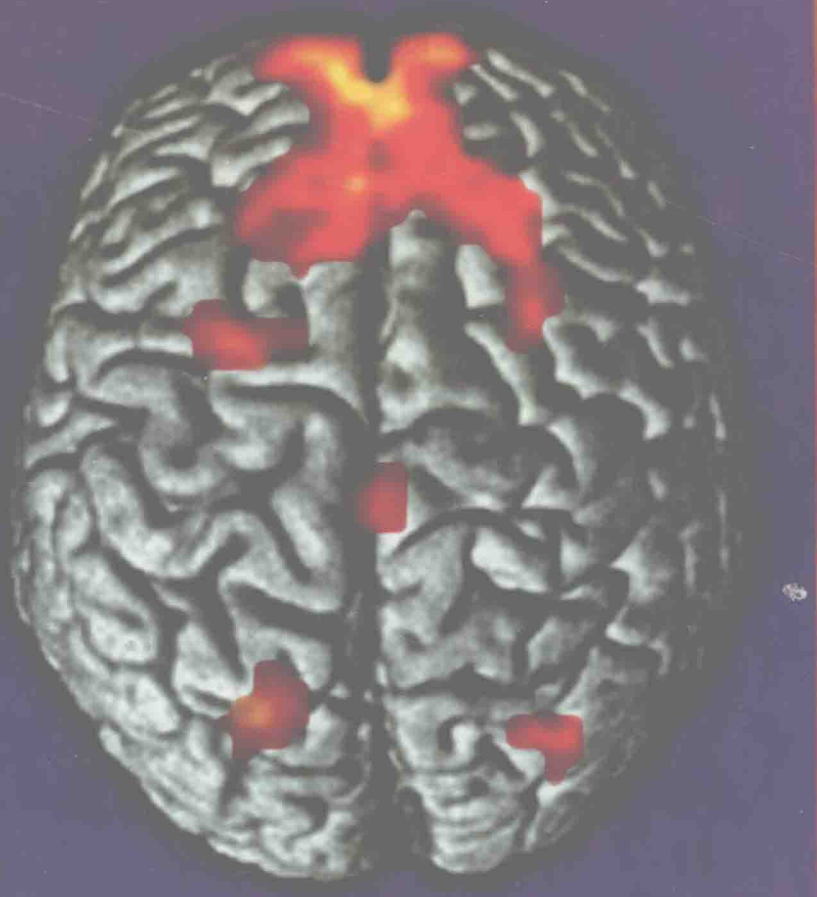
Second Edition

# Cognitive Neuroscience

## THE BIOLOGY OF THE MIND



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# COGNITIVE NEUROSCIENCE

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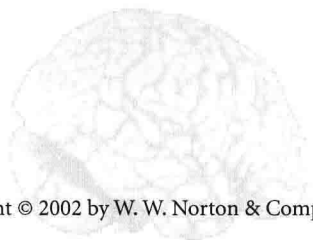



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*FOR FRANCESCA AND ZACHARY*
*M.S.G.*

*FOR HENRY AND SAM*
*R.B.I.*

*FOR ALEXANDER*
*G.R.M.*

# PREFACE

Welcome to the second edition! When new enterprises like cognitive neuroscience emerge, it is not always clear if they will survive. The youthful enthusiasm of a new field is not unlike a young doe standing up for the first time after birth. Can she make it? Will this new life develop and grow? Will true meaning emerge from the new life?

Five years later, we are confident that cognitive neuroscience has not only survived its infancy, it has blossomed in a spectacular fashion. This can be measured in many ways. Leading universities have undertaken major initiatives to develop dedicated cognitive neuroscience programs. The number of journals devoted to the field has increased exponentially. The annual meeting of the Society for Cognitive Neuroscience has burst its seams with attendance increasing 600% between 1994 and 2001.

What constitutes the first principles that make cognitive neuroscience distinct from physiological psychology, neuroscience, cognitive psychology, or neuropsychology? This question was our first challenge in laying the groundwork for our first edition, and constituted our defining point. We concluded that it is indeed a critical question—but paradoxically, not a question at all. Cognitive neuroscience certainly overlaps with and synthesizes these traditional approaches, but our book went beyond that function to define how cognitive neuroscientists will address the neural bases of cognition in the years ahead.

Our approach remains to balance cognitive theory with neuropsychological and neuroscientific evidence, plus add examples of the use of computational techniques to complete the story. We make liberal use of patient case studies, but this is to illustrate essential points, not to provide an exhaustive description of brain disorders. In every section, we strive to include the most current information and theoretical views, supported by cutting-edge technology that is such an important part of cognitive neuroscience. In contrast to purely cognitive or neuropsychological approaches, this text emphasizes the convergence of evidence that is a crucial aspect of any science, particularly studies of higher mental function.

Cognitive neuroscience takes on cognitive concepts and studies mind/brain matters with psychophysical and brain imaging techniques such as fMRI, MR, PET, and ERPs. The field requires one to become knowledgeable in each of these areas and to practice several different approaches when undertaking a single study. This book is intended to prepare students of cognitive neuroscience to do just that.

Since the first edition, there have been many major developments, both methodological and theoretical. There has been an explosion of brain imaging studies, almost 1,500 a year for the past four years. Other technologies such as transcranial magnetic stimulation have been added to the arsenal of the cognitive neuroscientist. New links have emerged with genetics, comparative anatomy, and robotics. All of the chapters in the second edition have been updated to capture these changes.

In addition, we have added two new chapters to the textbook. First, we now include a chapter on emotion. This information was interspersed across a number of chapters in the first edition. With the emergence of affective neuroscience as an important subfield, it became clear that the book needed a dedicated chapter. Second, the growth and importance of the fundamentals of neuroscience that are essential for any student of cognitive neuroscience led us to split this chapter into two, one focused on the basics of molecular and cellular neurobiology and the other on gross and functional anatomy.

Throughout this second edition we have updated each topic with new information. All of the chapters have undergone major revisions with the additions mostly devoted to incorporating results and ideas that have emerged from new studies. The second edition also allowed us to correct any errors in the first edition.

As usual, we are indebted to a number of people. Of special note are three colleagues who lent their expertise to specific chapters of the text, as noted in the table of contents. We thank Elizabeth Phelps for her contribution to Chapter 13, Emotion. Not only has Liz produced some of the most spectacular work in this field over the past few years, she provides a broad perspective to the topic and deep understanding of the issues. Leah Krubitzer wrote the first section of Chapter 14, Evolutionary Perspectives. She provides a convincing argument for why cognitive neuroscientists should understand comparative anatomy. As with the first edition of this textbook, Chapter 9, Language and the Brain, was coauthored by Tamara Swaab whose ability to lead the reader from current psycholinguistic theory to brain physiology and language dysfunction makes a complex field accessible.

As in the first edition, we make a special effort to bring cognitive neuroscience alive with color. Frank Forney is again the book's artist and is to be congratulated for his continued fine work. We also thank our many colleagues who have provided original artwork or scientific figures.

In sum, this book has been an interactive effort between ourselves, our colleagues, our students, and our reviewers! The product has benefited immeasurably from these interactions, but we will not rest here. We stand ready to modify and improve any and all of our work. In our first edition, we asked our readers to contact us with your suggestions and questions, and we do so again. We live in an age where interaction is swift and easy. We are to be found as follows: gazzaniga@dartmouth.edu; mangun@duke.edu; ivry@socrates.berkeley.edu. Good reading and learning.

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# 1

# A Brief History of Cognitive Neuroscience

What is the field of cognitive neuroscience all about? Where did it come from? Where is it going? We start this book with a brief history of the people and ideas that led to the new field of cognitive neuroscience, one that has roots in neurology, neuroscience, and cognitive science. Modern-day cognitive neuroscience represents a hybrid of disciplines, and therefore the student of the mind must become aware and knowledgeable in many areas to fully understand the issues studied in cognitive neuroscience. And the field changes rapidly. At the end of this chapter we introduce the short and very new history of brain imaging. Brain imaging has become central to the study of the mind in the last few years.

## PONDERING THE BIG QUESTIONS

Do you wonder about big things
like the meaning of life, or the meaning of meaning? Or are you the type who does not wonder about such evanescent questions? If you are the latter, do not read this book—even though you should. This book is for those who wonder what life, mind, sex, love, thinking, feeling, moving, attending, remembering, communicating, and being are all about. And better, it is about scientific approaches to these grand issues. So prepare yourself for learning about a fantastic story still in the making.

The scientific field of cognitive neuroscience received its name in the late 1970s in the back seat of a New York City taxi. One of us (M.S.G.) was riding with the great cognitive psychologist George A. Miller on the way to a dinner meeting at the Algonquin Hotel. The dinner was being held for scientists from Rockefeller University and Cornell University, who were joining forces to study how the brain enables the mind, a subject in need of a name. Out of that taxi ride came the term *cognitive neuroscience,* which took hold in the scientific community.

Now the question is, What does it mean? In answering this ponderous question, we need to step back and look at not only the history of human thought but also the history of the scientific disciplines of biology, psychology, and medicine.

To grasp the miraculous properties of brain function, one must bear in mind that Mother Nature built it, not a team of rational engineers. Although the earth formed approximately 5 billion years ago, and life first appeared around 3.5 billion years ago, human brains in their present form have been around only about 100,000 years. The primate brain appeared approximately 20 million years ago, and evolution took its course to build our present human brain, capable of all sorts of wondrous—and banal—feats.

During most of history, humans were too busy to think about thought. While there can be little doubt that human brains could engage in such activities, life was given over to more practical work such as surviving in tough environments, developing ways to live better by inventing agriculture or by domesticating

animals, and so forth. However, as soon as civilization developed to the point when day-to-day survival did not occupy every hour of every day, our ancestors began to spend time constructing complex theories about the motives of fellow humans. Examples of attempts to understand the world and our place in it include *Oedipus Rex,* the ancient Greek play that deals with the nature of the child-parent conflict, and Mesopotamian and Egyptian theories on the nature of religion and the universe. The brain mechanisms that enabled the generation of theories about the nature of human nature thrived inside the heads of ancient humans. Yet they had one big problem: They did not have the ability to systematically explore the mind through experimentation.

In a diary entry of 1846, the brilliant philosopher Søren Kierkegaard wrote:

> . . . That a man should simply and profoundly say that he cannot understand how consciousness comes into existence—is perfectly natural. But that a man should glue his eye to a microscope and stare and stare and stare—and still not be able to see how it happens—is ridiculous, and it is particularly ridiculous when it is supposed to be serious. . . . If the natural sciences had been developed in Socrates' day as they are now, all the sophists would have been scientists. One would have hung a microscope outside his shop in order to attract custom, and then would have had a sign painted saying: "Learn and see through a giant microscope how a man thinks (and on reading the advertisement Socrates would have said: 'That is how men who do not think behave')."

The Nobel laureate Max Delbrück (1986) began his fascinating account of the evolution of the cosmos in his book *Mind from Matter?* with the foregoing quote of Kierkegaard. Delbrück is part of the modern tradition that started in the nineteenth century. Observe, manipulate, measure, and start to determine how the brain gets its job done. Armchair thinking is a wonderful thing and has produced fascinating science such as theoretical physics and mathematics. But to understand how a biological system works, a laboratory is needed and experiments have to be performed. Ideas derived from introspection can be eloquent and fascinating, but are they true? Philosophy can add perspective, but is it right? Only scientific method can move a topic along on sure footing. And just think about the rich phenomena to study. Take the perception of faces. Some say that the brain has a special system for recognizing faces. This specialized system was revealed because patients with certain brain lesions had a hard time recognizing faces of all kinds. Scientists immediately debated whether there was a specialized system. No, some said, the impairment is with object perception in general, not faces in particular. They pointed to research which suggested that people who had a hard time recognizing faces also had a hard time seeing objects or faces of animals.

But then comes a new case. A patient has a terrible time seeing everyday objects but has no problem seeing faces! In fact, if the faces are composed of fruit arranged to look like a face, the patient says he sees the face but does not realize it is made up of fruit! Incredible but true. It appears as though a special system in the brain sees faces; it is triggered to produce the percept for our conscious lives by the configuration of elements. The special face processor does not know or care about what elements it is composed of; as long as they are in proper arrangement, a face is perceived. What could be more fascinating than to study how the brain does such things?

## THE BRAIN STORY

You are given a problem to solve. A hunk of biological tissue is known to think, remember, attend, solve problems, want sex, play games, write novels, exhibit prejudice, and do a zillion other things. You are supposed to figure out how it works. Before starting, you might ask a few questions. Does the blob work as a unit with each part contributing to a whole? Or is the blob full of individual processing parts, each carrying out specific functions, with the result being something that looks like it is acting as a whole unit? After all, the blob of the city of New York looks like an integrated whole from a distance, but it is actually composed of millions of individual processors, which is to say people. Perhaps people, in turn, are made of smaller, more specialized units.

This central issue—whether the whole brain working in concert or parts of the brain working independently enable mind—is what fuels much of modern research. As we will see, the dominant view has changed over the past 100 years, and continues to do so today. It all started in the nineteenth century when **phrenologists,** led by Franz Joseph Gall and J.G. Spurzheim (1810–1819), declared that the brain was organized around some thirty-five specific functions (Figure 1.1). These functions,