THE IDEA OF THE BRAIN

ALSO BY MATTHEW COBB

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THE IDEA OF THE BRAIN

THE PAST AND FUTURE OF NEUROSCIENCE

MATTHEW COBB

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In memory of Kevin Connolly (1937–2015),
Professor of Psychology at the University of Sheffield,
who set me on the road to here.

The brain being indeed a machine, we must not hope to find its artifice through other ways than those which are used to find the artifice of the other machines. It thus remains to do what we would do for any other machine; I mean to dismantle it piece by piece and to consider what these can do separately and together.

Nicolaus Steno, *On the Brain*, 1669

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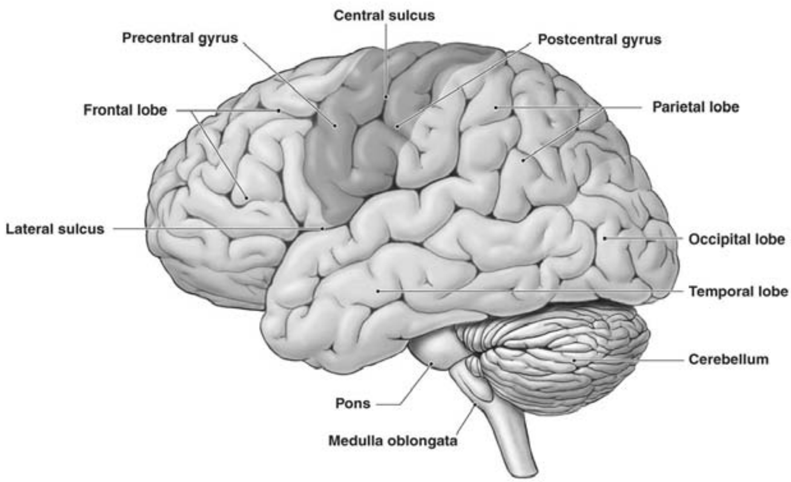

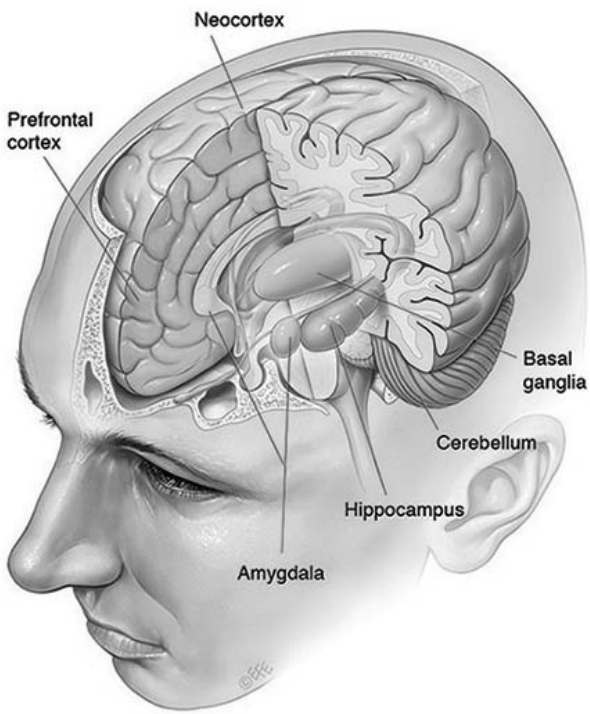

Key areas of the human brain.

INTRODUCTION

In 1665 the Danish anatomist Nicolaus Steno addressed a small group of thinkers gathered together at Issy, on the southern outskirts of Paris. This informal meeting was one of the origins of the French Académie des Sciences; it was also the moment that the modern approach to understanding the brain was set out. In his lecture, Steno boldly argued that if we want to understand what the brain does and how it does it, rather than simply describing its component parts, we should view it as a machine and take it apart to see how it works.

This was a revolutionary idea, and for over 350 years we have been following Steno's suggestion – peering inside dead brains, removing bits from living ones, recording the electrical activity of nerve cells (neurons) and, most recently, altering neuronal function with the most astonishing consequences. Although most neuroscientists have never heard of Steno, his vision has dominated centuries of brain science and lies at the root of our remarkable progress in understanding this most extraordinary organ.

We can now make a mouse remember something about a smell it has never encountered, turn a bad mouse memory into a good one and even use a surge of electricity to change how people perceive faces. We are drawing up increasingly detailed and complex functional maps of the brain, human and otherwise. In some species we can change the brain's very structure at will, altering the animal's behaviour as a result. Some of the most profound consequences of our growing mastery can be seen in our ability to enable a paralysed person to control a robotic arm with the power of their mind.

We cannot do everything: at least for the moment, we cannot artificially create a precise sensory experience in a human brain (hallucinogenic drugs do this in an uncontrolled way), although it appears that we have the exquisite degree of control required to perform such an experiment in a mouse. Two groups of scientists recently trained mice to lick at a water bottle when the animals saw a set of stripes, while machines recorded how a small number of cells in the visual centres of the mice's brains responded to the image. The scientists then used complex optogenetic technology to artificially recreate that pattern of neuronal activity in the relevant brain cells. When this occurred, the animal responded as though it had seen the stripes, even though it was in complete darkness. One explanation is that, for the mouse, the pattern of neuronal activity was the same thing as seeing. More clever experimentation is needed to resolve this, but we stand on the brink of understanding how patterns of activity in networks of neurons create perception.

This book tells the story of centuries of discovery, showing how brilliant minds, some of them now forgotten, first identified that the brain is the organ that produces thought and then began to show what it might be doing. It describes the extraordinary discoveries that have been made as we have attempted to understand what the brain does, and delights in the ingenious experiments that have produced these insights.

But there is a significant flaw in this tale of astonishing progress, one rarely acknowledged in the many books that claim to explain how the brain works. Despite a solid bedrock of understanding, we have no clear comprehension about how billions, or millions, or thousands, or even tens of neurons work together to produce the brain's activity.

We know in general terms what is going on – brains interact with the world, and with the rest of our bodies, representing stimuli using both innate and acquired neural networks. Brains predict how those stimuli might change in order to be ready to respond, and as part of the body they organise its action. This is all achieved by neurons and their complex interconnections, including the many chemical signals in which they bathe. No matter how much it might go against your deepest feelings, there is no disembodied person floating in your head looking at this activity – it is all just neurons, their connectivity and the chemicals that swill about those networks.

However, when it comes to really understanding what happens in a brain at the level of neuronal networks and their component cells, or to being able to predict what will happen when the activity of a particular network is altered, we are still at the very beginning. We might be able to artificially induce visual perception in the brain of a mouse by copying a very precise pattern of neuronal activity, but we do not fully understand how and why visual perception produces that pattern of activity in the first place.

A key clue to explaining how we have made such amazing progress and yet have still barely scratched the surface of the astonishing organ in our heads is to be found in Steno's suggestion that we should treat the brain as a machine. 'Machine' has meant very different things over the centuries, and each of those meanings has had consequences for how we view the brain. In Steno's time the only kinds of machine that existed were based on either hydraulic power or clockwork. These soon proved limited in the insights they could provide about the brain in terms of its structure or function, and no one now looks at the brain this way. With the discovery that nerves respond to electrical stimulation, in the nineteenth century the brain was seen first as some kind of telegraph network and then, following the identification of neurons and synapses, as a telephone exchange, allowing for flexible organisation and output (this metaphor is still occasionally encountered in research articles).

Since the 1950s our ideas have been dominated by concepts that surged into biology from computing – feedback loops, information, codes and computation. But although many of the functions we have identified in the brain generally involve some kind of computation, there are only a few fully understood examples, and some of the most brilliant and influential theoretical intuitions about how nervous systems might 'compute' have turned out to be completely wrong. Above all, as the mid-twentieth-century scientists who first drew the parallel between brain and computer soon realised, the brain is not digital. Even the simplest animal brain is not a computer like anything we have built, nor one we can yet envisage. The brain is not a computer, but it is more like a computer than it is like a clock, and by thinking about the parallels between a computer and a brain we can gain insight into what is going on inside both our heads and those of animals.

Exploring these ideas about the brain – the kinds of machine we have imagined brains to be – makes it clear that, although we are still far from fully understanding the brain, the ways in which we think about it have become much richer than in the past. This is not simply because of the amazing facts we have discovered, but above all because of how we interpret them.

These changes have an important implication. Over the centuries, each layer of technological metaphor has added something to our understanding, enabling us to carry out new experiments and reinterpret old findings. But by holding tightly to metaphors, we end up limiting what and how we can think. A number of scientists are now realising that, by viewing the brain as a computer that passively responds to inputs and processes data, we forget that it is an active organ, part of a body that is intervening in the world and which has an evolutionary past that has shaped its structure and function. We are missing out key parts of its activity. In other words, the metaphors we use shape our ideas in ways that are not always helpful.

The tantalising implication of the link between technology and brain science is that tomorrow our ideas will be altered yet again by the appearance of new and as yet unforeseen technological developments. As that new insight emerges, we will reinterpret our current certainties, discard some mistaken assumptions and develop new theories and ways of understanding. When scientists realise that how they think – including the questions they can ask and the experiments they can imagine – is partly framed and limited by technological metaphors, they often get excited at the prospect of the future and want to know what the Next Big Thing will be and how they can apply it to their research. If I had the slightest idea, I would be very rich.

*

This book is not a history of neuroscience, nor a history of brain anatomy and physiology, nor a history of the study of consciousness, nor a history of psychology. It contains some of these things, but the history I tell is rather different, for two reasons. First, I want to explore the rich variety of ways in which we have thought about what brains do and how they do it, focusing on experimental evidence – this is rather different from telling the story of an academic discipline. It also means that the book does not deal solely with how we have thought about the human brain – other brains in other animals, not all of them mammals, have shed light on what is happening in our heads.

The history of how we have understood the brain contains recurring themes and arguments, some of which still provoke intense debate today. One example is the perpetual dispute over the extent to which functions are localised in specific areas of the brain. That idea goes back thousands of years, and there have been repeated claims up to today that bits of the brain appear to be responsible for a specific thing, such as the feeling in your hand, or your ability to understand syntax or to exert self-control. These kinds of claims have generally soon been nuanced by the revelation that other parts of the brain may influence or supplement this activity, and that the brain region in question is also involved in other processes. Repeatedly, localisation has not exactly been overturned, but it has become far fuzzier than originally thought. The reason is simple. Brains, unlike any machine, have not been designed. They are organs that have evolved for over five hundred million years, so there is little or no reason to expect they truly function like the machines we create. This implies that although Steno's starting point – treating the brain as a machine – has been incredibly productive, it will never produce a satisfying and full description of how brains work.

The interaction between brain science and technology – the thread that runs through this book – highlights the fact that science is embedded in culture. So an element of this story reveals how these ideas have reverberated through the works of Shakespeare, Mary Shelley, Philip K. Dick and others. Intriguingly, cultural history shows that metaphors can flow both ways – in the nineteenth century, just as the brain and the nervous system were thought of as a telegraph network, so too the flow of Morse Code messages down the telegraph wires and the responses they evoked in their human readers were seen in terms of nervous activity. Similarly, at its birth the computer was seen as a brain – biological discoveries were used to justify John von Neumann's plans to build the first digital computer, rather than the other way around.

The second reason why this is not simply a history can be seen from the contents page – the book is divided into three parts: Past, Present and Future. The conclusion of the 'Present' section, which deals with how our understanding of the brain has developed over the last seventy years or so under the computational metaphor, is that some researchers sense we are approaching an impasse in how we understand the brain.

This might seem paradoxical – we are accumulating vast amounts of data about structure and function in a huge array of brains, from the tiniest to our own. Tens of thousands of researchers are devoting massive amounts of time and energy to thinking about what brains do, and astonishing new technology is enabling us to both describe and manipulate that activity. Every day we hear about new discoveries that shed light on how brains work, along with the promise – or threat – of new technology that will enable us to do such far-fetched things as read minds, or detect criminals, or even be uploaded into a computer.

In contrast to all this exuberance, there is a feeling among some neuroscientists, as shown by think-pieces in academic journals and books over the last decade or so, that our future path is not clear. It is hard to see where we should be going, apart from simply collecting more data or counting on the latest exciting experimental approach. That does not mean that everyone is pessimistic – some confidently claim that the application of new mathematical methods will enable us to understand the myriad interconnections in the human brain. Others favour studying animals at the other end of the scale, focusing our attention on the tiny brains of worms or maggots and employing the well-established approach of seeking to understand how a simple system works, and then applying those lessons to more complex cases. Many neuroscientists, if they think about the problem at all, simply consider that progress will inevitably be piecemeal and slow, because there is no Grand Unified Theory of the brain lurking around the corner.

The problem is twofold. Firstly, the brain is mind-bogglingly complicated. A brain – any brain, not just the human brain, which has been the focus of much of the intellectual endeavour described here – is the most complex object in the known universe. The astronomer Lord Rees has pointed out that an insect is more complex than a star, while for Darwin the brain of an ant, which is so tiny but which can produce such diverse behaviour, was 'one of the most marvellous atoms of matter in the world, perhaps more so than the brain of a man'. That is the scale of the challenge before us.

Which leads to the second aspect. Despite the tsunami of brain-related data being produced by laboratories around the world, we are in a crisis of ideas about what to do with all that data, about what it all means. I think that this reveals that the computer metaphor, which has served us so well for over half a century, may be reaching its limits, just as the idea of a brain as a telegraph system eventually exhausted its power in the nineteenth century. Some scientists are now explicitly challenging the usefulness of some of our most basic metaphors about the brain and nervous systems, such as the idea that neuronal networks represent the outside world, through a neuronal code. This suggests that scientific understanding may be chafing at the framework imposed by our most deeply held metaphors about how the brain works.

It may prove to be that even in the absence of new technology, developments in computing, in particular relating to artificial intelligence and neural networks – which are partly inspired by how brains do things – will feed back into our views of the brain, giving the computational metaphor a new lease of life. Perhaps. But, as you will see, leading researchers in deep learning – the most fashionable and astonishing part of modern computer science – cheerfully admit that they do not know how their programs do what they do. I am not sure that computing will provide enlightenment as to how the brain works.

One of the most tragic indicators of our underlying uncertainty about the brain is the very real crisis in our understanding of mental health. From the 1950s, science and medicine embraced chemical approaches to treating mental illness. Billions of dollars have been spent developing drugs, but it is still not clear how, nor even if, many of these widely prescribed treatments work. As to future pharmaceutical approaches to major mental health problems, there is nothing on the horizon – most of the large drug companies have abandoned the search for new drugs to treat conditions such as depression or anxiety, considering that both the costs and the risks are far too great. This situation is not surprising – if we do not yet properly understand the functioning of even the simplest animal brains, there does not seem much prospect of responding effectively when things apparently go awry in our own heads.

A great deal of energy and resources are being devoted to describing the myriad connections between neurons in brains, to create what are called connectomes, or more crudely and metaphorically, wiring diagrams. There is currently no prospect of creating a cell-level connectome of a mammalian brain – they are far too complex – but lower-definition maps are being established. Such efforts are essential – we need to understand how bits of the brain are connected – but on their own they will not produce a model of what the brain does. Nor should we underestimate how long this might take. Researchers are currently drawing up a functional connectome that includes all 10,000 cells in a maggot brain, but I would be amazed if, in fifty years' time, we fully understand what those cells and their interconnections are doing. From this point of view, properly understanding the human brain, with its tens of billions of cells and its incredible and eerie ability to produce the mind, may seem an unattainable dream. But science is the only method that can reach this goal, and it will reach it, eventually.

There have been many similar moments in the past, when brain researchers became uncertain about how to proceed. In the 1870s, with the waning of the telegraph metaphor, doubt rippled through brain science and many researchers concluded it might never be possible to explain the nature of consciousness. One hundred and fifty years later we still do not understand how consciousness emerges, but scientists are more confident that it will one day be possible to know, even if the challenges are enormous.

Understanding how past thinkers have struggled to understand brain function is part of framing what we need to be doing now, in order to reach that goal. Our current ignorance should not be viewed as a sign of defeat but as a challenge, a way of focusing attention and resources on what needs to be discovered and on how to develop a programme of research for finding the answers. That is the subject of the final, speculative part of this book, which deals with the future. Some readers will find this section provocative, but that is my intention – to provoke reflection about what the brain is, what it does and how it does it, and above all to encourage thinking about how we can take the next step, even in the absence of new technological metaphors. It is one of the reasons this book is more than a history, and it highlights why the four most important words in science are 'We do not know'.

Manchester, September 2019

PAST

The history of science is rather different from other kinds of history, because science is generally progressive – each stage builds upon previous insights, integrating, rejecting or transforming them. The result is what appears to be an increasingly accurate understanding of the world, although that knowledge is never complete, and future discoveries can overthrow what was once seen as the truth. This underlying progressive aspect leads many scientists to portray the history of their subject as a procession of great men (and it generally has been men), each of whom is given approval if they are seen as having been right, or criticised – or ignored – if they were wrong. In reality, the history of science is not a progression of brilliant theories and discoveries: it is full of chance events, mistakes and confusion.

To properly understand the past to provide a full background to today's theories and frameworks, and even to imagine what tomorrow may hold, we must remember that past ideas were not seen as steps on the road to our current understanding. They were fully fledged views in their own right, in all their complexity and lack of clarity. Every idea, no matter how outdated, was once modern, exciting and new. We can be amused at strange ideas from the past, but condescension is not allowed – what seems obvious to us is only that way because past errors, which were generally difficult to detect, were eventually overcome through a great deal of hard work and harder thinking.

Where people in the past accepted mistaken or what now appear to be unbelievable ideas, the challenge is to understand why. Often, what now might be taken as ambiguity or lack of clarity in an approach or set of ideas in fact explains why those ideas were accepted. Such imprecise theories may allow scientists with different views to accept a common framework, pending the arrival of decisive experimental evidence.

We should never dismiss past ideas – or people – as stupid. We will be the past one day, and our ideas will no doubt seem surprising and amusing to our descendants. We are simply doing the best we can, just as our forebears did. And, like previous generations, our scientific ideas are influenced not only by the internal world of scientific evidence, but also by the general social and technological context in which we develop those ideas. Where our theories and interpretations are wrong or inadequate, they will be proved so by future experimental evidence and we will all move on. That is the power of science.

– ONE –

HEART

PREHISTORY TO 17TH CENTURY

The scientific consensus is that, in ways we do not understand, thought is produced by the activity of billions of cells in the most complex structures in the known universe – the human brain. Surprising as it may be, this focus on the brain seems to be a relatively recent development. Virtually all we know from prehistory and history suggests that for most of our past we have viewed the heart, not the brain, as the fundamental organ of thought and feeling. The power of these old, pre-scientific views can be seen in our everyday language – words and phrases like 'learn by heart', 'heartbroken', 'heartfelt', and so on (similar examples can be found in many other languages). These phrases still carry the emotional charge of the old world-view that we have supposedly discarded – try replacing the word 'heart' by 'brain' and see how it feels.

Our earliest written artefacts show the importance of this idea to past cultures. In the *Epic of Gilgamesh*, a 4,000-year-old story written in what is now Iraq, emotions and feelings were clearly based in the heart, while in the Indian Rigveda, a collection of Vedic Sanskrit hymns written around 3,200 years ago, the heart is the site of thought.[1] The Shabaka Stone, a shiny grey slab of basalt from ancient Egypt, now in the British Museum, is covered in hieroglyphs that describe a 3,000-year-old Egyptian myth focused on the importance of the heart in thinking.[2] The Old Testament reveals that at around the same time as the Shabaka Stone was carved, the Jews considered the heart to be the origin of thought in both humans and God.[3]

Heart-centred views also existed in the Americas, where the great empires of Central America – the Maya (250–900 CE) and the Aztecs (1400–1500 CE) – both focused on the heart as the source of emotions and thought. We also have some insight into the beliefs of those peoples from North and Central America who did not develop extensive urban cultures. In the early years of the twentieth century, US ethnographers worked with indigenous peoples, documenting their traditions and beliefs. Although we cannot be certain that the recorded views were typical of the cultures that existed before the arrival of Europeans, most of the peoples who contributed to these studies considered that something like a 'life-soul', or an emotional consciousness, was linked to the heart and to breath. This view was widespread, from Greenland to Nicaragua, and was held by peoples with ecologies as diverse as the Eskimo, the Coast Salish of the Pacific north-west, and the Hopi of Arizona.[4]

These views are remarkably congruent with the account of the Swiss psychoanalyst Carl Jung, who in the early decades of the twentieth century travelled to New Mexico. On the roof of one of the white adobe buildings built by the Pueblo people on the high Taos plateau, Jung talked with Ochwiay Biano of the Taos Pueblo. Biano told Jung that he did not understand white people, whom he considered cruel, uneasy and restless – 'We think that they are mad', he said. Intrigued, Jung asked Biano why he thought this:

> 'They say they think with their heads,' he replied.
>
> 'Why, of course, what do you think with?' I asked him in surprise.
>
> 'We think here,' he said, indicating his heart.[5]

Not all cultures have shared this widespread focus on the heart. On the other side of the planet, a key aspect of the outlook of the Aboriginal and Torres Strait Islander peoples in Australia was (and is) their link with the land, which extends to ideas about mind and spirit. Locating the seat of thought within the body appears not to have been part of their world view.[6] Similarly, traditional Chinese approaches to medicine and anatomy were primarily focused on the interactions of a series of forces, rather than localisation of function. However, when Chinese thinkers did seek to identify the roles of particular organs, the heart was the key.[7] The Guanzi, a document originally written by the Chinese philosopher Guan Zhong in the seventh century BCE, argued that the heart was fundamental for all functions of the body, including the senses.

Heart-centred views correspond to our everyday experience – the heart changes its rhythm at the same time as our feelings change, while powerful emotions such as anger, lust or fear seem to be focused on one or more of our internal organs, and to course through our bodies and change our way of thinking as though they are transported in, or simply are, our blood. This is why those old phrases about being 'down at heart' and so on have persisted – they correspond to the way we perceive an important part of our inner life. Just as with the appearance that the sun goes around the Earth, everyday experience of being human provided a simple explanation of where we think – our hearts. People believed this idea because it made sense.

*

Even though the heart was universally seen as the centre of our inner life, certain cultures recognised that the brain had some kind of function, even if this could only be detected through injury. For example, in ancient Egypt a number of scribes created a medical document known as the Edwin Smith Papyrus.[8] The manuscript includes a brief description of the convolutions of the brain and the recognition that damage to one side of the head could be accompanied by paralysis on the opposite side of the body, but for these writers, as for all ancient Egyptians, the heart was nevertheless the seat of the soul and mental activity.

The first recorded challenge to our global heart-centred view occurred in ancient Greece. In the space of about three and a half centuries, between 600 and 250 BCE, Greek philosophers shaped the way that the modern world views so many things, including the brain. The early Greeks, like other peoples, considered that the heart was the origin of feelings and thought. This can be seen in the epic oral poems now attributed to Homer, which were created sometime between the twelfth and eighth centuries BCE; similarly, the ideas of the earliest recorded philosophers were focused on the heart.[9] In the fifth century BCE the philosopher Alcmaeon took issue with this view. Alcmaeon lived in Croton, a Greek town on the 'foot' of Italy, and is sometimes presented as a physician and as the father of neuroscience, although everything we know of him and his work is hearsay. None of his writings survive – all that remain are fragments quoted by later thinkers.

Alcmaeon was interested in the senses, and this naturally led him to focus on the head, where the key sense organs are grouped. According to subsequent writers, Alcmaeon showed that the eyes, and by extension the other sense organs, were connected to the brain by what he called narrow tubes. Aetius, living 300 years after Alcmaeon, is reported as having said that, for Alcmaeon, 'the governing facility of intelligence is the brain'. It is not clear how exactly Alcmaeon arrived at this conclusion – subsequent writers imply that he based his ideas not simply on introspection and philosophical musings, but also on direct investigation, although there is no evidence of this. He may have dissected an eyeball (not necessarily a human one) or he may have witnessed the culinary preparation of an animal's head, or he may simply have used his fingers to see how the eyes, tongue and nose were connected to the inner parts of an animal's skull.[10]

Despite these insights, the earliest unambiguous statements about the centrality of the brain were written several decades after Alcmaeon died; they came from the school of medicine on the island of Kos, whose most famous member was Hippocrates. Many of the works produced by the Kos school of medicine are attributed to Hippocrates, although the actual authors are unknown. One of the most significant of these documents was *On the Sacred Disease*, which was written around 400 BCE for a non-specialist audience and dealt with epilepsy (why epilepsy was considered a sacred or divine disease is unclear[11]). According to the author(s):

> It ought to be generally known that the source of our pleasure merriment, laughter, and amusement, as of our grief, pain, anxiety, and tears, is none other than the brain. It is specially the organ which enables us to think, see, and hear, and to distinguish the ugly and the beautiful, the bad and the good, pleasant and unpleasant … It is the brain too which is the seat of madness and delirium, of the fears and frights which assail us, often by night, but sometimes even by day, it is there where lies the cause of insomnia and sleep-walking, of thoughts that will not come, forgotten duties, and eccentricities.[12]

The argument in *On the Sacred Disease* was based partly on some pioneering but rudimentary anatomy ('the brain of man, as in all other animals, is double, and a thin membrane divides it through the middle', the author(s) stated) but it also revealed a great deal of confusion. For example, the document claimed that 'when a person draws in air by the mouth and nostrils, the breath goes first to the brain', arguing that the veins transport air around the body. Epilepsy was explained by the idea that a humour or fluid called phlegm entered the veins, preventing the air from getting to the brain and so causing the fit. Some people took the implications of localising epilepsy to the brain very seriously. Aretaeus the Cappadocian, a Greek physician who lived around 150 BCE, treated it by trepanation – drilling holes in the skull – a tradition that lived on in European medical manuals until the eighteenth century.[13] Aretaeus did not invent this operation – the earliest traces of any medical intervention are holes that were drilled or scraped into people's skulls and which can be found all over the planet, sometimes from over 10,000 years ago.[14] Although it is tempting to view prehistoric trepanation as an early form of psychosurgery (it is often suggested that trepanation was performed to let out 'evil spirits'), the global dominance of heart-centred ideas about the origins of thought suggests this is unlikely. There are more credible justifications for such a dangerous operation, including relief of painful sub-cranial bleeding or removal of bone fragments following a head injury.

Despite the arguments of Alcmaeon and of the Kos school, in the absence of any evidence to prove that the brain is the site of thought and emotion, there was no reason to prefer this claim to the apparently obvious explanation that the heart plays this role. This led one of the most influential Greek philosophers, Aristotle, to dismiss the idea that the brain played any significant part in thinking or movement. As he wrote in *Parts of Animals*:

> And of course, the brain is not responsible for any of the sensations at all. The correct view [is] that the seat and source of sensation is the region of the heart … the motions of pleasure and pain, and generally all sensation plainly have their source in the heart.

Aristotle's argument for the centrality of the heart was based on apparently self-evident principles, such as the link between movement, heat and thought. Aristotle noted that the heart clearly changed its activity at the same time as emotions were felt, whereas the brain apparently did nothing; he also claimed that the heart was the source of blood, which is necessary for sensation, while the brain contained no blood of its own. Furthermore, all large animals have a heart, whereas – he claimed – only the higher animals have a brain. His final argument was that the heart is warm and shows movement, both of which were seen as essential features of life; in contrast, the brain is immobile and cold.[15] Given there was no actual proof of any link between thought and the brain, Aristotle's logical arguments were just as valid as those to be found in the writings of the Kos school. There was no way to choose between them. Elsewhere around the planet, things continued as before: for the vast majority of people, the heart was what counted.

*

After Aristotle's death, insight into the role of the brain emerged from Alexandria, at the western edge of the Nile Delta, in Greek-ruled Egypt. With a grid system of streets, underground plumbing and a multicultural population, Alexandria was one of the most significant centres of the Greco-Roman world. Among those who benefited from this fertile intellectual atmosphere were the two leading Greek