

## Cognitive Neuroscience

Updated fully, this accessible and comprehensive text highlights the most important theoretical, conceptual, and methodological issues in cognitive neuroscience. Written by two experienced teachers, the consistent narrative ensures that students link concepts across chapters, and the careful selection of topics enables them to grasp the big picture without getting distracted by details. Clinical applications such as developmental disorders, brain injuries, and dementias are highlighted. In addition, analogies and examples within the text, opening case studies, and “In Focus” boxes engage students and demonstrate the relevance of the material to real-world concerns. Students are encouraged to develop the critical thinking skills that will enable them to evaluate future developments in this fast-moving field. A new chapter on Cognitive Neuroscience and Society considers how cognitive neuroscience issues relate to the law, education, and ethics, highlighting the clinical and real-world relevance. An expanded online package includes a test bank.

**Marie T. Banich** uses brain imaging techniques to understand the neural systems that enable us to direct actions and thoughts in a goal-oriented manner, often referred to as executive function. Her research findings have been published in leading journals, including *Science*. Among her professional experiences, Professor Banich has been a member of the MacArthur Foundation on Adolescent Development and Juvenile Justice, a Fulbright Senior Scholar in Verona, Italy, and a recipient of a James Cattell sabbatical award. Currently she serves as the co-Principal Investigator for the Colorado site of the Adolescent Brain Cognitive Development study, an unprecedented 10-year longitudinal study that uses neuroimaging to provide an unrivaled window on development of the adolescent brain and its influences on cognitive and emotional development.

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## PREFACE

THE FOURTH EDITION of this book, although extensively revised, retains the spirit, organization, and many of the features of the first three editions. Like the earlier editions, it provides a systematic introduction to the neural basis of mental function. It includes state-of-the-art research from experimental work performed with humans and animals, as well as findings from clinical populations. The goal, as before, is to provide a balanced, synthesized, and integrated view of what we know both about the brain and about cognition. Simultaneously, the text aims to provide these views in accessible prose that will excite students to think critically about the potential of cognitive neuroscience to yield new insights.

While the entire text has been revised and updated, two sets of major changes are especially notable. First, the content of the book has been modified in line with the changing nature of the field. The introductory chapters have been reorganized to provide an integrated overview of the nervous system at both cellular and neuroanatomical levels in Chapter 1, followed by a new chapter on the historical development of cognitive neuroscience (Chapter 2). Two new chapters have been included, one on Social Cognition (Chapter 13) and another on Cognitive Neuroscience and Society (Chapter 17). The inclusion of these chapters reflects rapid expansions in new research in these subfields combined with awareness of the need for cognitive neuroscientists to address questions of societal interest. In addition, material on hemispheric specialization from prior editions has been integrated with coverage throughout the text, rather than parceled into a separate chapter as in prior editions. Second, the book has been revised to make the content more accessible to students. It has been rewritten to focus on major concepts and to present them, and the experiments that support them, in a way that makes the critical ideas clear to students without bogging them down in detail. Finally, recognizing the importance of visual elements in learning, the four-color art program has been completely revised with an expanded set of figures in every chapter.

In addition to these major changes, every chapter has been thoroughly updated to reflect current findings in the fast-growing field of cognitive neuroscience. While the current edition still includes findings from traditional methods, such as the study of brain-damaged patients, which have provided foundational knowledge to the field, we pay special attention to the integration of findings from a variety of newer approaches, including transcranial magnetic stimulation, diffusion tensor imaging, multi-voxel pattern analysis, and studies examining functional connectivity. Throughout, our intention is to provide students with a thorough and solid grounding in the basic principles and findings of cognitive neuroscience, tools that they can then use to further understand applied and clinical problems.

### Text Organization and Features

The book's soul remains very much the same as in the first three editions, as the following main features have been retained.

#### ■ The book provides a systematic survey of the neural bases of a wide variety of mental functions

The overall organization of the book is divided into three main sections: fundamentals (Chapters 1–3), neural bases of specific mental functions (Chapters 4–13), and broader applications (Chapters 14–17). The first part of the book, comprising the first three chapters, provides students with a basic foundation for the exploration of cognitive neuroscience. The first chapter provides information about the basic parts and divisions of the central nervous system and the fundamentals of neural transmission. This chapter may be unnecessary for students who have already completed a course in physiological psychology, but will be of use to students who have not. The second chapter outlines the historical milestones in the development of the field, with special attention to methodological and conceptual developments that advanced the field in different eras. The third chapter acquaints students with the myriad of burgeoning techniques, both standard and novel, that are available to scientists and clinicians in their quest to understand the neural bases of mental function.

The second part of the book, Chapters 4 through 13, provides a survey of the neural bases of mental function, with each chapter devoted to a distinct mental function. The chapter topics discussed are, in order, motor processes, early perceptual processing, object recognition, spatial cognition, language, memory, attention, executive function, emotion, and social cognition.

The last part of the book, comprising the last four chapters, examines broad-based applications in cognitive neuroscience, including development, aging, clinical syndromes, and the interface between neuroscience and society. Instructors may view these chapters as more discretionary than earlier ones, in the sense that they cover more advanced issues. In our teaching, we've found that these advanced, applied, and clinical issues are of special interest to many students, as they find it very rewarding to use the knowledge that they have gained earlier in the text to approach these broader applications. Chapter 14 examines mental conditions such as schizophrenia, depression, anxiety disorders, and substance abuse from a cognitive neuroscience perspective. Chapter 15 examines neural plasticity from a lifespan perspective, including developmental changes during childhood, adolescence, and aging. In addition, it discusses recovery of function in children and in adults, and the

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neural bases of developmental disabilities. Chapter 16 examines syndromes that are characterized by generalized cognitive disorders (rather than the more localized and specific disorders discussed in Chapters 4 through 13), including closed head injury, dementia, demyelinating diseases, and epilepsy. Finally, the text ends with Chapter 17, Cognitive Neuroscience and Society, which critically examines the ways in which cognitive neuroscience knowledge can be applied to domains of broad societal concern such as education, social inequality, the law, and morality.

### ■ The sequence of the chapters is designed for progressive learning

The chapters have been carefully sequenced so that information in later chapters builds upon information in earlier ones. Notably, the processes most linked to motoric and sensory functions are presented earlier, and those that depend on more integrative aspects of brain function, such as executive function and emotion, are presented later. For example, the chapter on object recognition directly precedes that on spatial processing, so that the student is introduced to the ventral and dorsal visual processing streams in consecutive chapters. The chapter on memory is preceded by the language and object-recognition chapters so that the distinction between generalized memory disorders and the “memory” problems that are specific to certain domains (e.g., anomia in language or agnosia with regard to objects) is clear. Yet, despite the intentional progression of ideas across chapters, chapters are written to be self-contained so that instructors may alter the order of material depending on specific syllabus needs.

### ■ The book is designed to actively engage students in the process of learning

Most chapters begin with an opening case history to pique the students’ interest and preview issues that are discussed later in the chapter. For example, the opening case history in Chapter 4 discusses how Muhammad Ali’s boxing career led him to have a Parkinsonian disorder, and the opening case history in Chapter 16 discusses the mental decline of Marie’s maternal grandmother due to dementia. The text is written in a conversational tone rather than in a technical style, to grab the students’ interest and retain it. We use analogies extensively so that difficult conceptual issues can be presented in a tractable manner. Each chapter includes an “In Focus” box that explores in depth a specific applied issue in cognitive neuroscience, helping students to see the implications of research for everyday life.

To keep students oriented to terminology, key terms are introduced in boldface and defined in a glossary at the back of the book. Chapter summaries allow students to review the material learned or preview what is to be discussed, and

outlines at the beginning of each chapter provide a clear conceptual structure of the contents. All these features are designed to make this book as user-friendly as possible.

### ■ State-of-the-art knowledge in the field is presented without sacrificing accuracy or oversimplifying the material

As researchers who maintain highly active and visible research programs, we are in a position to ensure that the book contains not only a discussion of the “classic” findings in the field, but also the cutting-edge portion of our knowledge. Never, however, are students overwhelmed with a laundry list of findings or with overly technical arcane issues. Rather, representative studies are used to highlight the nature of current debates, so that students can understand, and think critically about, the conceptual issues under consideration and how researchers attempt to reason based on experimental evidence. Our extensive work in both research and teaching in cognitive neuroscience allows us to present issues in a manner that is precise and sophisticated, yet also accessible and integrative.

## WHAT’S NEW IN THIS EDITION

While the approach of the prior editions has been retained, this fourth edition has nevertheless been extensively revamped. The main new additions are as follows.

### ■ The use of an integrated four-color art program

With this edition, we have thoroughly revised the art program, emphasizing systematic depiction of information across the figures, so as to enhance students’ ability to understand the material. All figures from earlier editions have been redrawn, and many new figures have been added. Some figures highlight regions of the brain so the reader can quickly see “where” and “what” in the brain are important. Other figures present data from representative studies in the field, so that students can gain experience in viewing and interpreting data; still others depict important experimental paradigms so that students can quickly grasp how a key study was conducted.

### ■ Addition of two new chapters

Two chapters have been added to the text to reflect growing areas of research over the last decade. A new stand-alone chapter covering social cognitive neuroscience (Chapter 13) is now included due to the burgeoning growth of research in this area. In the previous edition of the text, this material was relegated to a relatively short section of the chapter on Emotion. The new Social Cognition chapter addresses how new knowledge from neuroscience expands our understanding of how we perceive



the mental states of other people, categorize people into social groups, and control our behavior to align with social norms.

In addition, completely new to this edition is Chapter 17, Cognitive Neuroscience and Society. This chapter, which concludes the book, covers issues of broader societal significance to which the field can speak. For example, the chapter addresses research on how laypeople view neuroscience research, what neuroscience may add to our understanding of the effects of social inequality on development, and how neuroscience knowledge is being used in criminal justice settings. As students of cognitive neuroscience enter a wide range of professions, such as law, education, and business, it is crucial

for them to be able to critically evaluate what neuroscience can and cannot add to discussions of issues in these arenas.

■ **Extensive updating of the material to incorporate the acceleration of knowledge in the field**

The field of cognitive neuroscience continues to explode with new discoveries. As a result, all of the chapters of the book were extensively rewritten to incorporate this vast amount of additional knowledge, which is reflected in hundreds of new references from studies using diverse methodologies.

## ACKNOWLEDGMENTS

This book has benefited greatly from the generous help of many colleagues who reviewed it. We were genuinely touched by the time and effort that these people, listed below, took to share their expert advice to improve the book for the fourth edition. Their enthusiasm for the project bolstered us and kept us on our toes. Although we may not have taken all of their advice, we thought carefully about every one of their suggestions. We are most appreciative of their input. We also thank Doug Bernstein and Phil Meneely for their insights and wisdom regarding the textbook publishing process, which spared us many headaches. In addition, we thank the reviewers of prior editions; although they are too numerous to be listed here, their contributions helped to build a solid foundation upon which this new edition could be built. We thank the following reviewers for their comments on both the content and presentation of the material in the book, which we found invaluable: David Badre, Brown University; Erin Bigler, Brigham Young University; Kyle Cave, University of Massachusetts; Rosie Cowell, University of Massachusetts; Laurie Cutting, Vanderbilt University; Erica Dixon, American University; Russ Epstein, University of Pennsylvania; Kelly Goedert, Seton Hall University; Elizabeth Heaton and Averi Gaines, Haverford College; Greg Hickok, University of California, Irvine; Tiffany Ito, University of Colorado; Sabine Kastner, Princeton University; Mary Ellen Kelly, Haverford College; Ben Levy, University of San Francisco; Jared Medina, University of Delaware; Eric Pakulak, University of Oregon; Ken Paller, Northwestern University; Cathy Reed, Claremont-McKenna College; Gretchen Reeves, Eastern Michigan University; Paige Scalf, Durham University; Rachael Seidler, University of Michigan; Penny Seymoure, Carthage College; Rebecca Silton, Loyola University.

Finally, we are most grateful to the superb editorial staff at Cambridge. Matthew Bennett inspired us and guided us through our conceptual approach to the revisions; Claire Eudall skillfully shepherded us through chapter revisions with impressive attention to detail as well as patience and good humor; Charles Howell supervised the production of the manuscript with impressive professionalism; and Simon Tegg brought our ideas for illustrations to life. It was wonderful to have our materials in the hands of such outstanding editors. As this is the fourth edition of the book, it builds on editorial advice we have received on previous editions from Jane Knetzger, Danielle Richardson, and Tali Beesley, respectively, and the support of Jane Potter, whom we thank as well.

In the end, we were able to write this book not only due to the professional contributions of all the people named above, but also due to those who personally inspired and supported us. Those include our families – Jeremy Meyer, Gwen Compton-Engle, David Compton, Laura Edwards – and, most

importantly, our mothers, Serafina Banich and Judy Ellis, to whom we dedicate this book. We conclude here with words of dedication from each of us to the women who taught us to be who we are.

### FROM MARIE

I have been incredibly fortunate to be my mother's daughter. She was my first and best teacher, and through the decades someone whose perspective has enlivened my life immeasurably. If we are lucky in life, one's path crosses with a mythic figure who teaches us and shapes us, but who more importantly shows us the magical possibilities that exist right under our noses in our seemingly very unmagical and everyday world. My mother has been that mythic figure to me. Countless times she has unmasked for me those treasures that I would have inadvertently trod over, such as pointing out the brush strokes in a painting used to convey the delicacy of a flower's petals, or selecting the perfect word to convey the richness and complexity of an idea.

While my mother's love of learning and expertise in education spurred, in part, my desire to write a textbook, it has been these last five years since her stroke during which she has taught me the most. Through her stroke, I was confronted in a very visceral and personal way with both the expanse and limits of my knowledge about the brain. Working with her to recover what abilities she could, and grieving with her in the abilities forever lost, has been a partnership unlike any other I have ever experienced.

I will always be grateful to her for her patience as I pushed and probed to understand the new and restricted landscape of her mind, even though at times it laid her deficiencies bare. And I appreciated her understanding and fortitude, especially during those times when I purposely steered her into mental waters that I knew, while once familiar, were now foreign. She was willing to be taken there to struggle through her sea of confusion, as she knew its purpose was to try and encourage her brain to reconnect to knowledge it once had. But mostly I am honored that she trusted me to try my best not to let her drift too long nor without aim or reason.

If I am lucky, my mother will be around for the next edition of this textbook. Because even as she marches into the middle of her tenth decade on this earth, she continues to teach me something with each of our interactions.

### FROM REBECCA

My mother taught me how to use my brain. She taught me to look at the world with wonder and joy. A former high school chemistry teacher, social worker, university administrative

assistant, jack-of-all-trades – one who might have been an engineer in a different era of opportunity for women – she always conveyed a fascination with “how things work” that I later rediscovered in my own love affair with the brain. Through her example, she taught me that women can enjoy tinkering with mechanical things, that they can ride their bikes without worrying about mussing their hair, that they can have an excellent sense of direction, that they can make of themselves what they

want to be. Most importantly, though, she continues to teach me that in the end, achievement isn’t measured in the number of pages published, grants obtained, or status acquired, but rather in a person’s compassionate actions in the world. I strive to live up to her example.

Marie T. Banich  
Rebecca J. Compton

To my (left-handed) mom,

Who after her stroke displayed so much grace and grit,

And who in her brain-damaged state has taught me so much more than  
I ever could have imagined not only about the intricacies and  
resilience of the human brain, but also about the human spirit.

M.T.B.

To mom, who continues to teach me all of the important things in life.

R.J.C.