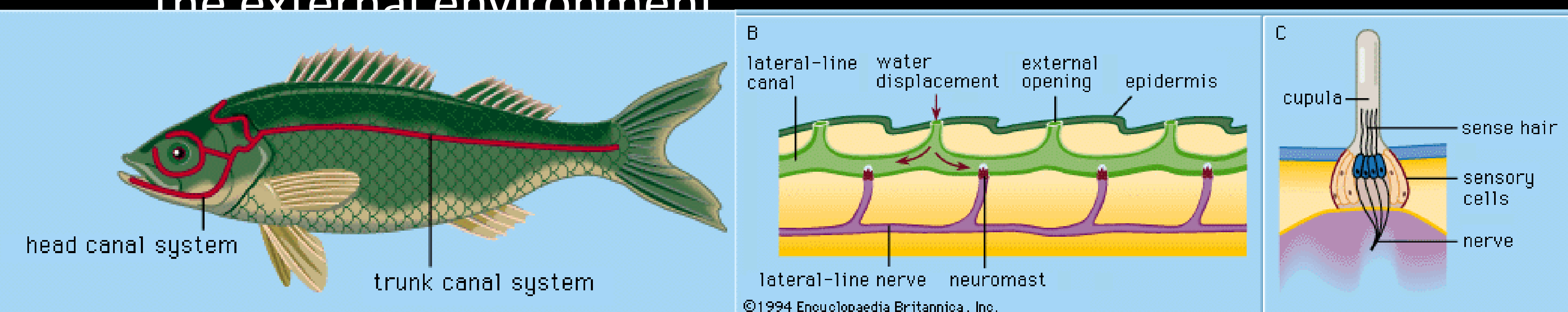
A lateral view of the left side of the anterior portion of the vertebral region of an otophysan fish. The Weberian ossicles transmit sound vibrations from the swim bladder to the inner ear.

Lateral line system

The LATERAL LINE SYSTEM consists of a CANAL SYSTEM ON THE HEAD and a CANAL SYSTEM ON THE TRUNK.

There are often 3 major canals on the head, and a single major trunk canal running along the length of the body.

The CANALS IN TELEOSTS are WELL-OSSIFIED, PIERCED WITH PORES through which the FLUID-FILLED canal is linked to the external environment.



The canals on the head can be CLASSIFIED INTO FOUR TYPES: narrow simple, reduced, widened and branched.

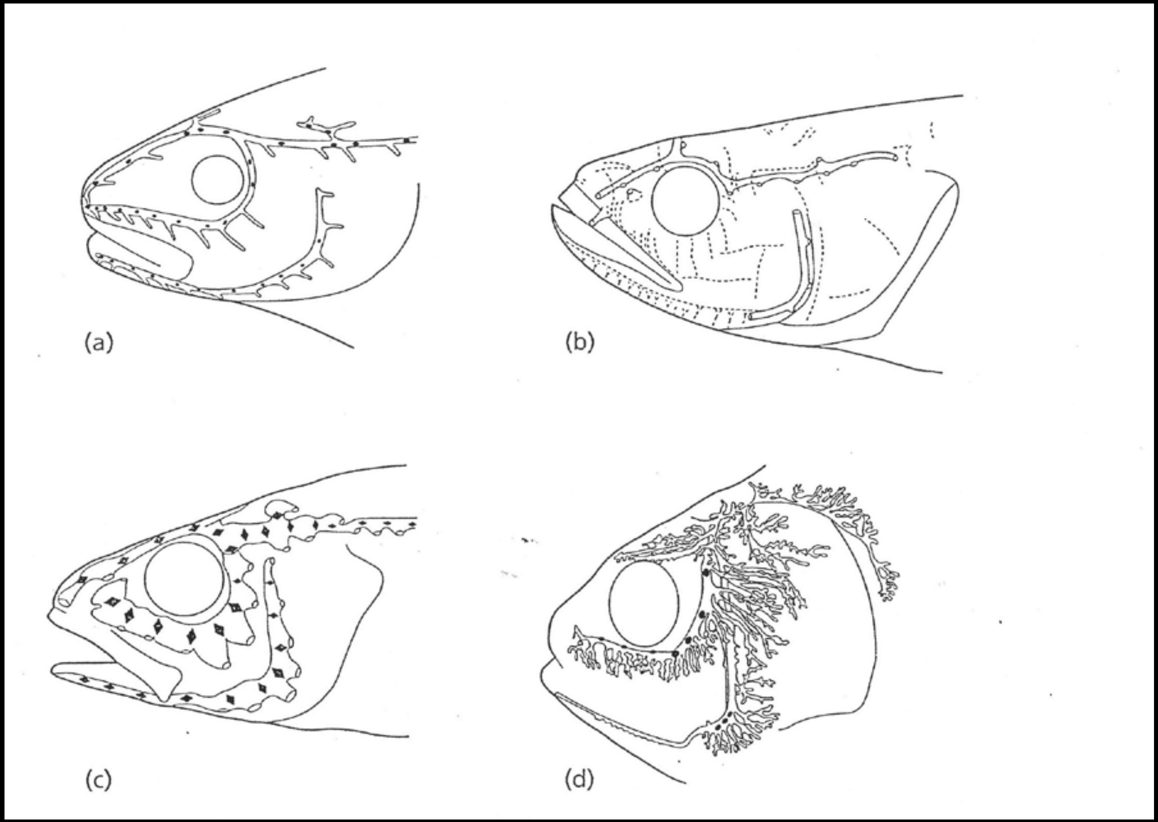
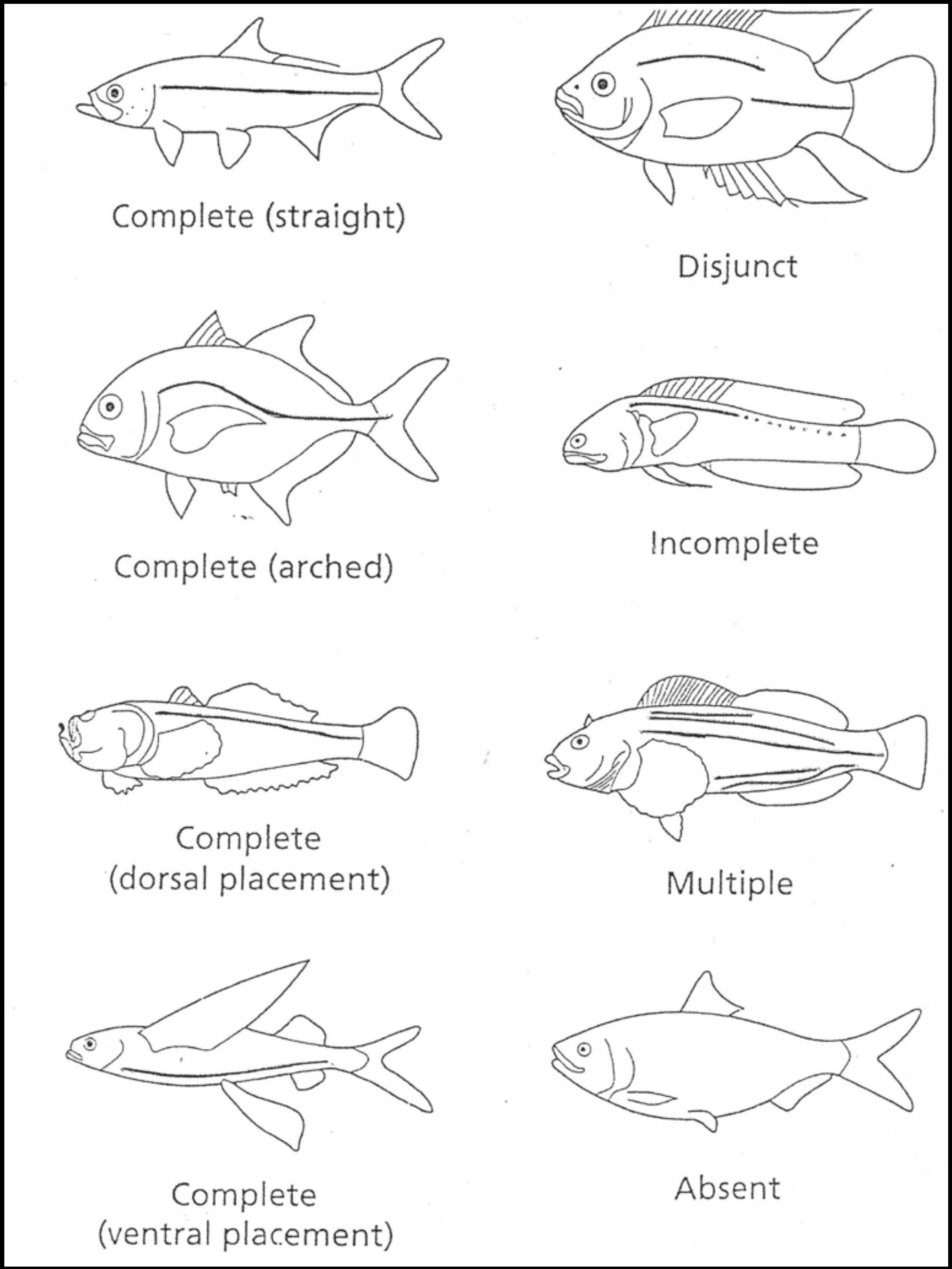


Figure 3.6: Four Types of head canal systems among teleost fishes: (a) narrow-simple canal system; (b) reduced canal system; (c) widened canal system; (d) branched canal system.



There are EIGHT TRUNK CANAL PATTERNS are present in teleost fish.

Receptor organs

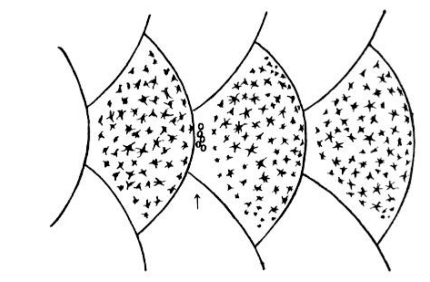


Fig. 10-1. A group of small 'pit organs' on a scale of the medaka. Original.

The lateral line canals are lined by a thin epithelium in which the NEUROMASTS are embedded.

Neuromasts can be classified into different types, depending on their location:

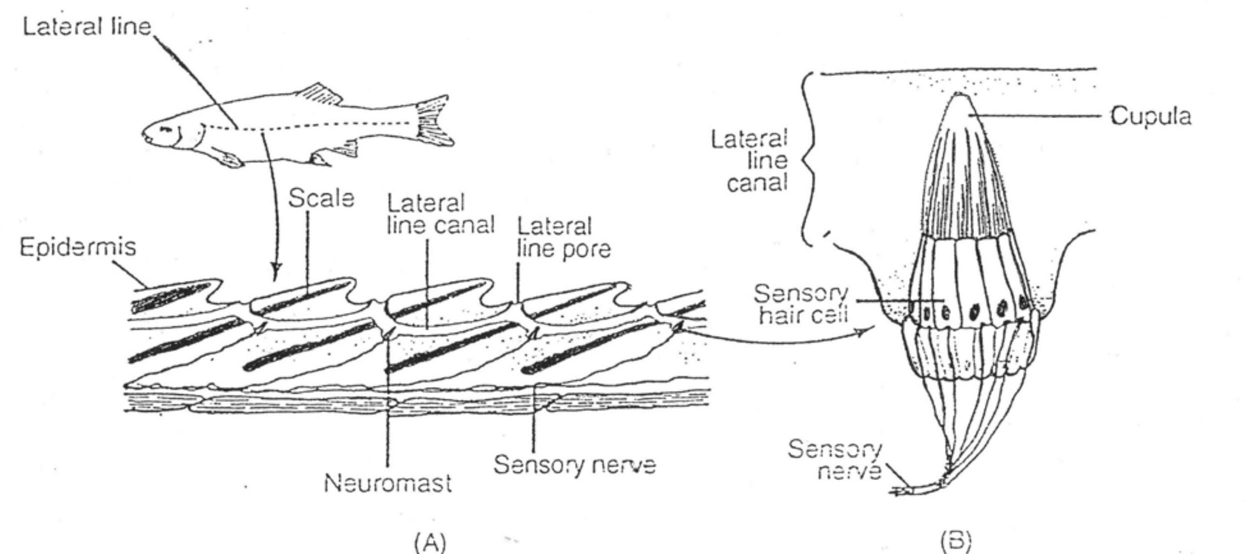
1) FREE OR SUPERFICIAL NEUROMASTS - forms patches on the skin, often in groups or lines called "stitches" or "pit lines".

2) CANAL NEUROMASTS - forms similar patches, but are located within the fluid-filled lateral line canals that lie under the skin.

The HAIR CELLS of the neuromasts are usually ORIENTED IN TWO OPPOSING DIRECTIONS.

The MOVEMENT OF THE FLUID within the canals STIMULATE THE HAIR CELLS, which in turn are innerved by lateral line nerves, specific to the different neuromast regions.

These nerves also have SPECIAL GANGLIA and specific projection sites in the HIND BRAIN, distinguishing them from other nerves.



Cross-section through the trunk of a minnow, showing the distribution and innervation of neuromast receptors and the location of the pores that connect the canal to the external environment. B) Each neuromast is composed of several hair cells, supporting cells and innervating sensory neurons. The apical kinocilia and stereocilia project into the cupula that overlies the entire neuromast.

Acoustic communication: sound production and reception

SOUND is a particularly USEFUL CHANNEL FOR COMMUNICATION in water.

Acoustic signals are NOT AFFECTED BY MURKINESS OR DARKNESS of the environment

SOUND TRAVELS 5 TIMES FASTER IN WATER THAN IN AIR (1500m/s as opposed to 300m/s).

Sound production mechanisms

Fishes from 50 different families are able to produce sound in a variety of ways.

STRIDULATION by pharyngeal teeth or spines and fin rays (Gurnards, grunters).

The swim bladder often acts as a RESONATOR, it increases the amplitude of the sound wave (eg croakers/Kob).

Some marine catfish have special drumming muscles that vibrate the walls of the swim bladder (an 'EXTRINSIC' system)

In other fishes, sound is produced by an 'INTRINSIC' system, the muscles have their origin on the swim bladder, and the frequency of the sound depends on the rate of contraction of the muscle (toadfish, *Opsanus*).

http://www.dosits.org/audio/fishes/barredgrunt/

http://www.dosits.org/audio/fishes/atlanticcroaker/

http://www.dosits.org/audio/fishes/hhseacatfish/

http://www.dosits.org/audio/fishes/oystertoadfish/

Sound reception

Sound reception, how do they hear?
A sound produces TWO TYPES OF STIMULI within water.

Back-and-forth motion of the particles in the medium = PARTICLE DISPLACEMENT
production of SOUND PRESSURE

Head of a FISH VIBRATES in a sound field → OTOLITHS overlying the maculae will also VIBRATE.

Because OTOLITHS ARE DENSER than the surrounding tissue, the vibrations will be smaller than that of the surrounding tissue.

Causes hairs of the HAIR CELLS to BEND.

This bending will fire the hair cells if their polarity is appropriate to the direction of the vibration.

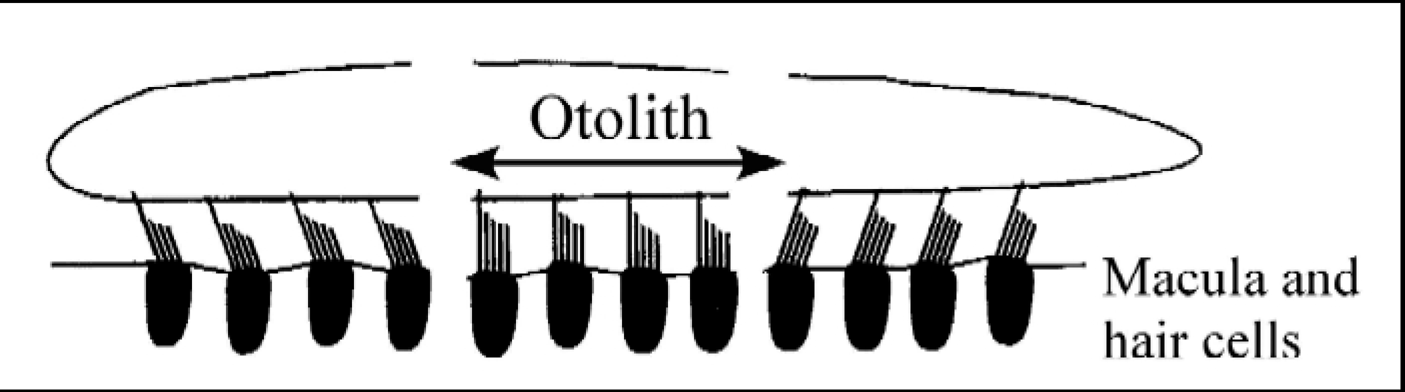
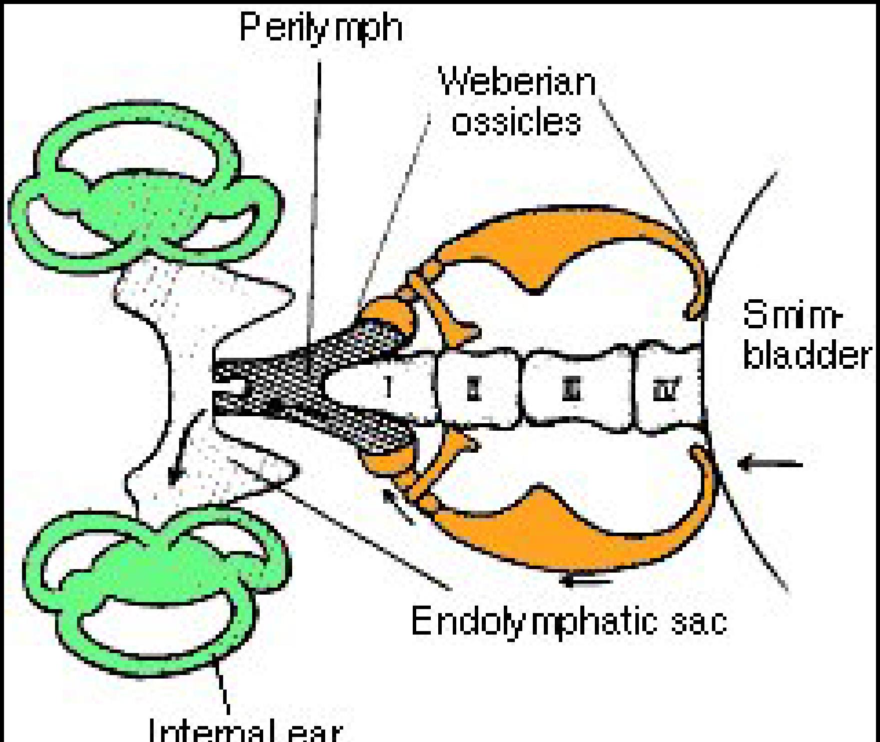


Figure 1 Otolith oscillating above the macular hair cells

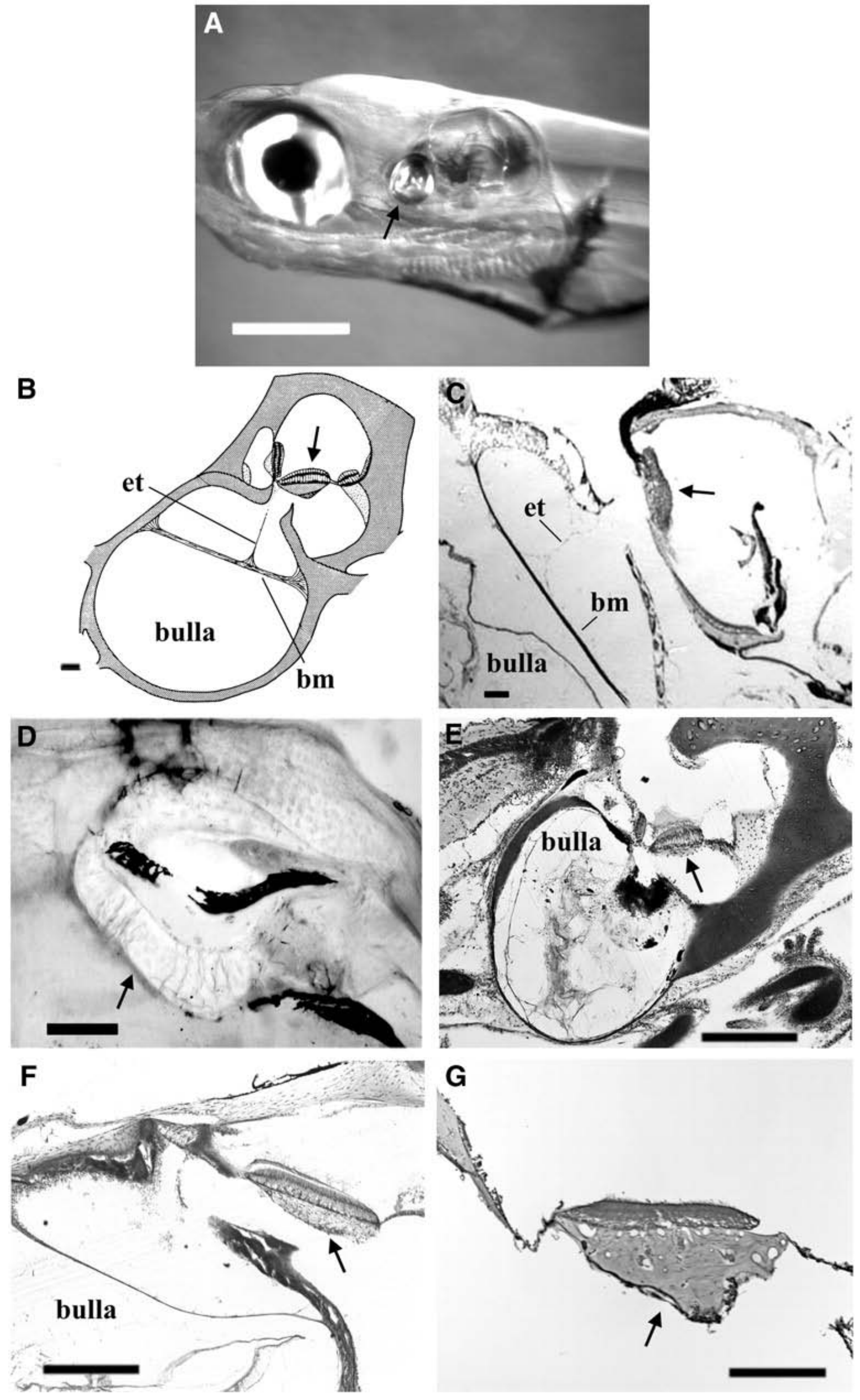
The WEBERIAN APPARATUS is a particularly EFFECTIVE STRUCTURAL MODIFICATION that enhances the hearing of otophysan fishes (Cypriniformes, Characiformes, Siluroidei, and Gymnotoidei). Swim bladder pulsates in the SOUND PRESSURE FIELD AND ROCKS THE TRIPUS. Relayed through other bones to a sinus containing perilymph adjacent to the saccular macula.

CLUPEOIDS, such as anchovy, have an OTIC BULLA, which is closely associated with the UTRICULUS, on either side of the head.

The bulla ACTS AS A PRESSURE-DISPLACEMENT TRANSDUCTION MECHANISM.



(A) Relationship of the prootic bulla to the inner ear of American shad, as demonstrated in a 12.5 mm *TL* larva. The prootic bulla (arrow) sits just anterior to the utricle. (B) Diagram (modified from Denton and Gray, 1979) and (C) transverse section showing the relationship of the prootic bulla to the utricle in adult American shad. The bulla is connected to the middle macula (arrow) of the utricle by an `elastic thread' (as defined in Denton and Gray, 1979) connected to the bullar membrane. et, elastic thread; bm, bullar membrane. Sections through the utricle of (D) 12 mm *TL*, (E) 16.5 mm *TL*, (F) 26 mm *TL* and (G) adult American shad. Arrows in B, C, E, F, G and H represent the middle utricular epithelium. Scale bar in A=1 mm, in B=100 µm and in C,E–H=10 µm. Orientation of plates B–G is as shown in A (anterior is to the left and dorsal up in all cases).



Higgs, D. M. et al. J Exp Biol 2004;207:155-163

The Journal of Experimental Biology

Locomotion and posture

The VESTIBULAR SYSTEM (pars superior, canals of the ear) is concerned with the MAINTENANCE OF BODY ORIENTATION = control of posture and positioning and movement of the body during locomotion.

Changes in the ACCELERATION OR ORIENTATION will cause the ENDOLYMPH WITHIN THE VESTIBULAE TO MOVE. This causes a DISPLACEMENT OF THE CUPULA that encloses the cilia of the hair cells.

The downward pull of GRAVITY ON THE LAPILLUS (utricle otolith) triggers impulses from the sensory cells. This provides the fish with information regarding its VERTICAL ORIENTATION in the water.

Adaptations: Most fishes maintain their bodies in an upright position.

Flatfish: The VESTIBULAR SYSTEM IS AT 90° RELATIVE to other fishes. In fishes that are oriented "upwards", the utricle is horizontal, and the saccule more vertical.

Upside-down catfish: Synodontus nigriventris often swims with its dorsal side down, while it feeds on the underside of floating vegetation. These fish also show NO STRUCTURAL MODIFICATIONS TO THE INNER EAR, and changes to the central nervous system have been inferred.

Tail-standers or head-standers: These fish can tilt their bodies by as much as 30° - SENSORY MACULA OF THE UTRICULAR OTOLITH IS TILTED.

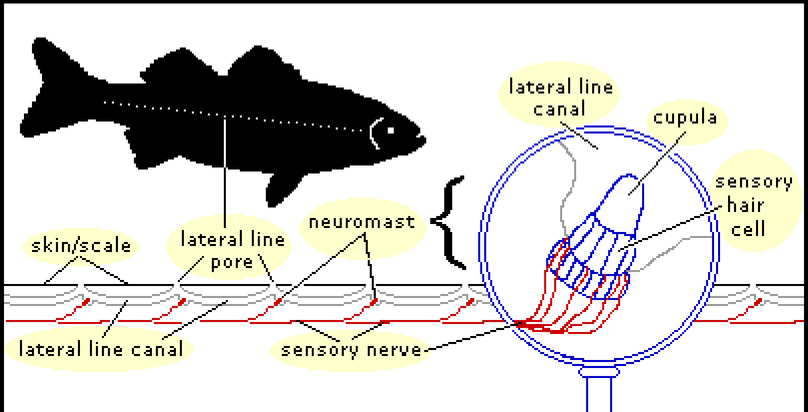
The Lateral line and fish behaviour

DETECTION OF MOVEMENT: Predator and prey

RESPONSE PROPERTIES: Functional differences exist between narrow and widened head canal systems. Widened canals have increased sensitivity and response time. The response properties of wide canals are also similar to that of superficial neuromasts and can explain the evolution of reduced canals, where superficial neuromasts predominate.

DETECTION OF OBSTACLES: When the water moves, a `flow field' occurs around a stationary object.

SCHOOLING: to maintains position and velocity relative to its nearest neighbour



Question - schooling or shoaling?

School - a group of fish that swim in a synchronised manner, i.e. with similar speeds and direction. They also display a consistent Nearest Neighbour Distance (NND), which means they maintain the same distance between all immediately adjacent fish. This NND is usually about 0.5 to 1 times the length of the fish.

Shoal - a group of fish that are randomly orientated within a group and exhibit a variable NND. Shoals of fish on the move nearly always form schools.