NEUROBEHAVIORAL ANATOMY
To my father, Giles Franklin Filley,
whose scholarship remains an inspiration.
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This book began as a series of Neurobehavior Seminars given to Neurology residents, students, and fellows at the University of Colorado School of Medicine in the late 1980s. Those talks were intended to be selective, practical, and brief, allowing listeners to go away with a reasonable summary of a complex field that they could readily apply in a number of academic settings. Noting at the time that reading about behavioral neurology could be intimidating because of the variety of puzzling concepts and terms as well as the inherent difficulty of capturing in writing the subtleties of altered behavior, I purposely limited the work to a concise description of a group of topics most crucial for the field. I am most gratified that many found the 1995 edition of this book useful as an accessible introduction to behavioral neurology, and I have learned with pleasure that the book has helped as a handy reference for clinical questions and board examination preparation. Some even read it simply because it was interesting. The second edition in 2001 was prepared in the same spirit, and a number of relatively minor changes were made that did not expand the book’s size.
In this, the third edition of *Neurobehavioral Anatomy*, the reader will immediately note several more notable changes. While still not a big book, this volume is larger than its predecessors, and the content has been substantially modified. Every chapter has been thoroughly revised to reflect new developments, and more depth has been added to elaborate on what was originally a series of expanded lecture notes. I did not wish to restructure the organization, as I believe the original topics are all still worthy of their inclusion in the table of contents, but each chapter has been updated to discuss new knowledge that has appeared in the last several years. These advances include both data from new technologies that permit a closer look at the brain as it mediates behavior and a number of shifts in emphasis and nuance that occur as thinking in the field moves briskly along. It is, in fact, thrilling to witness the rapidly changing and vigorous subspecialty of behavioral neurology working with its collaborative disciplines to reveal with ever greater clarity the rich tapestry of brain-behavior relationships.

The neuroanatomy of behavior as disclosed by the study of brain disorders remains the central focus of this book. Whereas some comments on other areas of neuroscience can be found, the major emphasis is on the structure of the brain—particularly as understood through the concept of distributed neural networks—and how this extraordinary organ can be understood as the source of human behavior and its disturbances. Consistent with this goal, treatment will not be a main theme; without doubt, the treatment of many neurobehavioral disorders has improved substantially, but to keep this book within a reasonable length, that important aspect of behavioral neurology will mostly be deferred to other sources of information.

The book is written from a clinical perspective. I considered including a substantial number of neuroimaging figures to illustrate key points, but opted otherwise because behavioral neurology rests squarely upon the clinical evaluation of altered behavior and not primarily on perusal of structural or functional images of the brain. This is not a neuroradiology book, and the reader can choose from several excellent texts to learn more of this rapidly advancing field. Brain-behavior relationships can be elucidated by careful clinical evaluation and knowledge of neuroanatomy and neuropathology, and reliance on a brain image, while clearly helpful, is no substitute for detailed patient evaluation.

In the preface to the first edition of this book, I referred to the brain as “the most fascinating and impressive biological structure known in the universe.” Experience has taught me that physicians and medical scientists in other areas feel just that way about the part of the body they study, and that is of course as it should be. Yet in the years I have done this kind of work, the appeal of the brain as the organ of the mind has not diminished in the slightest, and it is indeed a privilege once again to present a view of how the brain actually makes possible
what we regard as our minds. And again, I am most grateful to the patients who serve to inspire our thinking through providing access to their singular human experiences in the process of enduring neurobehavioral dysfunction.

It must be realized that every behavior has an anatomy.

NORMAN GESCHWIND
NEUROBEHAVIORAL ANATOMY
Human behavior has an enduring appeal. Who among us has not reflected from time to time on how it is that a memory is formed, a sentence produced, or an emotion experienced? What is the origin of the thoughts and feelings that seem so distinctively to characterize the human species? Despite the enormous interest of this subject, however, our knowledge of human behavior is remarkably limited. The principle that the brain is the source of behavior has been acknowledged—with some notable exceptions—since the time of Hippocrates in ancient Greece, but the study of this relatively small organ encased in the skull presents challenges like none other in human biology. Many scientific investigators are deterred by the extraordinary complexity of brain-behavior relationships and, thus, select other areas of inquiry in which meaningful advances—and research grants—are assumed to be more easily attainable. Much of the formal study of behavior is descriptive, and even at this level there are formidable difficulties in the reliable characterization of the observed phenomena. Correlating the vast expanse of human behavior with the intricate neurobiology of the brain in health and disease is still more imposing. This state of relative ignorance is particularly
regrettable since a better understanding of behavior could provide limitless benefits both in enhancing the achievements of our species and in reducing its destructiveness. Indeed, a more complete view of behavior as a function of the brain would have important implications for every realm of human activity.

By way of introduction to the core information presented in this book, it will be useful first to consider some philosophical and historical background that influences the study of behavior. Then follows a discussion of selected features of brain anatomy that pertain to neurobehavioral function in general. A brief digression into the intriguing but discredited area of phrenology is then presented as an illustration of the perils of simplistic thinking. Finally, we consider behavioral neurology and its unique viewpoint, hoping to demonstrate how knowledge of brain structure and function is critical to a comprehensive understanding of human behavior.

The Mind-Brain Problem

Traditionally, philosophers have taken a primary role in considering the phenomena of human behavior. The introspective method of thinking about one’s own thoughts and feelings was the sole available technique throughout most of human history. Scientific investigation of how and why people act as they do has a rather short history. Only in recent times has there been the development of a systematic empirical approach to the study of behavior, first with the rise of psychology in the nineteenth century (James 1890), and then with the explosive growth of neuroscience in the twentieth (Corsi 1991). These two traditions can be seen as “top down” and “bottom up” to signify their different approaches, and both have made major contributions to our understanding of behavior. Yet it hardly need be stated that these empirical endeavors have not laid to rest ancient philosophical issues. Science has by no means provided answers to all questions about the nature of the mind, and some would maintain that it never can (Horgan 1994). Biology can, however, provide provocative information with which to explore these issues. Although it may seem imprudent for a clinical neuroscientist to indulge in the discussion that follows, there is good reason to suppose that old philosophical problems can be more clearly addressed in the light of new biological knowledge (Young 1987).

One of the oldest and most difficult questions in philosophy is that of the relation of mind to body, commonly known as the mind-body problem. Human beings can reasonably assume that there exists, by virtue of daily experience, a conscious mind and, because of equally evident physical realities, an entity known as the body. Of all body parts, it is also apparent that the brain very likely has the most to do with the mind, and the issue is therefore more precisely called the mind-brain problem. The difficulty arises when one realizes
that mental states are clearly subjective, whereas the brain is an objective reality. Consciousness, to most people an obvious, albeit mysterious, human characteristic, does not readily appear to spring from the physical object we recognize as the brain. Many question whether a collection of nerve cells and chemicals can explain the ineffable phenomenon of consciousness, which is often equated with or regarded as akin to such concepts as the soul or spirit. As the philosopher John Searle bluntly poses the mind-brain problem: “How, for example, could this grey and white gook inside my skull be conscious?” (Searle 1984, 15). Consciousness does indeed appear to be the most mystifying feature of the human mind, and establishing it as a property of the brain is by no means straightforward.

Two fundamental solutions have dominated philosophical inquiry into this dilemma. For the sake of simplicity, these may be termed dualism and materialism. Dualism, most notably propounded by René Descartes in the seventeenth century, holds that mind and brain are independent; the famous *Cogito ergo sum* (“I think, therefore I am”) asserts the primacy of mind over matter (Descartes 1637) and implies that mental activities are divorced from physical events. Descartes did imagine there to be a point of intersection between the mind and the body and suggested the unpaired pineal gland as the site where the mind receives sensory traffic and acts upon the brain. But his steadfast separation of the immaterial mind from the material brain has exerted enormous influence for hundreds of years.

Materialism, advanced in various ways by thinkers as diverse as John Locke, Bertrand Russell, and Francis Crick, contends in general that mind and body are inseparable; as a result, mental events are nothing more than the expression of the brain’s physical activities. Advocates of this “identity theory” argue that the Cartesian division between mental and physical substances is no more than an assertion, in the trenchant phrase of Gilbert Ryle, that there exists a “ghost in the machine” (Ryle 1949). An extreme variant of materialism is B. F. Skinner’s behaviorism, an influential movement in twentieth-century American psychology emphasizing the manipulation of behavior by environmental conditions (Skinner 1971), and which, in effect, holds the concept of mind to be irrelevant to the scientific study of behavior.

The mind-brain problem continues to be pursued with vigor. Among modern philosophers who have continued the debate are Karl Popper (Popper and Eccles 1977), an advocate of dualist interactionism, and those who reject dualism, such as Searle (1984, 2004), Patricia Churchland (1986), and Daniel Dennett (1991). In particular, Churchland and Dennett have embraced neuroscience to the extent that they employ the term “mind-brain” to express complete acceptance of the identity of mind and brain (Churchland 1986; Dennett 1991).

At first glance, the dualist position may seem untenable in view of modern conceptions of neuroscience, but difficult problems remain nonetheless.
Prominent among them is the question of free will. Do people act “freely” or under strictly determined laws of physics and chemistry? This dilemma can be more precisely posed as follows: If the mind and brain are in fact identical, and the actions of the brain can eventually be understood and predicted, then where is an escape from the determinist trap into which materialism must fall? Will not all behavior be governed by physical forces, and thus free will be impossible? Here are other questions to which science has not yet offered an answer. Arguments such as these continue to pose for some a significant obstacle to an enthusiastic acceptance of the materialist position.

Notwithstanding the lingering uncertainties raised by dualism, it is difficult to deny the practical utility of the materialist perspective. Advances in science are no less impressive if they pertain to the neural basis of behavior than if they lead to the discovery of penicillin for the treatment of bacterial pneumonia. It is undeniable that investigation of the brain has informed the understanding of a wide range of human behaviors that were previously inexplicable as physical phenomena. In clinical practice, experience with stroke, dementia, or traumatic brain injury patients leaves little doubt that activities of the mind are reliably and often dramatically affected by physical alterations in the brain. The fact that uncertain or inconsistent relationships between brain and behavior continue to challenge neuroscientists—as they clearly do—is testimony to the extraordinary complexity of the brain, not evidence that such relationships do not exist.

Although occasional neuroscientists can be found who adopt a dualist position (Penfield 1975; Popper and Eccles 1977), the great majority find that physical events are providing increasingly complete and satisfying explanations for the activities of the mind. As a heuristic principle, the notion that brain events underlie and are directly correlated with mental events has been remarkably productive to date. Without necessarily presuming to answer the thorny philosophical questions introduced above, neuroscience has nevertheless assembled an impressive body of data indicating that the mind’s activities are an unequivocal result of the brain’s structure and function. In this sense, scientific advances shed light on old problems that, while not solved, at least seem less imposing.

The position taken in these pages derives from an unhesitating embrace of the methods and findings of neuroscience, and therefore follows in the materialist tradition. Although neuroscience cannot comment on a nonphysical reality, there seems little to gain by postulating a spiritual or mystical essence that cannot be reduced to the level of scientific analysis, especially when such complex human capacities as memory, language, and emotion are already yielding to this kind of inquiry. Indeed, as we will see in Chapter 9, a neurology of religion is a plausible approach to understanding a human experience that has traditionally been seen as representing divine influence (Saver and Rabin 1997). In this respect, the dualist tradition does remind us that many mental events have been inter-
Behavior and the Brain

interpreted as dissociated from any apparent physical basis. Because the task ahead requires developing an understanding of how these mental events are organized by the brain, Searle has recently proposed the idea of “biological naturalism” as a perhaps more harmonious solution to the mind-brain problem (Searle 2004). Whatever the terminology preferred, the proposition that mental events are in fact caused by neurobiological processes in the brain has a compelling rationale and much empirical support (Geschwind 1985; Churchland 1986; Dennett 1991; Searle 2004), and there is ample reason to expect that continuing explication of the brain’s operations will also unravel the secrets of the mind.

General Features of Brain Anatomy

Neuroanatomy has been a foundation of behavioral neurology and continues to provide many insights into the neural organization of human behavior. Just as the elemental motor and sensory functions of the nervous system can be understood as emanating from the operations of brain neurons, so too can the myriad phenomena of cognition and emotion (Mesulam 2000; Kandel, Schwartz, and Jessell 2000). This book is concerned with the anatomy of higher functions, and clinically relevant regions of the brain will be covered in the chapters that follow. As an introduction, however, it will be helpful to begin with some general neuroanatomic features of the brain as they bear upon neurobehavioral concepts; complete accounts of neuroanatomy can be found elsewhere (Nauta and Fiertag 1986; Parent 1996; Nolte 2002).

The human brain is a soft, gelatinous collection of gray and white matter encased in the cranium and weighing about 1,400 grams (roughly three pounds) in the adult. Estimates vary, but there may be 100 billion or more neurons in the brain, and at least ten times this number of glial cells (Kandel, Schwartz, and Jessell 2000). As an indicator of the astonishing degree of connectivity between cerebral neurons, each one makes contact with as many as 10,000 others (Kandel, Schwartz, and Jessell 2000). Interneurons, situated between afferent and efferent neurons, constitute by far the largest class of brain neurons, so that the great majority of the brain’s neuronal activity is concerned with the processing and transfer of information that occur between sensory input and motor output (Kandel, Schwartz, and Jessell 2000). In other words, a large quantity of nervous tissue lies interposed between the sensory and motor systems to elaborate the phenomena of behavior.

The brain is made up of the cerebrum, the brainstem, and the cerebellum (Figures 1.1 and 1.2). Most important for the higher functions is the cerebrum, which comprises the paired cerebral hemispheres and the diencephalon, the main components of which are the thalamus and hypothalamus. Why the hemispheres are paired, and why they have distinct functional affiliations in contrast...
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