THE FUNCTION OF THE BRAIN IN PLANARIA MACULATA.

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IN a recent article I described several characteristics of the functional activity of the nervous system in Planaria maculata. I therein called attention to a fact previously noted by Loeb, that the body of a Planarian from which the head, including eyes and brain, has been removed, is still capable of "spontaneous" movement, and of reacting definitely towards light. Loeb showed that the headless body of a planarian reacts more slowly towards light and other stimuli than does that of a normal worm. From this and similar experiments conducted on other invertebrates Loeb concludes that the function of the central nervous system is to act as a quick, convenient, but not always necessary path for the distribution of sensory impulses to motor organs.

In my previous article I showed that even a small piece of a Planaria maculata may exhibit spontaneous movements, react to light, and give rise to specific internal regenerative changes, provided that it contain a part of at least one of the two nerve cords; otherwise no such activities take place. In headless pieces the portion of nerve cord left in each piece acts as a central nervous system until a new nervous system has been regenerated. In this animal sensory-motor coordination takes place only through a central neural apparatus.

Many of the reactions of a Planaria maculata are exhibited when the brain is removed. Are we, therefore, to conclude that the most complicated part of the central nervous system of this worm has no specific functions?

On a priori grounds one might assume that the function of the brain in these creatures, as in most animals, is to act as a centre of association for the control of the more complex relations of the indi-

1 BARDEEN: This journal, 1891, v, p. 1.
2 LOEB: Archiv für die gesammte Physiologie, 1894, lvi, p. 247.
3 LOEB: Comparative physiology of the brain and comparative psychology, 1900, pp. 38, 45, 86, 101, 125.

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individual to its environment. The most complex activities of the planarian which I could well study in isolated individuals were those having to do with feeding. If a planarian be removed from its natural habitat and be kept in pure water for two weeks it will usually be rendered "hungry." If such a planarian be resting on the side of a dish it may not be attracted for some time by a bit of snail placed in the water near it. But if the dish containing the planarian be brought from the dark into the light the resting planarian will commonly be aroused into activity. Once in motion it quickly finds the food material. When the swimming or crawling animal comes within a centimetre or two of a bit of snail it is apt to turn its head in the direction of this food and to proceed toward it. It is difficult to determine the source of the impulse which gives rise to this purposeful activity. It is possible that the auricular appendages here act as delicate organs capable of stimulation by slight currents in the water set up by the minute organisms that prey at once upon the flesh of the dead snail. At any rate, after the first planarian has found the piece of food others are more quickly brought to the spot.

The planarian gently approaches the piece of food. Having reached this the animal raises its head and sways it to and fro as if to examine the food. The auricular appendages meanwhile are raised and exhibit a slight wave-like motion. As a rule, the planarian now crawls upon the piece of snail and finally wraps its body about a small bit of its flesh. The pharynx is extended and becomes attached at its distal extremity to some of the food stuff. The worm now often turns about and faces away from the piece of snail so that the pharynx is extended at full length and in a direct line with the axial gut. It seems probable that at the mouth of the pharynx secretions are furnished which have a powerful digestive action when applied to animal tissue. Strong planarians often prey upon weak ones. In such instances the strong individual attaches its pharynx somewhere upon the body of the weak one, usually near the head. The flesh of the victim seems to melt as it disappears with great rapidity into the pharynx. Along the margin of the wound the flesh turns black. Such scarred pieces are frequently seen where planarians are found. In a similar way the tissue of the snail seems to dissolve partially in the pharyngeal secretions, and it is then rapidly poured into the axial gut and thence into all of the intestinal branches.
Occasionally a planarian stops before reaching a bit of food and extends the pharynx toward it. If this be reached feeding will take place as before.

In this process of natural feeding we have therefore to distinguish two processes, finding and recognizing the food, and devouring it. Both sets of processes require a coordinated complex of movements upon the part of the worm. The following experiment was performed to determine whether a brain is necessary for the performance of these processes.

Experiment I.—Feeding of Decapitated Worms. From some planarians found in a small stream near Baltimore I selected thirty well developed individuals. These I placed in tap water in a clean glass dish and kept them for two weeks without food. I then divided them into three lots of ten each and treated them as follows. In the first lot the heads were severed just posterior to the auricular appendages (c-f, Fig. 1). In the second the tail was severed just posterior to the pharyngeal pocket (g-h, Fig. 1); by this procedure more tissue was removed from each body than by the removal of the heads in Lot 1 and as much tissue was exposed at the wound. The third lot was left uninjured for purposes of control.

Each lot of worms was placed in a separate dish and the dishes were left in a dark place for twenty-four hours. They were then brought into the light. The transition from darkness to light set the worms in all three dishes in locomotion. In each dish a small portion of snail was placed. Within ten minutes all of the normal worms had found the morsel of snail and were eagerly devouring it. Within the same length of time all of the tailless pieces, except one, were attached closely to the portion of snail in their dish. On examination it was found that in the unattached worm the tip of the pharynx had been removed in the attempt to cut off the tail. At the end of half an hour not one of the headless pieces of Lot 1 had attacked the portion of snail placed in the same dish. I then spent fifteen minutes in placing portions of snail in the way of the headless pieces and at last succeeded in getting a headless piece to eat. This piece happened to settle down upon a bit of food which the pharynx reflexly engulfed. Several times other pieces settled down for a moment on a morsel of food and the pharynx was reflexly extended. But the worm moved on without responding to this opportunity to rest while food was consumed. In other words these worms failed to find food and failed usually to react normally when in contact with it.
From this experiment it seems fair to conclude that the head is an organ necessary for putting the planarian into definite relations with its natural food. The headless pieces were experimented with from day to day until the heads had regenerated. Only after the heads were well formed did these pieces behave in a natural manner toward food placed in the dish. However, if left constantly near food, headless pieces may at times consume that with which they accidentally come in contact.

On the other hand, the simple reflexes of extending the pharynx and of swallowing are preserved after removal of the head. I found, by repeated trials, that one of the headless pieces could usually be made to eat if it was placed on its back on a slide in a small drop of water. Under the conditions mentioned the pharynx is usually protruded and will engulf bits of food placed in the mouth.

That the loss of power to recognize food exhibited by the headless worm is not due to the pathological action of the wound as such is shown by the normal reactions of the tailless pieces.

Experiments similar to that described above were repeated with like results. The normal reactions of these worms are best seen in specimens freshly collected. As Loeb pointed out, the power to respond to stimuli becomes weakened in worms long in confinement.

Observations were now made to determine how much of the planarian brain is necessary for the recognition of food.

Experiment II.—Feeding of Worms from which a Part of the Head was Removed. Twelve fasting worms were divided into two lots which were treated as follows. (1) From six worms I separated the end of the "nose" by a section midway between the eyes and the anterior extremity of the body a-b, Fig. 1. (2) From six worms the anterior portion of the head was separated by a section through the region of the eyes, c-d, Fig. 1. In each dish were placed several portions of snail. All the planarians in Lot 1 ate of the food within fifteen minutes. In Lot 2 only one took any notice of the food. This one after half an hour became attached to a portion of snail. On removal and careful examination it was found that in this piece the section had passed in front of the eyes instead of through them.

From this experiment it appears that complex reactions, such as the recognition of food, cannot be performed by planaria unless the brain is intact as far forward as the anterior margin of the eyes.

Conclusions.

1. In Planaria maculata nerve cords and brain constitute the central nervous system.

2. A fragment of this planarian will exhibit no sensory-motor coordination unless it contain a part of the central nervous system.

3. If the anterior extremity of the body be removed by a transverse section passing through the eyes or through the body posterior to this region the worm will lose the power of recognizing food and of reacting normally towards it. The simple swallowing reflexes are maintained.

4. For the more complex reactions of the individual the brain must be intact as far forward as the anterior margin of the eyes.