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THE NERVOUS SYSTEM[1]

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The lower creatures do not meet to discuss the factors which determine their behavior. "Know thyself" is a precept reserved for *homo sapiens;* indeed the more academic our discussion the better we shall demonstrate our true position in the animal kingdom.

We are animals with powers of reflection and foresight, who can use tools and form propositions. Our knowledge and attainments can increase from one generation to another because our children can learn from our successes and failures. In the last hundred years we have found out so much about the material world that we have acquired immense new powers of action on it. What have we found out meanwhile about ourselves?

There have been no practical achievements comparable to the radio set or the flying machine, but no one can doubt that ideas about human behavior are vastly different from what they were over fifty years ago. Our conduct is no longer as right or wrong as it was. We think of it still as the outcome of a conflict between opposing forces, but we do not postulate forces wholly good and wholly evil. In some lands they are now thought of as racial or class instincts: here we have more choice and are free, if we wish to see ourselves driven by the more primitive forces which Freud has made respectable. But everywhere human behavior has become something to be studied by the methods of natural science, as objectively as possible.

As a foundation to this study there is a mass of information about the mechanism of the body. The behavior of any animal must depend in part on general structure—its shape, size, number of limbs, arrangement of sense organs, etc., and with man there

[1] Given at the Harvard Tercentenary Conference of Arts and Sciences, Cambridge, September 7, 1936.

are the important structural modifications which allow the forelimbs to be used for wielding tools. Yet the chief factor which determines the range of our activities is the nervous system. Every movement is the result of the messages which pass from the central mass of nerve cells to the muscles, and the outgoing messages are varied according to the reports submitted by the sense organs. These show what is happening in the world outside, and the central nervous system must evolve a plan appropriate to the occasion. But only the simplest plans are possible if the central nervous system is ill developed. The earthworm can take to its burrow when it feels the shock of footsteps on the grass and such an immediate reaction needs only a few hundred nerve cells and fibers; but we can sell out an investment when we hear rumors that the company is unsound, and this reaction needs the ten thousand million cells of the human cerebral cortex.

Our concern is with behavior of this characteristically human type. It represents by far the most complex synthesis achieved by any nervous system. Neurology, therefore, is not to be blamed because it can not yet analyze such a product into an affair of nerve networks and impulses. But from one aspect human behavior is an affair of networks and impulses; it may be useful to picture it in these terms in spite of the fact that we know far more about our thoughts and actions than we do about the mechanisms in our brains.

The central nervous system may be divided into the forebrain, the cerebral hemispheres which elaborate the general plan of behavior and the brain stem and spinal cord which have to carry out the plan and attend to the administrative details. The whole system is made up of cells with thread-like extensions, some running as nerve fibers to the periphery and some forming the interlacing networks of the central apparatus. The cells and their extensions are excitable; within them are stores of available potential energy, ready to be discharged as soon as the restraining forces are weakened but replenished as soon as the discharge is over. All nervous activity involves discharges of this kind. Thus the long distance signalling from sense organs to brain and from brain to muscles is carried out by the conduction down the nerve fibers of repeated impulses, momentary waves of activity traveling like the spark along a fuse, and everywhere in the nervous system is liberated in brief outbursts rather than in a continuous stream. This fact by itself has little bearing on our actions, save that it sets an upper limit to the rate at which activity can change. What is of more importance is the fact that in some nerve cells the outbursts seem to occur spontaneously, without the need for an external stimulus to start the discharge.

The best example is the respiratory center, the group of cells in the brain stem which controls the rhythmic movements of breathing. For these cells the normal state is one in which periods of rest and activity alternate regularly. There are various devices for controlling the rhythm and prolonging one or other phase to suit the convenience of the organism, but the regular cycle must return in the end, and it is due, not to a sequence of reflexes, but to the cycle of breakdown and repair in the nerve cells. The movements of walking and running are determined in the same way by an automatic rhythm in a group of nerve cells. With these, however, the organism has a greater measure of control and can start or stop the rhythm by the appropriate signals. The work of Coghill and others on the development of behavior in the embryo has shown that many complex activities have this same semi-automatic origin, the outside world giving signals to begin and end and the complex organization of the nerve cells supplying all the detail.

Admittedly there can be no real separation of activities which are spontaneous from those which are evoked by the environment. It is of interest none the less to find that the region in which spontaneous activity seems most ready to occur is in the great surface network of the forebrain—the cerebral cortex. Even in deep anesthesia the cortex is alive with the electrical pulsations which are the index of nerve cell activity. They vary from a simple rhythmic beat to an irregular succession of waves. The latter are not merely a reflection of the irregular world outside, for the anesthetic has cut off all incoming sensory messages; they are due rather to the automatic discharges of nerve cells, linked together, but differing in position and structure and in the past history of their activities. In these cells a steady state is impossible because their internal tension is constantly increasing to the point of discharge.

Although the cortex can not be kept completely at rest for more than a few seconds, the degree of activity in it can vary enormously. The variations are due in part to the world outside and in part to the internal necessities of the nerve cells. Activity in one cell tends to foster activity in its neighbors and so to build up the general level of excitation. The level will rise until the process is checked by the falling reserves of available energy. Similarly, rest breeds rest, and this process is checked by the internal tensions rising ultimately to the point of breakdown. The sudden increase of activity when we wake in the morning illustrates the change of level brought about by external stimuli acting on a recharged nervous system, though other factors are concerned as well. Inhibition, the process by which one cell can suppress instead of enhance the activity of other cells, is no doubt a factor which helps to shift the focus from one part of the cortex to another. In general, however, we may think of the forebrain as a complex society of nerve cells, the units of which can not remain for long either in intense activity or in complete rest.

These electrical changes give a picture of cerebral activity which recalls certain features of mental activity. The environment can start or stop a train of thought and keep it within certain channels, yet the sequence of ideas is often dictated almost entirely by past events, and certain sequences seem to obtrude themselves unbidden. Such comparisons are dangerous, for they suggest that we have already a reasonable knowledge of the connection between mental and neutral events, whereas in fact we know almost nothing. We can be sure, nevertheless, that the connection is extremely close.

The activity of the cerebrum, determined largely by the past and continually changing even in a steady environment, is in sharp contrast with that of the rest of the central nervous system. This has no memory. Its function is to carry out the plans dictated by the cerebrum and at the same time to keep the machinery of the body running smoothly. It must regulate the intake of food and oxygen, the circulation of the blood, its temperature and acidity. It must keep the body in its correct position in space, balancing it in spite of its shifting center of gravity. It must minimize the disturbances which are likely to result from great exertion or injury. For all this there is a beautiful reflex machinery coordinating the messages from sense organs specially adapted to register the blood pressure, the tension in muscles, the pull of gravity, etc. But an animal without its cerebrum is no more than an automaton: it can stand and breathe and live after a fashion, but its behavior is reduced to a number of reflexes or, at the most, habitual patterns of action.

Long ago Claude Bernard insisted that the internal environment must be constant if life is to be unrestricted. His dictum has been supported lately by two distinguished physiologists from the two Cambridges. Cannon has shown how the visceral nerves prepare the body for sudden emergencies, and Barcroft has studied the factors which lead to a breakdown of normal activity. It is significant that man has more need of a constant environment than any other animal, since it is the cerebrum which has the most delicate organization and can least withstand any change.

Human behavior, then, is preeminently the affair of the cerebral cortex. This is made up of the same structures as the rest of the nervous system, though there are more nerve cells in it, larger networks, in proportion to incoming and outgoing pathways and more spontaneous discharge. What is new is its power to combine past activity with present. As Sherrington has said: "The great new surface net of the brain is educable. Before it, truly, there were educable systems in the animal world, but this is so educable as to be practically a new thing in the world. In the dog it can acquire new links even in a few repetitions and links can be combined even to the third degree. In man it seems they can develop almost without limit."

The cortex can learn and can use its learning to generalize and to solve new problems. But even the simplest kind of learning involves a factor which must still be expressed in psychological terms. As Pavlov's work has shown, there must be interest, a prospect of reward or punishment, an emotional stress which will change to satisfaction when the lesson is learned or the problem solved.

We are still quite ignorant of the neural changes which take place when new associations are formed in the brain, and we can only guess why an incentive is necessary. Twenty or even ten years hence we shall know much more, for there are definite changes in the electrical activity of different regions when we direct our attention from the visual field to the auditory and *vice versa.* These are not beyond analysis. It is perhaps too much to hope that in revealing the neural mechanism of attention they will reveal that of consciousness as well, but at least they may show what kind of influence is exerted by emotional interest and why that influence is exerted on particular mental and neural sequences.

We may guess that the state favorable to learning involves an increase of excitability and possibly a change in the chemical environment of those parts of the brain in which the new connections are established; and probably it is brought about by the more primitive parts of the forebrain, the hypothalamus and the basal ganglia. These regions prepare the nervous system for its cycle of sleep and waking; they are linked with the hormone system and they control various kinds of instinctive and emotional behavior. Sinister proof of their importance comes from cases of injury or disease. But whatever the regions concerned, it is safe to assume that there must be some activity on the emotional or instinctive level to direct the attention and prepare the brain for new associations.

For discriminating behavior, therefore, there must be some interest. Yet, if there is too much, the behavior will cease to be discriminative. Under intense emotional stress the behavior tends to conform to one of several stereotyped patterns. These are managed by the more primitive parts of the forebrain, and the cortex has little to do with them beyond directing the behavior towards a particular object. Thus a cat whose cortex has been destroyed may give all the signs of rage, though it is a blind rage and useless to the animal. With the brain intact the rage is directed. It is still a stereotyped response, but it is often the best response for the cat to make, since its cortex has not the capacity to plan more elaborately. In man, however, the cortex, when it is allowed free play, can be far more patent, and emotional reactions which force the behavior along one line and allow no scope for discrimination are far less so. Moreover, emotional reactions tend to spread through all the members of a group and to build themselves up to higher and higher levels.

There is no need to pursue a devious argument to its certain but commonplace conclusion—that our behavior will be most effective when there is enough emotional tension to arouse the activity of the forebrain but not enough to submerge it in a stereotyped response. We know well enough that our emotions can cloud our judgment, and the psychologists have shown that they do so far more than we suspect. We know that some interest is necessary, that moral indignation supplies the driving force for great reforms, but that rage does not help them. Need we care greatly whether the neurologist can produce a scheme of nervous mechanism which will account for these things?

Most of us, I think, would welcome the knowledge gained, but we might reasonably doubt whether it would make us more effective units of society. It is, in fact, unlikely that neurological research will give new methods of control over human behavior. What it will certainly do is to improve some of the methods which exist already—for instance, the control of behavior by drugs. Tea and alcohol are homely examples, and the new narcotics which can give peace of mind before a surgical operation have shown what we may expect in future from this method of regulating our brains. For more continuous action there are the drugs which the body manufactures for itself—the hormones. These, fortunately, have a place reserved to themselves in to-day's discussion.

But when all is said, a knowledge of physiology offers only one certain, though perhaps unattainable, method by which human behavior could be improved. That is to breed men with larger brains. Our cerebral hemispheres are not so much larger than those of the chimpanzee and contain no new structures, but our behavior is of a different order. We can pile one box on another without thinking; Professor Köhler's chimpanzees could succeed by chance, but the essentials of the problem were quite outside their mental range. It is tantalizing to think of the new relations we should see, of the new world of thought we should live in, if our brains were but twice their present size. Our behavior would then be superhuman! it would be determined by the same physiological factors, but the importance of the cortex would be so magnified that the result must be beyond the power of human thought.

SUMMARY STATEMENT OF THE WORK OF THE NATIONAL RESEARCH COUNCIL

By Dr. FRANK R. LILLIE
CHAIRMAN

THE annual report of the National Research Council is printed each year in the Report of the National Academy of Sciences, a Senate Document, by the Government Printing Office in Washington. As the report for the year ending June 30 usually appears in April of the following year, and is relatively inaccessible to the scientific public, a summary statement of the year's work has been published in SCIENCE in recent years.

The past year completes the twentieth year of operation of the National Research Council since its organization by the National Academy of Sciences in the summer of 1916 after the academy had offered its services to the Federal Government in the interests of national security. Since the termination of the world war the Research Council has endeavored to serve the interests of scientific research in this country as a mechanism of coordination operated by American scientific men themselves, in relation to academic, industrial and governmental interests in science. It is clear that the Council has little, if any, effectiveness apart from the use which these men may make of the facilities of such relationships, under the auspices and coordinated support which it offers.

The National Research Council is an agency of the National Academy of Sciences and operates under its Congressional Charter of 1863. During the year just passed the president of the academy acted also as chairman of the National Research Council. At the close of the year this arrangement was terminated, and Dr. Ludvig Hektoen, of Chicago, was elected chairman of the National Research Council.