The Human Brain

Dick Gilling and Robin Brightwell

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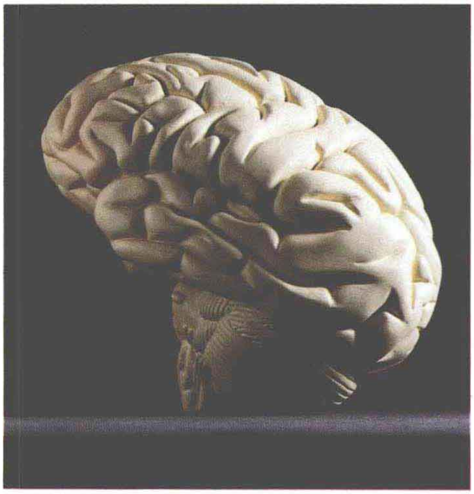

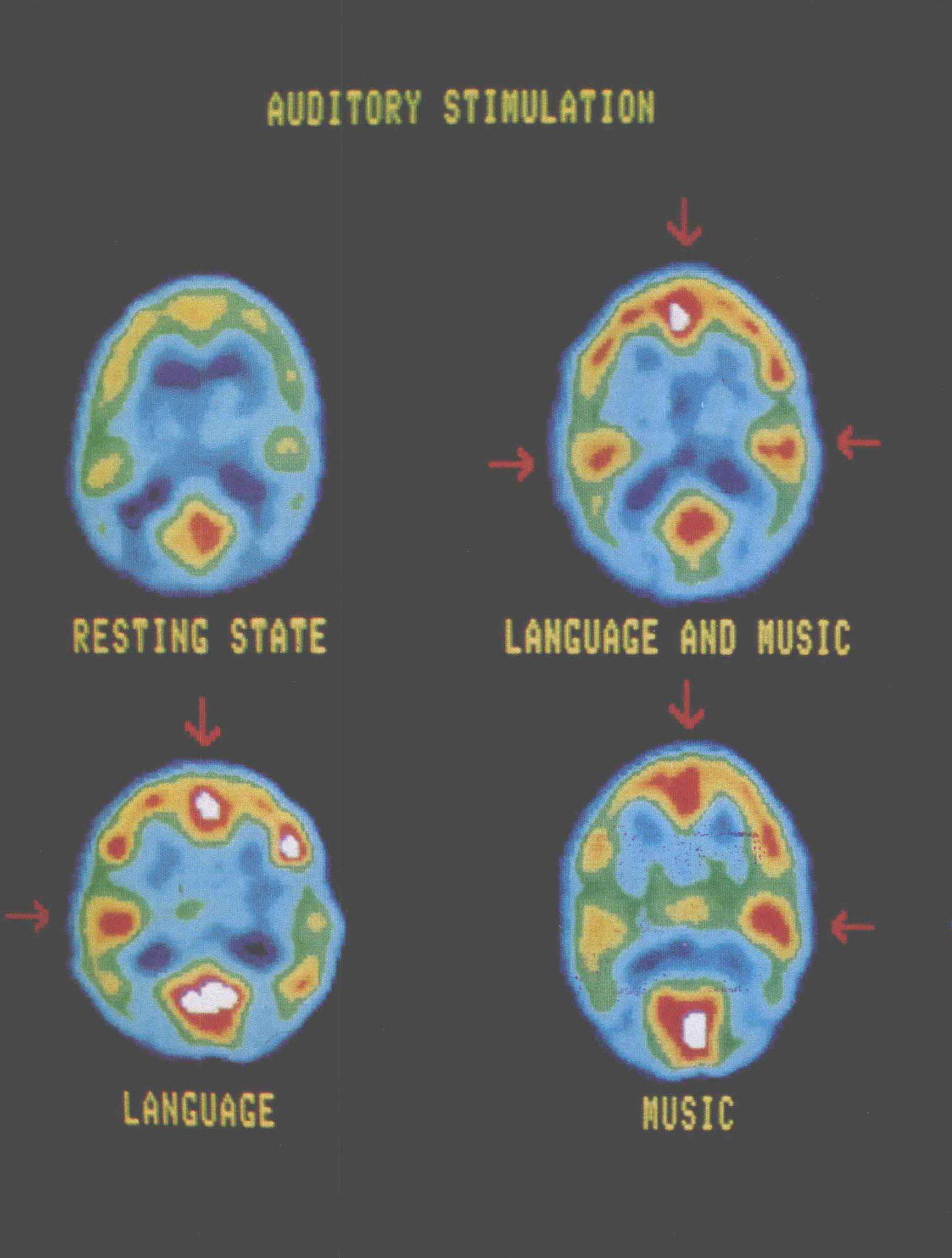
AUDITORY STIMULATION
RESTING STATE
LANGUAGE AND MUSIC
LANGUAGE
MUSIC

The Human Brain

Dick Gilling and

Robin Brightwell

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British Broadcasting Corporation

Dedication

To those whose handicaps and disabilities have helped towards the understanding of the healthy human brain.

Half-Title Page

The human brain: increasingly the symbol of scientific controversy and daring investigation.

Frontispiece

A PET scan of a living human brain. Areas which are most active are shown in red, and in these examples it can be seen that listening to language causes the left side of the brain to show activity, while listening to music causes more activity on the right side. Even at rest, the brain remains active in some areas.

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AUTHORS' ACKNOWLEDGMENTS

Soon after we started research for the television series on which this book is based, we agreed that it would be futile even to attempt to deal with all the science of the brain. This could not be done in seventy programmes, much less in seven, and so this book is not an encyclopaedia of the brain. But we have added a short Atlas of the Brain to which the reader can refer for clarification of words or terms used in the rest of the text, and which gives a simple account of how the brain is put together, and how it works. There are very many schools of thought in the field, and we have tried to reflect all of them as fairly as we can, but in the process many details have been omitted to give an overall view.

During the two years that it has taken to make our programmes, we have relied with our colleagues, on the goodwill and the advice of over a hundred scientists in all fields, in Europe, Britain, and the United States. It is their information that we have used in constructing the programmes and in writing this book; our effort has been to combine that information in a comprehensible way, and to simplify without, we hope, misleading. These scientists have given us their time generously, have answered (often stupid) questions courteously, and have in many cases subjected themselves to the stress and indignity of being filmed. Only a few could be included in the programmes; but many others helped to construct the series by their advice, or pointed us in new directions. Without the generosity of all these people in the scientific community our work would have been impossible, and we owe them a great debt of gratitude. With their help, we have been guided on a voyage of discovery, the results of which are contained in this book; and in many happy memories.

Even the most apparently iron-bound results of these scientists may be subject to different interpretations; science progresses by disproving theories as well as by proving them. Inevitably, we have sometimes been arrogant enough to give opinions, or theories, as well as facts. We hope that they are well-founded.

It would also have been impossible to make the programmes or write this book without the collaboration of the many patients who generously agreed to be filmed. A person who is in some way handicapped, who cannot speak clearly, whose memory is grossly defective, or who has spent many years in psychiatric hospitals, is easily hurt. Many people shared their pains and frustrations with us, and allowed us to watch them and film them in conditions that throw a revealing and potentially cruel light on their handicap. Like us, they were convinced that meeting a problem face to face may not be the easiest way to live; but it gives understanding where that is most needed. Most of these brave people will never be cured, but they taught us that they were not cases, or examples, but always people, like those of us lucky enough not to be maimed by injury or disease. They gave us perhaps the most important information of all: the brain is not so sacred that an injury to it takes away our humanity. To all of them we are deeply grateful.

A television programme is a collective enterprise. We are also in the debt of all those who worked on these programmes, not only for their professional skills and advice, but because their questions and conversation obliged us to re-work and clarify our ideas, and led us into paths we might have otherwise missed. Our thanks are due also to the BBC, and to Belgian Radio and Television and the Australian Broadcasting Commission, who provided the finance and encouragement to produce the programmes.

We would also like to thank the researchers, Gill Nevill and Max Whitby; the picture researcher, Pamela Smith; the production assistants, Ann Larman and Jane Amin; the film cameramen, Colin Munn and Ian Stone; the assistant cameramen, Richard Adam and John Rhodes; the sound recordist, Alan Cooper; the film editors, Les Newman, Paul Pierrot, David Lee and Michael Flynn; the assistant film editors, David Good, Christy Hanna and Nick Morris; the graphic designer, Darrell Pocket; the visual effects designer, Mat Irvine, and the many other artists and technicians who contributed to the series.

INTRODUCTION

As infants grow through their first years of life they gradually develop an identity. Each child gets the feeling that he or she is a unique human being. It is that feeling, remaining with the individual until death, which makes it difficult for us humans to comprehend the contributions of our brains to ourselves.

To imagine how the firing of nerve cells in the brain and limbs can move an arm or leg is easy enough. But to accept that nerve cells and nerve cells alone are responsible for language, memory, imagination, and feeling of identity, the self, in fact the mind as a whole, is not easy and for most individuals has until now been impossible. How could the feeling of oneself arise from millions and millions of electrical signals in the brain? The complexity and actual perception of one's own feelings make this 'mechanistic' approach to the human being unacceptable to most individuals. Religion, particularly Christianity, argues that there is a soul, separate from the brain, even from the mind. Even those who are not believers often feel that to explain human function through the electrical and chemical signals of the brain is to convert man into nothing more than a machine.

In this one book we cannot hope, nor would we wish, to counter the arguments of religion, or to argue against the *feeling* that individuality must be more than the product of the firing of nerve cells, but we do wish to allay fears that this approach turns humans into nothing more than machines.

Allaying those fears was relatively easy in the actual programmes on which this book is based, since we could film those people whose brains and minds we were describing and show, merely by their behaviour and what they said, that they were humans, whatever mechanistic explanations we gave for their activities or disabilities. In a book it is more difficult to give that impression.

The individual is made up of the human faculties which depend entirely upon the firing of his or her nerve cells (and all the other cells in the body and brain). But the whole individual is far more than the mere sum of all his or her nerve cells parts. Human beings are often credited with a separate mind that is of a different nature from the nerve cells of the brain; the underlying and powerful reasons why the mind is so often seen in that light, as separate, are either failure of imagination, or of courage, or both, on the part of scientist, philosopher or plain ordinary person. Imagination is needed to see how nerve cells can give rise to the wildest dreams, greatest achievements, and worst excesses of man; courage is needed to be prepared to lay the human a little barer, metaphorically more naked, than he usually wishes to be. The idea that we arise from no more than electrical and chemical signals may create a lonely feeling, but not if one takes the wonderfully optimistic and natural human view that we are more than the sum of those parts. We still have choices, free-will. We still have moral values. We still have love and imagination. We still appreciate beauty. The modern, mechanistic approach does not make man into a laboratory rat, but it raises a fascinating question: if biological elements alone give rise to all that is human, how on earth do they actually achieve it?

We have used the mechanistic approach throughout this book because we believe science is just on the verge of throwing light on this question, far though we still are from a complete answer. In each of our chapters we have attempted to give some insight into the brain's control of such faculties, but in none of them are humans de-humanized. We hope this insight makes them marginally more aware of what might be going on inside their heads and possibly a little prouder of it.

An Atlas of the Brain

This brief, illustrated account of the parts of the human brain and their connections will make the following chapters easier to read. Some of its information may recur later, often in more detail, where it is of importance to the topic of a particular chapter.

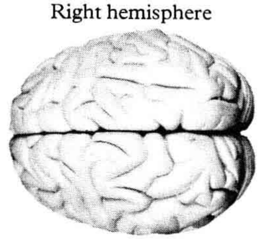
Inside the Skull

The brain of a human being, when exposed, looks rather like an enormous walnut; it weighs about three or three and a half pounds and is made up, like other organs, of cells. Unlike a walnut, it has been mapped in minute detail; even the apparently random surface corrugations by which we all recognize the brain have names. Since the learned men who first dissected the brain used Latin and Greek, the languages of scholars over the centuries, the names of various parts of the brain are based on Latin and Greek terminology, which may at first be alarming; but one soon realizes it only represents a series of valiant attempts at describing the indescribable. So, that wrinkled outside of the *cerebrum* (brain) is the *cortex* (bark) and is divided into *gyri* (ridges) and *sulci* (valleys). The small, ridged projection at the back is the *cerebellum* (little brain), and so on.

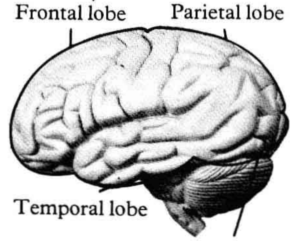
The Cerebral Hemispheres

The wrinkled cortex is the surface layer, about 3 or 4 mm thick, of the two most notable parts of the human brain, the cerebral hemispheres, which are far larger in the human than in any other animal. As a result of the wrinkling of the cortex, the area of cortex is much greater than that of the skull in which it is contained. The two cerebral hemispheres, almost but not quite mirror images of one another, together constitute the cerebrum; and each hemisphere is divided into lobes, the 'continents' of the cerebrum. At the front, of course, the frontal lobe; at the side, the temporal lobe; on top, the parietal lobe; and at the back of the head, the occipital lobe. Each lobe is roughly associated with a different function: the parietal lobes seem to contain areas responsible for co-ordinating the input of our sense organs and the output of instructions to our muscles;

View from the Top
The wrinkled surface of the two cerebral hemispheres, the cortex, much greater in area than the cortex of any comparable animal brain.



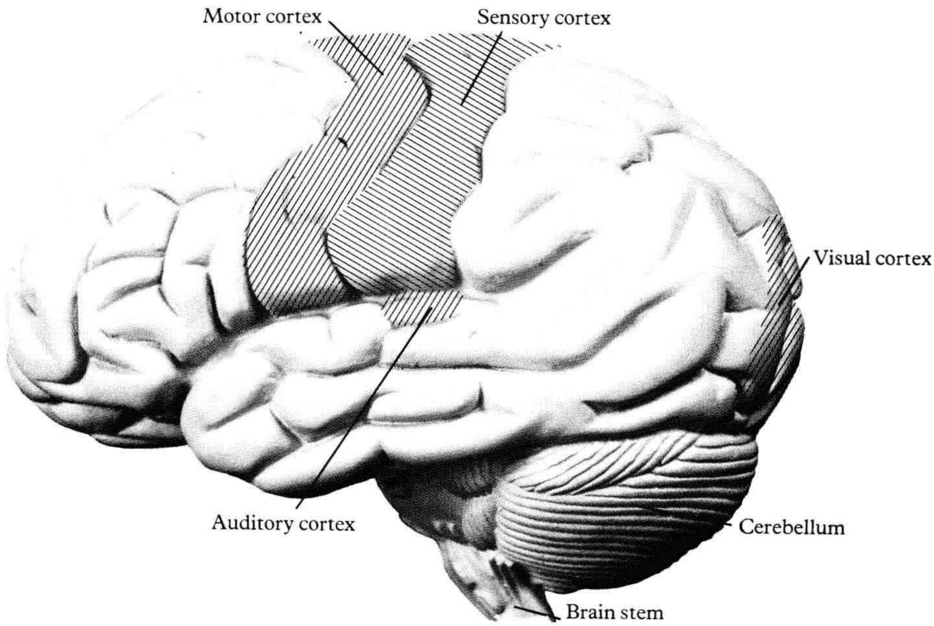
Lobes of the Brain
The frontal lobe (*left*) under the forehead, may deal with matters of the intellect, including planning; the parietal lobes (*top*) include sensory and motor areas; the temporal lobes (*centre*) include regions concerned with memory and emotion; the occipital lobe (*right*) includes visual regions.



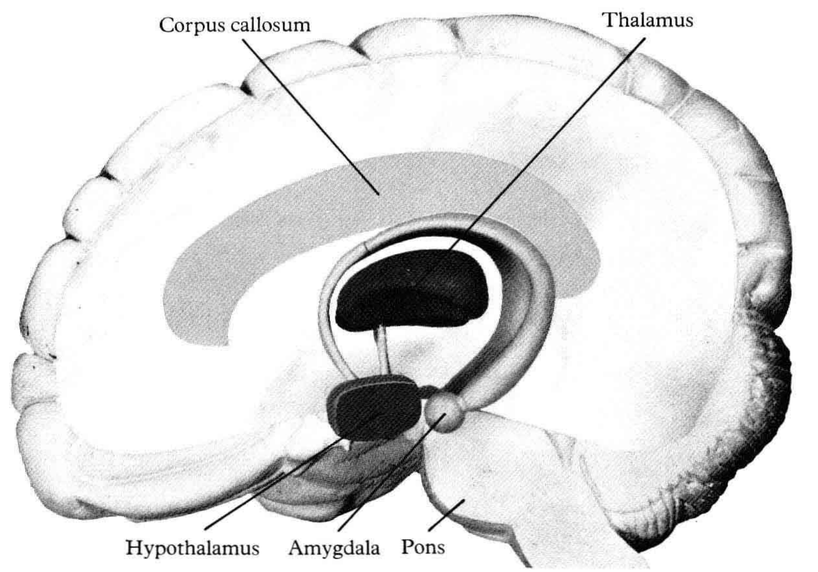
and the temporal and frontal lobes seem to deal in less concrete matters, such as speech and memory.

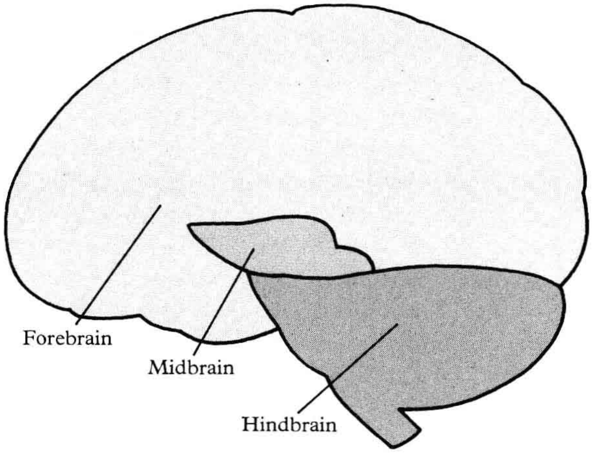
The two hemispheres are joined by a thick bundle of whitish fibres, the *corpus callosum* (or tough body). Bordering the corpus callosum is the *limbic* (bordering) lobe, an area involved in, among other things, emotion. Then comes the egg-shaped *thalamus* (inner chamber, or bedroom!) which is junction and interchange for many fibres, almost in the centre of the brain; below it, the *hypothalamus* (below the thalamus), concerned with emotions and regulation of body temperature and state, and with the secretions of the pituitary gland, nestling in a bony hollow at the base of the skull. All these structures, with many subdivisions, constitute the forebrain.

THE LEFT HEMISPHERE
This hemisphere, in the great majority of cases, is responsible for language. It also contains regions responsible for vision, sense and movement on the right side of the body.



INSIDE THE RIGHT HEMISPHERE
The connection between the hemispheres is the corpus callosum. The thalamus and hypothalamus both contain many nuclei dealing with specific functions of body and brain.





THE BRAIN HIERARCHY
The brain stem, of hind and midbrain, evolved earlier than the forebrain, which is more associated with so-called higher mental functions or conscious states.

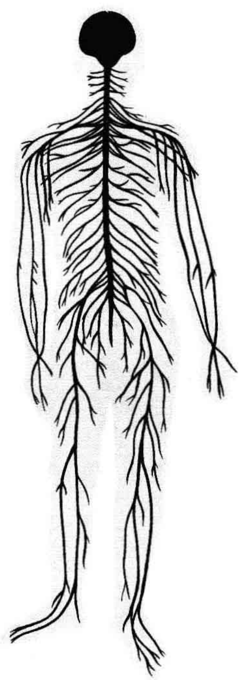
The midbrain (or *mesencephalon*) is much smaller; among its duties are the control of responses to sight and sound, and some control of sleep and waking. The hindbrain includes the cerebellum, involved in the management of movement, and many tiny bumps and lumps with particular functions, too numerous to name. Midbrain and hindbrain are often grouped together, and called the brain stem, one of the few instantly intelligible terms in the neurosciences.

FROM BRAIN TO BODY

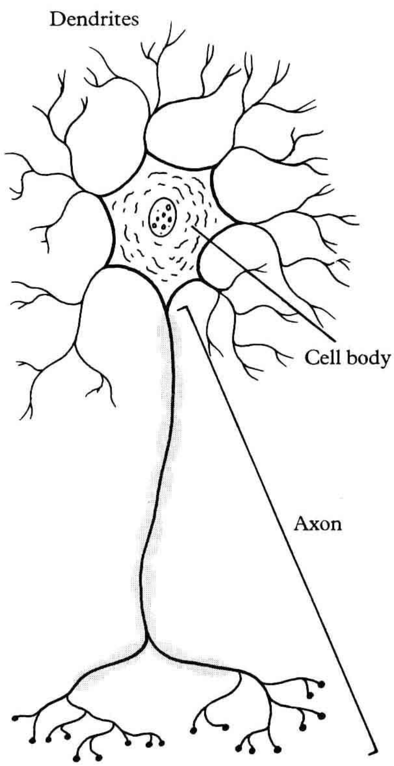
Connecting the brain stem to the rest of the body, the spinal cord contains regions which have their own functions; NCOs, perhaps, to the brain's officer-class. But much of its bulk carries fibres running from the brain to connect with muscles or sense organs far away from the brain, in fingertips or feet.

The brain, the brain stem and the spinal cord together are the central nervous system. The network running through the rest of our bodies, nerves telling us about toothache or biting fleas, is the peripheral nervous system. But beware of placing them in separate compartments; the peripheral nerves are constantly supplying the brain with information to update its plans, and the brain is constantly altering the receptivity of the peripheral nerves; there is a continuous dialogue between all parts of the brain and the rest of the nervous system. Our plan of lobes and Latin names does not divide the brain into separate compartments. The job of being human is shared among all of them, and the labels were attached only by fallible mortals trying to map a jungle.

There are many more parts of the brain, large and small, that have been identified and given names; too many to include in this survey. We have avoided the use of these technical terms as much as possible in the following chapters, but where their use is unavoidable, reference to the Glossary should help.



THE NERVE NETWORK
From the central nervous system of brain and spinal cord, peripheral nerves spread to each part of the body. The illustration shows only the main nerve trunks, from which other tiny nerves branch.



The Nerve Cell
All the nerve cells, or neurones, in the system have this general plan: from the cell body sprout dendrites, to receive impulses; and an axon, to send impulses.

The Nervous System Analysed

The whole of the nervous system is made up of cells. Nerve cells (or neurones; neurons in the United States), unlike other cells in the human body (blood cells, for example), send out many fibres or processes. Some, the dendrites, receive signals from other cells; others, the axons, which usually also branch, are the message senders; they may be as short as a tenth of a millimetre, or as much as a metre long. Each nerve cell or neurone is in contact with about 1000 other nerve cells. And the brain itself is made up of about 1,000,000,000,000 nerve cells; maybe ten times more or ten times less. The number is too big to comprehend: but, if you spent one second counting each nerve cell, you would be at it for 30,000 years or so; to count each contact, multiply by another few thousand, for nerve cells usually have more than one point of contact with each other. The grey matter of the brain, including the outer 3 or 4 mm of the cortex, and various other areas, is composed of the cell bodies; the white matter is composed of axons, coated with insulating sheaths of fat.

A cell passes information along its fibres in the form of electrical signals (varying not in strength but in frequency – a sequence of dots, fast or slow), but the message passes to the next cell, at a synapse, in chemical form. The *synapse* (handclasp) is the microscopic area in which messages pass from one cell to another. When the electric wave reaches the synapse, it causes the cell to release a chemical substance which diffuses across the synaptic gap to the next cell, which then converts the chemical message once again to electricity. Once used, the chemical is reabsorbed into the cell or destroyed by an enzyme.

Each nerve cell has thousands of synapses. The synapses, converging on a cell, determine democratically how the cell will act. Some, the excitatory synapses, will cause the cell to fire, while others, the inhibitory synapses, will prevent it firing. So rather roughly, if more excitatory than inhibitory synapses act, the cell will vote to fire; more inhibitory, and it will refuse to fire. And, since the synapses monitor the 'votes' of other nerve cells, the democracy is an all-embracing one.

In all likelihood, the position of synapses also determines the strength of their influence; synapses on the dendrites may be less powerful than those on the cell body, or vice versa. Different types of cell, and there are many, may process the 'vote' in different ways, but we do not yet know how. It is just possible that cell A may have an inhibitory effect on cell B but an excitatory effect on cell C; even the rule about chemical transmission is not inviolable; just after chemical synaptic action was established, in the 1950s, some electrical synapses were discovered. There are even axon-to-axon and dendrite-to-dendrite synapses, which deepen the puzzle still more. In short, the brain is full of surprises, and it seems to be the case that no simple rules will necessarily be obeyed in all circumstances.

THE CHEMICAL HANDSHAKE

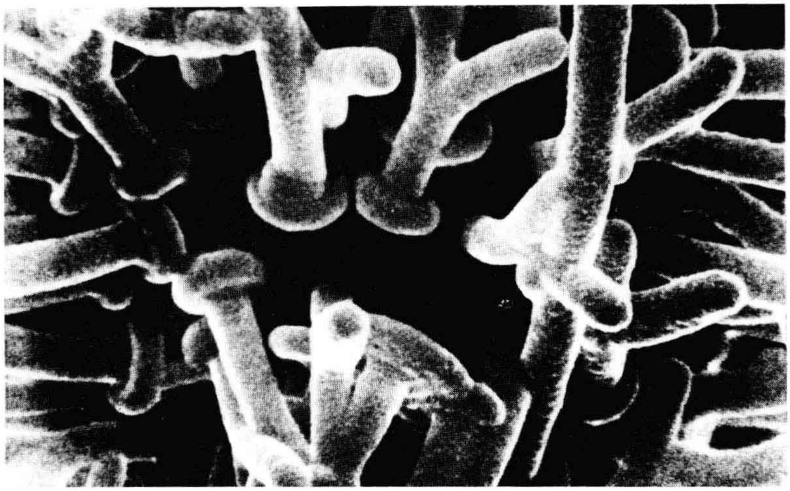
The chemistry of the brain, too, has turned out to be less straightforward and far more exciting than we dreamed of, even ten years ago. At that time, the general consensus was that only two chemicals, or two classes of chemicals, would be involved in synaptic transmission: one would be inhibitory, one excitatory. They were named neuro-transmitters; and it was held that each cell would produce and use only one, either inhibitory or excitatory. This dogma is no longer universally accepted. Furthermore, many more possible neuro-transmitters have been discovered; currently over thirty candidates exist. Each of these chemicals may well have different and complex pathways in the brain, augmenting or modulating the pathways that connect cells or regions we already know. And they may not act in the classical fashion of the neuro-transmitter. It seems possible that they may modulate the effects of the cell-to-cell transmission in some way by affecting the inner chemistry of the cell, and therefore its electrical properties.

This area of research is the most rapidly expanding of all, and without doubt new discoveries will add to, and alter, our present conception of the brain.

All of this complexity, however, can be made to conform, more or less, to a simple theory of what the brain does. Inputs from our sense organs, eyes, ears and so on, enter the brain, which decodes and processes them, and sends output to our muscles, resulting in actions. The only hitch is that we, as yet, know much less about processing than we do about input or output. Even so, we do know that some of the processes are born into us; hard-wired, as some neuro-scientists call it. Others seem to be learned, which suggests that not all the brain is hard-wired, but that its connections can be broken and reconnected in different ways.

Nerve cells in the brain die from about the time when we are eighteen, and new ones do not grow; but existing cells can put out new fibres, and send them long distances. This is easier for peripheral nerves than for nerve cells in the central nervous system, but even there it is not impossible. It may be that we can manage with fewer brain cells than we are born with; but we would be rash to surrender any of them without a struggle. The brain probably manages to cope with the death of cells, either through age or injury, by making new connections; but even for the hundreds of millions of cells in the brain, there has to be an end to this process somewhere.

In some ways, the central nervous system is cut off from the rest of the body. The so-called 'blood-brain barrier' serves to prevent many potentially unwelcome substances in the blood from



Nerve Fibres
At a magnification of 5000 times, mushroom-shaped swellings containing synapses are visible at the axon tips.

reaching the brain, presumably by a filtering process of some kind in the blood-vessels supplying the brain. The brain and spinal cord have their own fluid supply in the cerebro-spinal fluid that surrounds them and fills their cavities; but they have a blood supply, too. In fact, though the brain is only two per cent of the whole body's weight, it consumes twenty per cent of the oxygen and glucose carried by the blood – ten times more than its share. If the blood supply is interrupted for more than a couple of minutes or so, the cells are so starved (they carry no reserves) that they will die. That is what happens to part of the brain in a stroke.

It is one thing to describe the brain in terms of a simple atlas, as we have done here, or even in more detailed form, analogous to an Ordnance Survey map. (That the latter can now be done is a tribute to the industry and skill of brain anatomists, whose work continues to illuminate our picture of the structure of the brain.) It is another thing to relate this structure to the functions of its various elements, and then to relate those functions to our own behaviour.

But we can already take some infant steps along that road, and begin to see how the brain gives us our ability to speak, see, move or remember. The following seven chapters describe some of the ways in which we are beginning to understand how the brain may accomplish its formidable tasks. If we begin to understand how we act, some day we may understand also why we act as we do, come to terms with ourselves, and solve the problems that have pursued the human race ever since Cain killed Abel, or since Pandora opened her box, or even since Prometheus stole fire. We had better start somewhere.

CHAPTER I

MEMORY

It is not always possible to understand a machine by analysing its parts. We need to know what the machine is intended to do. There is no doubt that we use our brains for remembering, but before we try to track down memory in our brain cells, we must know the nature of the process of remembering. That is the business of the psychologist. Later in this chapter we shall see that we can begin to trace some connections between our memories and our brains in physical terms, but there is first of all much to reveal about our understanding of memory.

Memory takes many forms. It is the short-term memory which enables us to remember a telephone number, for example, just long enough for us to dial it. Once the number is ringing then we forget it. That memory needs to last only seconds. But what most of us mean by memory is what is called by psychologists 'long-term memory'.

Typically our long-term memories are our recollections of childhood, or of the events of last Christmas, and naturally their durability and vividness will inevitably vary from one person to the next, and according to circumstances.

There are also different categories of memories stored in the brain. We certainly have recollections stored variously in the form of words and pictures, but we can also recall sounds, smells and tastes from our memory store. Add to these the ability quickly to recover unpractised physical skills, like icing a cake or riding a bicycle, and the brain's memory function begins to look very impressive.

Perhaps impressive is the key word. For however else our memories differ, they have made sufficient impression upon us all to qualify for storage, then to be stored and, sometimes, to qualify for recall when we most need them.

In this chapter we shall investigate the nature of the process of remembering. We shall see that we can begin to trace some connections between our memories and our brains in physical terms. And by looking at the way in which memories disappear, the ways in which we forget, we shall gain a greater understanding of memory.