Development of the Perception of Changes in Position, Swimming Speed and Sounds in Fish and its Influence on Passage

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Development of the Perception of Changes in Position, Swimming Speed and Sounds in Fish and its Influence on Passage

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FROM

Sesile

TO

Body balanced

Otolith balanced
Sesile Sponge

Passage to nervous system

Mesohyl contains spongins fibers arranging crystals perceive from pressure the change of body position.

Choanocytes waving low pressure pulls food with inflow of water, but wasting out is 10 faster. Unequal pressure is controlled by like nerve action propagates on cell membrane electrical signals, rise \([\text{Ca}^{+2}]_i\) stop flagellum (Hexactinellids). Flagellum start beat if \([\text{Ca}^{+2}]_i\) is pumped out of the choanocyte. At depolarization, voltage + sink the hill of axon & depolarize adjacent region that propagates along as acoustic wave.

Cnidarians

31 m \(\cdot\) h\(^{-1}\)

H\(_2\)O

20 Hz

3.6 m \(\cdot\) h\(^{-1}\)

H\(_2\)O

Passage to open sea

Scyphozoan with nervous net
Medusa

High efficiency using low pressure, the changes work on body shape & statolith localizations – passage to pelagic

Body shape balanced

Statocyst

Radiant symmetry hold balance
Spherical statocysts at edge manage every side

Tentacle
Sensorial cell

Ring of neural net thickens at statocysts

Swimming strategy

Low pressure

High

Low

Push body to low R (spherical side)

Sockings

High

Hydrodynamic resistance, $R_{a,h}$

$R = 6$

$R = 24$

$R = 20$

Speed of swimming

2 - 19 cm·s$^{-1}$ = 0.004 – 0.07 km·h$^{-1}$, generate 1 – 0.5 Hz

Stop & jump at great R (concave)
Ctenophora
To high deep

Body shape balanced

3× faster due to smaller resistance from elongation. 1 statolite hold perception on all around.

Combs beat generate waves

Food is regurgitated? Passage for food digestion

Centralizes all: nerve ring, swimming, information, feeding & waist

Statocyst 1

New swimming strategy

Forward

Hydrodynamic resistance, $R_{a,h}$

Cestida, waving of the body.

Anus

$[Ca^{2+}]_i$

New swimming strategy

Low pressure

Backward

R = 2

R = 6

R = 24

Speed of swimming 0.009 km·h$^{-1}$; 3-5 Hz
Annelids

Faster as a result of streamlined shape & use transverse waves to swimming. Wider interpretations through hind- mid- & part forebrain.

Body shape

1 Stato-cyst

New Swimming strategy

Hydrodynamic resistance, \( R_{a,h} \)

Speed of swimming 0.01 km·h\(^{-1}\);
**Mollusca**

Biggest body (10 m squids) & speed among protostome with most smooth shape. Swimming is pulsation & its sounds across ontogeny are in otolith recorded.

**Body shape**

- **Squid**
- **Bilateral**
- **Aerodynamic**
- **Dorsal**
- **Ventral**

2 Stato cysts

New Swimming strategy

- Fast movement
- Sucking
- Throwing

Hydrodynamic resistance, $R_{a,h}$

$R = 1$

Speed of swimming 1 km·h$^{-1}$

Circular center? slow swimming larvae

High otolith? large vertical migration
Arthropods

The passage to gain communication and gain new space: air for flying

Class Insecta

Scolopidia

Johnston's organ, 480 neurons
Percept gravitational, mechanical & acoustic oscillation, 50 – 70 Hz

Trichoptera
Otolith in larvae of Insects

33 – 97 km·h⁻¹; 27 Hz

Krill, *E. superba*

Crayfish

Body shape

Beating

2

Stato cysts

New Swimming strategy

Flicking

Beating

Turning stop

Hydrodynamic resistance, \( R_{a,h} \)

\( R = 6 \)

\( R = 24 \)

\( R = 1 \)

Speed of swimming

3.6 - 29 m·h⁻¹; 3.3-4.3 Hz

33 – 97 km·h⁻¹; 27 Hz

2

Statocysts

New Swimming strategy

Flicking

Beating

Turning stop

Hydrodynamic resistance, \( R_{a,h} \)

\( R = 6 \)

\( R = 24 \)

\( R = 1 \)

Speed of swimming

3.6 - 29 m·h⁻¹; 3.3-4.3 Hz

33 – 97 km·h⁻¹; 27 Hz

2

Statocysts
**Echinoderms**

In the new phase of evolution, animals gain new opportunities. Their development require more secure lifestyle at the bottom.

Body shape

antennae

tube feet

5 Stato cysts

Swimming strategy

Crawling at the bottom

Hydrodynamic resistance, $R_{a,h}$

Speed of swimming $0.0011 \text{ km} \cdot \text{h}^{-1}$

Bilateral swimming larvae

5 statocysts

Radial adults

Lose statocysts & brain

While bending push the body forward to lesser resistance.

$R = 2$

$R = 6$

$R = 24$
**Chordates**

**Tunicates**

**Larvacea**
- Body shape
  - Tunicates larva
  - Notochord
  - Eye
  - Statocyst

**Thaliacea**
- Body shape
  - Brain
  - Mouth
  - Cloaca
  - Notochord

1. **Statoctyast**
- Central in brain central cavity

**New Swimming strategy**
- The larva Ascidiacea is more advanced carried in current, get quick sex & sessile
- Salp pumping generate low pressure to which it pulls its body

**Hydrodynamic resistance, R_{a,h}**
- **R = 1**

**Speed of swimming**
- **1.6 km·h^{-1}**
- **0.2 – 0.6 km·h^{-1}, 0.5 – 1.2 Hz**

**Central in brain central cavity**
- **R = 2**

**0.8 km·h^{-1}**
- **1000 km**
**Jawless**

Passage to be fast & conquer. Lymph oscillation extended on circular canals better measure fast turning of loosely body

**Body shape**

- Myxini
  - One canal
  - Cristae
  - Ampullaris
  - Macula communis

- Phylo- & ontogene
  - Two canals
  - Ciliated chambers

- Petromyzontiformes
  - Saccular

**2 circular Statocysts**

**New Swimming strategy**

- Large amplitude

**Hydrodynamic resistance, $R_{a,h}$**

- $R = 24$

**Speed of swimming**

- $1.6 \text{ km} \cdot \text{h}^{-1}$
- 66 - 132 Hz

- $7 - 22 \text{ km} \cdot \text{h}^{-1}$, 1.5 Hz
Chordates

Development various movement strategies to fullfil use all environment resources at different habits in time & space

Body shape

Ps. georgianus

2 statocysts

Not circular

3 pairs otolits

Vertical migrations

Horizontal migrations

Swimming strategy

pectoral fin

Hydrodynamic resistance, $R_{a,h}$

$R = 1$

Speed of swimming

1.6 km·h⁻¹, 0.9 Hz

S. japonicus

21 km·h⁻¹, 2.5 Hz

Lapillus

Astericus

Sagitta

Not circular

2 statocysts

Not circular
Where to swim?

**Ps. georgianus**
Fur seal *Arctocephalus gazella* are isolated by warmer more saline sub-Antarctic waters.

*Channichthyidae* are isolated by warmer more saline sub-Antarctic waters.
The catch location of Ps. georgianus are on the shelves of:

- Scotia Arc Islands 0-475 m; 53°S-66°S

Unusual catch

- S. Sandwich I. Germany 1975/76; 1980/81
- Kerguelen I. Australia 2003/04
- Balleny I. Russia 2004/05

Larvae spread in one way, in opposition separate

Barriers:
- Darkness
- No light

Distance, Currents, Depth, Cold

518 km · month⁻¹

Low genetic differentiation for many Antarctic fish species even benthic suggest their high connectivity between islands.
Sound low Hz provide information about currents, distances and other barriers.
With acoustic perception by otolith, icefish recognize & overgo barriers, find food & compete!
All species are at SOUND CANAL. Sounds their swimming lead them to concurrence & distribute to different sides.

2·10^6 of fish

1-10.II. 1989, S. Georgia
Young SGI choose only deep depth below 250 m. Adults prefer SOUND CANAL. Older spawn inshore.

Biomass ($t$) of Ps. georgianus

Species domination: >> in a square; > over SGI,

Fish larvae hatch nearshore

Old & young C. aceratus

Old Ps. georgianus for old krill

E. superba at strong currents.

Deep sea current

Strong whirls with krill

Surface current

Old & young C. aceratus

Young Ps. georgianus for krill

larvae at large depth

Species domination: >> in a square; > over SGI,

Fish larvae hatch nearshore

Old & young C. aceratus

Old Ps. georgianus for old krill

E. superba at strong currents.

Deep sea current

Strong whirls with krill

Surface current
Young *Ps. georgianus* for larvae of krill  
Middle age cross 250 km  

Old adult *Ps. georgianus* for adult krill  
Larvae near hatch side

**Ps. georgianus** 1.II.89-I.92  
N = 676

- 5, 92 larvae h⁻¹ of age group 0.  
- 2, 15, 176 fish h⁻¹ of age group I.  
- 4, 20 fish h⁻¹ of age group II.  
- 10, 101, 330 fish h⁻¹ of age above III,  
- 7, 32, 124 fish h⁻¹ of age group IV & V.
In night icefish prey krill

In days icefish migrate in dark to bottom

-100
-200
-300
-400
-500 [m]

300 - 900 Hz
3-5 dB louder

“Dinner bell” low HZ hum emit by krill in travelling down
Oscillation depend on size & shape of oscilator, that are change in ontogenetic development, which reflects phylogeny
Spongin – is the collagen polymerised fibers in Mesohyl that is between sponge cells.

Collagen fibers under magnification of 30 thousands times

The fish sclerite-protein has conservative structure across evolution (spongin, conchiolin, collagen), and can aggregate and growth in the water.
Extracellular process: Tropocollagen is capable to spontaneous polymerisation.

3 peptides

Collagen fiber increased by 100 thousands times.

260 × 1.2 nm

Surface unit

Rhomboeders
SEM. The collagen matrix contains a gap after CaCO$_3$

Collagen net on the surface

The otolith collagen net from icefish under high magnification
The otolith collagen net under low magnification with the same pattern on perpendicular surface.
Collagen fibers in the space

Rhomboeders on surface extending into space **tetrahedrons**

1. 18 × 10^{-2} mm
2. 3 dimension space unit
3. 560 nm

Rhomboeder surface unit

Otolith center

R = 0.11 mm

45 days
Spherical surfaces of otolith indicate that the crystallization of Aragonite (90%) determine fish sclerite-protein (less than 10%) that is go in endolymph transfering sound waves.
Oscillation of endolymph arrange dipoles of tropocollagens. This go for smaller resistance that arrange tropocollages with longer axis along direction of swimming. This give wide increments & elongate otolith in that direction.

Lymph oscillation

Otolith surface

260×1.2 nm

Increments:

Viscosity coefficient

→ Higher

→ Lower

Short

Wide
Sound ordering molecules give evolution passage to overcoming barriers: by otolith elongate that improve measure the deviations from direction of swimming elongate otolith

*S. japonicus*, ~21 km/h
Horizontally give faster swimming, that also stimulates body shape & swimming strategy.

Vertically give faster migration

*Ps. georgianus*, ~1.6 km/h
Collagen net change the width of daily increments & otolith shape is from ordering of tropocollagens by sound.
Aragonite crystallize precursors radially in the state of immobility. Each wall is rhombo.

Pearl

It crystallize in twinned Rhombohedrons filling with squeezing the pattern of space of collagen net.

In squeezing each wall is rhombo
Aragonite precipitates with the form, size & orientation determined by collagen gaps.

\[
\text{CO}_3^{-2} \text{ chelate anion}
\]

\[
\text{Ca}^{+2} \text{ form tetrahedrons with } \text{CO}_3^{-2} \text{ as base, 2 layers CO}_3^{-2} \text{ on 1 Ca}^{+2}
\]
Thanks to plascity of aragonite crystals the collagen arrangement obtained by acoustic oscillation contain their information. That informations are transferred via otolith aragonite to hair cells & brain. Became passages for overcame obstacles.

The smaller are pelagic

The higher are semipelagic

The larger are bottom
Conclusions

1. Extracellular growth of otolits is the base in the evolution for space acquisition with adaptation to environment changes.

2. Endolymph oscillations bearing environment & physiology information write them in otolith microstructure by ordering tropo-collagens & transfer to hearing.

3. At depth of about 200 m of sound canal all icefish species concentrate but they do not share the same places. In mesopelagic darkness they recognize themselves and their development stages inhabit separated opposite sides and periods.

3. *Ps. georgianus* living in a dark in currents recognize their 3-dim biotic & physics sound map and during evolution adapt to them its life cycle migrations.

4. Adults recognize in the dark krill adults concentrated by vertical whirls on North-East S. Georgia I, while young krill nauplius & calyoptis in deep currents bringing them from slope (2000 m) to shelf at depth to 500 m at South West.

5. Young SGI developmental stages migrate in darkness from East to South to cold deep currents below 250 m for appropriate food size & faster body growth.

6. Unlike the other icefish, not postlarvae but adults of *Ps. georgianus* with sound passage migrate in the mezopelagic darkness to neighbor islands.

7. In warm years SSI exchange SGI at the bottom on North East, while ANI increase schooling in mezopelagic appropriate to recognized organization level on krill swarms.
Thank You

Question: ryszardtraczyk@gmail.com
Discover and measurements:
The size of microvilli that percept low Hz is the same as size of tropocollagens - components of collagen like otoliths protein.
Collagen net measured by harmonic functions

\[
\text{fitted line } \quad y = \sum_{i=1}^{9} \left( A_i \times \sin\left( \frac{2\pi}{T_i} x + \varphi_i \right) \right) + \text{const}; \quad T_{sr} = 0.0021 \text{ mm}; \quad s = 0.00002
\]
Stages of extracellular otolith growth

Endolymph

1. Tropocollagens

2. Transport of mineral ions

3. Soluble proteins

4. Transport of mineral ions

5. Soluble proteins regulating

Cell

Movement activity

Sound passage

Bicrystal net

Aggregation & ordering

Net crystallizes

Attachment of Ca\(^{2+}\), CO\(_3\)\(^{2-}\) in the corners

Active network

Net stacked

Attachment of phosphoproteins to gaps

Thickening of ions Ca\(^{2+}\), CO\(_3\)\(^{2-}\) in the gaps

Formation of complexes Ca with CaCO\(_3\)

Liquid crystal

Sound ordering