A Study of the Lateral-line System in Fish
I. Quantitative Analysis of Fiber Calibers in the Lateral-line Nerves of Fishes

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INTRODUCTION

The function of the lateral-line organs of fishes has already been studied by many investigators, the early works of whom were done on the behaviour of fishes when the lateral-line organ had been destroyed, and the other works on the electrical response of the lateral-line nerve.

Judging from these previous works, it is known to be mainly one of the mechanoreceptors.

It is assumed that lateral-line organ is of use to fishes in feeding, escaping and schooling, being compensated by the other sense organs.

Since fishes, in general, may be divided into somewhat natural groups according to their habits and morphological variations are found in other sense-organs, it may be considered that there are structural or functional differences in the lateral-line organs of fishes according to their lives.

Now, the lateral-line organ in the side of the fish is innervated by the ramus lateralis of vagus (a pure sensory nerve branch). KATSUKI, YOSHINO and CHEN (1950—52) have already reported that the response of each lateral-line nerve fiber of the eel to various kinds of natural and artificial stimuli was different according to its diameter.

This information is very important to understand the relationships between structure and function of sense organ. It is very interesting morphologically as well as physiologically, to compare the relevant nerves in many kinds of fishes. It might be assumed that each of them has a characteristic in distribution of fibers according to its habit.

We attempted to make a quantitative analysis of fiber calibers in the lateral-line nerves on 81 different species of teleosts, and we found some marked difference among them, and this made it clear that we were able to discuss the problem on correlation of the functions of the sense organs and the habits of the fishes, from the result of this experiment.

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MATERIAL AND METHOD

The present experiment was done by using 81 different species of teleosts, which represented 50 families, as shown in Table 1. They were adult in all, and most of them were used in state of living.

First, fish was freshly pitched and pinned on a board, and a few cm. of the skin near the operculum was removed backward along the body. As the nerve is buried deep in the muscle, we cut off the ramus lateralis of vagus from the body, after having exposed about 3cm. of it. The nerve, moistened in the physiological salt solution* on a slide, was separated into each component with two needles, by using a binocular magnifer (×30).

The fiber-calibers of above three hundreds fibers were measured in fresh living state with a ocular-screw-micrometer, under a microscope (×150).

RESULTS

As the lateral-line nerve consisted of many myelinated fibers of various calibers, the diameter of each fiber was measured in size including myelin sheath.

As the results of pre-examinations made on the adult fishes of gold fish, catfish and eel, we found no individual variation in distribution of fibers, comparing the mean value and the range in diameter of fibers.

But the distribution of fiber diameters in one species was different from that of another species of fishes, and therefore it shows a characteristics of each species of fish.

The histogram for the fiber diameters had one prominent peak, and the mean value in diameter laid near it.

The results of measurement on 81 species of teleosts were shown in Table 1.

Looking over the whole fishes studied in the present experiment, the following three types might be distinguished in their fiber distribution.

1) The nerve consisted, for the most part, of relatively thin fibers, and most of them had diameter of 4 μ, to 6 μ, a smaller proportion 6 μ—10 μ, and a few 3 μ. No fiber with diameter exceeding 10 μ was observed.

2) The fiber varied from 3 μ to 15 μ in diameter, and the great part of them had diameters of 6 μ to 10 μ.

3) The fibers were thicker than another two types as mentioned above. The mean value in diameter was over 8 μ in all species, and the deviation in caliber was large, as there were found more kinds of fibers in the nerve varying their size.

Thus, it was noticeable that there were these three types on all fishes, both in marine and in fresh water.

Considering the properties above-mentioned, we could divide these 81 species into three groups.

Group I. In *Carassius auratus*, *Plotosus anguillicaudatus*, *Chasmichthys dolich-*

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* By YAMAMOTO (1949), for fresh water fish, NaCl 0.75 %, KCl 0.02 %, $CaCl_2$ 0.02 %, $NaHCO_3$ 0.002 % ; for marine fish, NaCl 1.35 %, KCl 0.03 %, $CaCl_2$ 0.025 %, $MgCl_2$ 0.035 %, $NaHCO_3$ 0.002 %.

ognatus gulosus, *Acheilognathus moriokae*, and *Sebastiscus marmoratus*, about 70 per cent of the nerve fibers had diameters of 3 μ—5 μ, and 30 per cent of diameters of 6 μ—10 μ [Table 1 (I—a)]. On the contrary, the ratio of fibers between 3 μ and 5 μ to fibers between 6 μ and 10 μ in diameter was 40 to 60 per cent in *Cathigaster rivulatus*, *Pseudolabrus japonicus*, *Oryzias latipes*, and *Pseudorabora parva* (I—b).

Group II. Of the nerve fibers, about 78 per cent had diameter of 6 μ—10 μ, 20 per cent diameters of 3 μ—5 μ, and 2 percent diameters of 11 μ—15 μ. For example,———— *Cyprinus carpio* and other 12 species (II—a).

Of the nerve fibers, about 85 per cent had diameters of 6 μ—10 μ, 7.5 per cent diameters of 3 μ—5 μ, and 7.5 per cent diameters of 11 μ—15 μ. For example———— *Scomber japonicus* and other 14 species (II—b).

Of the nerve fibers, about 74 per cent had diameters of 6 μ—10 μ, 24 per cent diameters of 11 μ—15 μ, and 2 per cent diameters of 3 μ—5 μ. For example————*Mugil cephalus*, and other 8 species (II—c).

No fiber with diameters under 5 μ was observed and the number of the fibers diameters of 6 μ—10 μ was nearly equal to that of 11 μ—15 μ, in *Salvelinus fontinalis fontinalis*, *Channa argus*, *Hippoglossides debius*, *Lepidotrigla microptera*, and *Chromis notatus*. However, in *Misgurunus anguillicaudatus*, 95 per cent had diameters of 6 μ—10 μ (II—d).

Group III. In *Oncorhyncus keta*, *Anguilla japonica*, *Conger japonicus* the nerve consisted of fibers ranging in size from 4 μ to 16 μ. About 60 per cent of them had diameters of 6 μ—10 μ, and 30 per cent had diameters of 11 μ—15 μ. The similar tendency was observed in other 18 species (III—a).

No fiber with diameters under 5 μ was observed, and the number of the fibers with diameter of 6 μ—10 μ was nearly equal to that of 11 μ—15 μ and that of 16 μ—20 μ was very small in *Cymnothorax kidako*, *Girella punctata*, *Chelidonichthys kumu*, *Hoplobriotula armata*, and *Paralichthys olibaceus*. Besides, there were also found the fibers over 20 μ in diameter, and the mean value of fiber diameters was large in *Cololabis saira*, *Hemiramphus sajori*, and *Prognichtys agoo* (III—b).

SUMMARY AND CONCLUSION

1. The quantitative analysis of fiber calibers in the lateral-line nerve of fish was done on 81 different species of teleosts.

2. The lateral-line nerve of the fish consisted of many kinds of fibers which differed in diameter, but the individual variation of fiber distribution was not found in the same species. Therefore, it is possible to compare the natures of the fiber in many species of fishes by measuring fiber calibers.

3. There were found three main types in fiber distribution of the relevant nerve in all fishes examined in the work. From this result, we attempted to divide the fishes into some groups according to the fiber distribution. But, there were found several subgroups in one group, and one form of fiber distribution gradually changed to that of another group

through these subgroups. From this fact, it appears that there are the differentiation in nerve fibers of the lateral-line nerve.

4. It may be remarked that the method of measuring fiber-calibers used in this experiment is more suitable to compare the lateral-line nerve in many species of fishes than that of measuring fixed fiber because anxiety of shrinking or swelling was eliminated by using unfixed and living fiber.

5. In the next report, we will discuss on the relation between the function of the lateral-line organ and the habits of fish from the ecological stand point of view.

References

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2. KATSUKI, Y., YOSHINO, S. and J. CHEN, 1952 : Response of the single lateral-line nerve fiber to the linearly rising current stimulating the endorgan. *Ibid.*, 2 : 219—231.

Table 1. Fiber diameter in the lateral-line nerve of fish.

Family	Species	$\bar{x}$ (μ)	σ (μ)	Group
Clupeidae	*Clupea pallasi* CUVIER et VALENCIENNES	8.6	1.9	II c
	Harengula zunasi (BLEEKER)	6.5	1.6	II a
Engraulidae	*Engraulis japonica* (HOUTTUYN)	6.0	1.6	II a
Salmonidae	*Oncorhynchus keta* (WALBAUM)	9.6	2.5	III a
	Salmo gairdnerii irideus GIBBONS	8.9	2.1	II c
	Salvelinus fontinalis fontinalis (MITCHILL)	9.4	2.1	II d
Plecoglossidae	*Plecoglossus altivelis* TEMMINCK et SCHLEGEL	9.1	2.3	II c
Cyprinidae	*Acheilognathus moriokae* JORDAN et THOMPSON	5.0	1.4	I a
	Hemibarbus barbus (TEMMINCK et SCHLEGEL)	8.7	1.9	II c
	Pseudorasbora parva (TEMMINCK et SCHLEGEL)	5.3	1.2	I b
	Tribolodon hakonensis hakonensis (GÜNTHER)	6.8	1.0	II a
	Carassius auratus (LINNÉ)	6.0	1.7	I a
	Cyprinus carpio (LINNÉ)	6.7	2.0	II a
	Misgurnus anguilicaudatus (CANTOR)	8.1	1.4	II d
Siluridae	*Parasilurus asotus* LINNÉ	8.8	1.9	II c
Plotosidae	*Plotosus anguillaris* (LACÉPÈDE)	5.0	1.5	I a
Anguillidae	*Anguilla japonica* TEMMINCK et SCHLEGEL	8.8	2.4	III a
Congridae	*Conger japonicus* BLEEKER	8.7	3.1	III a
	Astroconger myriaster (BREVOORT)	9.0	2.2	III a
	Rhynchocymba nystoromi nystormi (JORDAN et SNYDER)	8.1	2.9	III a
Muraenidae	*Gymnothorax kidako* (TEMMINCK et SCHLEGEL)	9.3	2.0	III b
Cyprinodontidae	*Oryzias latipes* (TEMMINCK et SCHLEGEL)	5.8	1.2	I b
Scombresocidae	*Cololabis saira* (BREVORT)	11.9	2.5	III b
Hemiramphidae	*Hemiramphus sajori* (TEMMINCK et SCHLEGRL)	13.2	3.4	III b
Exocoetidae	*Prognichtys agoo* (TEMMINCK et SCHLEGEL)	13.5	3.4	III b
Monocentridae	*Monocentris japonicus* (HOUTTUYN)	6.8	1.7	II a
Atherinidae	*Allanetta bleekeri* (GÜNTHER)	8.3	2.5	II c
Mugilidae	*Mugil caphalus* LINNÉ	8.9	1.8	II c
Sphyraenidae	*Sphyraena pinguis* GÜNTHER	9.8	2.8	III a
Channidae	*Channa argus* (CANTOR)	9.9	1.9	II d
Scombridae	*Scomber japonicus* HOUTTUYN	7.7	1.8	II b
Carangidae	*Trachurus japonicus* (TEMMINCK et SCHLEGEL)	6.4	1.8	II a
	Seriola purpurasens TEMMINCK et SCHLEGEL	7.1	1.9	II b
Labracoglossidae	*Labracoglossa argentiventris* PETERS	8.5	2.7	III a
Mullidae	*Upeneus bensai* (TEMMINCK et SCHLEGEL)	6.4	1.6	II a
Apogonidae	*Apogon semilineatus* TEMMINCK et SCHLEGEL	4.3	1.4	I a
Priacanthidae	*Pseudopriacanthus niphonius* (CUVIER)	7.0	1.5	II b
Pomatomidae	*Scombrops boops* (HOUTTUYN)	8.7	2.4	III a
Serranidae	*Lateolabrax japonicus* (CUVIER)	7.9	2.3	III a
	Epinephelus septemfasciatus (THUNBERG)	7.6	3.0	III a
	Niphon spinosus CUVIER et VALENCIENNES	7.3	1.8	II b
Sillaginidae	*Sillago sihama* (FORSKÅL)	7.4	1.8	II b
Girellidae	*Girella punctata* GRAY	9.3	2.3	III b
Sparidae	*Chrysophrys major* TEMMINCK et SCHLEGEL	7.0	1.7	II b

Pomadasyidae	*Parapristipoma trilineatum* (THUNBERG)	8.7	2.9	III a
	Plectorhynchus cinctus (TEMMINCK et SCHLEGEL)	7.4	1.6	II b
Aplodactylidae	*Goniistius zonatus* (CUVIER et VALENCIENNES)	6.8	2.2	II a
Parapercidae	*Cilias pulchella* (TEMMINCK et SCHLEGEL)	7.5	2.0	II b
Brotulidae	*Hoplobrotula armata* (TEMMINCK et SCHLEGEL)	10.6	2.4	III b
Gobiidae	*Acanthogobius flavimanus* (TEMMINCK et SCHLEGEL)	7.6	1.5	II b
	Pterogobius zonoleucus JORDAN et SNYDER	7.4	1.8	II b
	Chasmichthys gulosus (GUICHENOT)	4.5	1.4	I a
Embiotocidae	*Ditrema temmincki* BLEEKER	7.4	2.0	II b
Pomacentridae	*Chromis notatus* (TEMMINCK et SCHLEGEL)	10.0	1.9	II d
Labridae	*Thalassoma lutescens* (LAY et BENNETT)	7.6	1.6	II b
	Pseudolabrus japonicus (HOUTTUYN)	5.6	1.4	I b
	Halichoeres poecilopterus (TEMMINCK et SCHLEGEL)	8.6	2.5	III a
Acanthuridae	*Prinurus microlepidotus* LACÉPÈDE	8.6	2.1	III a
Aluteridae	*Stephanolepis cirrhifer* (TEMMINCK et SCHLEGEL)	9.6	3.9	III a
	Navodon modestus (GÜNTHER)	7.6	3.2	III a
Tetraodontidae	*Canthigaster rivulatus* (TEMMINCK et SCHLEGEL)	5.0	1.7	I b
	Fugu niphobles (JORDAN et SNYDER)	7.3	1.9	II b
	Fugu vermicularis vermicularis (TEMMINCK et SCHLEGEL)	6.8	1.6	II a
	Fugu pardalis (TEMMINCK et SCHLEGEL)	6.8	1.9	II a
	Fugu chrysops (HILGENDORF)	7.5	1.6	II b
Scorpaenidae	*Sebastes oblongus* GÜNTHER	9.0	2.3	III a
	Sebastiscus marmoratus (CUVIER et VALENCIENNES)	4.4	1.2	I a
	Pterois lunulata TEMMINCK et SCHLEGEL	6.4	1.9	II a
Hexagrammidae	*Hexagrammos otakii* JORDAN et STARKS	8.3	2.3	II c
Platycephalidae	*Suggrundus meerdervoorti* (BLEEKER)	8.6	2.7	III a
	Platycephalus indicus (LINNÉ)	10.1	2.6	III a
Cottidae	*Pseudoblennius percoides* GÜNTHER	6.7	1.5	II a
	Pseudoblennius zonostigma JORDAN et STARKS	6.4	2.3	II a
Triglidae	*Cheliodonichthys kumu* (LESSON et GARNOT)	10.2	2.4	III b
	Lepidotrigla microptera GÜNTHER	9.4	1.9	II d
Bothidae	*Paralichthys olivaceus* (TEMMINCK et SCHLEGEL)	10.6	2.3	III b
Pleuronectidae	*Hippoglossides dubius* (SCHMIDT)	9.1	2.0	II d
	Pleuronichthys cornutus (TEMMINCK et SCHLEGEL)	11.0	2.8	III a
	Kareius bicoloratus (BASILEWSKY)	9.8	2.2	III a
Soleidae	*Zebrias zebra* (BLOCH et SCHNEIDER)	7.7	1.6	II b
Gadidae	*Theragra chalcogramma* (PALLAS)	8.8	2.6	III a