# Brain, Mind, and Behavior



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Revised Printing

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# Brain, Mind, and Behavior

# Preface

Scientific study of the brain and behavior has attracted increased popular interest over the past few years. This is due in part to the rapidly accelerating pace of fascinating discoveries about the brain—its cellular structure, its chemical signals, and its operations. Equally stimulating is the challenge of trying to understand what is perhaps the most complicated living tissue, and the realization that it is, to some extent, at least, understandable. The goal of *Brain, Mind, and Behavior* is to make this ever-growing and exciting body of knowledge accessible to the interested student who may have had little or no background in either biology or psychology.

The orientation of the book is strongly biological and it emphasizes a central concept: everything that the brain does normally, and everything that goes wrong with it when it is diseased, will *ultimately* be explainable in terms of the interactions between the brain's basic components. To provide a clear starting point for this orientation, the student is first introduced to the basics of overall brain organization, using everyday language and a purposely simplified scheme. A more detailed presentation of the brain's components is then developed as we consider the structure of brain cells, neurons and glia, and describe how they work together. From these details, a set of basic principles underlying the structure and function of the brain is developed, upon which the subsequent chapters are based.

The next two chapters examine how the brain enables the body to sense the world and move through it, and how at the same time the brain is able to maintain appropriate internal conditions for optimal physical and mental performance. We then turn our attention to the issues underlying the brain's behavioral responsibilities. We see that the ability of the brain to meet the demands of the environment depends on its ability to coordinate the activity of its several functional systems. Its varying levels of activity are not merely fluctuations, but are, in fact, rhythmic variations in activity that depend in turn on systems coordinating the body with the world around it.

The places in the brain where these coordinating events take place also work within larger systems wherein emotional weight is attached to the sensing of specific environmental signals. These emotional highs and lows help determine which of many possible responses should be given to those signals. Throughout these discussions, the student is urged to recognize an underlying biological basis for complex behavioral phenomena, in essence, to demystify some of the mysteries of the brain. It is in this spirit that the most complex issues of brain function—learning, memory, thinking, and consciousness—are then considered. The student is offered new insights into the very human aspects of brain research which have emerged from studies of the animal nervous systems and from powerful new methods of investigating the brain in human subjects. The examination of mental illnesses provides still another avenue for the role of biological understanding. Comparing neurological and behavioral disorders establishes a basis for the understanding of psychiatric diseases in terms of biologically verifiable changes. The final chapter considers the possible future developments in this rapidly moving field.

This body of beginning knowledge is, on the one hand, a complete textbook, capable of serving as an introductory text at the college level. However, that objective, while certainly a useful one in its own right, was not the only motivating factor in developing this book. What gave this project a special appeal, and encouraged its authors to meet a tight deadline, was the opportunity to incorporate this book into a new multimedia teaching package built around the Public Broadcast Television System's eight-part series, *The Brain*. Produced by WNET in New York for PBS, *The Brain* will be the most exhaustive attempt to date to make use of television's great educational capacity. The beauty of the

brain in its intrinsic structure and the compelling human drama of the brain's disorders are both brought out powerfully in the series. Undoubtedly, the series could stand alone and still attract new audiences to the scientific study of the human brain and human behavior. But taken together, the television series and this text offer complementary information that should stimulate interest and at the same time provide a more complete background than the time constraints of a 1-hour video program would permit.

To round out this teaching effort, and to place the course on a level of student presentation that would not require a faculty trained in neuroscience, Dr. Tim Teyler was asked to develop an instructional package. An Instructor's Manual offers suggestions for discussions of text material, its interfaces with the television program, and the opportunities for further pursuit of the subject matter. A Study Guide provides students with a synopsis of each chapter and each video program and contains a glossary, self-test questions, bibliography, and other useful instructional aids.

Finally, the authors of the textbook were aided enormously in their efforts to simplify the presentation of this often complex subject matter by the informative medical illustrations created especially for this book by the noted *Scientific American* illustrator Carol Donner, and by the sketches, charts, and graphs rendered by artist Sally Black.

There are many to whom the authors owe their gratitude for directing our efforts and helping us work toward the final product. This list includes our many teacher-readers, whom we hope will find that the final product has taken their useful suggestions into account. Most critical for giving the book clarity, relative freedom from scientific obfuscation, and a style that overcame the personal peccadillos of the authors, was our editor Cheryl Kupper, without whose efforts and encouragement, we have no doubt, this book could not have been completed.

*Floyd E. Bloom*
*Arlyne Lazerson*
La Jolla, California July 1984

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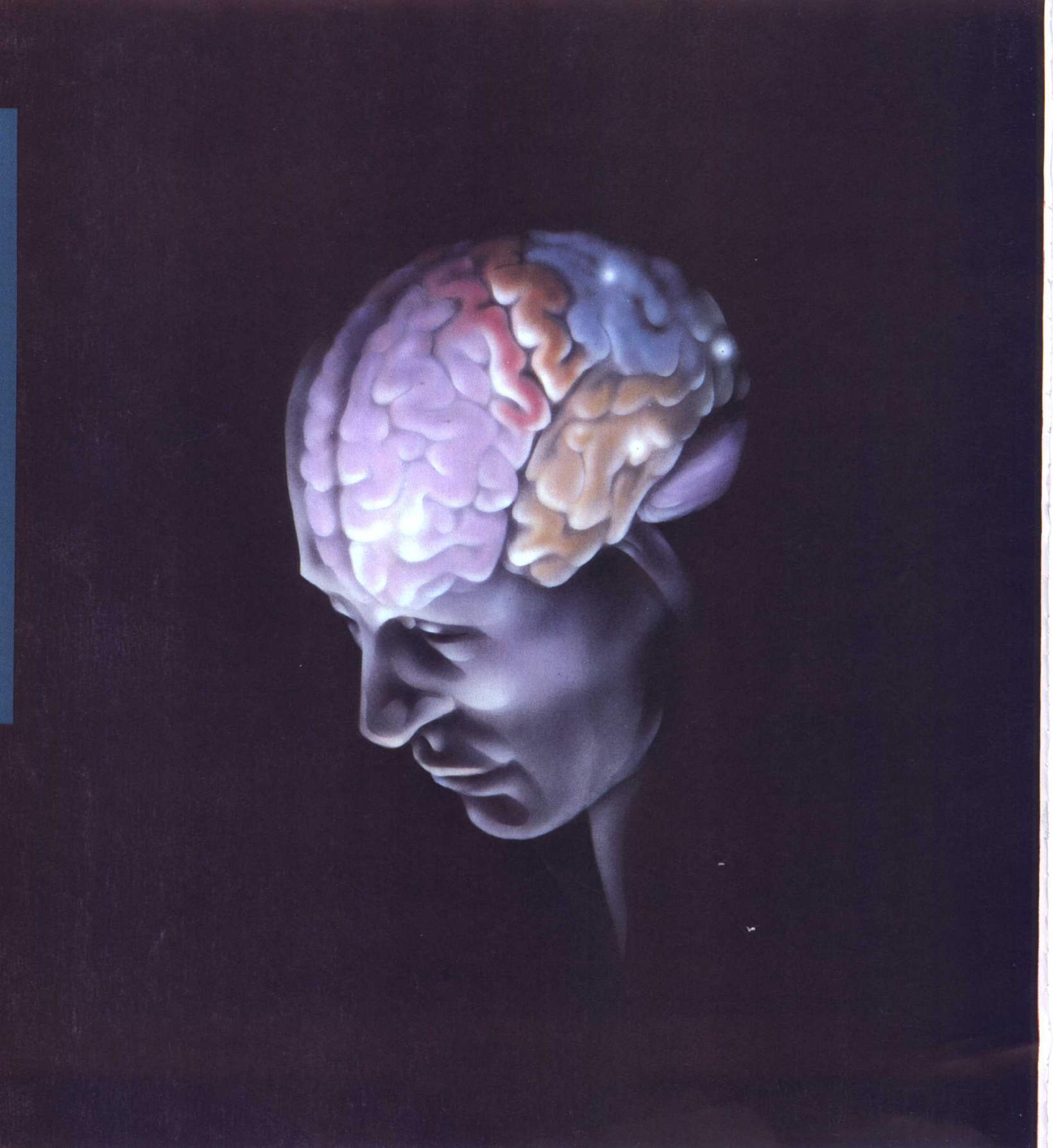


# 1 Introduction to the Nervous System

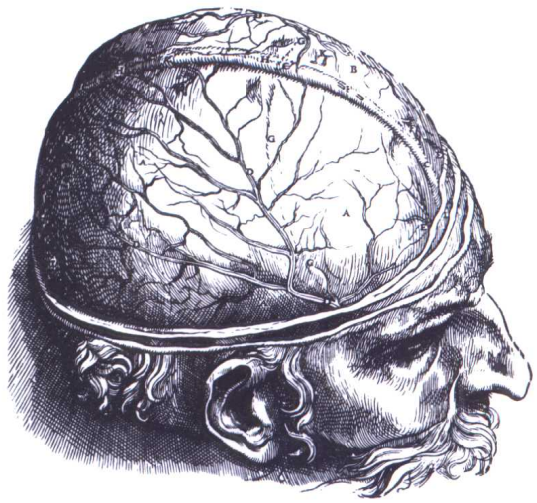
# 1

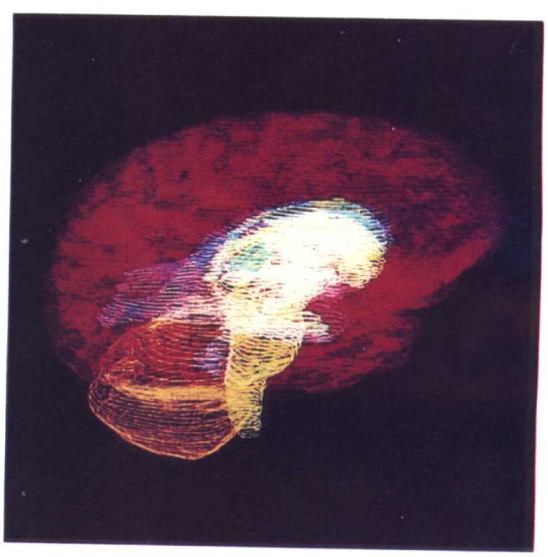
## Why Study the Brain?

The human brain may be the most complex living structure in the universe. If you doubt that claim, just consider that your brain is packed solid with billions of nerve cells, each communicating with thousands of preselected listeners over miles and miles of living wires. We refer to this whole system of structures as the nervous system. Scientists who devote their lives to understanding how the brain works, whatever "works" means, believe that they face the ultimate challenge, namely, the questions of why and how human beings do what they do.

For the past two decades, scientific research on the organization and operation of the brain has progressed at an accelerating pace. Within the past decade, scientists have found out how to examine the organization of the brain in ways that reveal how its specific parts relate to one another. They have also begun to work out some of the principal mechanisms that regulate the activity of the conscious brain. Many, many scientists have been participating, and because a common set of concepts allows them to profit from each other's discoveries, advances in the field have come at a rapid pace.

These advances in understanding the structure and function of the brain mean that some of the more complex feats of behavior, such as memory, can now be studied in ways not previously possible. Instead of asking only how well a person or a laboratory animal remembers, investigators can now examine specific changes in the operations of the cells of the brain as the events of "remembering" occur. Some scientists have begun to conclude from such progress that we are beginning to penetrate the mystery long associated with the concept of the "mind." However, none of the "thinking" operations that we attribute to the "mind" have yet been directly associated with any specific part of the brain. Therefore,





*Images of the body and the brain change as new tools for observation become available. Andreas Vesalius revolutionized anatomy with the 1543 publication of* De Humani Corporis Fabrica, *illustrated by artists of Titian's studio working from the dissected heads of decapitated criminals (top). The computer-generated display of a normal brain (above), made at Robert B. Livingston's laboratory at the University of California, San Diego, is based on images of a brain surface cut at regular intervals, traced into a computer memory, and projected in three dimensions.*

Table 1·1 ***Some activities controlled by the brain***

| Interactions with the environment | Actions controlling the body | Mental activities | | |
|---|---|---|---|---|
| Seeing | Breathing | Learning | Creating | Concentrating |
| Listening | Regulating blood pressure and heat | Remembering | Analyzing | Ignoring |
| Feeling | Regulating body positions | Writing | Deciding | Feeling |
| Smelling | Regulating locomotion, e.g., moving | Drawing | Calculating | Sleeping |
| Tasting | Regulating reflexes, e.g., blinking | Reading | Imagining | Dreaming |
| Speaking | Eating | | | |
| | Drinking | | | |
| | Regulating hormones | | | |

arguments about the physical basis of the mind continue to take a strongly philosophical tone. We can perhaps begin to see how certain brain structures, reacting to signals in the world around us, can produce certain traceable signs through the brain's myriad circuits that lead to specific behaviors. But how do we make the leap to understanding the processes that produce mental acts—the silent analysis of a mathematical or a verbal problem in your head, the creation of a poem, the invention of a better mousetrap, or the sudden "Aha!" that results in an insight into the behavior of a friend or a theory of relativity?

Investigations of mental acts and the world of the human mind have historically been separated from studies of the physical brain and the behavior of animals. "Mind" was an abstract, private haven that, depending on your beliefs, included the personality, or self-identity, or "soul." Some observers believe that the lack of a physical basis for contemplative acts means that conscious experience can exist apart from the brain. To them, the mental world exists independently, unconnected to the physical entity of the brain. Others believe that any complete account of mental function must be based on the scientific examination of the brain.

"Mind" is a complex and touchy subject. As you begin to acquire some knowledge about the physical properties of the brain and its operating units, you may, indeed, revise your opinion about it. Perhaps, for now, the best thought to keep in mind is that, whatever it is, the mind works best when open.

All of this may fascinate clinicians, researchers, and philosophers, but what about everyday inquirers like you? In a very immediate way, even an introductory look at brain science can help you understand better some of the factors that make you a unique person. You have been using your brain all of your life without knowing much, if anything, about it. At the very least, some awareness of what goes on in there may enable you to do whatever it is that you do with much more appreciation of this wonderful apparatus. This book is not an operating manual, but it should help you begin a study that is likely to fascinate you from now on.

## What Does the Brain Do?

Stop for a moment now and make a list of all the actions your brain is engaged in controlling at this very moment. You had better write these items down, because remembering long lists is not something our brains can do easily. When you have your list finished, check it against the categories in Table 1·1.

Certainly right now the action most prominent in your mind is reading. This act breaks down into several complex subordinate acts: seeing the symbols on the page, assembling those symbols into words, connecting those words with meanings, and then integrating those meanings to form thoughts. While you focus on this book, you are more-or-less blocking out other background sounds around you—the whispers of those around you, footsteps, the sounds of cars going by, the ticking of the clock. Stop again and listen for those sounds. You did not go temporarily deaf. Without thinking about it you simply suppressed those noises while you concentrated on something else. You have also been suppressing a lot of data pouring into and through you along other sensory channels: where your arms and legs are and whatever position you have just shifted to without thinking; the location of things in the room; the time of day; the relative position of where you are now to where you live. Your brain constantly monitors all that information, updating it as the sun comes out or goes behind the clouds, waiting for you to turn your attention to something new.

Has your list been exhausted? In fact, it has only begun. Your brain is performing countless actions even farther out of the reach of your active awareness. It is accurately controlling your breathing to maintain just the right amounts of oxygen in your bloodstream, as well as your blood pressure to keep that fresh, oxygenated blood going to your head. It is monitoring and regulating almost all the other vegetative responsibilities of your body, from the nutrient content in your bloodstream, which provides one of the signals to eat again, to your body temperature, to the amount of water your body needs to stay in balance, to the hormonal control of your whiskers or your lack of them. The brain works actively at these and many other duties and still maintains energy to spare for the special plans it has ready in case of an emergency. If a fire were to break out, your brain would enable you to jump up, grab the baby or the dog, run to the door (whose location has just reentered your active awareness), and escape, all the while adjusting your blood pressure and blood oxygen to proper limits.

Now let us look at the intelligent brain at work.

"Wedlock suits you," he remarked. "I think, Watson, that you have put on seven and a half pounds since I saw you."

"Seven!" I answered.

"Indeed, I should have thought a little more. Just a trifle more, I fancy, Watson. And in practice again, I observe. You did not tell me that you intended to go into harness."

"Then how did you know?"

"I see it, I deduce it. How do I know that you have been getting yourself very wet lately, and that you have a most clumsy and careless servant girl?"

"My dear Holmes," said I, "this is too much. You would certainly have been burned, had you lived a few centuries ago. It is true that I had a country walk on Thursday and came home a dreadful mess, but as I have changed my clothes, I can't imagine how you deduce it. As to Mary Jane, she is incorrigible, and my wife has given her notice; but there, again, I fail to see how you work it out."

He chuckled to himself and rubbed his long, nervous hands together.

"It is simplicity itself," said he; "my eyes tell me that on the inside of your left shoe, just where the firelight strikes it, the leather is scored by almost parallel cuts. Obviously they have been caused by someone who has very carelessly scraped around the edges of the sole in order to remove crusted mud from it. Hence, you see, my double deduction that you had been out in vile weather, and that you had a particularly malignant boot-slitting specimen of the London slavey. As to your practice, if a gentleman walks into my rooms smelling of iodoform, with a black mark of nitrate of silver upon his right forefinger, and a bulge on the right side of his top-hat to show where he has secreted his stethoscope, I must be dull, indeed, if I do not pronounce him to be an active member of the medical profession."

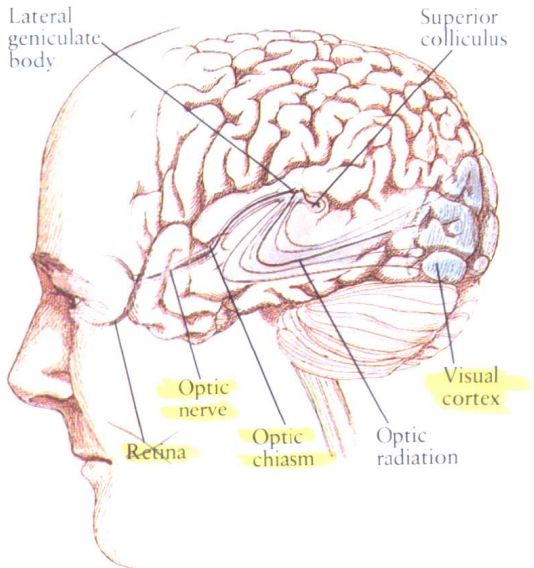



Figure 1·1 (right)
*Vision. Connections are shown from the primary sensory receptors in the retina, through relay connections in the thalamus and hypothalamus, to first targets in the visual cortex.*

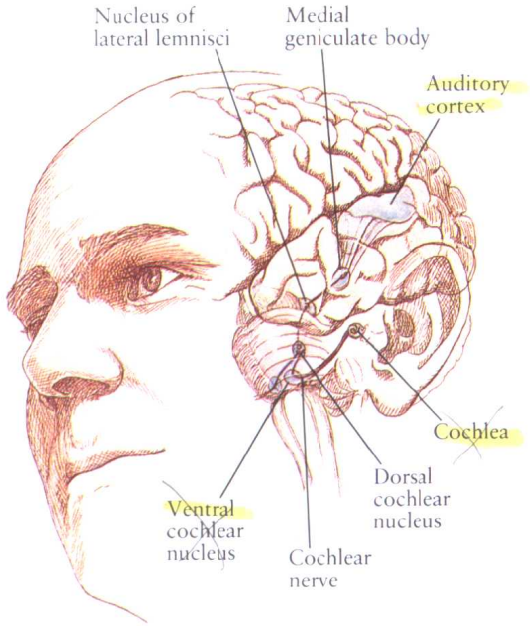



Figure 1·2 (far right)
*Hearing. Connections are shown from primary sensory receptors in the cochlea, through initial targets in the thalamus, to first targets in the auditory cortex.*

I could not help laughing at the ease with which he explained his process of deduction. "When I hear you give me your reasons," I remarked, "the thing always appears to me to be so ridiculously simple that I could easily do it myself, though at each successive instance of your reasoning, I am baffled until you explain your process. And yet I believe that my eyes are as good as yours."

"Quite so," he answered lighting a cigarette, and throwing himself down into an armchair. "You see, but you do not observe. The distinction is clear."

As always, Sherlock Holmes demonstrates the powers of the experienced eye and the analytical brain. Your brain has these same capabilities, but you may not yet have learned to move from the seeing level to that of observing and analyzing. Our scientific examination of the brain will require such an effort. Let us, then, see what kind of conclusions we can draw from some of the facts that we have assembled.

If you look again at the list of activities attributed to the brain, you may see that they fall into five major categories: sensation, motion, internal regulation, reproduction, and adaptation to the world around us.

## Sensation

The five major means by which we sense the world are: *vision* (sight), *audition* (hearing), *gustation* (taste), *olfaction* (smell), and *somatic sensation* (touch) (see Figures 1·1, 1·2, 1·3, 1·4, 1·5). Each of these senses has its specific organs and its specific segments of the nervous system through which its information is channeled.

One other kind of sensing almost never appears in such lists, partly because its organ is hidden from view, but largely because it hardly ever goes wrong. Deep within the bony structure at the side of the skull and beneath the ears lies a complex called the *vestibular apparatus* (see Figure 1·6). This structure provides us with the *sense of gravity* that we use to monitor the movements of our heads and body and to orient ourselves in space.

## Motion

The body has at its command two different types of movement: *voluntary* motions—those you can control when you want to—and *involuntary* motions—those you cannot control (see Figure 1·7). Voluntary movements