A STUDY OF THE VAGAL LOBES AND FUNICULAR NUCLEI OF THE BRAIN OF THE CODFISH.

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WITH EIGHT FIGURES.

INTRODUCTION.

The peripheral and central organs of taste have received more or less careful study in three distinct groups of teleostean fishes in which taste buds are known to occur plentifully in the outer skin; viz.: the cyprinoids (carp, etc.), the siluroids (Ameiurus and other catfishes) and the gadoids (cod, tom-cod, hake). The structure of the cutaneous taste buds of the carp was described by LEYDIG in 1851 and more accurately in 1863 and 1870 by F. E. SCHULZE, who correctly inferred their function. Their gustatory function was subsequently demonstrated physiologically in Ameiurus and various gadoids (HERRICK '04), and it was shown that either tactile or gustatory stimuli alone may be correctly localized in the outer skin, though ordinarily both senses coöperate in the locating of the food. The same reaction may follow either a tactile or gustatory stimulation of the outer skin or the simultaneous stimulation of both kinds of sense organs in the same cutaneous area.

The distribution of the nerves of touch in the skin of fishes is very accurately known and the general arrangement of these nerves is nearly constant throughout the phylum. The innervation of the cutaneous taste buds has also been studied in the three types here considered—exhaustively in Ameiurus (HERRICK '01) and less completely in Gadus (HERRICK '00) and Carassius (HERRICK '04, p. 249). The nerves for the cutaneous taste buds spring from the communis root of the facial nerve, without exception in Ameiurus and with but small exception in Gadus. The same facial root supplies also taste buds in the anterior part of the mouth.

The central gustatory paths have been investigated in cyprinoids and siluroids (HERRICK· '05). In view of the demonstratioι in the works cited in the preceding paragraphs, of the essential similarity in the structure, innervation and function of the cutaneous *taste* buds of cyprinoids, siluroids and gadoids, we should expect their central connections in the group last mentioned to resemble those described for the two former groups. But the facts seem to be quite the contrary, and the primary purpose of this inquiry was to determine the extent and if possible the functional significance of these differences. This naturally led to a study of the tactile centers also in Gadus, for the underlying problem in both this and my previous study ('06) is the central relations of those tactile and gustatory nerves which innervate the same areas of skin and have independent local signs but common pathways of motor discharge in the reaction.

THE CENTRAL GUSTATORY PATHS OF AMEIURUS AND GADUS.

In siluroids and cyprinoids practically all the nerves supplying taste buds in the outer skin, lips and palate terminate in a single huge nucleus which forms a dorsal protuberance on the medulla oblongata, the facial lobe, while taste buds of the pharynx and gill region are innervated from the vagal lobe farther back in the oblongata.

In the gadoid fishes a facial lobe has been described and figured by several previous authors; but my examination of the brain of the cod shows that the facial lobe does not exist in the form described by these authors. Nevertheless I find the peripheral distribution of the gustatory root of the facial nerve of Gadus is practically the same as in Ameiurus. What, then, are the central connections of the cutaneous taste buds in Gadus?

Taste buds are scattered over the whole body of Ameiurus but most abundantly on the barblets, and experiment shows that these are very sensitive to both tactile and gustatory stimulation. They are constantly used for the exploration of the bottom and the maxillary barblets are actively waved about whenever a savor diffuses through the water. In the gadoids, particularly the tom-cod and the hake, the free filiform rays of the pelvic fin function in a similar fashion and are likewise richly supplied with end-organs of both taste and touch.

In Ameiurus the facial lobe, which receives all the gustatory nerves from the outer skin, gives rise to two chief secondary tracts. One passes upward into the mid-brain and one downward toward the spinal cord. The first of these accompanies the ascending cerebral tract for taste from the vagal lobes and is feebly developed or absent in the cod. It will therefore receive no further consideration here. The descending path terminates, as shown in Fig. 1, in the primary tactile correlation center of the brain, the funicular nuclei, and farther caudad in the spinal cord. From this correlation center a common motor pathway runs out by way of the funiculus ventralis for the innervation of all the somatic muscles of the body.

Now remembering that the body, considered as a reflex mechanism comprises two primary systems (the somatic system for reaction of the body as a whole to external stimuli, and the visceral system for correlation of the internal parts by reaction to visceral stimuli), we may summarize the reflex connections of the taste buds of Ameiurus as follows: The primary gustatory center is differentiated into a visceral region (vagal lobe) for taste buds lying in mucous membranes and a somatic region (facial lobe) for taste buds lying in the outer skin. The somatic character of this latter region has been secondarily acquired. It was without question phylogenetically derived from the visceral center. Both centers send an ascending tract to a common mid-brain nucleus. Their descending paths are strikingly different. The visceral center (vagal lobe) makes reflex connections only with the visceral musculature of the jaws, gills, œsophagus, etc. The somatic center (facial lobe) connects broadly with the funicular nuclei and there the gustatory stimuli from the skin are correlated with tactile stimuli from the same cutaneous areas and from this common sensory correlation station the motor pathways go out to the somatic muscles. There is also a direct path from the facial lobe to the motor V nucleus which innervates the muscles of the barblets, these being waved about when stimulated either by taste or touch. The preceding description applies with but slight modification also to the carp and other cyprinoid fishes.

Now, in the cod there is no well defined facial lobe. Gustatory fibers from the mouth and from the outer skin terminate in the vagal lobe, a condition which was entirely inexplicable to me after my demonstration physiologically that the taste buds on the fins

of the gadoids and on the barblets of Ameiurus function similarly as organs of taste, that the fishes can localize pure gustatory stimuli applied to these organs and that ordinarily both taste and touch coöperate in finding food by means of them, though the two sensation factors may be experimentally isolated by training.

Accordingly, I have reëxamined the vagal lobes and their connections in the cod and find that the gustatory nerves of the somatic type, those from the outer skin, and the gustatory nerves of the visceral type, from the mucous membranes, do have distinct central connections, though in quite a different way from that found in the catfish. The facts are these (*cf.* Fig. 2).

The vagal lobe of the cod is internally divided by a longitudinal septum into median and lateral lobules of about equal extent (Figs. 3 and 4). The median lobule is primarily visceral and receives the gustatory roots of the IX and X nerves, as in other fishes. The gustatory root of the facial nerve, which carries practically all of the fibers from taste buds in the outer skin and a smaller number of fibers from the mucous membrane of the anterior part of the mouth (ramus palatinus VII, etc.), terminates in both lobules, but chiefly in the lateral one. While I have not been able to demonstrate that the facial fibers which reach the median lobule are from visceral buds within the mouth, yet this is very probable. In any case, it is clear that the lateral lobule is primarily, if not exclusively, the terminal nucleus for the gustatory fibers of the somatic type; that is, it is the physiological, if not the morphological, equivalent of the facial lobe of siluroids and cyprinoids.

The two important papers on the brains of teleosts published in the GEGENBAUR *Festschrift* (GORONOWITSCH '96, and HALLER '96) give figures of the medulla oblongata of Lota vulgaris, a form closely allied to Gadus. Both of these authors were so dominated by the endeavor to reduce all cranial nerves to segmental units of the spinal type as to vitiate to some degree their observation. Their two figures of the brain of Lota bear very little resemblance to one another, or to the brain of Gadus, which is somewhat remarkable in view of the fact that both authors were studying the internal courses of the nerve roots microscopically. HALLER shows (Plate I, Fig. 6) a series of four pairs of enlargements in the vagal region, the first belonging to the IX nerve, the others to the vagus. The figure of GORONOWITSCH (Plate I, Fig. 3) is evidently much more accurate as to externals, but is in part incorrectly interpreted. He figures a lobus facialis (my lobus vagi lateralis), to which he correctly traces the communis VII root; a lobus glossopharyngei (my lobus vagi medialis), to which he correctly traces the IX and X nerves; a lobus vagi impar (my visceral commissural nucleus), to which he traces vagus fibers; and a lobus vagi which corresponds to my somatic commissural nucleus. The error in the latter point is due to his failure to recognize the distinction between the somatic and visceral regions of the oblongata. With this point in mind it is impossible to confuse the vagal lobes with the somatic commissural nucleus.

The subdivision of the vagal lobe of Gadus into median and lateral lobules is mentioned in the catalogue of the Museum of the Royal College of Surgeons of London (BURNE '02. p. 93) but unfortunately in the absence of a knowledge of the internal structure Mr. BURNE here was led by external appearances and by the previous figures of Lota by GORONOWITSCH ('96) into error in the interpretation of this region. Jn the two dissections of the brain of the codfish there figured and in the accompanying text the true vagal lobes are termed facial lobes and the somatic commissural and funicular nucleus complex of my descriptions is termed lobus vagi and is said to give rise to the sensory roots of the vagus nerve. Examination of the internal courses of these nerves at once corrects this mistake. The dissections of the codfish brain figured in T. J. PARKER's Zoötomy ('00, p. 125) show the vagal lobes very small with no designation. The "lobi posteriores," which might be mistaken for the vagal lobes, are the tubercula acustica. The excellent series of transections of the codfish brain given by KAPPERS ('06) extends back only to the cephalic end of the vagal lobe. Fig. 4 of the present paper is from a section taken a short distance caudad of Fig. xcix of Plate VII of KAPPERS' memoir.

In Fig. 3 I present a photograph of this region of the brain of a large codfish (Gadus morrhua), whose internal connections are as shown in Fig. 2. From the figure and description of GORONOWITSCH, I have no doubt that the relations are essentially similar in Lota.

The central tracts leading from the median lobule are the same as those from the vagal lobe in other fishes; and caudad this lobe merges into the visceral commissural nucleus of CAJAL in the typical way. The lateral lobule, which receives only facialis fibers, is wholly unlike the facial lobe of the siluroid and cyprinoid fishes in its secondary connections. It contributes few, if any, fibers to the long ascending secondary gustatory tract, this tract being derived from the median lobule (Fig. 4). Moreover, there does not arise from any part of the vagal lobe a large, clearly defined descending secondary gustatory tract, like that from the facial lobe in Ameiurus and Cyprinus, entering the dorso-lateral fasciculus for the funicular nucleus region and spinal cord. The lateral lobule is directly continuous caudad with the funicular nucleus region. A considerable tract of delicately medullated fibers accumulates on the ventro-lateral border of the lateral lobule and passes directly back to enter the cephalic end of the funicular nucleus where it joins the substantia gelatinosa Rolandi. My Wiegert sections do not show positively whether these fibers are ascending or descending, but I assume the latter by analogy; for this tract seems to correspond with the descending secondary gustatory tract from the facial lobe of Ameiurus. But in the cod this is a small and unimportant tract.

The chief secondary connection of the lateral lobule is by a very strong and heavily medullated tract which passes from its entire extent into the ventral commissure and enters the ventral funiculi of the same and the opposite side. These appear to be descend-

ing fibers. Some of them may pass over into the opposite tractus bulbo-tectalis (lemniscus), but it is not possible to be certain on account of the confusion in the ventral commissure of the internal arcuate fibers from the lateral vagal lobule with those from the *t*uberculum acusticum. This connection through the ventral commissure puts the lateral vagal lobule into connection with the long conduction paths of the somatic system, and thus directly connects the primary center for cutaneous taste buds and the ventral cornua of the spinal cord, from which the muscles of the fins and body are innervated. These relations are shown diagrammatically in Fig. 2.

The representatives of the Ostariophysi which I have studied (Ameiurus, Cyprinius, Catostomus, etc.) agree in possessing a distinct center (the facial lobe) for all of the fibers from cutaneous taste buds, the secondary connections of this center being partly with visceral motor and partly with somatic motor centers via the funicular nuclei. The fact that Gadus accomplishes a somewhat similar result by the different and more direct method of separating at the start the facialis root fibers into those for visceral and somatic centers is another illustration of the distinctness of the Ostariophysi from other teleostean fishes.

The end result is similar in the case of the cod and the catfish. Peripheral areas of skin may receive both tactile and gustatory stimulation simultaneously. The fish reacts to the composite stimulus by a single movement of the body adapted to reach and seize the food object. The *tactile* path in both cases leads to the funicular nuclei, and thence to the somatic muscles. The somatic gustatory path in the catfish leads to the tactile correlation center (funicular nuclei), whence it reaches the somatic muscles by the same tracts as the tactile. In the cod the somatic gustatory path passes directly from the primary center to the somatic motor centers in the ventral cornu without interruption in the tactile centers.

In searching for the explanation of this difference two lines of inquiry are at once suggested. First, are there any mechanical necessities of cerebral structure sufficient to account for them; and, second, do the habitual modes of reaction to external stimuli, *i. e.*, the habits of the animals, suggest an explanation. I believe that both of these factors have operated.

In the first place, why do the somatic gustatory nerves of the cod end in a specialized part of the vagal lobe and those of Ameiu-

rus in a separate lobe in front, the lobus facialis ?   Why should not the cutaneous gustatory nerves of Ameiurus end likewise in the vagal region ?   That there is no mechanical impediment to the necessary enlargement of the vagal lobe is evident from the fact that in the carp the vagal lobe suffers much greater enlargement to provide a terminal nucleus for an increased number of taste buds within the mouth.

In Ameiurus many, though by no means all, of the cutaneous taste buds are in the head.   These areas of skin receive their tactile innervation from the trigeminus nerve.   Now, I have found in this fish two centers of correlation between the nerves of touch and taste from the skin of the head.   One is the funicular nuclei, already referred to.   The other is in the facial lobe, in whose deeper layers trigeminus root fibers have been found to end.   The demand for a correlation center in front of the vagal lobe is probably the motive which in Ameiurus has drawn the facialis gustatory center cephalad of the vagal lobe, thus providing also an immediate path from end organs of both touch and taste to the motor centers of the barblets and jaws.   In the gadoids, on the other hand, some of the most important areas of distribution of cutaneous taste buds are on the fins, which are freely moved about in the exploration of food objects.   These receive their tactile innervation from spinal nerves which enter behind the vagal lobes and, therefore, the motive for a forward movement of the somatic gustatory center to correlate with the corresponding tactile nerves does not exist to so high a degree, or possibly has been counteracted by stronger spinal tactile impulses associated with gustatory stimuli on the fins.

But this explanation still leaves unaccounted for the short-circuiting of the somatic gustatory path in the cod by which it passes under the tactile centers without connection with them and reaches the motor centers directly.   The peculiar feeding habits of the cod may explain this arrangement (HERRICK '04).

The body taste buds of Gadus and its allies are most abundant on the filiform pelvic fins, and these are the organs most used in the detection of food, serving a purpose closely similar to that of the barblets of Ameiurus.   In Ameiurus the somatic reaction consequent upon contact of a barblet with food is a lateral turning of the whole body by a single movement to reach the food object.

But in Gadus the movement is quite different, since the food stimulus is under the center of the body when it is detected. Before the food can be taken, the fish must check the forward movement and back up until the mouth has reached the object. This involves a very precise movement of the pectoral fins in particular, and if the prey be living it must be very rapidly done. These features, taken in connection with the more active life of the gadoids in general, are sufficient to account for the short-circuiting of the reflex path between the gustatory root of the facial nerve and the ventral cornu of the spinal cord, so that a gustatory stimulus on the fins alone may cause the reaction promptly without the coöperation of the tactile centers.

We have then, in summary, the following striking series of structural adapations correlated with the appearance of taste buds in the outer skin of fishes. Such buds occur in fishes generally in the mouth and on the lips, the latter being innervated by the facial nerve. LANDACRE has shown in a recent embryological research ('07) that in Ameiurus the cutaneous buds appear first in the region of the lips and then progressively farther caudad. It is probable that this was also the order of their appearance phylogenetically, a supposition which is supported by the course of the branches of the facial nerve which supply these cutaneous buds in the adult. As these facial gustatory nerves increased in importance, especially those from the barblets, central correlation was required with the tactile and motor centers for the barblets in the region of the trigeminus. This anatomical connection finally caused the cutaneous gustatory center to move forward from the vagus region into the facial, and a further correlation was effected between the gustatory and tactile centers by means of the descending secondary gustatory tract from the facial lobe to the funicular nuclei.

In the gadoids the fins, particularly the free pelvic fin rays, serve as motile organs of tactile-gustatory sensation. The gustatory innervation is as before through the facial nerve, but the tactile through spinal nerves which enter the brain behind the vagal lobes. Accordingly, the somatic gustatory center does not migrate forward, but remains stationary, and the secondary gustatory path passes from it directly to the motor centers of the spinal cord instead of first to the tactile correlation center. This pro-

vides a shorter path from taste buds on the fins to the muscles which move the fins and the body as a whole.

THE COMMISSURA INFIMA AND FUNICULAR NUCLEI OF GADUS.

The analysis of the region of the commissura infima Halleri and funicular nuclei is much more difficult in Gadus than in some other types where the visceral and somatic elements of this complex are more highly differentiated, as in Ameiurus. For the typical arrangement and nomenclature of these parts the reader is referred to my recent paper ('06) on the centers for taste and touch in Ameiurus and to Fig. 1 of the present article, which summarizes the chief conclusions reached in that inquiry.

The somatic division of the commissura infima of Gadus is large and heavily medullated; the visceral division is unmedullated. The commissural nucleus is large and the somatic part is more extensive than the visceral.

The median lobule of the vagal lobe passes directly back into the visceral commissural nucleus, which occupies the mid-dorsal line caudad of the vagal lobes (Figs. 3 and 5). This nucleus contains no medullated fibers; it does, however, contain many small cells and a dense neuropil of unmedullated fibers, many of which cross the median line, forming the most cephalic part of the commissura infima. The nucleus ambiguus lies below it and gives rise to motor roots of the vagus. The most caudal sensory root of the vagus is seen in Fig. 5 entering the caudal tip of the vagal lobe laterally of the commissural nucleus. In the Weigert sections of young fish here examined (the specimens were about 7 cm. long) no vagus root fibers are seen to enter the commissura infima. In this, I confirm the statements made for Gadus by KAPPERS ('06), who also worked with Weigert preparations. It is, however, by no means clear from my preparations that no unmedullated termini of these root fibers cross in the commissure. In fact, the appearance of the sections strongly suggests that this is the case, as I have also found it in both Ameiurus and Cyprinus.

Immediately behind the last sensory root of the vagus the somatic commissural nucleus fills the wide space embraced between the spinal V tracts and their nuclei of the two sides, and is composed of dense neuropil, large cells and medullated fibers in very complex

formation (Figs. 3 and 6).   Just cephalad of the level of this figure there is a large transverse band of thick medullated fibers which connects the substantia gelatinosa of one side with that of the other or possibly with the opposite commissural nucleus.   There is shown in this figure a broad medullated connection between the commissural nucleus and the homolateral spinal V nucleus and formatio reticularis, and also fascicles of commissural fibers in the commissural nucleus.

A very short distance caudad of the level of Fig. 6 the commissural nucleus greatly expands and merges laterally with the spinal V nucleus and funicular nucleus and ventrally with the formatio reticularis (Fig. 7).   This complex area may also contain a portion of the visceral sensory commissure and nucleus, though no part of it can be recognized as such.   It is not possible to analyze this area into its component parts on the basis of microscopical appearances in Weigert sections, as I have done in Ameiurus. Short tracts of medullated and unmedullated fibers pass through it in all directions, many crossing the median line.   A vestige of the nucleus ambiguus extends as far back as the level here figured under the commissural nucleus.   The relations shown in this figure continue essentially unchanged far back into the spinal cord, where the area in question gradually shrinks in size and passes over into the dorsal cornua.

The first spinal nerve is a fusion of two or more nerves.   The dorsal roots enter the complex area just mentioned, which at the level shown in Fig. 8 is designated cornu dorsalis.   At the level of the origin of the second spinal nerve (which joins the first in the brachial plexus) the relations are similar, though the dorsal cornu complex is much smaller and in its dorsal portion the true dorsal cornu is structurally well defined, with a small but distinct funiculus dorsalis laterally of it.   At the level of the dorsal root of the third spinal nerve the dorsal area of gray matter is still further reduced, the dorsal cornu and funiculus are still more distinct and the other portions of the dorsal gray complex are reduced to a small median vestige.   The ventral ramus of this nerve also effects connection with the brachial plexus for the innervation of the pectoral fin.   The fourth spinal does not enter the brachial plexus. The pelvic fin is innervated chiefly from the ramus ventralis of this nerve and by a smaller twig from the fifth spinal.

The dorsal cornua at the levels of the fourth and fifth spinals are reduced to the meager dimensions commonly seen in teleosts. The cross-section of the spinal cord at this level is almost completely filled with very large medullated fibers, showing that long conduction paths are here more important than short reflex connections. The dorso-lateral fasciculi, in particular, are large and heavily medullated. In this respect the cod resembles the eel and other fishes with highly developed body musculature, in striking contrast with the sluggish catfish. Even the cyprinoids, like the carp and the gold-fish, have far smaller longitudinal spinal tracts. At the cephalic end of the spinal cord (third spinals to vagal lobes) the same compact formation of the long tracts is evident as farther caudad, save in the dorsal cornu and funicular nucleus region. The dorsal funiculi disappear in the most caudal part of these nuclei and the dorso-lateral fasciculus sends large tracts into them for their entire extent, suffering corresponding reduction in size cephalad. A considerable proportion of this fasciculus, however, passes farther cephalad to terminate in the oblongata. The ventro-lateral fasciculi also decrease greatly in size in the funicular nucleus region, or more properly expressed, they increase as they pass caudad under the funicular nuclei by accretions from this region. The lateral fasciculi (tracts midway between dorsal and ventral funiculi) also suffer considerable diminution in this region; but some strong bundles of these fibers pass directly cephalad from the spinal cord into the brain as the tractus spino-tectalis, to be greatly augmented in the region of the tuberculum acusticum by the tractus bulbo-tectalis.

We conclude, then, that in Gadus the region of the funicular and commissural nuclei is, as in other types of fishes, a correlation center for all tactile impressions from the skin and their motor responses. The pectoral and pelvic fins of the gadoids are particularly delicate tactile organs and the dorsal cornua of the anterior end of the spinal cord have been enlarged and intimately related to the funicular nuclei and somatic commissural nucleus to serve these sense organs. This process has been carried to a much greater extreme in the gurnards (Trigla, Prionotus, etc.). But the taste buds located on these fins in the gadoids, as we have seen above, are not centrally connected with this tactile correlation center, as they are in the siluroids and cyprinoids, but effect an

independent and more direct connection with the ventral horn cells and other motor centers by way of the ventral funiculi.   For summary of these connections, see p. 74.

Finally it is a pleasure to acknowledge my indebtedness to the U. S. Bureau of Fisheries for the specimens of young codfish upon which the histological part of this paper is based, and to my colleague, Professor FRANK CARNEY, for assistance in the preparation of the illustrations.

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Fɪɢ. 1.   Diagram of the gustatory and tactile paths in the medulla oblongata of Ameiurus, as seen from above.   The gustatory connections are shown on the lower (left) side of the figure, the tactile on the upper (right) side.   The gustatory centers are bounded by the fine dotted lines, the tactile centers by the broken lines (short dashes).   The neurones of the commissural nuclei are not shown in the diagram.   The position of the visceral commissura infima and its nucleus is indicated by two vertical crosses (‡) behind the vagal lobes; that of the somatic commissure and its nucleus by a single oblique cross (×) farther caudad between the two median funicular nuclei.   Only the long secondary tracts are indicated.   The short secondary and tertiary tracts from both visceral and somatic centers to the formatio reticularis, etc., are omitted.

The data from which the diagram is constructed will be found in two previous papers (Hᴇʀʀɪᴄᴋ, '05 and '06), where cross sections and other figures of the oblongata of Ameiurus are given.

Fɪɢ. 2.   Diagram of the gustatory and tactile paths in the medulla oblongata of Gadus morrhua, as seen from above.   The plan of the diagram is the same as that of Fig. 1, both gustatory and tactile centers being bounded by fine dotted lines.   As before, the position of the visceral commissura infima and its nucleus are indicated by two vertical crosses (‡) and that of the somatic commissure and its nucleus by oblique crosses (× × ×).
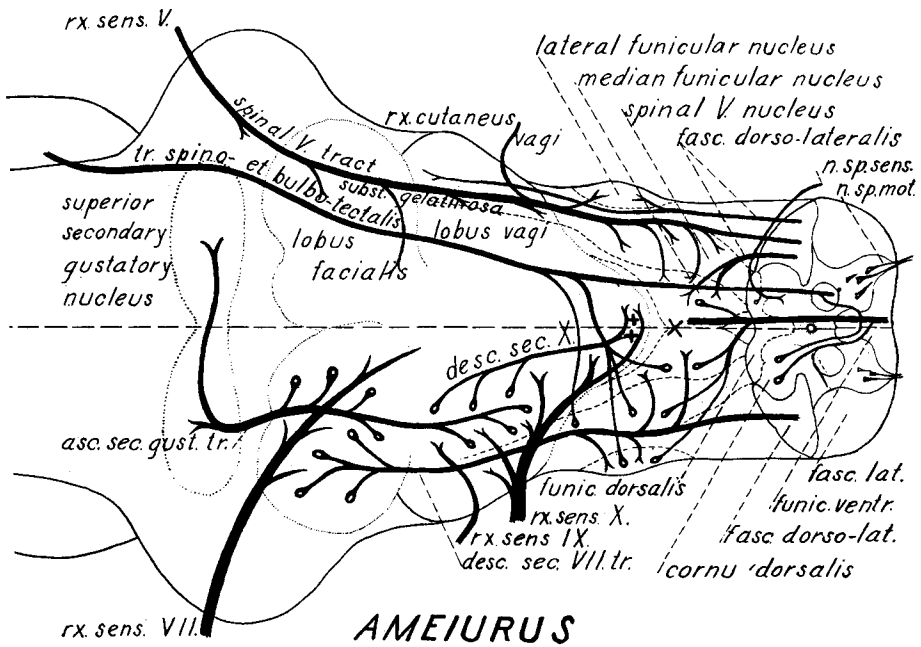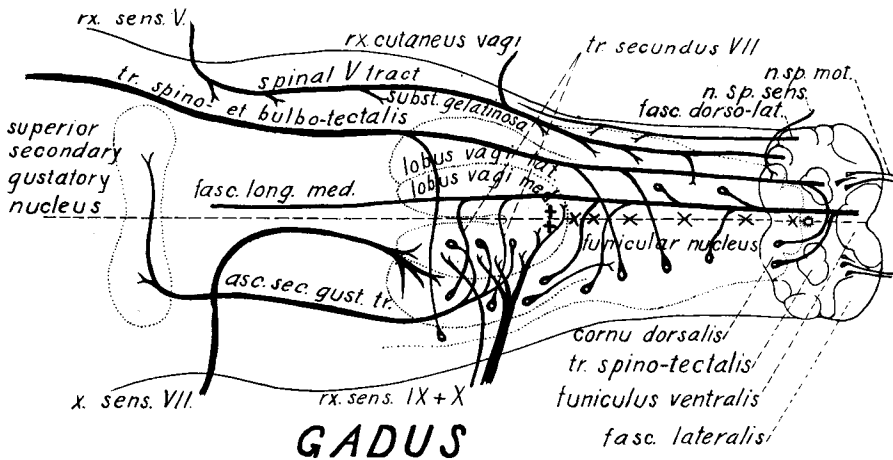
FIG. 1.

FIG. 2.

FIG. 3.   A photograph of a dissection of a brain of a large specimen of Gadus morrhua. $\times$ 1.3.

The cerebellum and a portion of the tubercula acustica have been dissected away, the cut surfaces being indicated by parallel shading on the accompanying outline.   The dissection exhibits the relations of the lateral and median vagal lobes and the commissural nuclei.   For the internal connections of these structures compare Fig. 2 and the following figures of cross sections.

FIG. 4.   Transverse section through the medulla oblongata of Gadus morrhua. $\times$ 35.

The section is taken through the middle of the vagal lobes and illustrates the relations of their median (visceral) and lateral (somatic) lobules.   Vagus root fibers are seen entering the median lobule on its lower border.   Secondary facialis tracts pass from the lateral lobule to the ventral funiculi and from the median lobule to the ascending secondary gustatory tract.   Dorsally of the latter is the fasciculus dorso-lateralis, containing the spinal V tract, tracts between the oblongata and the spinal cord and probably the tr. spino-cerebellaris.

FIGS. 4 to 8 are taken from a single series of transverse sections of an entire fish 7 cm. long, fixed in FLEMMING's stronger fluid and stained by the method of WEIGERT.   The external form of this young brain does not differ materially from that of the very large adult shown in Fig. 3.
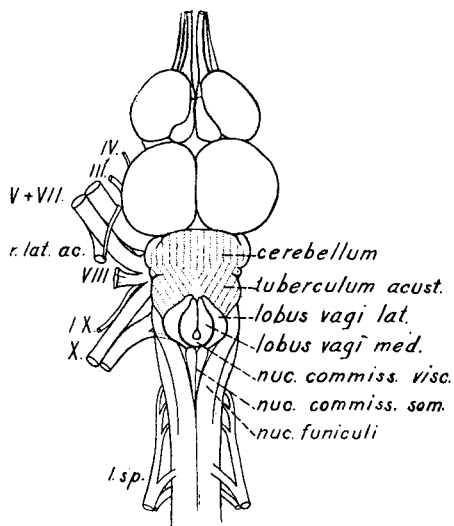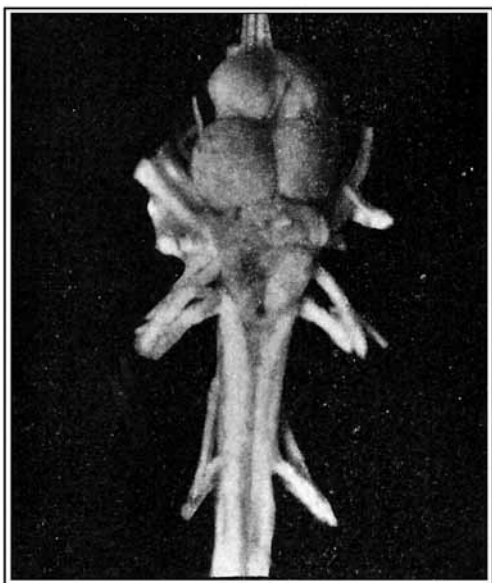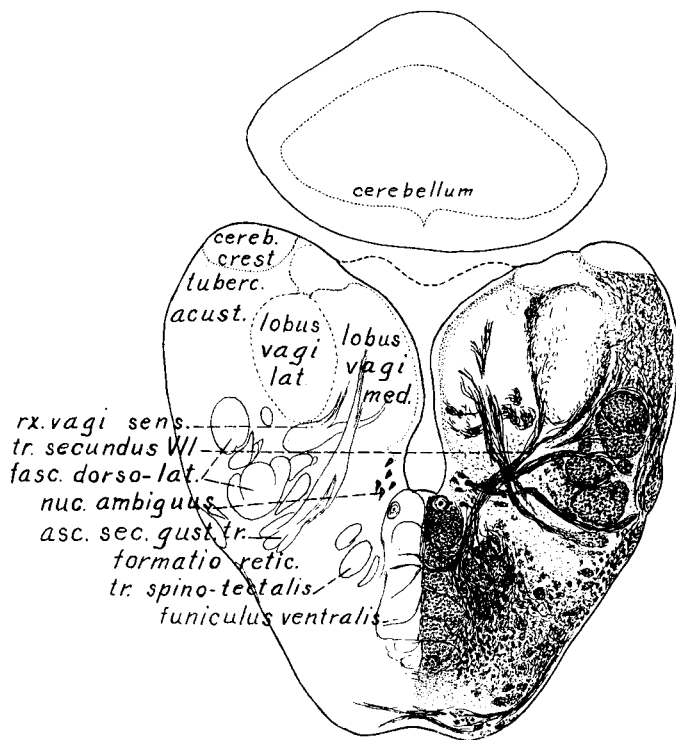
FIG. 3.

FIG. 4

Fɪɢ. 5.   Transverse section 0.4 mm. caudad of the last, passing through the caudal tip of the median division of the vagal lobe at the point where it passes over into the cephalic end of the visceral commissural nucleus.   The caudal end of the lateral division of the vagal lobe may be seen two sections farther cephalad in the area here designated *substantia gelatinosa.*   ✕ 35.

Fɪɢ. 6.   Transection a little farther caudad through the beginning of the somatic portion of the commissura infima.   The vagal lobes and visceral commissural nucleus lie farther cephalad and the corresponding region is here occupied by the somatic commissural nucleus (*cf.* Fig. 3).   The substantia gelatinosa has begun to enlarge and a little farther caudad (Fig. 7) has expanded into the spinal V nucleus. Short tracts pass between the commissural nucleus and the substantia gelatinosa and formatio reticularis, and secondary tactile paths pass from all of these regions to the ventral cornu and, as internal arcuate fibers, into the ventral commissure.   ✕ 35.
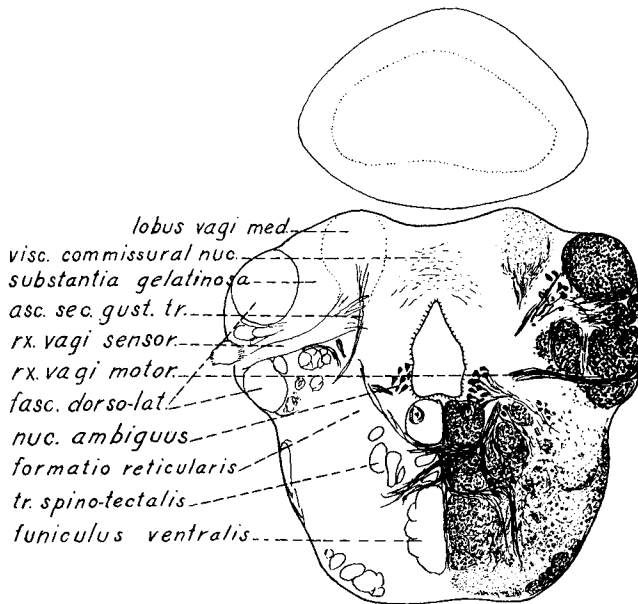
lobus vagi med.
visc. commissural nuc.
substantia gelatinosa
asc. sec. gust. tr.
rx. vagi sensor.
rx. vagi motor.
fasc. dorso-lat.
nuc. ambiguus
formatio reticularis
tr. spino-tectalis
funiculus ventralis

FIG. 5.

som. commissural nucleus
commissura infima
substantia gelatinosa.
f. dorso-lat.
form. reticularis.
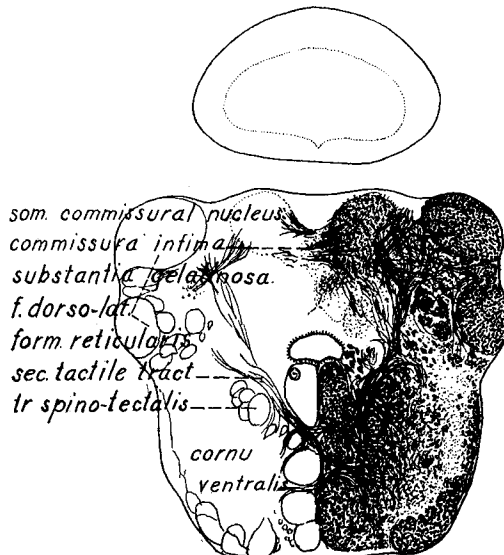sec. tactile tract
tr spino-tectalis
cornu
ventralis

FIG. 6.

FIG. 7. Transection a short distance farther caudad. The area designated *funicular nucleus* contains in addition to that structure the somatic commissural nucleus and probably also a spinal prolongation of the visceral sensory column, though the latter cannot be separately distinguished. The spinal V nucleus is so intimately related to the same area that no line of demarcation can be found between them. The whole area 'seems to function as a unit. The lateral funicular nucleus is not separately developed. The most cephalic ventral root fibers of the first spinal nerve appear in this section. × 35.

FIG. 8. Transection farther caudad which passes through a dorsal and a ventral rootlet of the first spinal nerve. The cornu dorsalis is considerably larger than in the remainder of the spinal cord and still includes a vestige of the funicular nucleus complex and commissura infima. × 35.
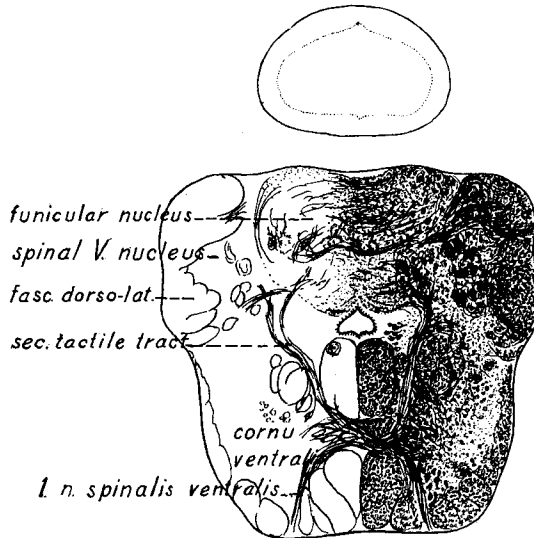
funicular nucleus
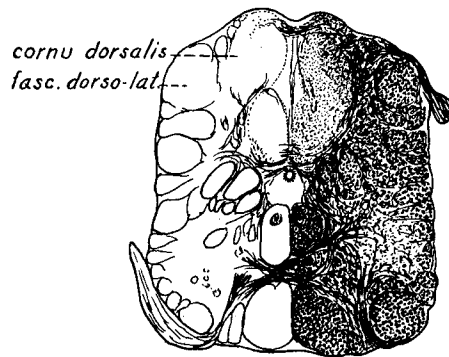spinal V. nucleus
fasc. dorso-lat.
sec. tactile tract

cornu
ventral
1 n. spinalis ventralis

FIG. 7.

cornu dorsalis
fasc. dorso-lat.

FIG. 8.