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Soumya Hilal
Department of Zoology, BJM Govt. College, Chavara, Kollam, Kerala, India

Fouzia Hilal
Department of Botany, MSM College, Kayamkulam, Alappuzha, Kerala, India

Correspondence
Soumya Hilal
Department of Zoology, BJM Govt. College, Chavara, Kollam, Kerala, India

A study on phenotypic brain variation in some teleosts

Soumya Hilal and Fouzia Hilal

Abstract
The ways in which challenging environments during development shape the brain and behaviour are increasingly being addressed. Conditions fish encounter during embryogenesis and early life history can leave lasting effects not only on morphology, but also on growth rate, life-history and behavioural traits. Fish brains and sensory organs may vary greatly between species. With an estimated total of 25,000 species, fish represent the largest radiation of vertebrates. From the agnathans to the teleosts, they span an enormous taxonomic range and occupy virtually all aquatic habitats. This diversity offers ample opportunity to relate ecology with brains and sensory systems. In a broadly comparative approach emphasizing teleosts, we surveyed classical and more recent contributions on fish brains in search of evolutionary and ecological conditions of central nervous system diversification. This review summarizes that there is a profound effect of environmental factors on brain size and brain morphology. The size and structure of an animal's brain is typically assumed to result from either natural or artificial selection pressures over generations. However, because a fish's brain grows continuously throughout life, it may be particularly responsive to the environmental conditions the fish experiences during development. The present study was undertaken on five teleosts collected from local fish farms and aquarium of Kollam district, Kerala. This study reveals phenotypic variation in fish brain of some teleosts: *Cirrhinus cirrhosus, Etroplus suratensis, Heteropneustes fossilis, Mugil cephalus* and *Tilapia mossambica.* Within the fishes marked phenotypic variation was observed in hindbrain lobes of fishes. Well-developed cerebellum was observed in *Heteropneustes fossilis.* Somatic sensory lobe concerned with sense of taste and touch is found only in *Heteropneustes fossilis.* Vagal lobes concerned with mouth tasting nature are found in all selected fishes. Facial lobe associated with skin tasting nature was found only in *Cirrhinus cirrhosus* and *Heteropneustes fossilis.*

Keywords: Phenotypic; brain variation*; Cirrhinus cirrhosus; Etroplus suratensis*

Introduction
Fishes have been found advantageous as experimental animals for biological research under simple laboratory conditions owing to their short generation time and availability. Number of factors governs the fish life and other aquatic organisms. Brain is the seat of mental faculties of a fish. Parallel changes in the size of specific brain parts and ecological adaptations have been demonstrated in many vertebrate taxa ranging from fish [1, 2] to bats [3] and primates. Fishes are primarily useful for comparative studies because the primary target of sensory modalities are distinct brain divisions which can be measured in the intact brain (eg-Facial and Vagal lobe concerned with taste, the Optic lobe for vision and Olfactory lobe for smell). The brain of fishes is divisible into forebrain or Prosencephalon, Mid brain or Mesencephalon and Hindbrain or rhomb encephalon. The Prosencephalon is further constricted into two sub regions namely the telencephalon and diencephalon. The prosencephalon consists of olfactory lobes, cerebrum and diencephalon. The telencephalon differentiates to from the cerebrum and in most vertebrate groups, the olfactory bulbs. The diencephalon contains thalamus and hypothalamus. The pituitary gland hangs from hypothalamus. The cerebrum is divided into right and left cerebral hemispheres, they are concerned with olfaction receiving fibres from the olfactory bulbs. The telencephalon is regarded as the "nose brain". The midbrain or mesencephalon consists of optic lobes and cruracerebri. The midbrain is designated as "eye brain". The hind brain or rhomb encephalon consists of metencephalon and myelencephalon, the former is regarded as "skin brain" and latter the "Visceral brain" Metencephalon consists of cerebellum and myelencephalon consists of medulla oblongata. The walls of medulla oblongata are thick and made up of nerve tracts that connect the spinal cord with various parts of brain. Cerebellum coordinates muscular activity and is responsible for muscle tone, posture and equilibrium.

The principal factor that brings about variations in the structure of hind brain is widely regarded as their feeding habits [4]. Primary divisions of the brain which consists of the medulla oblongata with the cerebellum and other less constant appendages in fishes is called "epencephalon" is relatively larger, occupies a greater portion of the cranium and is more complex and diversified in this than any of the higher class of vertebrates [5]. The important lobes of the medulla oblongata are the vagal and facial lobes, which are the terminal centres for the nerve fibres of the vagal and the facial nerves respectively. The size of these lobes depends upon the extent to which their nerve fibers supply taste buds.

1. Fishes that feed with help of sight.
2. Fishes that feed with help of barbels and olfaction.
3. Fishes that feed with help of taste.

1. Fishes that feed with help of sight

In the present study fishes like *Tilapia mossambica, Mugil cephalus, Etroplus suratensis* feed with help of sight. They have well developed optic lobes which occupies the largest portion of brain.

2. Fishes that feed with help of barbels and olfaction

In the present study cat fishes which are both bottom feeders, barbel tasters ant that feed with help of olfaction such as *heteropneustes fossilis* is included.

3. Fishes that feed with help of taste

Heteropneustes fossilis, Etroplus suratensis feed with help of taste. They are capable of taste discrimination.

Materials and Methods

The project reported herein has largely utilized live specimens collected from ponds, lakes, aquarium and nearby places of Kollam district in Kerala. The following specimens were examined.

S No	Type	Family
1	Cirrhinus cirrhosus	Cyprinoidae
2	Etroplus suratensis	Cichlidae
3	Heteropneustes fossilis	Heteropneustidae
4	Mugil cephalus	Mugilidae
5	Tilapia mossambica	Cichlidae

The fishes selected for the study includes 5 species of fishes belonging to 4 families which were collected from local fish farms and aquarium. Identification of the specimens was done according to the method of Day [6].

The brains were dissected out and fixed in 10% neutral buffered formalin solution and morphology were studied [7]. Then length of fishes and weight of fishes was measured using millimeter scale and weighing pan. Brains of fishes were inspected by making incision with a single edge razor blade in the cranium across the nasal region. The incised area was picked up with forceps. Soft tissue was removed from the brain using fine forceps. The brains were dissected out and the different parameters like length of brain, weight of brain, length of cerebellum, length of vagal lobe, length of facial lobe and length of somatic sensory lobe were measured carefully using millimeter scale.

Results

Cirrhinus cirrhosus

The morphology of brain of *Cirrhinus cirrhosus* is shown in figure 1 and observations are shown in table II and IV. The brain of *Cirrhinus cirrhosus* is short and broad and completely fills the cranial cavity. The brain is divided into 5 parts namely – Telencephalon, Diencephalon, Mesencephalon, Metencephalon and Myelencephalon. The Metencephalon and Myelencephalon constitutes the parts of hind brain. The metencephalon consists of a dorsoventally compressed lobe cerebellum (CLM) just below the two optic lobes. The cerebellum occupies about 25% of the total brain length. It is responsible for the maintenance of body posture during the swimming. The myelencephalic part of hind brain consists of paired facial lobes (FL), paired vagal lobes(VL) and it develops into medulla oblongata(MO). The facial lobes are large and the two lobes meets in the mid-dorsal line. A portion of facial lobe is also covered by cerebellum. The facial lobe constitutes about 33% of the total brain length. Small rhomboidal fossa is seen in the middle of the anterior part of the facial lobes. The vagal lobes are less prominent than the facial lobes and the two lobes meets at the mid dorsal line of the posterior part of the medulla oblongata. The vagal lobe occupies about 20.83% of the total brain length and the medulla oblongata occupies 12.5% of the total brain length. The facial lobes indicate its skin tasting nature and vagal lobes indicates the mouth tasting nature of fish.

Etroplus suratensis

The morphology of brain of *Etroplus suratensis* is shown in figure 2 and observations are shown in table II and IV. The brain of *Etroplus suratensis* is well developed and is broadly divisible into five parts namely: - Telencephalon, Diencephalon, Mesencephalon, Metencephalon and Myelencephalon. Metencephalon and Myelencephalon forms the hind brain. The metencephalon represents a single large, almost rounded lobe, the cerebellum (CLM) which is median in position and extends between the optic lobes of the anterior end. It protrudes externally as corpus cerebelli. Cerebellum occupies 20% of the total brain length. Its function is to maintain the body posture during swimming. Most of the modification in response to feeding habits in *Etroplus suratensis* have been found at the myelencephalic part situated at the posterior region of the brain. The whole region is represented by the vagal lobe (VL) representing as much as 12% of the total brain length. Facial lobes (FL) are rudimentary and less conspicuous in this fish. Due to its surface feeding habit facial lobe (FL) and vagal lobe (VL) are poorly developed. The Vagals are in the form of 2 prominent wings like structure. It is concerned with mouth tasting. The rudimentary facial lobes help in skin tasting. The medulla oblongata is narrow and represents 16.6% of total brain length.

Heteropneustes fossilis

The morphology of brain of *Heteropneustes fossilis* is shown in figure 3 and observations are shown in table II and IV. The brain of fish is well developed and completely fills the cranial cavity. It consist of five parts namely:- Telencephalon, Diencephalon, Mesencephalon, Metencephalon and Myelencephalon. Of which the metencephalon and myelencephalon constitute hind brain. The metencephalon comprises a large lobe called Cerebellum (CLM). It is responsible for maintenance of body posture during swimming. The myelencephalic part shows greater modification in *Heteropneustes fossilis* with reference to their feeding habits. The Myelencephalon comprises somatic sensory lobe (SSL), bilobed facial lobes (FL), vagal lobes(VL) and medulla oblongata(MO). The somatic sensory lobe occupies about 46.66% of the total brain length. Bilobed facial lobes are located centrally to somatic sensory lobe and vagal lobe. The facial lobes occupies about 10% of the total brain length and vagal lobe occupies about 6.66% of the total brain length. The medulla oblongata occupies 6.66% of the total brain length. The somatic sensory lobes, vagal lobes and facial lobes accounts for the sense of taste and touch in abundant measures. *Heteropneustes fossilis* is the most active bottom feeder of all the fishes taken for the study.

Mugil cephalus

The morphology of brain of *Mugil cephalus* is shown in figure 4 and observations are shown in table II and IV. The brain of fish is divided into five parts namely:- Telencephalon, Diencephalon, Mesencephalon, Metencephalon and Myelencephalon. The Metencephalon and myelencephalon forms the hind brain. The metencephalon represents a single large dorsoventrally flattened cerebellum which is median in position and extends between the optic lobes at the anterior end. It measures about 25% of total brain length. It is responsible for maintenance of body posture during swimming. The presence of large cerebellum indicates the active feeding habits of the fish. The myelencephalon is situated at the posterior region of the brain. The whole region is represented by vagal lobe (VL) and medulla oblongata (MO). Vagal lobe measures about 16.6% of the brain length. Facial lobes are rudimentary. Vagal lobes denote mouth tasting nature in *Mugil cephalus*. The medulla oblongata measure about 8.33% of the total brain length.

Tilapia mossambica

The morphology of brain of *Tilapia mossambica* is shown in figure 5 and observations are shown in table II and IV. The brain of Tilapia mossambica is divided into five parts – Telencephalon, Diencephalon, Mesencephalon, Metencephalon and Myelencephalon. The divisions of hind brain are metencephalon and myelencephalon. The metencephalon consists of a single large almost oval shaped lobe just below the two optic lobes called the cerebellum (CLM). Cerebellum occupies about 11.11% of the total brain length. It helps in the maintenance of body posture during swimming. The myelencephalic part of hind brain consists of Vagal lobes (VL) posteriorly surrounding the cerebellum. It constitutes about 7.4% of the total brain length. It accounts for the mouth tasting nature in fish. The medulla oblongata (MO) is an extension of vagal lobe. It occupies about 5.5% of the total brain length.

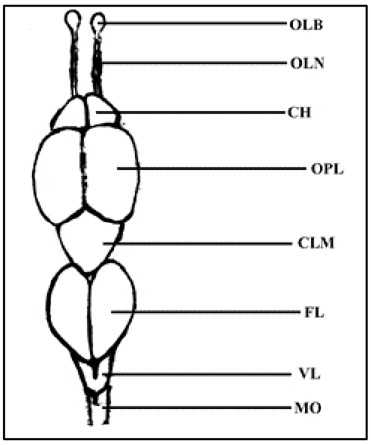

Fig 1: Brain of *Cirrhinus cirrhosis*

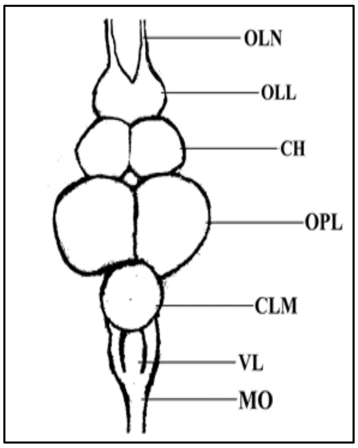

Fig 2: Brain of *Etroplus suratensis*

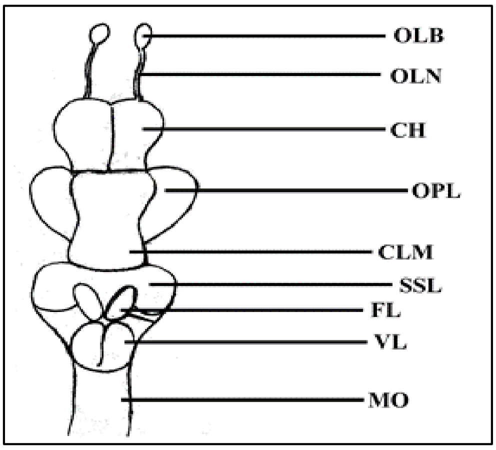

Fig 3: Brain of *Heteropneustes fossilis*

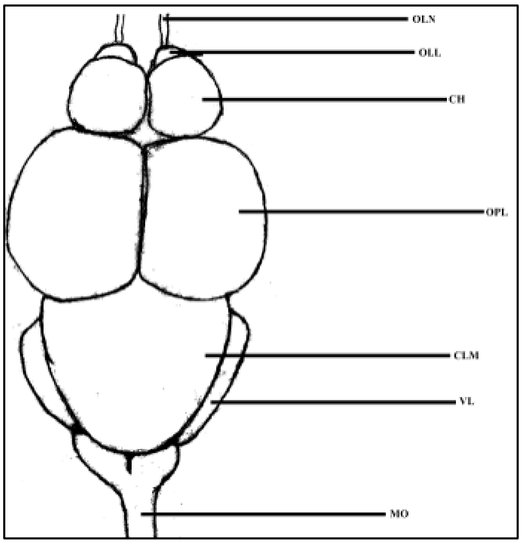

Fig 4: Brain of *Mugil cephalus*

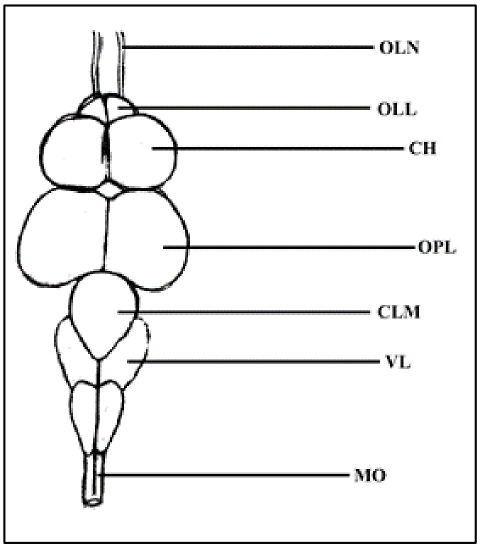

Fig 5: Brain of *Tilapia mossambica*

Abbreviations Used

CH - Cerebral Hemisphere, CLM – Cerebellum, FL - Facial Lobe, MO - Medulla Oblongata, OLB - Olfactory Bulb, OLL - Olfactory Lobe, OLN - Olfactory Nerve, OPL - Optic Lobe, SSL - Somatic Sensory Lobe, VL - Vagal Lobe.

Table 1: showing different brain lobes in some teleosts (+) Presence; (–) Absence

Name of fishes	Cerebellum	Somatic Sensory lobe	Facial lobe	Vagal lobe
Cirrhinus cirrhosis	+	–	+	+
Etroplus suratensis	+	–	–	+
Heteropneustes fossilis	+	+	+	+
Mugil cephalus	+	–	–	+
Tilapia mossambica	+	–	–	+

Table 2: Showing Measurements of Various Brain Lobes In Teleosts

Name of fishes	Total length of fish (mm)	Total length of brain (mm)	Cerebellum (CLM)	Somatic sensory lobe (SSL)	Facial lobe (FL)	Vegal lobe (VL)	Medulla oblongata (MO)
Cirrhinus cirrhosus	120	12	3	–	4	2.5	1
Etroplus suratensis	136	25	5	–	–	3	4
Heteropneustes fossilis	125	15	7	2.5	1.5	1	1
Mugil cephalus	158	24	6	–	–	4	2
Tilapia mossambica	180	27	3	–	–	2	1.5

Measurements are in 'mm'

Table 3: showing variation of brain lobes in percentages

Name of fishes	Total length of brain in%	Cerebellum lobe in%	Somatic sensory lobe in%	Facial lobe in%	Vegal lobe in%	Medulla oblongata volume in%
Cirrhinus cirrhosus	12	25	–	33	20.83	12.51
Etroplus suratensis	26	20	–	–	12	3.84
Heteropneustes fossilis	15	46.66	16.66	10	6.66	6.66
Mugil cephalus	24	25	–	–	16.66	8.33
Tilapia mossambica	27	11.11	–	–	7.4	5.5

Table 4: showing relationship between brain and brain weight

Name of fishes	Total length of brain in mm	Weight of brain in mg
Cirrhinus cirrhosis	12	0.72
Etroplus suratensis	26	0.84
Heteropneustes fossilis	15	0.50
Mugil cephalus	24	0.60
Tilapia mossambica	27	0.85

Discussion

The present study reveals the morphological variation in brain of some teleosts like *Cirrhinus cirrhosus, Etroplus suratensis, Mugil cephalus, Heteropneustes fossilis* and *Tilapia mossambica* belonging to 4 families.

Several authors attempted on ecomorphological classification of teleostean brain. Evans [8, 9] distinguished the cyprinid brain types as mud feeders, sight feeders, barbel feeders accordingly. Evans [10] used the same topology and distinguished between "mouth feeders", "sight feeders" and "skin feeders" (large vagal, optic and facial lobes respectively). The presence of olfactory nerves and well developed olfactory organs indicates better sense of smell in fishes [11]. The telencephalon in brain is mainly olfactory in function [12]. The size of cerebellum is associated with the habitats [13]. The lobes of medulla oblongata are an index of feeding behaviour of fishes. The lobes of medulla oblongata may be single, bilobed or multilobed.

Brain morphology varies considerably in configuration and size. The marked distinctiveness suggests the presence of different mechanisms based on diverse habitats. There exists large variations in absolute brain volume and cerebellum volume in fishes taken for this study. The environmental factors are all known to be important in shaping brain evolution [14] correlate with this study. The cerebellum of fishes is associated with the muscular activities of fishes. Highly developed cerebellum is found in *Heteropneustes fossilis* and *Cirrhinus Cirrhosus* They are bottom feeders. This agrees with the findings of Karamian who stated that size of cerebellum is associated with habitats [13].

Large and well developed cerebellum indicates the active feeding habits of these fishes.In *Tilapia mossambica* the cerebellum is moderately developed. The lobes of medulla oblongata constitute an index of feeding behaviour of fishes and they are variable according to the variability of taste buds on the body, lips, barbels and buccal cavity. *Heteropneustes fossilis* use their long barbels for searching food and correspondingly their facial lobes are enlarged. Sato found highly developed facial lobes in mouth feeders and skin tasters [15]. Facial lobes are enlarged in fishes possessing dense external buds [16] or in the barbel taste feeders [11, 17]. From the phenotypic observation of the different brain lobes shown in Table I. It is clear that *Cirrhinus cirrhosus* possess bilobed facial lobes.

Vagal lobes are related with mouth taste and taste buds present in the IX and X nerves [8, 4, 11, 18, 19]. *Cirrhinus cirrhosus* and *Tilapia mossambica* have poorly developed vagal lobes. In this study well developed vagal lobes are seen in teleosts, *Mugil cephalus* and *Etroplus suratensis*. Vagal lobes are concerned with mouth tasting nature of fishes.

The enlarged somatic sensory lobe is due to a more active habit of the fish [4]. In this study *Heteropneustes fossilis* possess somatic sensory lobes. Somatic sensory lobes are correlated with an aggressive feeding habit. It is active as well as sensitive in perceiving the movements of objects in water.

Conclusion

1. Highly developed cerebellum indicates active feeders. It is found in brain of *Heteropneustes fossilis* and *Cirrhinus cirrhosus.*

2. The presence or absence of barbels is an important factor influencing the brain structure and consequently their feeding habits
3. The development of facial lobe was associated with skin tasting in fishes. It was well developed in *Cirrhinus cirrhosus.*
4. The development of vagal lobes is related to mouth tasting in fishes. Well-developed vagal lobes are shown by *Mugil cephalus* and *Etroplus suratensis*.
5. Somatic sensory lobes are found in *Heteropneustes fossilis*. This testifies its aggressive feeding habit.

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