

# *Principles of Human Neuropsychology*



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**Cover Images:** The cover shows four self-portraits made by the German artist Anton Räderscheidt in the months following a stroke that damaged his right parietal lobe. In the first painting, done 2 months after the stroke (upper left), he omitted the left half of the face and everything else on the left side. This is characteristic of his pervasive neglect of the left side of space during this period, despite his preserved visual acuity. Over the next several months he gradually recovered his ability. This is evidenced by the progressively more detailed depiction of the left side of the face and the left background in the portraits done 3.5 months (upper right), 6 months (lower left), and 9 months (lower right) after his stroke. Unilateral neglect of space is discussed in chapter 7.

Text, photo, and illustration credits appear on a continuation of the copyright page, pages 547–551.

*To three who inspired me:*

*Gregg Rains, to be curious about the wonders of the universe*

*Rita Rains, to recognize the compass of my reaching*

*Mary Rains, to grasp the meaning of it all*



# Preface

I wrote this book because I wanted my students to have access to an account of neuropsychology that was at once clear and in-depth. I wanted them to experience the sense of wonder that I have felt since I first became captivated by this field 25 years ago. It seemed to me that the way to do this was to create a text that, without overwhelming the student, would provide sufficient detail and depth of treatment to kindle a sense of wonder and to whet the appetite for further forays into this at-once most mysterious and most intimate of all domains of science. An in-depth treatment achieves this end, it seems to me, by paradoxically making the material *easier* to grasp by offering deeper explanation. And, of course, a by-product of a deeper understanding is the even more exciting revelation of the questions that remain to be answered. The search for ways to achieve these ends has guided the writing of this book.

The other guiding principle has been the essential unity of knowledge and, particularly in a domain as fraught with difficult problems as neuropsychology, the necessity of integrating insights gleaned from widely disparate levels of analysis. Although the continually expanding breadth of the neurosciences demands that any single book focus its attention, adhering to the perspective of a single level of analysis runs the risk of providing only a two-dimensional view of brain-behavior relationships. One of my central objectives has been to provide the reader with the in-depth view that is possible when the attempt is made to integrate the perspectives afforded by different disciplines and the data derived from different levels of analysis. One of the most exciting results of this integrative attempt is the often stunning degree to which findings derived from different levels

of analysis inform and illuminate each other, and I have tried to share this excitement with my readers. We have moved far beyond the time when the reports of different levels of analysis seem like the isolated reports of the many blind men feeling different parts of the proverbial elephant; we are beginning to integrate different levels of understanding into a coherent representation of the animal itself.

The book is divided into three major sections: The Foundations (chapters 1–5), Neuropsychology of Major Functional Systems (6–12), and Application of Neuropsychology to Broad Functional Domains (13–15). It ends with an Epilogue.

## Part I: Foundations

The first three chapters of this text approach neuropsychology from three different levels. Chapter 1 provides an overview of neuropsychology in the context of its historical development. In addition to serving as a general introduction to the field, this chapter offers insights into the processes underlying the development of our understanding of brain-behavior relationships. These processes are always at work in any evolving field. A consideration of their influence in the past sheds light on how future developments are likely to unfold.

Chapter 2, Neural Mechanisms at the Molecular and Cellular Levels, approaches the function of the nervous system at the micro level. This has great intrinsic interest because much has been learned in recent years about events at these levels. The chapter's examination of the ways in which neurons interact also provides insight into the integrative function of the nervous system as a whole. The discussion of

recently elucidated neuronal mechanisms of simple forms of learning in relatively uncomplicated organisms that concludes the chapter serves as an example of how the principles derived from investigations into processes at the micro level can be applied to psychological functions on a more molar level. In doing this, it also previews the kinds of explanation of other cognitive processes that may be possible in the future.

Chapter 3, *Introduction to the Structure and Function of the Nervous System*, introduces the basic structures of the nervous system and discusses general aspects of their function. In addition to providing information that is critical for understanding material in subsequent chapters, this chapter surveys the relationship between gross anatomical structures and behavior.

Chapter 4, *Methods in Neuropsychology*, provides information about how insight into and understanding of brain-behavior relationships is achieved. The answers to our questions are inextricable from the methods we use to ask them. A thorough grounding in and appreciation of methodology is thus essential to an understanding of the current state of neuropsychology and its probable future directions. The methods reviewed in this chapter range from the most recent advances in PET, fMRI, and magnetoencephalography to classical methods employed to study the effect of cerebral lesions on behavior and psychological functioning. An emphasis is placed on the importance—or rather, the necessity—of applying a wide range of methods in our attempts to approach an integrated understanding of the relationship between brain and behavior.

Chapter 5, *The Visual System as a Model of Nervous System Functioning*, integrates the levels of analysis and approach addressed in the first four chapters. It does this by examining the most completely understood system of the brain, the visual system, at a number of different levels. Knowledge in this area has been expanding at an ever-increasing pace in recent years as new techniques and research strategies have been aimed at unlocking the mysteries of the visual brain. This chapter focuses on recent findings at a variety of levels, from the study of the

individual neuron and small populations of neurons, to the anatomical microstructure of the visual cortex, and the gross anatomy of the visual system. The combination of these levels of approach reveals the elegant segregation—both anatomical and functional—inherent in the magnocellular and parvocellular streams, as well as the remarkable localization of specific visual function within selected regions of the extrastriate cortex.

In addition to providing information about the neuropsychology of an important and relatively well understood functional system, chapter 5 also provides a model of how several different levels of analysis can be integrated into a comprehensive understanding. In doing this, it serves as a preview of the kind of understanding of other brain systems that will some day be achieved and that is already in the process of evolving.

## **Part II: Neuropsychology of Major Functional Systems**

The seven chapters of Part II (chapters 6–12) address the major domains of higher functioning: language, spatial processing, visual recognition, voluntary action, memory, emotion, and the higher-order regulation of behavior by the prefrontal cortex.

Language, perhaps the most exclusively human function, is also the first functional domain to be localized in specific regions of the cerebral cortex—a discovery that ushered in the modern era of neuropsychology. Chapter 6 surveys the investigation of the neural basis of language from Broca's classical findings to the use of recently developed functional imaging techniques that have revealed areas of brain involved in relatively complex linguistic processes, such as word generation. These recent findings have suggested an unexpected modularity of function in the neural mechanisms underlying language.

Analogously, chapter 7's survey of spatial processing emphasizes how the insights revealed by early lesion studies have been extended by such findings as the recent discovery of single cells in the hippocampus that fire when an animal is in a specific location and location-specific attention-enhanced



cells in monkey parietal cortex. This extension of classical findings implicating these two regions in aspects of spatial processing to findings on the level of the single neuron suggests that we may be approaching an integrated understanding of spatial processing, an understanding nourished by data from widely disparate levels of analysis. Also highly illuminating is recent work indicating that the same structures mediating visual perceptual processing may also underlie visual imagery and that the two hemispheres are specialized with regard to the ways in which they process images. These were unexpected findings, and they hold promise for further understanding of the relationship between visual perception and visual thought processes.

The recurring theme of attempts to achieve understanding through the convergence of findings from disparate levels of analysis also pervades the remaining chapters in part II. In chapter 8, we examine visual agnosia, first identifying problems with classical theories of visual recognition and then examining how recent theories attempt to resolve these problems. In particular, recent massively parallel constraint-satisfaction models of object recognition are reviewed, as are the most recent neurobiologically based conceptualizations of visual agnosia. These constitute two explanatory approaches based on widely different levels of analysis. For the present, the possibility of integrating the two approaches into a unified understanding remains remote, although a satisfactory account of visual recognition will eventually have to draw on data and conceptualizations from the levels of explanation addressed by both of these theories.

The leitmotif of understanding through converging levels of analysis also pervades the remaining chapters dealing with the major functional systems. In the discussion of voluntary action (chapter 9), data from classical studies on the effect of cerebral lesions on movement are interfaced with current advances in the neurophysiology of movement. For example, the recent use of studies simultaneously recording from more than 100 single neurons in the motor cortex has revealed a stunning distribution of function in that region, a distribution that helps to

explain the extremely high correlation between actual and intended movement in persons without brain lesions and the disruption of that correlation after lesions of motor cortex. Analogously, as we see in chapter 10, single-unit recording in prefrontal cortex has revealed neurons that are intimately involved in the neural processes underlying spatial working memory. This discovery of individual neuronal activity correlated with memory processes is among the most exciting recent advances in the understanding of the neural basis of higher cognitive processes.

Although sometimes neglected in accounts of brain-behavior relationships, emotion is clearly an important, if enigmatic, domain of psychological functioning. In the examination of emotion in chapter 11, we first discuss classical theories of the relationship between brain and emotion and then proceed to see how these have been superseded by more recent advances. In particular, recent investigations into the neural basis of learned fear have not only provided further support for the notion that the amygdala plays a central role in emotional response, they have also made significant progress in elucidating the neural mechanisms through which the amygdala exercises this role.

As one explores each of the major functional domains, one must eventually confront the problem of the highest level of control within that domain, a level frequently referred to as executive function. Although there is a separate chapter on executive function (chapter 12), the text also addresses the problem of executive function within each chapter, in the context of the domain under consideration. This allows the reader to view executive function in the context of the functions that are its tangible manifestations, rather than presenting it as a rarefied function isolated from specific functional domains.

Chapter 12 examines aspects of prefrontal cortex and the higher-order regulation of behavior. Humans suffer an extremely broad range of symptoms after prefrontal lesions, and these are reviewed in some detail with an eye toward bringing some conceptual coherence to their apparently bewildering range. The latter part of this chapter considers the hypothesis

that the essence of prefrontal function is the guidance of behavior by representational knowledge. True to the theme of converging levels of analysis, this discussion focuses on recent advances in devising an animal model of prefrontal function. This makes possible investigations on the anatomical, physiological, and behavioral levels that would not be possible with human subjects. The data from human subjects with prefrontal lesions, taken together with those derived from the animal models, emphasize once again how different levels of analysis inform each other. This approach also makes possible the beginning of a coherent picture of the neural basis of prefrontal function.

### **Part III: The Application of Neuropsychology to Broad Behavioral Domains: Psychopathology, Developmental Neuropsychology, and Recovery of Function**

The three chapters in part III address areas of application of neuropsychology: psychopathology, developmental neuropsychology, and recovery of function. Currently there is a great deal of investigative work in the neuropsychology of psychopathology (chapter 13), particularly schizophrenia. In this disorder—or, more aptly, this spectrum of disorders—a wide range of neurobiological correlates have been identified. Of particular interest are recent findings of specific metabolic abnormalities in prefrontal cortex during tasks, such as the Wisconsin Card Sorting Test, that tap the functional capacity of this area. This combination of functional imaging and neuropsychological measures appears to be an extremely promising research strategy for future attempts to elucidate biological factors in schizophrenia as well as other psychiatric disorders.

The chapter on developmental neuropsychology (chapter 14), in addition to reviewing the almost miraculous events involved in the development of the nervous system, focuses on recent attempts to infer the course of development of different brain systems from the course of development of function. From this perspective, chapter 14 reviews recent work in the development of visual function, executive function, and language. It also surveys recent

advances in our understanding of developmental abnormalities, both those in which considerable progress in understanding the cause has been made and those in which causal factors remain obscure.

Chapter 15 considers recovery of function, including the factors that affect recovery and the neural mechanisms that have been shown to underlie it. Particular attention is paid to the development of therapeutic approaches to the consequences of brain lesions. Of special interest are recent advances in the development of compensatory interventions, such as strategies that utilize intact implicit memory in severely amnesic patients to enhance their capacity for adaptive functioning.

### **Epilogue**

Finally, the Epilogue considers philosophical issues in neuropsychology, particularly the issue of whether psychological and behavioral processes can be reduced to more micro levels. It presents a case for the possibility of such reduction. More generally, the chapter provides a broad context for considering issues in the relationship between brain and behavior that are implicit in earlier discussions. In addition, the Epilogue is intended to provide a more formal argument for what has been a central theme of this book: the virtue, if not the necessity, of striving for an understanding of brain-behavior relationships derived from the integration of different (and often seemingly incommensurable) levels of analysis. This is an understanding that to date has been most fully realized in our current understanding of the visual system. Yet, as the pages of this book testify, it is a goal toward which progress is being made in all domains of functioning.

### **Pedagogical Features**

Each chapter begins with a chapter outline to help orient the reader and ends with a summary that touches on the central content of the chapter. Captions are often extensive, supplementing descriptions in the body of the text. Major terms are boldfaced and defined both in the context of the discussion and in a glossary at the end of the book.

Complete references to cited studies will hopefully encourage students to embark on the direct exploration of published research, an endeavor always rewarded by more intimate understanding.

### Supplementary Materials

There is a student web site for the book at [www.mhhe.com/rains](http://www.mhhe.com/rains). Matt Heinly, one of my former students, who possesses an intense passion for neuropsychology, helped develop the web site. Matt's ability to locate interesting web sites is matched only by his ability to locate restaurants that serve the finest and largest steaks. The web site also includes review questions and key terms and definitions for each chapter.

Melvyn King of the State University of New York at Cortland and Debra Clark, a neuropsychologist in private practice, have prepared a test bank that includes multiple-choice, fill-in, true-false, and essay questions for all chapters.

### Acknowledgments

A project of this magnitude is the product of many influences going far back in time. While it is impossible to mention all of the early influences, I mention some of them here. Thomas McDonald of St. John's College inspired a love of intellectual exploration and adventure that has never left me. Many at Cornell University were inspiring and guiding during my time as a graduate student there, including Barbara Finlay, Ulrick Neisser, Frank Keil, Eleanor Gibson, and J. J. Gibson. During my neuropsychology internship, at Upstate Medical Center in Syracuse, I was able to learn from John Wolf, who had an exuberant passion for brain dissection and neurological diagnosis, even at 6 a.m.

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ing and energizing, as were Gabriel Leonard, Enda McGovern, and Laughlin Taylor. I spent many hours in dialogue with Michael Patrides, whose love of all things neuropsychological is contagious and whose energy for conversation about the mysteries of the brain is inexhaustible. I feel deep gratitude to Brenda Milner, my thesis advisor, who made work in Montreal possible and whose indefatigable passion for neuropsychology and impeccable investigation of its mysteries has served as an inspiration for me, as it does for so many throughout the world. I also owe an enormous debt of gratitude to all the patients in Montreal, and later at Friends Hospital in Philadelphia, from whom I have learned so much.

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