GREAT MYTHS OF THE BRAIN

Christian Jarrett

WILEY Blackwell

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Praise for *Great Myths of the Brain*

"The more we are interested in the brain and how it explains our behavior, the more important it is that we rid ourselves of untruths and half-truths. Myth-buster extraordinaire, Christian Jarrett is an engaging and knowledgeable guide who spring-cleans the cobwebs of misinformation that have accumulated over recent years. You will be surprised at some favorite beliefs that turn out to be scare stories or wishful thinking. Yet Jarrett conveys a strong optimism about fresh approaches that will result in new knowledge. All claims are well substantiated with references. It will be fun to learn from this book."

Professor Uta Frith DBE, UCL Institute of Cognitive Neuroscience

"Christian Jarrett is the ideal guide to the fascinating, bewildering, and often overhyped world of the brain. He writes about the latest discoveries in neuroscience with wonderful clarity, while cleanly puncturing myths and misinformation."

Ed Yong, award-winning science writer, blogger, and journalist

"*Great Myths of the Brain* provides an incredibly thorough and engaging dismantling of neurological myths and misconceptions that abound today. For anyone overwhelmed by copious bogus neuroscience, Christian Jarrett has generously used his own mighty brain to clear this cloud of misinformation, like a lighthouse cutting through the fog."

Dr Dean Burnett, Guardian *blogger, Cardiff University*

"Lots of people cling to misconceptions about the brain that are just plain wrong, and sometimes even dangerous. In this persuasive and forceful book, Christian Jarrett exposes many of these popular and enduring brain myths. Readers who want to embrace proper neuroscience and arm themselves against neurononsense will enjoy this splendid book, and profit greatly from doing so."

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University of California, Irvine

"Christian Jarrett, one of the world's great communicators of psychological science, takes us on a neuroscience journey, from ancient times to the present. He exposes things we have believed that just aren't so. And he explores discoveries that surprise and delight us. Thanks to this tour de force of critical thinking, we can become wiser – by being smartly skeptical but not cynical, open but not gullible."

Professor David G. Myers, Hope College, author, Psychology, *11th edition*

"A masterful catalog of neurobollocks."

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"In this era of commercialized neurohype, Christian Jarrett's engaging book equips us with the skills for spotting the authentic facts lost in a sea of brain myths. With compelling arguments and compassion for the human condition, Jarrett teaches us that the truth about the brain is more complicated, but ultimately more fascinating, than fiction."

The Neurocritic, neuroscientist and blogger

"Christian Jarrett has written a wonderful book that is as entertaining as it is enlightening. When it comes to brain science, a little knowledge is a dangerous thing. Jarrett has done us all a great service by peeling back the layers of hype to reveal what we really do know – and don't know – about how the brain functions."

Professor Christopher C. French, Goldsmiths, University of London

"*Great Myths of the Brain* is essential reading for anyone who wants to navigate the maze of modern neuroscience, separating fact from fiction and reality from hype. Jarrett is an insightful, engaging guide to the mysteries of the human mind, providing an always smart, often humorous account that will equip you with the tools you need to understand both the power and the limitations of your own mind."

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For my dear mother,
Linda, my inspiration

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I should note that several passages in this book, or variants of them, have appeared as blog posts either on my Brain Myths blog at Psychology Today (http://www.psychologytoday.com/blog/brain-myths), or more recently on my Brain Watch blog at WIRED (http://www.wired.com/category/brainwatch/). Also, some of the quotes from experts in this book were originally provided to me for articles I wrote while working as staff journalist on *The Psychologist* magazine.

I might never have been a writer at all, if my mother Linda hadn't encouraged me down that path when I was still completing my doctoral research. She also turned her eagle eyes to the Brain Myths manuscript, and gave me supportive feedback throughout. Thanks Mum for believing in me!

Finally, to my beautiful family – my wife Jude, and our baby twins Charlie and Rose, who were born this year – thank you for everything. I love you more!

Christian Jarrett, June 2014

INTRODUCTION

"As humans, we can identify galaxies light years away, we can study particles smaller than an atom. But we still haven't unlocked the mystery of the three pounds of matter that sits between our ears." That was US President Barack Obama speaking in April 2013 at the launch of the multimillion dollar BRAIN Initiative. It stands for "Brain Research through Advancing Innovative Neurotechnologies" and the idea is to develop new ways to visualize the brain in action. The same year the EU announced its own €1 billion Human Brain Project to create a computer model of the brain (see p. 105).

This focus on neuroscience isn't new – back in 1990, US President George H.W. Bush designated the 1990s the "Decade of the Brain" with a series of public awareness publications and events. Since then interest and investment in neuroscience has only grown more intense; some have even spoken of the twenty-first century as the "Century of the Brain."

Despite our passion for all things neuro, Obama's assessment of our current knowledge was accurate. We've made great strides in our understanding of the brain, yet huge mysteries remain. They say a little knowledge can be a dangerous thing and it is in the context of this excitement and ignorance that brain myths have thrived. By brain myths I mean stories and misconceptions about the brain and brain-related illness, some so entrenched in everyday talk that large sections of the population see them as taken-for-granted facts.

With so many misconceptions swirling around, it's increasingly difficult to tell proper neuroscience from brain mythology or what one science blogger calls neurobollocks (see neurobollocks.wordpress.com), otherwise known as

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neurohype, neurobunk, neurotrash, or neurononsense. Daily newspaper headlines tell us the "brain spot" for this or that emotion has been identified (see p. 80). Salesmen are capitalizing on the fashion for brain science by placing the neuro prefix in front of any activity you can think of, from neuroleadership to neuromarketing (see p. 188). Fringe therapists and self-help gurus borrow freely from neuroscience jargon, spreading a confusing mix of brain myths and self-improvement propaganda.

In 2014, a journalist and over-enthusiastic neuroscientist even attempted to explain the Iranian nuclear negotiations (occurring at that time) in terms of basic brain science.[1] Writing in *The Atlantic*, the authors actually made some excellent points, especially in terms of historical events and people's perceptions of fairness. But they undermined their own credibility by labeling these psychological and historical insights as neuroscience, or by gratuitously referencing the brain. It's as if the authors drank brain soup before writing their article, and just as they were making an interesting historical or political point, they hiccupped out another nonsense neuro reference.

This book takes you on a tour of the most popular, enduring and dangerous of brain myths and misconceptions, from the widely accepted notion that we use just 10 percent of our brains (see p. 51), to more specific and harmful misunderstandings about brain illnesses, such as the mistaken idea that you should place an object in the mouth of a person having an epileptic fit to stop them from swallowing their tongue (see p. 284). I'll show you examples of writers, filmmakers, and charlatans spreading brain myths in newspaper headlines and the latest movies. I'll investigate the myths' origins and do my best to use the latest scientific consensus to explain the truth about how the brain really works.

The Urgent Need for Neuro Myth-Busting

When Sanne Dekker at the Vrije Universiteit in Amsterdam and her colleagues surveyed hundreds of British and Dutch teachers recently about common brain myths pertaining to education, their results were alarming. The teachers endorsed around half of 15 neuromyths embedded among 32 statements about the brain.[2] What's more, these weren't just any teachers. They were teachers recruited to the survey because they had a particular interest in using neuroscience to improve teaching.

Among the myths the teachers endorsed were the idea that there are left-brain and right-brain learners (see p. 55) and that physical coordination exercises can improve the integration of function between the brain hemispheres. Worryingly, myths related to quack brain-based teaching programs (see p. 207) were especially likely to be endorsed by the teachers. Most disconcerting of all, greater general knowledge about the brain was associated with stronger belief in educational neuromyths – another indication that a little brain knowledge can be a dangerous thing.

If the people educating the next generation are seduced by brain myths, it's a sure sign that we need to do more to improve the public's understanding of the difference between neurobunk and real neuroscience. Still further reason to tackle brain myths head on comes from research showing that presenting people, including psychology students, with correct brain information is not enough – many still endorse the 10 percent myth and others. Instead what's needed is a "refutational approach" that first details brain myths and then debunks them, which is the format I'll follow through much of this book.

Patricia Kowalski and Annette Taylor at the University of San Diego compared the two teaching approaches in a 2009 study with 65 undergraduate psychology students.[3] They found that directly refuting brain and psychology myths, compared with simply presenting accurate facts, significantly improved the students' performance on a test of psychology facts and fiction at the end of the semester. Post-semester performance for all students had improved by 34.3 percent, compared with 53.7 for those taught by the refutational approach.

Yet another reason it's important we get myth-busting is the media's treatment of neuroscience. When Cliodhna O'Connor at UCL's Division of Psychology and Language Sciences, and her colleagues analyzed UK press coverage of brain research from 2000 to 2010, they found that newspapers frequently misappropriated new neuroscience findings to bolster their own agenda, often perpetuating brain myths in the process (we'll see through examples later in this book that the US press is guilty of spreading neuromyths too).[4]

From analyzing thousands of news articles about the brain, O'Connor found a frequent habit was for journalists to use a fresh neuroscience finding as the basis for generating new brain myths – dubious self-improvement or parenting advice, say, or an alarmist health warning. Another theme was using neuroscience to bolster group differences, for example, by referring to "*the* female brain" or "*the* gay brain," as if all people fitting that identity all have the same kind of brain (see p. 65 for the truth about gender brain differences). "[Neuroscience] research was being applied out of context to create dramatic headlines, push thinly disguised ideological arguments, or support particular policy agendas," O'Connor and her colleagues concluded.

About This Book

This introductory section ends with a primer on basic brain anatomy, techniques, and terminology. Chapter 1 then kicks off the myth-busting by providing some historical context, including showing how our understanding of the brain has evolved since Ancient times, and detailing outdated myths that are no longer widely believed, but which linger in our proverbs and sayings. This includes the centuries' long belief that the mind and emotions are located in the heart – an idea betrayed through contemporary phrases like "heart break" and "learn by heart." Chapter 2 continues the historical theme, looking at brain techniques that have entered psychiatric or neurological folklore, such as the brutal frontal lobotomy. Chapter 3 examines the lives and brains of some of neurosciences mythical figures – including the nineteenth century rail worker Phineas Gage, who survived an iron rod passing straight through his brain, and Henry Molaison, the amnesiac who was examined by an estimated 100 psychologists and neuroscientists.

Chapter 4 moves on to the classic brain myths that refuse to die away. Many of these will likely be familiar to you – in fact, maybe you thought they were true. This includes the idea that right-brained people are more creative; that we use just 10 percent of our brains; that women lose their minds when they are pregnant; and that neuroscience is changing human self-understanding. We'll see that there is a grain of truth to many of these myths, but that the reality is more nuanced, and often more fascinating, than the myths suggest.

Chapter 5 deals with myths about the physical structure of the brain, including the idea that bigger means better. And we'll look at mythology surrounding certain types of brain cells – the suggestion that mirror neurons are what makes us human and that you have in your brain a cell that responds only to the thought of your grandmother.

Next we turn to technology-related myths about the brain. These relate to the kind of topical claims that make frequent appearances in the press, including the ubiquitous suggestion that brain scans can now read your mind, that the Internet is making us stupid, and that computerized brain training games are making you smart.

The penultimate chapter deals with the way the brain relates to the world and the body. We'll debunk the popular misconception that there are only five senses, and we'll also challenge the idea that we really see the world exactly how it is.

The book concludes in Chapter 8 by dealing with the many misconceptions that exist about brain injury and neurological illness. We'll see how conditions like epilepsy and amnesia are presented in Hollywood films and tackle the widespread belief that mood disorders somehow arise from a chemical imbalance in the brain.

The Need for Humility

To debunk misconceptions about the brain and present the truth about how the brain really works, I've pored over hundreds of journal articles, consulted the latest reference books and in some cases made direct contact with the world's leading experts. I have strived to be as objective as possible, to review the evidence without a pre-existing agenda.

However, anyone who spends time researching brain myths soon discovers that many of today's myths were yesterday's facts. I am presenting you with an account based on the latest contemporary evidence, but I do so with humility, aware that the facts may change and that people make mistakes. While the scientific consensus may evolve, what is timeless is to have a skeptical, open-minded approach, to judge claims on the balance of evidence, and to seek out the truth for its own sake, not in the service of some other agenda. I've written the book in this spirit and in the accompanying box on p. 7 I present you with six tips for applying this skeptical, empirical approach, to help you spot brain myths for yourself.

Before finishing this Introduction with a primer on basic brain anatomy, I'd like to share with you a contemporary example of the need for caution and humility in the field of brain mythology. Often myths arise because a single claim or research finding has particular intuitive appeal. The claim makes sense, it supports a popular argument, and soon it is cemented as taken-for-granted fact even though its evidence base is weak. This is exactly what happened in recent years with the popular idea, accepted and spread by many leading neuroscientists, that colorful images from brain scans are unusually persuasive and beguiling. Yet new evidence suggests this is a modern brain myth. Two researchers in this area, Martha Farah and Cayce Hook, call this irony the "seductive allure of 'seductive allure.'"[5]

Brain scan images have been described as seductive since at least the 1990s and today virtually every cultural commentary on neuroscience mentions the idea that they paralyze our usual powers of rational scrutiny. Consider an otherwise brilliant essay that psychologist Gary Marcus wrote for the *New Yorker* late in 2012 about the rise of neuroimaging: "Fancy color pictures of brains in action became a fixture in media accounts of the human mind and *lulled people* into a false sense of comprehension," he said (emphasis added).[6] Earlier in the year, Steven Poole writing for the *New Statesman* put it this way: "the [fMRI] pictures, like religious icons, inspire uncritical devotion."[7]

What's the evidence for the seductive power of brain images? It mostly hinges on two key studies. In 2008, David McCabe and Alan Castel showed that undergraduate participants found the conclusions of a study (watching TV boosts maths ability) more convincing when accompanied by an fMRI brain scan image than by a bar chart or an EEG scan.[8] The same year, Deena Weisberg and her colleagues published evidence that naïve adults and neuroscience students found bad psychological explanations more satisfying when they contained gratuitous neuroscience information (their paper was titled "The Seductive Allure of Neuroscience Explanations").[9]

What's the evidence against the seductive power of brain images? First off, Farah and Hook criticize the 2008 McCabe study. McCabe's group claimed that the different image types were "informationally equivalent," but Farah and Hook point out this isn't true – the fMRI brain scan images are unique in providing the specific shape and location of activation in the temporal lobe, which was relevant information for judging the study. Next came a study published in 2012 by David Gruber and Jacob Dickerson, who found that the presence of brain images did not affect students' ratings of the credibility of science news stories.[10]

Was this failure to replicate the seductive allure of brain scans an anomaly? Far from it. Through 2013 no fewer than three further investigations found the same or a similar null result. This included a paper by Hook and Farah themselves,[11] involving 988 participants across three experiments; and another led by Robert Michael involving 10 separate replication attempts and nearly 2000 participants. Overall, Michael's team found that the presence of a brain scan had only a tiny effect on people's belief in an accompanying story.[12] The result shows "the 'amazingly persistent meme of the overly influential image' has been wildly overstated," they concluded.

So why have so many of us been seduced by the idea that brain scan images are powerfully seductive? Farah and Hook say the idea supports non-scanning psychologists' anxieties about brain scan research stealing all the funding. Perhaps above all, it just seems so plausible. Brain scan images really are rather pretty, and the story that they have a powerful persuasive effect is very believable. Believable, but quite possibly wrong. Brain scans may be beautiful but the latest evidence suggests they aren't as beguiling as we once assumed. It's a reminder that in being skeptical about neuroscience we must be careful not to create new brain myths of our own.

Arm Yourself against Neurobunk

This book will guide you through many of the most popular and pervasive neuromyths but more are appearing every day. To help you tell fact from fiction when encountering brain stories in the news or on TV, here are six simple tips to follow:

1. Look out for gratuitous neuro references. Just because someone mentions the brain it doesn't necessarily make their argument more valid. Writing in *The Observer* in 2013, clinical neuropsychologist Vaughan Bell called out a politician who claimed recently that unemployment is a problem because it has "physical effects on the brain," as if it isn't an important enough issue already for social and practical reasons.[13] This is an example of the mistaken idea that a neurological reference somehow lends greater authority to an argument, or makes a societal or behavioral problem somehow more real. You're also likely to encounter newspaper stories that claim a particular product or activity really is enjoyable or addictive or harmful because of a brain scan study showing the activation of reward pathways or some other brain change. Anytime someone is trying to convince you of something, ask yourself – does the brain reference add anything to what we already knew? Does it really make the argument more truthful?
2. Look for conflicts of interest. Many of the most outrageous and far-fetched brain stories are spread by people with an agenda. Perhaps they have a book to sell or they're marketing a new form of training or therapy. A common tactic used by these people is to invoke the brain to shore up their claims. Popular themes include the idea that technology or other aspects of modern life are changing the brain in a harmful way, or the opposite – that some new form of training or therapy leads to real, permanent beneficial brain changes (see p. 217 and p. 201). Often these kinds of brain claims are mere conjecture, sometimes even from the mouths of neuroscientists or psychologists speaking outside their own area of specialism. Look for independent opinion from experts who don't have a vested interest. And check whether brain claims are backed by quality peer-reviewed evidence (see point 5). Most science journals require authors to declare conflicts of interest so check for this at the end of relevant published papers.
3. Watch out for grandiose claims. No Lie MRI is a US company that offers brain scan-based lie detection services. Its home page states,

"The technology used by No Lie MRI represents the first and only direct measure of truth verification and lie detection in human history!" Sound too good to be true? If it does, it probably is (see p. 184). Words like "revolutionary," "permanent," "first ever," "unlock," "hidden," "within seconds," should all set alarm bells ringing when uttered in relation to the brain. One check you can perform is to look at the career of the person making the claims. If they say they've developed a revolutionary new brain technique that will for the first time unlock your hidden potential within seconds, ask yourself why they haven't applied it to themselves and become a best-selling artist, Nobel winning scientist, or Olympic athlete.

4 Beware of seductive metaphors. We'd all like to have balance and calm in our lives but this abstract sense of balance has nothing to do with the literal balance of activity across the two brain hemispheres (see also p. 196) or other levels of neural function. This doesn't stop some self-help gurus invoking concepts like "hemispheric balance" so as to lend a scientific sheen to their lifestyle tips – as if the route to balanced work schedules is having a balanced brain. Any time that someone attempts to link a metaphorical concept (e.g. deep thinking) with actual brain activity (e.g. in deep brain areas), it's highly likely they're talking rubbish. Also, beware references to completely made up brain areas. In February 2013, for instance, the *Daily Mail* reported on research by a German neurologist who they said had discovered a tell-tale "dark patch" in the "central lobe" of the brains of killers and rapists.[14] The thing is, there is no such thing as a central lobe (see also p. 69)!

5 Learn to recognize quality research. Ignore spin and take first-hand testimonials with a pinch of salt. When it comes to testing the efficacy of brain-based interventions, the gold standard is the randomized, double-blind, placebo-controlled trial. This means the recipients of the intervention don't know whether they've received the target intervention or a placebo (a form of inert treatment such as a sugar pill), and the researchers also don't know who's been allocated to which condition. This helps stop motivation, expectation, and bias from creeping into the results. Related to this, it's important for the control group to do something that appears like a real intervention, even though it isn't. Many trials fail to ensure this is the case. The most robust evidence to look for in relation to brain claims is the meta-analysis, so try to search for these if you can. They weigh up all the evidence from existing trials in a given area and help provide an

accurate picture of whether a treatment really works or whether a stated difference really exists.

6 Recognize the difference between causation and correlation (a point I'll come back to in relation to mirror neurons in Chapter 5). Many newspaper stories about brain findings actually refer to correlational studies that only show a single snapshot in time. "People who do more of activity X have a larger brain area Y," the story might say. But if the study was correlational we don't know that the activity caused the larger brain area. The causal direction could run the other way (people with a larger Y like to do activity X), or some other factor might influence both X and Y. Trustworthy scientific articles or news stories should draw attention to this limitation and any others. Indeed, authors who only focus on the evidence that supports their initial hypotheses or beliefs are falling prey to what's known as "confirmation bias." This is a very human tendency, but it's one that scrupulous scientists and journalists should deliberately work against in the pursuit of the truth.

Arming yourself with these six tips will help you tell the difference between a genuine neuroscientist and a charlatan, and between a considered brain-based news story and hype. If you're still unsure about a recent development, you could always look to see if any of the following entertaining expert skeptical bloggers have shared their views: www.mindhacks.com; http://blogs.discovermagazine.com/neuroskeptic/; http://neurocritic.blogspot.co.uk; http://neurobollocks.wordpress.com; http://neurobonkers.com. And check out my own WIRED neuroscience blog www.wired.com/wiredscience/brainwatch/

A Primer on Basic Brain Anatomy, Techniques, and Terminology

Hold a human brain in your hands and the first thing you notice is its impressive heaviness. Weighing about three pounds, the brain feels dense. You also see immediately that there is a distinct groove – the **longitudinal fissure** – running front to back and dividing the brain into two halves known as **hemispheres** (see Plate 1). Deep within the brain, the two hemispheres are joined by the **corpus callosum**, a thick bundle of connective fibers (see Plate 2). The spongy, visible outer layer of the hemispheres – the cerebral **cortex** (meaning literally rind or bark) – has a crinkled appearance: a swathe of swirling hills and valleys, referred to anatomically as **gyri** and **sulci**, respectively.

The cortex is divided into five distinct **lobes**: the frontal lobe, the parietal lobe near the crown of the head, the two temporal lobes at each side near the ears, and the occipital lobe at the rear (see Plate 1). Each lobe is associated with particular domains of mental function. For instance, the frontal lobe is known to be important for self-control and movement; the parietal lobe for processing touch and controlling attention; and the occipital lobe is involved in early visual processing. The extent to which mental functions are localized to specific brain regions has been a matter of debate throughout neurological history and continues to this day (see pp. 40, 45, and 80).

Hanging off the back of the brain is the cauliflower-like **cerebellum**, which almost looks like another mini-brain (in fact cerebellum means "little brain"). It too is made up of two distinct hemispheres, and remarkably it contains around half of the neurons in the central nervous system despite constituting just 10 percent of the brain's volume. Traditionally the cerebellum was associated only with learning and motor control (i.e. control of the body's movements), but today it is known to be involved in many functions, including emotion, language, pain, and memory.

Holding the brain aloft to study its underside, you see the **brain stem** sprouting downwards, which would normally be connected to the **spinal cord**. The brain stem also projects upwards into the interior of the brain to a point approximately level with the eyes. Containing distinct regions such as the **medulla** and **pons**, the brain stem is associated with basic life support functions, including control of breathing and heart rate. Reflexes like sneezing and vomiting are also controlled here. Some commentators refer to the brain stem as "the **lizard brain**" but this is a misnomer (see p. 137).

Slice the brain into two to study the inner anatomy and you discover that there are a series of fluid-filled hollows, known as **ventricles** (see p. 22 and Plate 7), which act as a shock-absorption system. You can also see the **midbrain** that sits atop the brainstem and plays a part in functions such as eye movements. Above and anterior to the midbrain is the **thalamus** – a vital relay station that receives connections from, and connects to, many other brain areas. Underneath the thalamus is the **hypothalamus** and **pituitary gland**, which are involved in the release of hormones and the regulation of basic needs such as hunger and sexual desire.

Also buried deep in the brain and connected to the thalamus are the horn-like **basal ganglia**, which are involved in learning, emotions, and the control of movement. Nearby we also find, one on each side of the brain, the **hippocampi** (singular hippocampus) – the Greek name for "sea-horse" for that is what early anatomists believed it resembled. Here too are the almond-shaped **amygdala**, again one on each side. The hippocampus plays a vital role in memory (see p. 46) and the amygdala is important for memory and learning, especially when emotions are involved. The collective name for the hippocampus, amygdala, and related parts of the cortex is the **limbic system**, which is an important functional network for the emotions (see Plate 3).

The brain's awesome complexity is largely invisible to the naked eye. Within its spongy bulk are approximately 85 billion **neurons** forming a staggering 100 trillion plus connections (see Plate 4). There are also a similar number of **glial cells** (see Plate 5), which recent research suggests are more than housekeepers, as used to be believed, but also involved in information processing (see p. 149). However, we should be careful not to get too reverential about the brain's construction – it's not a perfect design by any means (more about this on p. 135).

In the cortex, neurons are arranged into layers, each containing different types and density of neuron. The popular term for brains – "**gray matter**" – comes from the anatomical name for tissue that is mostly made up of neuronal cell bodies. The cerebral cortex is entirely made up of gray matter, although it looks more pinkish than gray, at least when fresh. This is in contrast to "**white matter**" – found in abundance beneath the cortex – which is tissue made up mostly of fat-covered neuronal **axons** (axons are a tendril-like part of the neuron that is important for communicating with other neurons, see Plate 6). It is the fat-covered axons that give rise to the whitish appearance of white matter.

Neurons communicate with each other across small gaps called **synapses**. This is where a chemical messenger (a "**neurotransmitter**") is released at the end of the axon of one neuron, and then absorbed into the **dendrite** (a branch-like structure) of a receiving neuron (see Plate 6). Neurons release neurotransmitters in this way when they are sufficiently excited by other neurons. Enough excitation causes an "**action potential**," which is when a spike of electrical activity passes the length of the neuron, eventually leading it to release neurotransmitters. In turn these neurotransmitters can excite or inhibit receiving neurons. They can also cause slower, longer-lasting changes, for example by altering gene function in the receiving neuron.

Traditionally, insight into the function of different neural areas was derived from research on **brain-damaged patients**. Significant advances were made in this way in the nineteenth century, such as the observation that, in most people, language function is dominated by the left hemisphere (see p. 41). Some patients, such as the railway worker Phineas Gage, have had a particularly influential effect on the field (see p. 37). The study of particular associations of impairment and brain damage also remains an important line of brain research to this day. A major difference between modern and historic research of this kind is that today we can use medical scanning to identify where the brain has been damaged. Before such technology was available, researchers had to wait until a person had died to perform an autopsy.

Modern brain imaging methods are used not only to examine the structure of the brain, but also to watch how it functions. It is in our understanding of brain function that the most exciting findings and controversies are emerging in modern neuroscience (see p. 177). Today the method used most widely in research of this kind, involving patients and healthy people, is called **functional magnetic resonance imaging** (fMRI; see Plate 8). The technique exploits the fact that blood is more oxygenated in highly active parts of the brain. By comparing changes to the oxygenation of the blood throughout the brain, fMRI can be used to visualize which brain areas are working harder than others. Furthermore, by carefully monitoring such changes while participants perform controlled tasks in the brain scanner, fMRI can help build a map of what parts of the brain are involved in different mental functions. Other forms of brain scanning include **Positron Emission Tomography** (PET) and **Single-Photon Computed Tomography**, both of which involve injecting the patient or research participant with a radioactive isotope. Yet another form of imaging called **Diffusion Tensor Imaging** (DTI) is based on the passage of water molecules through neural tissue and is used to map the brain's connective pathways. DTI produces beautifully complex, colorful wiring diagrams (see Plate 13). The **Human Connectome Project**, launched in 2009, aims to map all 600 trillion wires in the human brain.

An older brain imaging technique, first used with humans in the 1920s, is **electroencephalography** (EEG), which involves monitoring waves of electrical activity via electrodes placed on the scalp (see Plate 23). The technique is still used widely in hospitals and research labs today. The spatial resolution is poor compared with more modern methods such as fMRI, but an advantage is that fluctuations in activity can be detected at the level of milliseconds (versus seconds for fMRI). A more recently developed technique that shares the high temporal resolution of EEG is known as **magnetoencephalography**, but it too suffers from a lack of spatial resolution.

Brain imaging is not the only way that contemporary researchers investigate the human brain. Another approach that's increased hugely in popularity in recent years is known as **transcranial magnetic stimulation** (TMS). It involves placing a magnetic coil over a region of the head, which has the effect of temporarily disrupting neural activity in brain areas beneath that spot. This method can be used to create what's called a "virtual lesion" in the brain. This way, researchers can temporarily knock out functioning in a specific brain area and then look to see what effect this has on mental functioning. Whereas fMRI shows where brain activity correlates with mental function, TMS has the advantage of being able to show whether activity in a particular area is necessary for that mental functioning to occur.

The techniques I've mentioned so far can all be used in humans and animals. There is also a great deal of brain research that is only (or most often) conducted in animals. This research involves techniques that are usually deemed too invasive for humans. For example, a significant amount of research with monkeys and other nonhuman primates involves inserting electrodes into the brain and recording the activity directly from specific neurons (called **single-cell recording**). Only rarely is this approach used with humans, for example, during neurosurgery for severe epilepsy. The direct insertion of electrodes and cannulas into animal brains can also be used to monitor and alter levels of brain chemicals at highly localized sites. Another ground-breaking technique that's currently used in animal research is known as **optogenetics**. Named 2010 "method of the year" by the journal *Nature Methods*, optogenetics involves inserting light-sensitive genes into neurons. These individual neurons can then be switched on and off by exposing them to different colors of light.

New methods for investigating the brain are being developed all the time, and innovations in the field will accelerate in the next few years thanks to the launch of the US BRAIN Initiative and the EU Human Brain Project. As I was putting the finishing touches to this book, the White House announced a proposal to double its investment in the BRAIN Initiative "from about $100 million in FY [financial year] 2014 to approximately $200 million in FY 2015."

Notes

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