The nervous system

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P. N.

Introduction

Neurology is the study of the nervous system. The nervous system is made up of the brain, the spinal cord and the nerves throughout the body. The structure of the nervous system is neuroanatomy and its functioning is neurophysiology. The disorders and diseases of the nervous system that bring patients to neurologists are paralyses, tremors, shingles, Parkinsonism, epilepsy, multiple or disseminated sclerosis and others, most of which are not yet satisfactorily treated.

Theoretically psychology is a part of neurology, for every sort of behaviour is the result of the functioning of the brain. But in practice, it is convenient to keep it as a separate subject. Psychologists are not usually doctors of medicine. They do mental testing, carry out tests for what is called intelligence, vocational guidance, and they do research on certain aspects of brain functioning, such as vision, sensation, reading, writing and topographical memory.

Psychiatrists are medically trained; they specialize in the diagnosis and treatment of psychotic patients and of neuroses and illnesses in which social and emotional features play an important role.

The boundaries between neurology, psychiatry and psychology are fluid and indistinct. If someone starts behaving oddly, he may need the help of a psychiatrist, a neurologist or a neurosurgeon; it depends whether he is suffering from depression, from senile dementia or a brain tumour. It is the neurologist who makes the diagnosis.

As the adjective 'nervous' has popularly come to mean anxious, apprehensive or frightened, it will be avoided in this book; the adjective 'neural' will be used instead, which is present practice in neurology.

A book on psychoanalysis, psychotherapy or psychology can be understood by anyone who has had no education in biology. But neurology, like the rest of medicine, requires some knowledge of physics, chemistry and anatomy.

This book is a new edition of the author's Pelican book *The Nervous System*. It has been altered in many ways; it is not for the author to say it has been improved. Some illustrations have been brought up-to-date, and some electron micrographs have been added. Some chapters needed to be re-written as advances in the subjects have been made by continuous research work. I have tried to make the account simpler without leaving out any information. These chapters are those on

Listening, of which the section on echo-location has been enlarged and to which a history of the subject has been added; Tasting and Smelling, each of which now has a chapter on its own; Smelling includes a section on pheromones; Touching and Feeling, which includes recent investigations on man, which allow us to omit investigations on other species; Balance and the Vestibular System. A chapter on pain has been added. Another new chapter is on chemical neurotransmitters and their targets; great advances have been made in this subject. The chapter on Nerves and Nerve Fibres has been re-done and a section added on the trophic activity of nerves and transport of substances within nerve fibres. The chapters on Communication within the Central Nervous System and Moving have also been totally re-done. Throughout, a little more about diseases of the nervous system has been given; although this book is about the normally functioning nervous system, so many people have asked me to explain where neurological diseases fit into this general account of the nervous system, that I have made comments on how things go worng. The chapter on being awake or asleep has been much enlarged; we now know more about sleep in human beings and about the sleeping habits of various animals. I have added a short account of some sleep disorders, such as sleep paralysis and narcolepsy. The chapter on the hypothalamus has been largely altered and the chapter on hormones has been entirely re-done; in this subject advances and retreats are made every day.

The first chapter of the book is introductory, starting with a concise explanation of what the nervous system does, followed by basic fats of its anatomy. The five senses are discussed in chapters 2–7. Following the five senses, there is a chapter on the senses unnoticed by the Greek philosophers, the senses of the body itself, muscle sense, the sense of balance, the sensations of the visceral organs. Chapter 9 is on the physics of the nerve impulse; for this chapter some knowledge of physics and chemistry is an advantage. How neural messages are sent around the central nervous system is discussed in chapters 10 and 11. What the brain decides to make the body do is nearly always some sort of activity; otherwise it is repose from activity. Activity means moving. Chapter 12 concerns moving, and that includes everything like building a nest, moving your eyes up and down, standing and running, breathing, or playing the violin. The chapter on pain is chapter 13. Pain is not only a sensation; it is a sensation accompanied by emotion. It is the same for every kind of sensation, though the strongly unpleasant emotion accompanying pain forms an obvious example of this.

Psychologists used to imagine that animals did not react or behave until they were stimulated; they were just blanks waiting to be stimulated; and they then reacted. That is exactly how it is not. Animals are inquisitive and go out to explore the world. They are seeking what is interesting to them. Curiosity, as we know, killed the cat. This exploration and seeking stimulation, and its opposite, lying resting at home and going to sleep, is discussed in chapter 14. How animals are motivated is the theme of chapter 15 and the anatomical bases of motivation are the subject of chapter 16. Chapter 17 is on the endocrine glands and hormones, the chemical messengers affecting the structure of tissues and the animal's total behaviour.

With chapter 18, we come to the higher levels of neural activity and the higher levels of the brain. What we have learned about the brain by the electrical stimulation of parts of the brain in conscious patients during operations is reported in chapter 19. Chapter 20 is about sensation. A section on what the visual cortex receives has been added; this is based on the work of Professors Hubel and Wiesel and subsequent investigations; a similar section on the auditory cortex has been added.

People tend to think of what the brain does only in relation to what are called the higher nervous activities: these are thinking, calculating, remembering, learning, reading and writing. This part of neurology is discussed in chapters 21, 22, and 23. The chapter on speech has been written at a more advanced level than before; it now includes an account of American psychologists' work on teaching chimpanzees to read and write. The short section on congenital dyslexia has been enlarged, as this trouble is now generally recognized to have a neural and anatomical basis. The ability of a unicellular animal, the paramoecium, to learn is now discussed, and how cockroaches' legs learn is also reported, as well as how human beings can learn to control the involuntary or autonomic nervous system. More has been added about phrenology, which was at first a real advance in our knowledge of the anatomy and physiology of the brain. The final chapter on some aspects of personality and the brain now reports another case of a man who had a bullet through his brain, which he introduced by shooting himself in the wrong way. The part on the results of leucotomy has been shortened, as this operation is no longer carried out.

Although the writer of any book imagines his ideal reader starting on page 1 and continuing absorbed to the hard-won words—'The End', I have tried to write this book so that any single chapter may be read on its own or left out.

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1 Functions and structure of the nervous system of vertebrates

The function of a nervous system is to keep its possessor informed about the world. All animals need to have a continuous supply of information about what is happening; and things are happening in two worlds, the world outside the body and the world of the body itself. The actual state of affairs around the animal is not reported; the nervous system provides a selected representation of the environment which is meaningful to that animal Anything changing is noticed with vigilance, for it could be desirable or dangerous. Particular notice is always given to the behaviour of other animals, especially those of one's own group. Adaptation to one's environment, and this includes one's fellows, is a first law of life. It requires, among other attributes, memory and the continual filling of the memory store.

The function of the nervous system is to provide its possessor with the ability to move, both move around the world and move its own body. It arranges the movements of the parts of the body, the limbs and tongue, and the unseen parts, such as the stomach and other viscera, the bladder and the rectum.

Nervous systems of vertebrates consist of the brain and spinal cord, called the central nervous system, and the nerves running to and from the central nervous system, called the peripheral nervous system. There is another part of the nervous system, the autonomic nervous system, sympathetic and parasympathetic. This is the nervous system of the viscera and blood vessels, the glands and the skin. It helps to adjust the animal to its environment, either in preparing for action or for relaxation and sleep.

In the earliest and simplest vertebrates the central nervous system was a tube running the length of the body; later it became encased in bone. During evolution the front end of this neural tube enlarged into three swellings which developed into the brain. As the central nervous system is buried inside the body, it has to be kept in touch with the world and with everything that is happening in the body. Peripheral nerves are cables of nerve fibres that bring messages to and from the central nervous system. The ones going to the central nervous system, called afferent nerves, report what is happening outside the body, things that can be seen or heard. The nerves coming away from the central nervous system called efferent nerves go to muscles, glands and viscera. The nerves are joined to the spinal cord and brain, passing through holes in the skull and vertebral column. Nerve fibres convey messages coded in pulses, like the morse code. These pulses are simply called, nerve impulses. When the nerve impulse reaches the end of the nerve fibre, it puts out a chemical substance that acts on the structure to which the nerve is running. Some nerve fibres are specialized in secreting this substance, so that the difference between this kind of nerve and a gland pouring out a chemical substance is a matter of degree.

The nervous system is made up of cells, like every other tissue of animals and plants. The principle cell is the nerve cell or neuron. There are two sorts, excitatory and inhibitory; the excitatory cell brings other cells into activity and inhibitory neurons cancel this out, tending to stop the activity of other neurons. Neurons of the central nervous system are collected together in layers and in small groups; these groups of cells are called nuclei and one is a nucleus. Both nuclei and layers of neurons are often called centres, particularly when their function is being thought of; and so one has visual centres, a vesical centre to work the bladder, and autonomic centres working the autonomic nervous system. To the naked eye, collections of neurons in nuclei or layers look grey and so they are called grey matter; nerve fibres are white and they make up the white matter.

A photograph of a living neuron is shown in Plate 1. This neuron was dissected out of the brain of a rabbit by Hydén of Göteborg University in Sweden. The neuron has been magnified 1·800 times. The main mass of this cell is the cell-body; the arm-like structures streaming out of it are the dendrites, branching prolongations of the cell. One of the cord-like prolongations of the cell-body is the axon; this might be the tentacle in the bottom on the left. The axon is the long thin telegraph wire of the neuron, conveying the message from the neuron to muscles, glands or other neurons. The pale circular spot in the middle is the nucleus of the cell, and in the middle of the nucleus is the black nucleolus. The little black spots on the surface of the cell-body and the dendrites are the nerve-endings of other neurons, passing excitatory or inhibitory messages to this neuron. Between these nerve-endings and this neuron is a minute gap, called the synapse (Greek for grasp).

The brain is an enormously enlarged part of the spinal cord. Where this enlargement starts is a part of the brain that is obviously an enlarged spinal cord; this is called the medulla oblongata, having no name in English. It is shown in Plates 10, 11, and 12. This basic part of the brain organizes basic functions—the heartbeat, the blood pressure, breathing, swallowing.

The position of the central nervous system in the body of man is shown in Plate 2. The lowest part of the brain, the medulla oblongata, is seen to lie behind the hard palate and the upper part of the cavity of the mouth. The cerebral hemispheres, of which the left one is seen here from the midline, are by far the largest part of the brain and they fill most of the cavity of the skull. The hypothalamus is in the centre of the front part of the brain. Running forward from it, the stalk of the pituitary gland can be seen. The various structures shown in this photograph will often be referred to in the subsequent chapters of the book; and reference to it will show why we speak of the parts as being in front, behind, above, and below.

2 Examining the world

All living organisms since the beginnings of life on earth have passed their lives under the influence of certain permanent physical features of the world. Such are night and day, the increasing duration of daylight as spring follows winter in the Northern and Southern Hemispheres, various kinds of movement of the environment, winds, currents, waves, tides in the sea; there are sounds, usually made by other animals; there is the ambient temperature and barometric pressure; and, less obvious, there is gravity and the earth's magnetic field.

In some organisms these forces are felt by all the tissues of the body, in others they are felt by special cells; these cells and the tissues in which they are encased are called receptors. The receptors are either specialized cells connected to nerve fibres which take the information to the central nervous system; or they are the nerve fibres themselves without specialized cells. Not all species of animals are sensitive to all the physical characteristics of the world. Birds, snails and fish can sense the geomagnetic field and they use it to find their way around. Termites tend to orient themselves in an east-west direction; this is also based on the earth's magnetic field. Although we human beings think we know nothing of the earth's magnetic field, Dr Robin Baker of Manchester University has discovered that we make use of it for finding our way about. He blindfolded volunteers and then took them on journeys; then he took the bandage off their eyes and told them to point towards their homes. They were surprisingly accurate, pointing in the right direction. They were better at getting the direction right when they had been blindfolded. If they had the usual visual clues or noted the position of the sun or tried to work it out intellectually, they did not do so well. If he repeated these experiments, this time with magnets fixed against their heads so as to disrupt the sensing of the geomagnetic field, the people no longer knew in which direction their homes were. All living organisms have developed over millions of years with the forces of geomagnetism exerting a constant influence. It is nevertheless surprising that the electromagnetic field has an influence as it is very weak, far weaker than that produced by hair-dryers and television masts. But it is continuous and ubiquitous.

Man is insensitive to two aspects of light which some other animals can sample—polarized light and ultraviolet light. Man's hearing is rather limited in the upper range compared to that of small mammals and the larger mammals of the sea. In general, animals have no sensory receptors designed to respond to features of the environment that they do not normally meet. Animals that live in caves are mostly pale and blind. There would be no point in going to all the trouble of being pigmented if there were no one there to see you. These troglodytes concentrate on smell, taste and touch. The tick can neither see nor hear, but its sense of smell is attuned to the sour smell of the mammals on which it feeds. It is also sensitive to warmth so that it can tell when it has landed on a warm-blooded creature.

Of the many kinds of animals that are sensitive to the same sort of energy, each class of animal does not have the same sort of receptor, nor does it have the receptors in the same part of the body. Many fish, for instance, have taste receptors not only in their mouths but also scattered over the surface of the body. These are not so much to enjoy food with as to detect it, to find the particles of it suspended in the water. Fish with barbels, such as the sturgeon or the red mullet, have taste receptors on the barbels. The barbels are like the antennae of insects, on which there are olfactory receptors, the sense organs for smelling. Mosquitoes also feel radiant heat with their antennae. The receptors of those spiders who build webs are on their legs; they feel the vibration which is set up by the insect caught in the web with their feet and legs. Many sorts of butterflies and most flies taste with their feet. Flies have their olfactory receptors for smelling on their antennae and palps. When a fly finds some food, it steps into it so as to taste it. It then makes use of other taste receptors on the hairs surrounding its mouth. If the food tastes good, it sucks it up. When it is replete, it vomits a little and then defaecates. If we behaved in this way, we would find a restaurant by smell and not by sight. We would go in and stand in the food. We would give a preliminary opinion on the food, put our moustaches in it, and then give a definite opinion on it. If the food was good, we would suck it up until we felt full, vomit some back on the plate, defaecate on the floor and go. Clearly, it takes all sorts to make a world.

We all have our limits; man is able to sample only certain aspects of the world. Mammals on the whole are less limited in their sampling of the environment than insects. Simpler animals may be able to use only one kind of sensory information. Female crickets recognize the male of their own species only by the chirping sound it makes with its wing-covers. If male crickets are placed beneath a glass from which no sound escapes, the females take no notice of them, even though they can see them. Wasps recognize female wasps entirely by their sense of smell.

Blinded wasps can easily find the females. But wasps in which the antennae have been removed do not recognize female wasps; for on the antennae are the chemoreceptors sensitive to the smell of the female abdominal gland secretion. So important is the sense of smell that after the female's scent glands have been dissected out, many male insects attempt to copulate with the glands and not with the female herself.

Bees and ants can see ultraviolet light, but they cannot see into the red part of the spectrum as far as we can. Red appears black to them. Many insects can see the direction of polarized light. Man is so intelligent that he makes use of the receptors and sensory systems of other animals. He trains pigs and truffle-hounds to smell out truffles beneath the ground; he uses bloodhounds to smell out the trails of men he wants to track down and St Bernards to find men lost on the mountainside. As we have only recently learned about animals being sensitive to sounds of very high freqnency and insects being sensitive to polarized light, we may well learn of further sensitivities of living organisms and through them come to appreciate other aspects of the world.

Receptors are used in the same way by all animals. Animals do not wait around until they are stimulated. They use the receptors of their sense organs to explore the world. Books usually say that the eye is for seeing. It is not, it is for looking; the ear is for listening, not hearing.

Receptors are usually classified as exteroceptive, those sampling the environment, interoceptive, those signalling what is going on within the body itself, and proprioceptive, used for controlling the position of the body and its parts. Exteroceptive receptors are for taste, smell, vision and hearing. The proprioceptive receptors or proprioceptors are receptors within the inner ear used to report the position of the body in space and those used for sampling the position and the movement of the head, the limbs, and parts of the limbs. The interoceptive receptors convey information about the bladder, the gut and the pressure the blood exerts against the walls of the heart, the blood vessels, and within the brain itself; others report on the amount of oxygen, carbon dioxide, and glucose in the blood, and others are sensitive to the osmotic pressure of the blood, others to the temperature of the circulating blood. There are receptors sensitive to stimuli that cause pain throughout most structures of the body. There are no receptors sensitive to painful stimulation in the brain itself. Patients carry on conversations unconcerned while needles are passed through their brains.

Receptors are also classified according to the sorts of stimuli to which they are sensitive. In this classification we have the chemoreceptors, for instance receptors sensitive to carbon dioxide or glucose; thermoreceptors, sensitive to changes in temperature; nociceptors, sensitive to stimulations that threaten to or actually do damage the body; and mechanoreceptors which are excited, by pressure on the skin, by pulling or stretching the skin or merely indenting it. Many mechanoreceptors are hairs of the skin or hairs on the cuticle of insects. Insects have mechano-sensitive hairs on the legs which tell them about vibration. One hardly knows whether to call these hairs tactile organs or hearing organs. For mammals use hairs in the skin to report low-pitched vibration and similar hairs in the inner ear to report high-pitched vibration; the first is called touch and the second is called hearing, yet the mechanism is similar in the two cases.

Receptors are also classified according to whether they report a constant state or a changing state. Constant state receptors continue to send in impulses to the central nervous system as long as a certain state, such as a temperature, remains constant. Changing state receptors signal a change in the stimulus. These are the commonest sort of receptors, for all animals need to know about new events. Whenever a stimulus first affects the body, that is something new and maybe important; so this kind of receptor sends in a volley of nerve impulses. It is of equal or almost equal importance to know when the stimulus goes; so that is signalled with equal intensity. The continued presence of the stimulus maybe less important, and so this is signalled with fewer and fewer impulses. In some cases there is a constant slow discharge of impulses; in others, they cease altogether.

There are two features of all kinds of stimulation: intensity of stimulation and localization. Intensity is reported to the central nervous system mainly by the number of impulses sent within a certain length of time. If the brain receives 500 nerve impulses a second, it concludes that stimulation is less intense than when it is receiving 2000 impulses a second. Localization in space, regarding both where stimulation is on the body and where the stimulus is in the environment around the body, is not a great problem; for the body itself and the brain are spread out in space. A cloud in the sky is at the top of the visual field and a worm on the ground at the bottom; they excite different parts of the retinae and are reported by different nerve fibres to different parts of the cortex of the cerebral hemispheres. It is the same with a thorn in the foot or in the finger. A different region in the brain is excited by the different regions of the body that have been pricked. Localization outside the body depends on having pairs of receptors, one on each side of the body. Tastes and smells are not clearly located in space; to do this well, one should have two noses and two tongues, one on each side of the head.

With two ears separated by the whole width of the head, we can tell where a sound is coming from. Two ears give us discrimination between sounds, allowing us to separate one voice out of a buzz of conversation or to hear it in a howling wind. Two eyes give a larger field of vision than one eye and they also provide stereoscopic vision or vision in depth. When our ancestors moved around among the branches of trees, stereoscopic vision must have been a great advantage. For in the forest, you need to tell which of two branches is nearer to or farther away from you. But having groups of receptors on the two sides of the head brings its own problems. We have to make a fusion of what we receive from each sensory organ. Two eyes do not tell us that there are two cats in the room; we interpret the information received by concluding that there is one cat. Our two ears tell us someone is talking to us, not that the sounds of his voice are coming to one ear at one time and to the other ear a fraction of a second later. We have to learn to make this interpretation in babyhood. In seeing, we learn to keep the visual axes of the two eyes parallel. When the young child does not do this, he is said to squint. This should be corrected as early as possible, in the hope that he grows up to use both eyes together.

There are some animals which have a third eye. This organ is on the top of the head; it functions in the reptile known by its Maori name of tuatara, and in some lizards, frogs, toads, in the inguana and lampreys. The third eye is believed to record the amount of sunlight. This information is necessary for the circadian rhythms of the body, which will be discussed in chapter 16. During the millions of years of evolution, plant and animal life has related itself to the cycle of dark and light of night and day. Many rhythms of the body depend on this alternation. In those animals with a third eye, the rhythms seem to depend on this eye; for the rest of us, the two eyes in the face supply the information.

3 Light receptors: looking

For he keeps the Lord's watch in the night against the adversary.
For he counteracts the powers of darkness by his electrical skin and glaring eyes.

Those bandwidths of the electromagnetic radiation that we experience as light have effects on the protoplasm of even the simplest single-celled organisms—in some cases light attracts, in others it repels. As animals evolved, it must have been an advantage to collect in one place all the receptor cells sensitive to light. To enable these cells to absorb the light effectively, a light-sensitive pigment developed in them. In the higher kinds of animal, this region became the retina.

The general arrangement of the eye remains the same throughout the animal kingdom. That is surprising. It appears to be that no better kind of eye could be formed during evolution. The simplest kinds of eye are pits in the skin lined with cells of light-absorbing pigment. These cells react to light and dark; they are the light detectors or photoreceptors. Light affects the molecules of pigment of these cells and this reaction sends off nerve impulses to the parts of the central nervous system developed to cope with reactions to light.

The eye is a ball, of which one can only see the front part. This part consists of a transparent conjunctiva, which gets inflamed in conjunctivitis, a transparent cornea, and behind that a transparent lens. Lining the eyeball is the retina. As has often been said, the eye is like a camera. In both eyes and cameras, there is a light-sensitive film, with black backing to absorb the light that has passed through the film. Both have an iris or diaphragm to adjust the amount of light, and both have a lens for focussing. The lens in the eye of the mammal is elastic; its curvature can be adjusted by muscles within the eye; and this changes its focal length. It is slightly yellow; this is like a yellow filter, and cuts out some of the violet light. As we become older, the lens becomes yellower and blue light is not seen so well. Colours appear more orange. It has been suggested that Turner's later pictures all have this orange tone and are lacking in blues on account of this change in his lens, of which he himself would not have been aware.

The human retina is amazingly sensitive to light; we can see a single candle at night five miles away. The range of light intensity to which the retina can respond is equally amazing, for between the slightest amount