RAY GUILLERY

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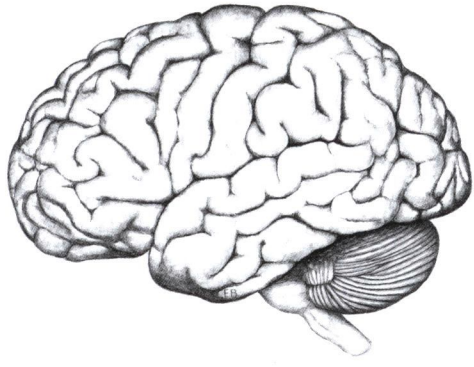

AS A TOOL

[A Neuroscientist's Account]

With original illustrations by Lizzie Burns

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'The late Professor Ray Guillery was a legendary figure in the field of brain science. Presented with exemplary clarity, this book is a living testament to his deep knowledge and insight of the complexity of the brain. Through his lifelong studies, the author has developed a distinct view about the interplay between the cerebral cortex and subcortical structures, briefly stated as the idealist view versus the standard realist one. Guillery clearly describes the differences and the reader will enjoy considering the alternative views. The low key and simple language makes it a pleasure to read and inspires one to pay serious attention to the beautiful illustrations of different brain regions and their interconnections.'

TORSTEN N. WIESEL, President Emeritus, The Rockefeller University, USA
Nobel Laureate, Physiology or Medicine 1981

'*The Brain as a Tool* provides a fascinating and thought-provoking analysis of how the brain works. Ray Guillery takes an evolutionary perspective and provides an account of how neuroscience has evolved over many years to our current views. He has a focus on the interaction between thalamus and cortex without forgetting other parts of the nervous system. Neuroscientists from the youngest student to senior researchers will enjoy reading this remarkable book and learn a lot.'

STEN GRILLNER, Professor in Neuroscience, Karolinska Institute, Sweden

'Ray Guillery wrote this book to promote the "interactive" view of brain function. This is the idea that sensory inputs and motor outputs are not separate, but are combined at every level of the nervous system. If you are not already a believer of this important concept you cannot find a better introduction and argument in its favor. However, I also loved this book for a completely different reason. It is a beautifully written introduction to the nervous system, told through the reflection of the author's long career. It is a joy to read. People often ask me what I recommend they read as they start their career in neuroscience. *The Brain as a Tool* is now on the very short list of books I recommend.'

JEFF HAWKINS, Founder, Numenta, USA

'In this wonderful work, neurophysiology meets embodied cognition. The result is a match made in heaven. Guillery foregrounds the neglected role of subcortical (thalamic) resources, which are always busy preparing our actions and responding to the world. But what emerges is a succession of tantalizing new ideas that reach all the way up to consciousness and the sense of self. This elegant book belongs in every cognitive scientist's toolkit.'

ANDY CLARK, Professor of Logic and Metaphysics, University of Edinburgh, UK
Author of *Surfing Uncertainty: Prediction, Action, and the Embodied Mind* (OUP, 2016)

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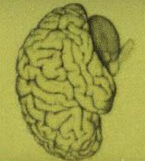

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A Neuroscientist's Account

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The Brain as a Tool

This book is dedicated to Murray Sherman, with thanks for many critical and helpful contributions to my thoughts about the brain and for many years of friendship and cooperation.

Preface

We rely on our brains for all aspects of our conscious lives, in health and disease. Neuroscientists need to understand the ways in which nerve cells communicate with each other and how the messages that are passed from one nerve cell to another link us to the world. Advances in understanding how messages pass along nerve fibres and from one cell to the next are well advanced in terms of understanding these events at molecular levels. Our understanding of what the messages mean and how the neural activity relates to our cognitive and behavioural lives is, in contrast, much more limited.

That is the focus of this book, and the title is an attempt to see how we depend on using the brain, its nerve cells and neural pathways, to learn about our interactions with the world. The brain on its own can do nothing. We use our brains to interact with the world. It is not until we start moving about, moving our eyes, or our fingers, that we can start using our brains to learn about the world by interacting with it. If we want to understand animals including ourselves and each other in health and disease, we need to understand the neural pathways and their functions. Models or theoretical proposals are most useful once they can be related to identifiable brain parts that can be studied down to molecular levels. That is the focus of this book: to raise answerable questions about living brains and identifiable intercommunicating nerve cells.

This book follows three earlier books on the pathways to the cerebral cortex (Sherman and Guillery 2001, 2006, 2013) written jointly with S Murray Sherman, now at the University of Chicago. It owes much to those books and to my more than four decades of lively, thoughtful, and productive interactions with Murray. I now see that the implications of the neural results summarized in those books lead to important conclusions, not only about how we plan and interpret further experiments, but also beyond that, to the territories of

psychologists and philosophers concerning the brain's highest functions. This book explores where, in order to understand these functions, knowledge about specific neural pathways and their actions will be relevant.

In the past, there have been two distinct views about how our brains relate to our bodies and the world: the standard view of most current neuroscience textbooks has the cerebral cortex receiving sensory messages from the world and then reacting to what it has received by sending messages out to the muscles. This, the sensory-to-motor view, is a realist view based on a real world that we can describe in our daily lives or read about in physics textbooks. An alternative view, an idealist or interactive view, has so far received more support from psychologists and philosophers than it has from neuroscientists. This view recognizes that we use the brain to *learn* about the meanings of the messages that the brain receives from the body and the world. Whereas the sensory physiologist identifies these meanings easily, knowing the details of stimuli, the cortex receives only the message, a pattern of neural impulses comparable to a Morse code. For an organism like us to understand or respond appropriately to these messages we have to use the brain as a tool for exploring the relevant parts of the world, moving our fingers to identify objects in the dark, moving our eyes to see the objects in the light, or moving our whiskers if we are a mouse. These sensorimotor interactions depend on the fact that each incoming message actually has two meanings, one about the sensory event and the other about the *forthcoming* action that is already being processed at lower levels of the brain.

A brief account of both views in Part I of the book shows how the standard view was established mainly between the 1850s and the 1950s by tracing sensory and motor pathways through the brain. Part I also introduces a number of pathways that have played a lesser role, or no role at all in the textbooks, but that can today be seen to provide strong neural evidence for the interactive view. I show throughout the later parts of the book that the questions we can ask about the brain, and the experiments we can get funded, depend significantly on which of these two views our questions are based on. The difference matters

not only to philosophers and psychologists, it matters particularly to neuroscientists.

In the first chapters of Part II, I go back to the early 1950s, when I was learning to be a neuroanatomist (neuroscientists were unheard of at the time). I do this partly to introduce a historical background and a personal angle to the book, but mainly to illustrate how a subject that had been growing rapidly since the mid-nineteenth century, describing the major pathways of the brain in terms of their connections and their functions, was suddenly lacking what had seemed until the 1950s to have been its own firm theoretical basis. Studies of nervous systems relied heavily on the 'neuron doctrine' together with a 'law of dynamic polarization' about the organization of individual nerve cells. Neither the doctrine nor the law survived undamaged through the 1960s and I was fortunate to have been taught that neuroanatomy is not a part of a separate discipline with its own doctrines and laws, but a part of biology, based on contemporary views of evolutionary relationships, where animals must be studied in terms of the uses that the parts serve in the lives of the animals. The brain has an evolutionary history and its parts can be expected to have specific uses. We still need to learn how we and our vertebrate relatives use our brains. In the later chapters of Part II, I apply such an evolutionary view of the brain to a cell group called the thalamus, an obligatory relay on the way to the cerebral cortex. Since this is present in mammals but largely lacking in our vertebrate ancestors, we face a key question. What is it about the thalamus and cortex that distinguishes mammalian behavioural and cognitive capacities from those of our ancestors? I was unable to answer this then, during the 1960s, but the question led me to study details of the structures in the thalamus, and these gradually led me to the contents of this book.

Part III is heavily based on my earlier publications with Murray Sherman between the 1970s and 2013. It describes the thalamic relay of the visual pathways to the cerebral cortex and shows that the thalamus as a whole serves as a relay and a gate for all the messages that reach the cerebral cortex, some coming from other sensory pathways, some from other lower centres of the brain, and some coming from the cerebral cortex itself. These last pathways, the transthalamic corticocortical

pathways, revealed a feature that has proved to be common to all of the pathways relayed in the thalamus of mammals. The messages passing through the thalamus to the cerebral cortex travel along branched axons, one branch carrying information about events in the world, the body, or the brain to the thalamus for relay to the cortex, and the other carrying motor instructions on their way to lower centres that control the muscles. Since a branched axon sends essentially the same message down both branches, the cortex receives a copy of motor instructions that are on their way to execution elsewhere. The transthalamic corticocortical connections are arranged in a hierarchical order with several levels, each area serving to monitor lower levels and also to contribute to the relevant motor controls at lower levels as needed.

Part IV explores the cognitive and behavioural implications of this hierarchical arrangement of cortical monitors. I describe each cortical area as receiving a dual message, one about a recent event in the world, the body, or the brain, and another about an instruction for a forthcoming related action, which in its turn will produce a new sensory message and a further, slightly later action. This generates the flow of sensorimotor interactions that provides a continuity to the flow of our conscious lives. Often this flow is interrupted by an unexpected event, perhaps in the world, perhaps in the brain. Then the mechanisms of the cortical hierarchies and the functions of the thalamic relay take over. As higher cortical levels monitor the lower levels, they can identify the problem and send their own motor instructions to correct the error; often with a copy of the instructions sent to a yet higher cortical area through a thalamic relay. In this way, the continuous flow of perceptions that lead to actions, which, in turn, lead to new perceptions, can produce and maintain the continuous flow of our conscious lives, providing us with a sense of the continuity of ourselves and the world. We describe them as conscious actions because we can anticipate them, thus clearly distinguishing them from the action of others.

When we experience a novel, unexpected sensory input, perhaps while learning a new skill, perhaps learning to back a car into a parking area or viewing the world through inverting lenses, the smooth flow of sensorimotor actions is not immediately achieved. The cortical

hierarchy must be brought into play to control our phylogenetically older motor centres, guiding them at difficult, unexpected moments until a well-integrated sensorimotor sequence is once more created. We can start to think of the cortex as a tool that is particularly useful for helping us to learn new skills.

If we ask why mammals in particular may have acquired this new hierarchy of cortical monitors, the answer may well be that mammals give birth to living young, commonly several, that are breastfed as a group. The new, early challenges of the social interactions required by such a family may well have required the rapid modifications of sensorimotor interactions that the cortical hierarchy of monitors can produce. Once the new mechanism had been established, their potential for new learning was, and almost certainly still is, almost unlimited.

For whom has this book been written? At first for neuroscientists, especially for young neuroscientists interested in the functional organization of the neural pathways, who are looking for new ways of seeing the brain and for new questions to ask about it. I also hope that it will interest many older neuroscientists and people in related fields, not only in psychology and philosophy but also in the many related fields that are contributing to our understanding of the brain, people who are looking to understand the functions of the brain from the point of view of their own disciplines. I have included a set of illustrations that should serve as a guide to the parts of the brain discussed for those who have a limited background in neuroscience. There is also a glossary of terms used. Both of these are designed specifically for the items that play a role in the book; they should not be regarded as a simplified primer in neuroscience generally.

There is an important message in the illustrations. They will strike a neuroscientist as representing the past rather than the future. That is deliberate. I am describing and reinterpreting the past, in order to raise issues that need to be studied in the future. There are now many new methods for studying the structures and functions of nerve cells that have enormous promise, but have not yet produced new conceptual structures for understanding the functional relationship of the brain's pathways. The illustrations in this book relate to the conceptual

structures we have, and the text raises issues about where new evidence can in the future be found, probably by one or another of the new methods, methods which are still increasing. The book is an effort to make sense of the information we have inherited from the past. It is written for those who will be generating new conceptual structures in the future, and who will be able to illustrate them with some of the wonderful images that the new methods generate.

This book owes thanks to many people. Outstanding among these, as the contents of the book demonstrate, are two people: one was JZ Young, my teacher, thesis supervisor, and senior colleague from 1948 to 1964 in the Department of Anatomy at University College London. He taught me much and gave me the freedom to learn from my mistakes; the other is Murray Sherman, who has shared my interest in the puzzles of the brain since the late 1960s, and has contributed to many joint publications and three books that provided a basis for the present book. Even more, he has been a good friend and valuable colleague for many years. Our conversations, discussions, and arguments often left the brain for other subjects, but always tended to come back to the same subject: the brain and our ignorance as to its functions.

Many others have contributed to my thoughts about the brain, and I will only list some of them here. I am grateful to them all. Lizzie Burns has earned my thanks not only for the figures themselves, but also for her enthusiasm about preparing them, and her interest in the text itself. Colin Beesely has helped with many of the copies of figures from the literature. Others who have been involved in the preparation of this book in one of many different ways include Andrew Parker, Andy Smart, Anna Mitchell, Beycan Gödze Ayhan, Carol Mason, Emily Mackevicius, Filiz Onat, Fritz Sommer, Husniye Haçiolu Bey, Kouichi Nakamura, Kutay Deniz Atabay, Paul Bolam, Peter HJ Ralston, Richard Boyd, Sowon Park, Sten Grillner, Stuart Judge, Charlotte Holloway, and April Peake. My thanks to them all.

Ray Guillery

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