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THE SOURCES OF NERVOUS ACTIVITY[1]

I CAN not proceed with what I have to say without speaking first a word of congratulation and thanks to those whose material and intellectual resources have made the Scripps Institution for Biological Research an actuality. Biologists the world over are coming to be more and more dependent for their training and inspiration upon just such establishments as this. The introduction into our institutions of learning of the laboratory with its unique and novel educational methods was indeed a vast step in modern progress, but it can be said in no sense to have rendered superfluous the laboratory designed for pure research. This, from the time of Davy and Faraday, has retained its original function unimpaired and has been the means of directing mankind to many of his most profitable lines of endeavor. Such research institutions, which by a happy concurrence of events have been much on the increase of recent years, must always remain the highest shrines of science. They originate, they conserve, they hand on; and all this is done without the interference of the pedagogue; in other words, their scholarship, to use that term in its best sense, is of the highest order. In them the true spirit of science is better exemplified than in any other type of institution that we possess. It is therefore a time for congratulation when the Scripps Laboratory can open its doors more widely than ever before to those who have reason to make use of its abundance.

It has been in such institutions as this

[1] A dedicatory address delivered August 9, 1916, at the Scripps Institution for Biological Research of the University of California.

that in the past few years I have been conducting studies on the origin of that most intricate and complex systems of organs, the nervous system, and in fact it is to this institution that I have come for a time to continue such investigations. It may not be inappropriate, therefore, if I attempt to tell you in as simple and direct a way as I can something of the problem on which I have been working and of the results that I believe I have attained.

Every one knows nowadays that there is an intimate and important relation between man's intelligence and his brain, that his eyes, ears and other sense organs deliver to him information concerning the exterior, and that by means of his muscles controlled through his nerves, he can mold his surroundings more or less to his liking. But perhaps few persons have realized how strictly nervous all these operations really are. Take, for instance, the apparently simple question of the seat of our sensations. To an untrained person the pain of a pin prick is located where the pin enters his skin. To him nothing seems more obvious and certain than that the punctured spot is the seat of the pain and any attempt to change his view on this point will usually be regarded by him with suspicion and mistrust, for it seems contrary to common sense. Such persons adopt more or less unconsciously the opinion held by many of the ancients that our sensations are spread completely through our bodies, an opinion which we have been obliged to give up. The reasons for this change of view are several. First, it has become well known that, if a nerve distributed to a given area of skin is cut at some distance from that area, the spot, though unaffected in any direct way by the operation, will give rise to no further sensations even when it is severely stimulated. Hence it is clear that the sensations do not reside simply in the skin. But not only may pain thus be absent from a given area of skin; it may be present when the skin with which it is supposed to be associated is absent. Persons who by accident or otherwise have lost an arm or a leg often experience long after the loss vivid and intense sensations from definite parts of the missing member. So precise and sharp are these sensations and so certainly do they seem to be associated with the lost part that some of the less knowing of these unfortunates have attempted to exhume or otherwise get possession of the lost member in an endeavor to alleviate their unpleasant sensations. These misunderstandings, for such they are, can be swept away and the matter put in its true light when we recognize that our sensations are not located in the peripheral parts affected but in the central nervous system, and within that portion of it known as the cerebral cortex. As long as this organ is intact, sensations may arise, and, though these are usually due to nervous impulses from the sense organs, they may be called forth by an internal stimulus as well. Thus it is that a missing arm may be represented by sensations years after it has been severed from the body. With a loss of an appropriate part of the cerebral cortex, however, comes a loss of sensation that is absolute and final. From this there is no recovery. Our sensations then are not spread throughout our bodies, as was taught in ancient times but are limited strictly to the nervous system and in all probability to that part known as the cerebral cortex.

Not only are our sensations thus activities of the cortical part of the brain, but there is good reason for believing that our whole conscious life is similarly restricted. In the cerebral cortex lies memory with its wealth of stored experiences, in this organ love, hate and fear come into being; here

arise the cool deliberations of the man of science, the dreams and aspirations of the poet, the passion of the religious enthusiast, and, when abnormalities intervene, the ravings of the madman. Contrary to ancient belief, the spleen does not engender temper, nor do the affections flow from the heart. These and all other like attributes proceed from the brain. And yet the old traditions have so strong a hold upon us that I doubt whether any modern suitor would forward his cause by offering to the lady of his choice the real organ of his affection, his cerebral cortex, rather than his heart.

Accepting the modern view that the conscious life of man is not a function of his body as a whole but an activity limited strictly to his nervous system, it follows that the evolution of this system becomes a question of special interest. In man and the other higher animals this system consists of a most intricate collection of transmitting fibers, end-stations, centers and the like so disposed as to receive and record the influx of surrounding changes and to respond to these by appropriate movements. The light of a friendly countenance reaches us through the eye and a word of salutation through the ear and off comes the hat in response. When we scrutinize more closely the machinery of these operations, we find it simple in outline, though inconceivably intricate in detail. There are first of all the sense organs of the body, the eyes, ears, nose, mouth and so forth each attuned to a particular set of influences or stimuli and each delivering to the central organs evidences of the momentary states of these stimuli in the exterior. Next are the central organs, the brain, spinal cord and the like, parts that receive the flood of sensory information from the outer world and pass it on unnoticed or store some remnant of it as a part of life's experience. Last of all are the voluntary muscles set in action by impulses from the central apparatus and capable of performing the thousand acts good or ill that make us the responsible beings that we are. These in gross outline are the three great categories of our nervous machinery, or better, of our neuromuscular machinery, for muscles are necessarily an integral part of this chain. When such a chain goes into action, sense organ, central nervous organ and muscle, we speak of this as a reflex, for it resembles light in that it passes from an external source inward to a central organ whence it is reflected, so to speak, outward to the muscle.

If we examine the nervous systems of animals lower than man, we find in them the same three categories of parts. All the vertebrates from the mammals to the fishes have sense organs, central nervous organs and muscles. The same is true of the snails, the clams, the insects, the crabs and many others. Even the worms possess these three classes of organs, though with less differentiation as a rule than in the higher animals.

But, when we study the jelly fishes, the sea anemones, or hydroids, the case is different. Here we meet with an obvious simplification and what is noteworthy is that all three parts are not equally reduced, but that one, namely, the central organ, has suffered almost complete obliteration. In these lowly creatures the sense organs, either in the definite form of eye spots and the like, or as broad receptive surfaces without great specialization, are superimposed almost directly upon the more deeply seated muscles. Such animals often have not even a trace of an intervening nervous organ that could be called a central organ. The sense organs may thus connect directly with the muscles. Obviously under these circumstances the sense organs lack entirely that function that they showed in so marked a degree in the higher animal,

namely, the supply to the central organs of information, so to speak, as to environmental changes. In these more simplified conditions they must be restricted to the simple process of exciting the muscles to activity in consequence of special forms of sensory stimulation. They act, in other words, as a series of local triggers to set off muscular activity in various parts of the body as needed. Here then we see a stage in the evolution of the nervous system in which the sense organ and the muscle are the essential parts, but the central organ is to all intents and purposes omitted. Obviously, this stage must precede that in which central organs are present and these organs, brain, spinal cord and the like, must be looked upon as of later racial origin than sense organs and muscles. It may at first sight seem strange that so significant and all-important an organ as the brain should have been evolved secondarily in relation to sense organs, but such seems to be the case and we are justified, I believe, in stating that animals possess a brain in consequence of their having previously had sense organs, not that they possess sense organs because they have a brain.

The absence of a central organ and the presence merely of sense organs and muscles in sea anemones and other like forms makes itself felt in the activities of these animals. As I have already pointed out, that feature above all others that makes one of the higher animals, and especially man, a unit, is the possession of mental traits. Our conscious life affords our strongest claim to individuality. When this is disturbed, as in cases of double personality or in the various forms of insanity, even so practical a matter as the law takes cognizance and we treat such individuals differently from the common run of men. This unifying influence of the nervous system, technically spoken of as its integrative action, is almost completely absent from such animals as the jelly fish and sea anemones. With them individuality is a very subordinate character, and it is questionable whether they possess any trace whatever of that trait which we denominate personality in ourselves. They possess no single organ to which the nervous experience of their various parts may be referred to the advantage of the whole. Hence such nervous organization as they have is appropriately styled diffuse, in contrast with the centralized condition of higher forms.

The significance of this state of affairs is well seen in the activities of sea anemones. Many years ago it was shown that, if a single tentacle is snipped from the mouth region of a sea anemone and held in sea-water so that the observer can recall which side of the tentacle was originally turned toward the mouth of the animal, the tentacle will be found to entangle food and to twist itself in a direction that would be appropriate for the delivery of the food to the mouth were that aperture still in its original relation with the tentacle. This response, which has been repeatedly confirmed by others, including myself, shows that each tentacle contains within itself the necessary nerve and muscle to carry out its own movements, and that it is not dependent, as in the case of the arms, legs, jaws and so forth of the higher animals, upon a distantly located central nervous organ to initiate, control and subdue its movements. In a similar way I have recently shown that the pedal disc with which many sea anemones creep about will, in certain species, carry out perfectly normal locomotor movements even after the other half of the animal, including the mouth and tentacles, has been cut away. This instance also demonstrates the neuromuscular adequacy of the part of the animal concerned and its relative independence of the rest. Auton-

omy of parts, then, is one of the most striking aspects of the neuromuscular organization of the sea anemones and is strong evidence in favor of the absence of a centralized nervous organ in these animals. The same conclusion can be drawn from certain aspects of the feeding habits of sea anemones. If one of these animals is persistently but slowly fed by the tentacles on one side of its mouth, it will sooner or later cease to take food by these tentacles, though the muscles of the tentacles are in no sense fatigued. If food is now applied to the tentacles on the opposite side of the mouth, feeding will recommence almost as though the animal had not been fed previously. Thus the change of response induced on one side of the mouth has had little or no effect on the other, a condition referable to the absence of a central nervous organ. It is thus evident how different the organization and the responses of an animal without a central nervous organ are as compared with those of forms possessing such an organ.

Sense organs and muscles may therefore be regarded as two elements more primitive than the central nervous organs in the evolution of the neuromuscular mechanism. What is the source of these two parts? Did they arise together, twins at a single birth, or is one the older, and, if so, which? Kleinenberg in his theory of the neuromuscular cell, and the Hertwigs in their account of the nervous system of sea anemones, were both led to declare in favor of the simultaneous and dependent origin of nerve and muscle. Claus believed that these two elements arose independently and came together secondarily, a view subsequently espoused by Chun. When, however, animals more primitive than sea anemones, such, for instance, as sponges, are studied, a different solution to the problem from those just suggested is obtained. These lowly forms as mature animals possess no powers of locomotion whatever and the few movements that their bodies exhibit are carried out with the utmost deliberation and slowness. They can very slightly and always with great slowness bend and unbend their bodies as a whole, and they can close and open the numerous inlets and the few outlets by which the spaces within their substance are set into communication with the surrounding water. All these movements are carried out by a very simple form of muscular tissue and so far as concerns the study of their bodies, both anatomical and physiological, there is no evidence whatever of the presence of sense organs or other forms of nervous tissue. It therefore seems quite certain that in sponges we have primitive animals possessed of muscle but devoid of nerve even in the form of sense organs, and we may therefore conclude that, between muscle and sense organs, the muscle is of more ancient origin and marks the beginnings of that series of functionally related parts that culminates in the central nervous systems of the higher animals.

These views as to the steps in the evolution of the nervous system, as to the sources of our nervous structures and activities, have already found expression. They carry with them, however, certain implications concerning the manner in which we should frame our hypotheses as to the springs of nervous action, implications that have not been so generally appreciated. In the early part of this address I sketched the commonly accepted view of the organization of nerve and muscle in the higher animals. From the standpoint of human interests the sense organ is the avenue through which we gather in the course of our lives that enormous body of information concerning our surroundings. By smell, taste and touch we gain a knowledge of the more elemen-

tary chemical and physical aspects of the environment. Touch, moreover, gives us form and position and passes imperceptibly into that vague but enormously important sense, the muscle sense, through which the movements of our bodies, our limbs and other parts are checked and adjusted and the whole problem of spatial relations receives a new setting. Closely allied to these senses is the ear as an organ of equilibration responding to the pull of gravity and to our sudden changes in position and, like the muscle sense, affecting our conscious states so slightly that we scarcely know we have such a sense till on sea or on train excessive stimulation due to the unusual form of motion draws on characteristic discomforts. Next may be mentioned the ear as an organ of hearing attuned to the sounds of nature and in man attentive to the voice, that marvelous means of signaling whereby the momentary mental life of one human being can be quickly and accurately imposed upon another. And finally the eye with its responsiveness to light three thousand times greater than that of the most sensitive photographic plate, adjusted to color and to form, and in no whit behind the ear in its social significance. Thus our sense organs literally deluge us with a flood of messages concerning our surroundings and yield us all the elements out of which our mental life is built. In fact there is good reason to believe that without this sensory inrush consciousness itself could never come into being. The newborn brain is not unlike the western desert; only after irrigation in the form of sensory inflow does consciousness begin to blossom.

Considering the enormous significance of the sense organs for man as the means of supplying him with the content of his mind, it is not surprising that in attacking the problem of the brain and our mental states students should have made their approach almost entirely from the sensory side. The quality and quantity of sensations were exhaustively investigated and even the central nervous organs were dealt with from the standpoint of their sensory relations. In brief, the sensation became more and more the established unit in considering nervous action, and we were led to interpret the nervous states of the whole range of lower animals by the sense organs they were shown to possess. If a particular worm or jelly fish had an unusually developed eye, it was assumed that the given animal enjoyed an excess of sensation akin to sight with us as compared with its less fortunate neighbors. If a crawfish inhabiting caves possessed degenerate eyes, but was covered with enormously developed tactile hairs, it was supposed to have realized something of that excessive development of touch which we know is characteristic of the human blind. Thus the well-known relations of our sense organs to our mental life gave a basis for the assumption of corresponding mental states in the lower animals.

If, however, the sources of our nervous organs are such as I have sketched, it is extremely doubtful whether the interpretations just mentioned are at all justifiable. In the beginning sense organs had nothing whatever to do with the delivery of messages to a conscious center. They were organs concerned merely with the calling forth of muscular movements. The animal with especially developed eyes or with unusual organs of touch is not necessarily endowed with special sensations in these directions; it may be an animal merely adapted to respond with unusual delicacy to light or touch and without central nervous relations at all. Thus the sense organs in the lower animals come to have a very different significance from that formerly attributed to them. They are special means

of exciting action rather than organs of an informing nature. It must also not be forgotten that though the sense organs of the higher animals are in many cases primarily organs of information, so to speak, they probably all still retain their original function of exciting muscles, at least indirectly, to action. They are the beginnings of practically all reflex arcs. Not only is this true, but not a few of them retain, so far as our conscious life is concerned, much of that hidden and submerged state that characterizes them in the lower animals. They lie in their activities below the conscious and even the subconscious level. This can be exemplified in one of the senses already named, the muscle sense. We are almost continuously cognizant of light, noise, smell and so forth, but we find it almost impossible to realize in our conscious states sensations from the muscle sense. Obscure, vague and indefinite, they impress us scarcely at all. Only here and there do they appear to rise into the region of strong sensation. Within the last few years it has been shown that the sensation of hunger is dependent upon stomach movements. Each hunger pang is due to a wave of muscular contraction passing over the walls of the stomach. It is, therefore, not improbable that the hunger pang is a muscle sensation that, from its organic importance, has lifted itself from the low level of unconscious activity into the higher strata of our conscious states.

The great majority of the sense organs of the lower animals are concerned with yielding impulses to motion that are in no way associated with consciousness, and this is undoubtedly their primitive function. Such animals often exhibit complicated systems of transmission tracts connecting their sense organs with their muscles, and these tracts collectively mark the beginning of a central nervous system. It is probable that a sensory equipment of this kind, with the well-established beginnings of a central apparatus, afforded the necessary settings for the appearance of consciousness, which thus found roughed out by the earlier necessities of the organism a system of sensory and central components capable of sustaining future growth. At this stage the sense organ must have added to its primitive function of calling forth muscle activity that of supplying messages to a growing central organ, a function that has become of such paramount importance in man.

If this outline of the sources of our nervous activity is true, it follows that any conception of the nervous system that assumes sensation as a basal phenomenon is most assuredly to be abandoned. Sensations are associated with only the later phases of nervous development. The feature that has been present throughout the whole period of this evolution is muscular activity. In fact, as I have already stated, we have reason to believe that muscular activity preceded nervous origins and that nervous tissue appeared in consequence of the presence of muscles. Our own sensations, then, are not our most fundamental and primitive nervous processes, but behind these and of much more ancient lineage are our impulses to action, our wishes, our desires, and the whole vague body of nervous states that drive us to do things. These are the most ancient and deeply seated of our nervous propensities, and immeasurably antedate in point of origin, our sensations with all that supergrowth that constitutes the fabric of our mental life. We do well to warn ourselves to think before we act. Action is the oldest and most ingrained of our nervous functions, thinking the newest.

You will pardon me if I have led you from the realm of simple fact and observation far afield into that of pure speculation, for the general scheme of the sources of our nervous action that I have outlined must be

regarded as largely speculative. Such outlines are, however, suggestive of the myriads of questions that science attempts to answer. And the answers, when found, are the means of correcting these outlines that they may coincide more nearly with the truth. It is to the attainment of this general truth that establishments such as the Scripps Institution are dedicated. May the increased facilities that we celebrate to-day yield an ample and worthy return.

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A SHORT ADDRESS TO THE GRADUATING CLASS OF THE HARVARD MEDICAL SCHOOL, 1917

It is on occasions such as this, at certain eras in the lives of young men, that we compel them to listen to words of counsel, however this ultimate end of giving counsel may be concealed in verbiage. Older men, in which class I have been rather reluctantly compelled to put myself, are generally selected to give utterance to these words, from the fact that, having had a wider experience, their views will have a greater importance, and indeed many of them and even their hearers really believe this. It must be said that there is no demand for this on your part and these addresses, like lectures, are forced upon you; at least I do not think you would rise up and clamor for them, but you passively submit.

If one looks over the literature of addresses—and the sum of the published ones would almost fill the Alexandrian Library—there is great similarity in the matter and in the form of presentation. In recent years there has been some decline in attempts at eloquence and you are no longer told that medicine is a useful and noble profession, with citation of examples, or that you are a vessel embarking on the sea of life, this associated with descriptions of lighthouses, cross currents, storms, etc. I speak feelingly, for on looking over some old addresses of mine I found that I also had once spoken of ships and storms and lighthouses, and I should like to humbly apologize to my former auditors.

This desire of ours to talk is partly due to the garrulousness of age, which is compelled to substitute words for action, and having found how much easier the process is, and how pleasant, indulges itself in the vice; and partly to the persistence of an utterly mistaken view of education. The idea that education, that process which aims at the development of the individual with the view that he shall be capable of greater service and of greater individual happiness, can be attained by telling the aspiring student things or having him study merely the product that others have wrought, has unfortunately not entirely passed. If I have learned anything in my now somewhat long life as a teacher it is that the process of education consists in giving the student opportunity, the material to study, be it mankind, books, ants or dead bodies, and in every way assisting him in the study, always recollecting that the result must be individual, the product of the material which his brain has received, digested and assimilated. We must not think that we can give him in words merely the conceptions which we have arrived at, although he may derive some profit by comparing our concepts with his own.

We should not think that in an address we can give a young man any thing of real value. What we are depends upon the individuality of our living material and the result of the action upon this of the special matter which education gives plus the more generalized influences of the environment. It is particularly now, when such enormous changes in environmental conditions, as compared with those under which