

THE IN A HURRY SERIES

The Brain

in a Hurry

A user's guide to your own head

Max Brocklesby

BOOKSINAHURRY.COM

Contents

The Whole Thing in One Page 4

Why You Should Care 6

The Core Ideas 8

How It Actually Works 22

What People Get Wrong 31

Use It 36

Terms 41

Go Deeper 46

Notes and Sources 47

Bibliography 53

The Whole Thing in One Page

The familiar brain is a grey control room with somebody inside it. The senses deliver a picture, a conscious self considers the options, and instructions go out to the body. Anatomy offers no such operator. It reveals living cells, specialised structures and recurrent connections, with each contribution depending on others.

Start with the living part. The brain requires a continuous supply of oxygen and fuel while helping regulate the body that supplies them. Blood pressure, sleep, illness and pain can change the conditions under which thought occurs. Those conditions do not explain the content of every thought. They make thought possible without dictating what it must concern.

Neurons turn chemical differences into electrical events. Ion channels change the membrane's permeability; spikes can travel along axons; transmitters alter receiving cells through receptors. Which cells respond, their timing and their connections matter more than activity alone. Inhibition helps organise the response. Glial cells help maintain, develop and modify the tissue in which signalling occurs.

The large structures are specialised but interdependent. Brainstem and hypothalamus contribute to bodily regulation and state. Cortex supports many forms of perception, knowledge and control. The basal ganglia participate in selecting and shaping actions; the cerebellum helps with timing, calibration and adaptation. White-matter pathways connect these contributions. Damage can impair a function by interrupting a route as well as by destroying a region.

A hand reaching for a glass shows why prediction matters. Feedback takes time, so advance estimates help prepare the movement. Sensory consequences then reveal what those estimates missed. The same dependence on context appears in perception: incoming signals are interpreted in relation to experience and the task. Useful prediction is a mechanism, not proof of one theory that explains the entire brain.

Attention determines which information gains influence when several demands compete. Working memory keeps selected material available for present use. Both have limits, shaped by the task and what has already been learned. A missed event or forgotten intermediate step can therefore reveal a particular constraint rather than a general lack of ability.

The brain also works beyond the present stimulus. Memory can reconstruct a past occasion, and imagination can combine known elements into an event that never happened. Language makes distinctions manageable and ideas shareable, but thought is wider than inner speech. These abilities cooperate without being identical, as selective losses after injury make painfully clear.

Experience changes the system through plasticity. Practice can improve a skill; it does not follow that any demanding exercise improves every mental capacity. Development, ageing, injury and present state alter the opportunities for change. Adaptation can restore a useful result by a different route without rebuilding the original tissue.

The cost follows from the organisation. A specialised contribution can become a bottleneck. Selection can miss something important. An expectation can be wrong, and learning can stabilise an unhelpful response. Adaptability is not invulnerability.

A user's guide therefore offers no secret control panel. It explains how to distinguish operations, examine evidence and recognise where practice, environmental support or medical care belongs. The person is not reducible to one chemical or one troublesome region. Better understanding begins with the task, the conditions and the connections that make it possible.

That is the book.

Why You Should Care

In 2024, researchers published a reconstruction of a fragment of human cerebral cortex with a volume of roughly one cubic millimetre. The tissue had been removed during surgery to reach an underlying focus of epilepsy. The reconstruction contained about 57,000 cells and 150 million synapses. The reconstructed image dataset ran to about 1.4 petabytes, equivalent to the nominal capacity of fourteen hundred one-terabyte drives.

Those drives would not contain the memories stored in the speck. They hold the images used to describe its structure. This was one surgical specimen, not a census of brain tissue. Yet the modest scale of the sample makes the achievement more arresting: fourteen hundred drives to map a speck, and still no account of what it contributed to a thought. The map is extraordinary. The explanation remains unfinished.

That gap between detail and understanding is part of the fascination. You can map a contact between cells without knowing how its influence changed during a conversation. You can identify a region associated with language without explaining how a sentence became funny. The challenge is not finding one missing magical ingredient. It is connecting cells, activity and behaviour at the right levels, without allowing an answer at one level to masquerade as an answer at all of them.

The subject also concerns an instrument you cannot put down. You rely on memory to judge whether your memory is reliable. You use attention to notice that attention has wandered. The feeling that an answer is obvious is itself an event that needs explaining, not a guarantee that the answer survived examination. Understanding the brain cannot remove these limitations, but it can change what you do with them.

Consider the difference between losing a fact and losing access to it. A name unavailable during a conversation may return later. A skill difficult to describe may be performed fluently. A person who struggles to speak may still understand or reason in ways that a casual observer misses. Such distinctions matter because explanations affect treatment, teaching and

ordinary patience. A faulty model can make somebody look lazy, unintelligent or uncooperative when a particular operation is difficult.

The commercial version of neuroscience often erases the distinctions again. A chemical becomes happiness. A bright patch becomes a personality. A training score becomes a promise of general improvement. These claims borrow the authority of physical measurement while leaving out what was measured. Knowing a little about receptors, pathways and task design makes the leap easier to spot.

There is a more constructive use than scepticism. You can distinguish practice from familiarity, recognise when an external reminder supports a limited resource, and see why sleep or pain can change performance without rewriting a person's identity. You can also understand why sudden loss of movement or speech requires medical attention rather than a new theory of motivation. A guide should improve recognition without pretending to turn the reader into a clinician.

The hour ahead will give you a workable anatomical map, an account of electrical and chemical signalling, and several ways of connecting that machinery to experience. A hand reaching for water will show how predictions and corrections cooperate. Memory and language will show why the same organ can work on things that are absent. Injury and adaptation will show what happens when familiar routes cease to be available.

The reward is not access to an unused percentage of your brain. It is a better understanding of what you are already doing, how different abilities can come apart, and where help can enter. The small piece of tissue on the laboratory bench is difficult enough. The remarkable thing is that the living whole can investigate it.

The Core Ideas

Thought Has Operating Conditions

Stand up too quickly and the abstract thinker can briefly become a problem in blood supply. The brain depends on a continuous circulation that delivers oxygen and fuel. When that supply falters, the ability to see clearly, remain upright or sustain awareness can falter with it. Thought has physical conditions before it has a subject.

The adult organ accounts for roughly two per cent of body mass and about one fifth of resting energy use. Those are approximate proportions, not a personal calorie calculator. Much of the expenditure maintains ion gradients, ongoing signalling and the cellular conditions for response. Difficult arithmetic does not switch on a previously idle brain. The tissue was already expensive before the question arrived.

It is protected, though never isolated. The skull encloses soft tissue cushioned by membranes and cerebrospinal fluid. Blood vessels penetrate it, and specialised vessel walls, supported by surrounding cells, regulate passage between blood and brain. This blood-brain barrier is selective rather than absolute. Oxygen and nutrients must arrive; chemical conditions must remain controlled. The organ's dependence on this supply helps explain why vascular disease belongs in a discussion of thinking, not merely in a discussion of the heart.

The brain also helps maintain the body on which it depends. Brainstem and hypothalamic circuits combine information about pressure, temperature and chemistry with other signals. Autonomic nerves, hormones and behaviour then alter what happens. Breathing changes with demand. Thirst encourages drinking. Regulation can prepare for an expected need rather than wait until conditions have already become dangerous.

The familiar word is *homeostasis*: maintaining internal conditions within viable bounds. It should not suggest one fixed temperature or one unchanging target. Exercise, sleep and illness require different patterns of

regulation. Some adjustments follow a disturbance; others anticipate it. A racing heart before exertion and a racing heart during exertion can therefore have different immediate causes while helping prepare or supply the same body.

Control is shared. Spinal circuits organise reflexes and contribute to patterned movement. The enteric nervous system coordinates much of digestion. Local tissues regulate blood flow and respond to injury. The brain does not send an individual instruction to every cell. It participates in a body with many interacting sources of regulation, receiving information and changing priorities where wider coordination is useful.

Bodily state consequently enters mental life. Pain can capture attention. Illness can alter energy and motivation. Hunger changes what looks worth pursuing. These are influences, not complete explanations of a person's thoughts. A disagreement does not become meaningless because one participant missed lunch, and persistent exhaustion should not be dismissed as a failure to manage the body better.

Nor does bodily dependence make abstract thought a disguised muscle twitch. You can imagine a place you will never visit or follow a proof with no immediate action to perform. Language, memory and internally generated activity allow the brain to work beyond the present stimulus. The important distinction is between a function's conditions and its content. Blood supply makes a proof possible; it does not explain the proof.

Cells Turn Chemistry into Timing

A neuron is a cell with an extreme geometry problem. In the familiar pattern, branching dendrites collect influence from many contacts, a cell body integrates some of it and an axon carries events towards targets that may be nearby or distant. At many endings, chemical messengers cross microscopic gaps and alter the probability that other cells will respond. Neurons vary sharply, but the standard diagram still looks like a wire with a bush at one end. The reality is wet, leaky and alive.

The cell itself was once disputed. Camillo Golgi's silver stain revealed a

sparse selection of neurons in black against a pale background, making their full branching forms visible. Santiago Ramón y Cajal used the same method to argue that nervous tissue was built from separate cells communicating at contacts rather than one continuous net. Golgi continued to defend the network view when the two men shared the 1906 Nobel Prize. Distinct cells became the foundation for asking how one could influence another.

For many neurons, the travelling event is an *action potential*. The cell maintains different concentrations of ions across its membrane, with sodium more concentrated outside and potassium inside. Channels provide selective routes across that membrane. During a typical spike, voltage-sensitive sodium channels open, sodium flows inward and voltage rises; sodium channels then inactivate while potassium currents help bring voltage back down. Pumps maintain the gradients over time. They are not a little engine pushing each spike along the fibre.

Local voltage changes trigger neighbouring membrane, regenerating the event along an axon. In 1952, Alan Hodgkin and Andrew Huxley described the relevant currents mathematically using a squid's unusually large axon. The precise model was built for that preparation, but the principle of voltage-dependent ionic conductances proved far more general. A nerve signal is an organised change in permeability, not an electron travelling from the toe to the brain.

A spike is approximately all-or-none at a given recording location. Stronger input does not produce a proportionately taller pulse. Information can instead be carried by which cells respond, how often, when, and in relation to other cells. Different systems use these features differently. There is no universal one-spike vocabulary in which a particular pulse means red, thirsty or tomorrow.

At a typical chemical synapse, an arriving spike opens calcium channels. Calcium entry helps trigger the release of transmitter from tiny vesicles. Transmitter crosses the gap and binds to receptors on the receiving cell. The effect depends on those receptors and the cell's state. Glutamate

commonly promotes excitation in the adult brain; GABA commonly produces inhibition. Neither molecule carries a fixed mental meaning inside it.

Excitation gets the heroic language because it appears to make things happen. Inhibition makes organised activity possible. It sharpens timing, prevents competing patterns from spreading, controls gain and helps keep networks away from runaway synchrony. An active inhibitory cell can prevent another pattern from taking over. Less firing in one population may therefore be the result of useful work elsewhere, rather than evidence that nothing happened.

Some chemical signals change the responsiveness of whole sets of circuits. This is neuromodulation. Its effects depend on source, target, receptor and timing, which is why one transmitter can participate in several functions rather than supplying a single mental ingredient.

Neurons are also not alone. A widely used estimate from four adult male brains found about 86 billion neurons and a comparable number of non-neuronal cells. The figure is an estimate from a small sample, not a serial number for the species. Those other cells include astrocytes that help regulate the chemical environment and synaptic function, oligodendrocytes that make central myelin, microglia involved in immune surveillance and response, and vascular cells that help support the blood supply. Their proportions differ sharply by region.

Myelin wraps selected axons, reducing current loss so that spikes can be regenerated at gaps between the insulated stretches. This supports rapid conduction without requiring an enormously thick axon. Synapses strengthen or weaken. Receptors move. Channels change. Cells alter gene expression. A neural circuit therefore computes with timing, probability, chemistry and history. The machine is not assembled once and then switched on. Each event occurs inside tissue already changed by the events before it.

There Is No Single Place in Charge

Anatomy tempts the label maker. The frontal lobe plans. The amygdala produces fear. The hippocampus stores memory. Broca's area makes speech. Once the arrows are coloured, the brain resembles an office plan and the reader begins looking for the chief executive.

First orient the map. Brain and spinal cord form the central nervous system. Peripheral nerves connect it with the rest of the body. The cerebrum's two hemispheres are linked by bundles of fibres, most conspicuously the corpus callosum. Its folded outer cortex is grey matter, rich in cell bodies and local connections; underneath lie white-matter pathways, so called because of their myelinated axons. Grey matter also forms deeper clusters called nuclei.

Start at the lower end. The brainstem contains circuits essential for breathing, cardiovascular control, sleep-wake regulation, eye movements and basic orientation. Damage can be devastating because many long pathways pass through a small space. Above it, the hypothalamus links bodily regulation, endocrine control, circadian timing and motivated behaviour. The thalamus is commonly called a sensory relay, but it is more active than a postal depot: most sensory pathways pass through it, and thalamic circuits coordinate traffic with cortex, attention, movement and state.

The basal ganglia form recurrent loops with cortex and thalamus that help select, initiate and shape actions. Their importance becomes visible in Parkinson's disease, where loss of dopamine-producing neurons changes the balance of those loops and makes movement difficult to release and scale. The cerebellum compares patterns, predicts consequences and supports timing and error correction across movement and other functions. In the small sample behind the 86 billion estimate, about four fifths of the neurons were in the cerebellum, not the cerebral cortex. The wrinkled outer sheet receives better publicity than the densely packed structure underneath.

Connections deserve equal billing with regions. White-matter pathways carry signals among cortical areas, deeper nuclei, brainstem and spinal cord. Their geometry imposes delays and bottlenecks, while myelin changes conduction speed. A patch of intact cortex can become functionally isolated when the fibres serving it are cut. Many symptoms attributed to a damaged area therefore arise partly from disconnection.

The cerebral cortex is specialised without being a row of sealed rooms. Occipital regions are heavily involved in vision. Temporal regions contribute to hearing, object knowledge and memory. Parietal regions link sensory information to space, body and action. Frontal regions contribute to movement, rule use, planning and control. These are broad gradients across interconnected tissue.

The history of language shows the correction. In the nineteenth century, Paul Broca linked damage in left frontal cortex to impaired speech production. That was a major advance over theories that assigned thought to undifferentiated tissue. The misleading shorthand turns a contributing region into a complete language box. Modern lesion and imaging work finds specialised language networks distributed across frontal and temporal cortex, with pathways and neighbouring systems affecting the result. In a 2021 study of 134 stroke survivors with selected left frontal injuries, damage to nearby white matter predicted persistent speech-production difficulty better than damage to Broca's area itself. That does not make the area dispensable; it makes the pathway and the recovery interval part of the explanation.

Even a function that looks local changes with the question. The amygdala helps detect and learn biological significance, including threat, reward, ambiguity and social cues. It is not a fear button. The hippocampal formation is critical for building relational and episodic memories, yet durable knowledge depends on wider cortical systems and retrieval conditions. The prefrontal cortex supports flexible control, but control also depends on parietal, thalamic, striatal, cerebellar and neuromodulatory systems.

Network language can become its own evasion. Invoking connections

without specifying them explains little. Connections have direction, strength, timing and anatomical constraints. Some nodes are bottlenecks. Some lesions produce selective losses. Specialisation is real. What fails is the claim that a familiar mental noun must correspond to one bounded piece of tissue.

No anatomical discovery has supplied a little observer to whom all these systems report. Explaining a person by putting another person inside the cortex would only move the problem. The useful map identifies contributions and communication, while leaving the explanation of conscious experience open. A location tells you where to investigate; its connections help tell you what the investigation must include.

Action Runs on Prediction and Correction

Movement exposes a problem that thought can hide. Feedback is late.

Reach towards a cup and signals from muscles, joints, skin and eyes will report what happened, but conduction, synapses and processing take time. If the brain waited for a complete report before issuing each next instruction, the hand would move as a chain of hesitant corrections. Skilled action is smoother because control uses expectations about what commands are likely to produce.

When motor systems prepare an action, related signals can be sent to circuits that predict its sensory consequences. The terms include *effERENCE copy* and *corollary discharge*. The prediction helps distinguish changes caused by the world from changes caused by your own movement. Every rapid eye movement sweeps the image across the retina, yet the room does not appear to jump. Part of the explanation lies in signals about the movement being used to interpret the incoming change.

The cerebellum is central to many accounts of this process. It receives rich information about intended commands, body state and sensory outcome. Its circuitry can support fast comparison between expected and observed consequences, allowing timing and force to be adjusted. Cerebellar damage may leave strength intact while making movement poorly scaled, irregular or

difficult to coordinate. The failure reveals the hidden computation: producing force and predicting its result are different jobs.

Prediction also appears in perception. The sensory signal arriving at the brain is incomplete and ambiguous. Context and prior experience influence which interpretation is favoured. That does not mean the brain invents any world it likes. Predictions are constrained by incoming evidence and by the consequences of acting on them. A model that repeatedly guides the hand past the cup pays a visible price.

Broad predictive-processing theories try to extend this account across brain functions. They offer useful hypotheses, but the established role of prediction in particular circuits does not prove one complete theory of thought. Different proposed mechanisms still need tests that distinguish them from alternatives.

These uses of prediction do not require a master prediction centre. Motor systems estimate bodily consequences; reward-learning circuits compare obtained and expected outcomes. In each case, the useful question is what is predicted, which signal reports a mismatch, and how that mismatch changes the next response.

The user experiences the benefit as fluency. A familiar movement can unfold without conscious supervision of every joint. A familiar sequence can be prepared without having to reconsider each component. The cost is that fast expectations can hide change, preserve bias or continue after conditions shift. A surprising result can supply information for updating the expectation.

For deliberate correction, an error must become informative and some part of the next attempt must be changeable. Repetition can improve performance, but it can also stabilise a poor response. Advance estimates make speed possible; comparison with outcomes helps keep them useful.

Selection Is the Price of Limited Capacity

At any moment, the nervous system receives more potential information and prepares more possible action than can control behaviour at once. Light reaches the whole retina. Sound arrives from every direction. The body supplies touch, balance, temperature, visceral state and pain. Memories and unfinished goals become active. Only a fraction can guide the next moment of thought or action.

Attention is the family of mechanisms that changes that competition. It can increase the effective gain of selected signals, suppress distractors, maintain a rule, orient eyes and body, or prepare a response. It is not one spotlight operated by the conscious self. Selection occurs at several stages, and the thing that wins can be chosen by a goal, captured by novelty, pulled by threat or made cheap by habit.

This is why looking is not the same as seeing. In the experiment made famous by Daniel Simons and Christopher Chabris, some people counting basketball passes missed a person in a gorilla costume crossing the scene. The result is often presented as a party trick. Its importance is structural. Concentrating on one task can reduce access to other information, including an event that an outside observer considers obvious.

Working memory keeps selected information available for immediate use. Its capacity depends on material, strategy, prior knowledge and interference. For a British reader who recognises the abbreviations, BBCNHSVAT can fall into BBC, NHS and VAT. The nine letters have not changed; prior learning has organised them into three familiar units. That is chunking. It helps explain why there is no single item limit for every mind and task: what counts as an item depends partly on what you already know.

Switching tasks also has a price. Laboratory studies repeatedly find slower or less accurate performance after a task changes, even when the switch is expected. The cost can come from reconfiguring rules, resolving interference and retrieving the right response mapping. Everyday multitasking adds interruption, memory for place and environmental

temptation. Two activities can overlap well when one is automated or uses different resources. Two tasks that both need linguistic selection, working memory or careful control usually compete.

Emotion is part of this selection system, not an invading force from below. Changes in heart rate, facial expression, memory, threat detection, reward expectation and social meaning alter what the brain treats as urgent. The amygdala, insula, striatum, hypothalamus and prefrontal systems participate in different parts of that work. None contains emotion as a substance. A decision without value would have no basis for preferring one outcome to another.

The basal ganglia help gate actions and cognitive operations through loops with cortex and thalamus. Dopamine can influence learning and the vigour with which actions are pursued, but the effect varies by circuit and timescale. Prefrontal systems can maintain a distant goal and bias competition towards it. They do not rule without opposition. Fatigue, stress, practice, reward and cue availability alter the contest.

Selection also operates on things that are not in front of you. Suppose you compare two possible routes without moving. You hold a goal, bring relevant knowledge into use and suppress tempting but irrelevant turns. Working memory is this temporary availability for thought and action, not a small storage drawer separate from the rest of the brain. Recurrent activity and other short-lived changes can keep information usable while the next operation is performed.

This is why a written intermediate step can change a problem. The paper preserves a result while you work on another relation. It does not supply missing intelligence; it reduces how much must remain internally available at once. Similar support can come from a diagram or another person's reminder. Thinking is done by a brain, but the effective task can extend across a desk.

Use Changes the Machine

A practised pianist can find a familiar sequence without deciding separately where each finger belongs. Practice has changed what the system can produce and how much supervision it needs. That is one everyday consequence of plasticity.

Plasticity refers to changes in neural function or structure produced by development, activity, injury, chemistry and experience. Synapses can become more or less effective. Dendritic spines can appear or disappear. Networks can change their coordination. Myelin and supporting cells can respond to patterns of use. Strategies can shift so that a task recruits a different balance of systems. These processes operate across timescales from milliseconds to years.

Change also requires stability. If every active connection rewrote itself without restraint, yesterday's learning would be erased by breakfast. Plasticity is gated by cell type, chemical state, timing and prior history. Networks preserve established patterns while allowing selected relations to move. Neuroscientists call versions of this the stability-plasticity problem, and the name describes an engineering constraint rather than one solved mechanism.

Development changes the terms of learning. Genes guide cell identity, migration, growth and molecular machinery, while spontaneous activity and experience refine connections. Some systems pass through sensitive periods in which particular inputs have unusual influence. That does not make childhood a blank slate or adulthood a sealed box. It means opportunities and constraints change with age, system and history.

Adult learning is real and measurable. London taxi drivers who had mastered the city's demanding street knowledge showed hippocampal differences associated with experience, though the original comparison could not by itself prove that driving caused every difference. Training studies have reported changes in structural or diffusion MRI after learning to juggle or practise a visuomotor skill. Such measures show altered tissue

properties at the scale of the scan. They do not reveal one new memory as a visible object or identify the microscopic cause without supporting work.

The more important correction concerns transfer. Practice usually improves the practised operation and close relatives. It does not follow that any demanding game strengthens a general mental muscle. In a six-week online trial reported in 2010, 11,430 people completed the intervention.

Participants improved on their practised tasks, but the study found no evidence of transfer to its untrained general cognitive measures, even where those measures were closely related. Other programmes can produce selected transfer, especially when training shares processes with the target. The result must be measured rather than assumed.

Specificity is not bad news. It tells you where to direct practice. Repeatedly solving the relevant problem, with feedback that distinguishes mistakes, gives the learner something to adjust. The mere fact that an exercise feels difficult tells you little about whether it trains the right thing. Variation can help a skill survive new conditions, but random variety can also prevent stable learning. Rest and sleep affect consolidation. Motivation affects exposure. None replaces the operation being learned.

Recovery after damage can involve plasticity, but also the resolution of temporary disruption. Surviving pathways may change their contribution, and new strategies can compensate for lost abilities. The result depends on lesion location and size, age, prior health, rehabilitation, environment and time. Recovery is not evidence that the damaged tissue grew back to its former state. A person may regain a function by accomplishing the task differently.

Plasticity does not guarantee a desirable outcome. Repeated avoidance can become efficient. A painful movement can acquire protective associations. Drug cues can gain control over seeking. A badly practised movement becomes a stable bad movement. The nervous system learns statistical regularities and consequences; it does not check whether the pattern will look admirable in six months.

Ask what changed, after what experience, and whether it improved the function that matters. The ability to change is established. The direction and usefulness of the change still need to be demonstrated.

Adaptability Is Not Invulnerability

Two people can have similar-looking injuries and quite different recoveries. What survives matters, but so do the work a task demands, the person's previous skills and the support available. A scan is one part of that account. It cannot show every route by which a life might be rebuilt.

The organisation that makes this possible also creates vulnerability. White-matter injury can disconnect regions that remain physically intact. Altered activity can affect places beyond the original lesion. A small area can matter greatly when important pathways converge there. Distributed function therefore does not mean that any surviving part can take over any other part's job. There are alternatives, and there are bottlenecks.

Some failures expose a distinction that ordinary success conceals. Weakness can make an arm difficult to move. Impaired position sense can make movement unreliable despite preserved strength. Neglect can prevent a person from attending to one side of space without being equivalent to blindness in one eye. These are different mechanisms hidden beneath a casual description such as clumsiness. The right help depends on making the distinction.

Adaptation can improve what a person achieves without restoring the previous mechanism. Someone may use vision to help guide a movement when other sensory information is unreliable. A reminder can support a task that once depended on unaided memory. A communication aid can make an intention expressible by a different route. Such achievements are real even when damaged tissue has not returned to its original condition.

Learning itself is not guaranteed to help. Repeatedly choosing the easier alternative can reduce opportunities to practise a weakened skill. A response that was protective in one setting can persist into another. Familiar cues can pull behaviour towards an outcome the person no longer values.

Change is possible because experience modifies the system; the same property means that unhelpful experience can leave durable effects.

None of this explains every neurological illness as the price of an otherwise clever design. Infection, inherited disease, trauma, vascular injury and degeneration have mechanisms that need their own account. Nor does every bad decision reveal a malfunction. Sometimes the information was poor, the incentives conflicted or the available options were bad. A biological explanation must add something more precise than the observation that a brain was involved.

Return to the dependence that began this book. The cells remain capable only within an adequate physical environment. Their networks remain useful through a balance of stability, responsiveness and change. Disruption at either level can alter what the person experiences and does. That is why advice aimed only at willpower, or only at one chemical, so often misses the question.

The implication is practical without being a promise of control. A difficulty may call for practice, a changed environment, an assistive device or medical care. Sometimes several are needed. Sometimes a loss remains despite the best available treatment. Plasticity is a property of nervous tissue, not an obligation placed on a patient to recover.

A brain capable of adapting is neither a fixed machine nor an infinitely repairable one. Understanding its conditions and constraints makes assistance more exact. It also makes success easier to recognise: not necessarily a return to the old route, but a workable way of thinking, communicating or acting again.

How It Actually Works

Before the hand moves

Imagine working at a desk, with a glass of water beside the keyboard. You reach for it. Later, away from the desk, you remember something you read there and try to explain it to a friend. Nothing about the afternoon sounds demanding. Yet the reach and the explanation pose quite different problems: one concerns an object within arm's length, the other an idea that is no longer in view.

The reach begins before the hand. Signals related to fluid concentration and volume, recent drinking and the mouth's condition help make water worth obtaining. Brainstem and hypothalamic systems participate in the regulation of fluid balance. But thirst need not produce an immediate reach. You can postpone drinking during a conversation or reject a glass that belongs to somebody else. Bodily demand meets knowledge of the situation.

Posture is already being controlled. The spinal cord, brainstem and cerebellum contribute to keeping the head and trunk within workable limits, informed by vision, signals from the body and the inner ear's balance apparatus. Muscles hold the arm against gravity. What looks like the beginning of an action is a change within ongoing activity, not the awakening of idle machinery.

From target to grip

Light reflected from the glass is focused on the retina. Photoreceptors convert light into changes in electrical signalling, and retinal circuits begin processing spatial contrast and change before information leaves through the optic nerve. No miniature photograph travels intact to a screen inside the skull.

Much of the visual information reaching cortex passes through a thalamic structure called the lateral geniculate nucleus. From primary visual cortex, interacting pathways process features relevant to recognition, motion, location and action. The familiar distinction between a ventral route

concerned with what an object is and a dorsal route concerned with where it is and how to act on it gives a useful first map. It is not a division into two independent departments. Connections return information as well as carrying it onwards.

For the glass to be grasped, its position must be related to the current position of the eyes, head and arm. Look towards the keyboard and the glass shifts within your visual field, although it has not moved on the desk. Parietal and frontal circuits combine sensory information with estimates of body position and possible movement. A target described as slightly right of the centre of vision is not yet a command telling shoulder and elbow muscles how much force to produce. The system has to relate where the object appears to where the hand can go.

Knowledge contributes something different. You recognise a drinking vessel rather than an arbitrary transparent shape. Its rim, usual contents and familiar grip have acquired meaning through experience. The goal determines which features matter: picking the glass up to drink and moving it out of somebody's way can require different movements towards the same object. What you see is used according to what you are trying to do.

Several actions remain possible. Continue typing, reach for the water, answer an alert or adjust position. Current goals and learned expectations bias these alternatives. Frontal and parietal systems help maintain relevant information; basal-ganglia loops contribute to the selection and organisation of action. This is a description of interacting influences, not a claim that every choice follows one fixed competition algorithm.

Once the reach proceeds, activity in premotor and motor systems helps organise it in relation to the target and the body. Descending pathways convey signals through brainstem and spinal cord. The corticospinal tract is especially important for skilled hand movements, while other pathways contribute to posture and orientation. Spinal interneurons combine descending influence with sensory information. Motor neurons activate muscle fibres. A pathway that ends in muscle has passed through several stages of coordination.

The fingers must close with enough force to prevent slipping and not enough to crush a fragile object. Previous encounters with similar objects help set an initial grip. Skin receptors report contact and slip; sensory endings in muscles and tendons supply information about the moving limb. Estimates made before contact can therefore be adjusted when the object supplies new evidence. A successful lift conceals how many different questions had to be answered.

A controlled miss

A laboratory can make the hidden correction visible. In prism-adaptation experiments, optical prisms shift the apparent location of a target. A person reaches and misses. Repeated attempts with information about the error allow performance to change. Remove the prisms and the next reaches may err in the opposite direction: a setting that helped under the altered view briefly outlives the alteration.

A 2015 study restricted participants' view of the hand during the reach, then briefly showed where it had landed. Healthy participants generally adapted more effectively than the selected patients with cerebellar disorders. The changed view was asking both groups to update a particular relation: where the eyes put the target relative to where the hand needed to go. Difficulty with that adjustment is more informative than a general verdict about somebody's ability to learn.

The after-effect matters because a verbal instruction to aim differently is not the whole explanation. Something about the relation between visual target and movement has been recalibrated. Explicit strategies can also contribute to prism performance; they need not be denied for sensorimotor adaptation to be real. The experiment separates a changed environment, repeated error and the behaviour that remains after the environment changes back.

The ordinary reach uses related capacities without requiring prism glasses. Advance estimates help compensate for the delay in sensory feedback. Feedback then checks what those estimates missed. A glass that is heavier than expected can expose an error in the initial command. The nervous

system must stay receptive to the actual outcome while making the next part of the action happen in time.

After the drink

The movement has an outcome beyond the hand. In everyday drinking, thirst can begin to ease before absorbed water has completed its effect on the blood. A detailed experimental account comes from mice: Christopher Zimmerman and colleagues recorded thirst-related neurons and found that their activity changed rapidly during eating and drinking, anticipating later changes in the body's fluid state. The mouse circuit demonstrates a mechanism for advance regulation; it is not a complete map of human thirst.

Early signals can begin an adjustment and later signals can correct it. The mouth supplies information sooner than the circulation supplies the full result. This helps explain why regulation need not wait for one final measurement. It also explains why early sensations are not infallible readings of the body's completed state.

The outcome also changes what is relevant. Once the glass is safely down, the hand can return to the keyboard and the page can regain priority. Completing one action changes the conditions for selecting the next.

The act can leave several kinds of learning. Grip calibration may change. A context may become associated with drinking. An unexpected outcome may alter what is worth checking next time. These changes concern different relations and timescales. Learning where the glass was left is not the same task as learning how hard to grip it, even though both occurred during one apparently simple action.

The event becomes a memory

Suppose you leave the room and later wonder whether the glass is still on the desk. The answer requires more than recognising what glasses are. It requires information about a particular event: this object, in this place, on this occasion. That is the territory of episodic memory.

The hippocampal formation and connected medial temporal structures help

establish relations among the elements of an experience. Sensory and association regions contribute information about its content. Later, a partial cue can support the recovery of a wider pattern. Remembering is consequently an active reconstruction, not the replay of a complete recording from a storage cabinet. Details can be unavailable, confused with another occasion or supplied by expectations about what usually happens.

The distinction between forms of memory became stark in the study of Henry Molaison, known for decades as H.M. In 1953, surgery intended to treat severe epilepsy removed tissue from both medial temporal lobes, including substantial parts of the hippocampal system and adjacent structures. Afterwards he had devastating difficulty forming lasting memories of new everyday events. Yet he could converse, retain some information briefly when it remained in attention, and use much knowledge acquired before the operation. Memory had not disappeared as one indivisible faculty.

Brenda Milner gave him a task that makes the distinction visible: trace a star while watching his hand in a mirror. With practice, his performance improved, although he did not remember the earlier practice episodes. The skill could survive into another session without the session itself becoming an ordinary remembered event. His nervous system had changed with experience; his autobiographical memory could not report that change. This was evidence for a separation between particular kinds of learning, not proof that every motor skill was intact.

That difference belongs in an ordinary user's guide. Knowing a fact, remembering the occasion on which it was learned and acquiring a fluent skill can come apart. Familiarity with a page can feel reassuring while leaving its argument hard to retrieve. Being able to describe a movement does not guarantee being able to perform it. The relevant question is which kind of access or learning the task requires.

The hippocampus should not become a new memory box in place of the old one. Long-term knowledge depends on wider systems, and the contribution of different structures changes with the kind of memory and the demands of

retrieval. The concise lesson is functional separation with cooperation: several ways of retaining and using experience, often working together, sometimes revealed by their unequal loss.

Thinking when the world is absent

Later, you try to explain the idea from the page. The page is no longer in view. You may recover fragments of wording, a diagram, an example or the sense of what followed from what. You choose what to keep active and what to leave out. The brain is generating a task whose immediate materials are largely internal.

Suppose you plan that conversation before meeting the friend. You picture a familiar face in a café where the two of you have never met. The face and the café come from experience; their combination need not. You can then imagine a question and consider a reply without either person speaking. Memory supplies material rather than a finished script, while control processes help keep the intended topic available. The result concerns something that might happen, not something the senses are currently reporting.

In an imaging experiment reported in 2007, Donna Rose Addis and colleagues asked participants to remember past events and imagine possible future ones. Some recruited regions overlapped, including parts of the hippocampal and broader memory-related systems, while other responses differed. Remembering and imagining recruit some of the same machinery without being the same operation. The overlap makes sense of a possibility already visible in the café example: experience can supply ingredients for an event that never occurred.

Abstraction lets you change the particulars while keeping a relation. Take the claim that the glass is still on the desk. You saw it there earlier, but somebody may since have moved it. The difference between evidence for where it was and evidence for where it is can be understood without returning to the room. The same distinction between an observation and what it warrants can be applied to a contract or a claim about a planet.

Learned concepts and working memory let the question survive the change of subject.

Language supplies an especially powerful set of resources. Words can identify distinctions, preserve intermediate conclusions and make thought available to other people. Networks distributed mainly across frontal and temporal regions support high-level linguistic processing. Their activity interacts with systems for memory, attention and speech movement, but those systems are not all doing the same job. Understanding a sentence, remembering its point and deciding whether it is true are distinguishable operations.

There is therefore no contradiction in saying that language transforms thought and that thought is wider than language. A person can imagine a spatial arrangement or perform some kinds of reasoning without silently narrating every step. Conversely, words can make a distinction manageable that would be difficult to sustain unaided. The relation is one of useful interaction rather than identity.

By now the glass has supplied an action, a memory and a question about evidence. These are related uses of experience, not variations on a muscle command. Activity can recur among systems while no overt response occurs, generating alternatives that will never be acted upon. The body sustains the thinking, but it does not confine the subject. You can put the glass down and still have plenty to think about.

Changing state

None of these operations occurs in a neutral condition. Wakefulness, sleepiness, pain, drugs and current concerns alter what information gains influence. A familiar paragraph may be manageable after rest and difficult late at night. That difference does not identify its cause on its own, but it shows why performance cannot be treated as a pure reading of permanent capacity.

Neuromodulatory systems help change responsiveness across networks. Noradrenaline, acetylcholine, serotonin and dopamine act through different

sources, projections and receptors. A widely distributed chemical signal need not have a uniform effect: its targets differ, and the receiving tissue has its own history and current activity. This is one reason a medication can have several effects rather than supplying one missing mental ingredient.

Sleep changes the organisation more extensively. Non-REM and REM states recur with different patterns of neural activity, muscle tone and responsiveness. The brain does not shut down. Sensitivity to the environment changes while internally generated activity continues, and sleep contributes to learning and memory as well as other physiological functions. No single story about filing memories or washing tissue explains the entire state.

Consciousness adds a question that anatomy alone does not settle. Wakefulness and the contents of awareness are related but not identical. A sleeper may have a vivid dream; an awake person processes much information without becoming aware of it. Recording a neural difference can help identify conditions associated with awareness, but it does not by itself explain why experience has a felt character. The biological evidence matters without licensing a claim that the philosophical problem is solved.

Age also changes the conditions, without moving every ability along one common curve. Older adults may need more time to learn unfamiliar material or retrieve a name while retaining substantial knowledge and skill. Normal variation should neither be turned into a verdict of inevitable incapacity nor used to dismiss a persistent new difficulty. A change that interferes with everyday life deserves attention to the pattern and possible causes. Age supplies context; it does not supply the diagnosis.

When the path is broken

Return to the hand. An intention can remain while the route to movement fails. Spinal cord injury can interrupt communication between brain and limbs without removing every cortical pattern associated with attempted movement. That distinction has made some assistive technologies possible.

In a study published in 2021, Francis Willett and colleagues recorded

cortical activity from one participant whose hand was paralysed after spinal cord injury. A trained system decoded patterns associated with attempted handwriting into text. It did not restore the original pathway or extract any thought the person happened to have. It linked a selected attempted action to an alternative means of communication, using implanted electrodes, calibration and a decoding model.

Other forms of assistance are less elaborate and no less meaningful to their users. Occupational therapy can help adapt a task or environment; physiotherapy can support movement practice; a reminder can reduce dependence on unaided memory. The outcome to care about is the capability achieved, alongside its effort, reliability and cost. Improved function need not imply that the original tissue or strategy has returned.

Recovery also depends on what damage occurred and what remains available. Some temporary disruption resolves. Other losses persist. Opportunities for practice, suitable equipment, fatigue, housing and another person's time can change what a patient manages. Treating recovery as a test of determination mistakes a whole situation for one attitude.

How we know

Anatomy identifies cells and pathways. Recording measures activity; stimulation tests consequences of altering it. Lesions reveal selective losses, though damage can affect fibres and distant regions as well as the tissue visibly injured. Behavioural experiments test what a person or animal can discriminate, remember or learn. No single method supplies the complete explanation.

EEG and MEG track fast population signals but locate their sources imperfectly. Structural MRI measures anatomy. Functional MRI usually measures blood-oxygen changes associated with neural activity, delayed relative to the underlying electrical events. Connectomics maps physical connections without recording their changing influence during life.

Agreement across these methods strengthens an account. A selective loss, a task-related signal and a response to intervention can constrain the same

explanation from different directions. Their populations still matter: a mouse circuit, one surgical specimen and a selected group of stroke survivors answer different questions. H.M.'s losses distinguish memory functions without making one person's injury a complete theory of memory. The remaining challenge is to connect levels while preserving these distinctions, rather than allowing an impressive measurement to answer a question it was never designed to test.

What People Get Wrong

“You use only ten per cent of your brain”

The myth survives because two true statements can be made to sound like one false one. People can improve their performance, and no ordinary task requires every neuron to fire at maximum rate. Neither means that ninety per cent sits unused.

Brain activity continues during rest because cells maintain gradients, exchange signals and coordinate ongoing functions. Different tasks alter different patterns rather than switching the whole organ from dark to bright. Functional images usually display a contrast between conditions after statistical processing; uncoloured tissue is not proved inactive. Nor does low firing mean no contribution, since inhibition and sparse coding can be functionally decisive. Damage supplies the harsher evidence. Small lesions in many locations can cause specific and lasting losses, while larger injuries rarely remove a silent reserve with no consequence.

The percentage itself has no defensible denominator. Ten per cent of neurons firing at once, tissue required for survival, metabolic expenditure, possible performance or conscious access would be different claims. None is established by the slogan.

You do not need a method for activating the missing ninety per cent. A seizure can recruit an enormous population and is not an upgrade. Useful performance depends on selective, timed activity and inhibition. The brain works by preventing most possibilities from controlling behaviour at the

same moment.

“The brain is three evolutionary layers”

The triune-brain story divides the organ into a reptilian core for instinct, a mammalian limbic system for emotion and a human neocortex for reason. It is memorable because it turns conflict into geology: an ancient animal lunges, a newer feeling system reacts and the civilised layer tries to regain control.

Evolution did not build vertebrate brains by leaving one finished animal inside another and wrapping new modules around it. Corresponding structures changed across lineages, expanded, contracted and reorganised together. Reptiles have forebrain circuits involved in flexible behaviour. Mammalian cortex participates in bodily regulation and emotion. Older structures contribute to planning and learning.

The model also flatters bad psychology. Reason is not produced by a pristine new layer while emotion leaks upward from a primitive basement. Valuation, bodily state, memory and social meaning help make a choice possible. Frontal cortex can support restraint, and it can also organise revenge with excellent timing.

Keep the history of structures. Discard the stack of animals. It explains neither evolution nor your last regrettable decision.

“People are left-brained or right-brained”

The hemispheres are not duplicates. Language is left-lateralised in most people. Spatial attention is often weighted towards right-hemisphere networks. Injury can reveal striking differences, and split-brain research shows how specialised processing can proceed when major connections are cut.

The leap is from lateralised functions to whole-person types. A resting-state imaging analysis of 1,011 people aged seven to twenty-nine found local lateralisation but not a global pattern dividing individuals into left-brained and right-brained types. Ordinary tasks commonly recruit systems on both

sides, connected through the corpus callosum and other pathways.

The myth persists because personality quizzes need clean categories and because hemispheric differences are real enough to lend them authority. It then mistakes relative weighting for exclusive ownership. Language can be lateralised while metaphor, prosody, memory, movement and control draw on bilateral systems. Art does not occur in one half of a painter.

Ask which process shows which asymmetry, in which population and by which measure. “Which side are you?” is usually the wrong question wearing a scan.

“Thinking is talking to yourself”

Inner speech makes the claim persuasive. Many people rehearse conversations, repeat instructions or argue silently. Words can hold an idea steady and let several steps be inspected. But the availability of an internal voice does not establish that every thought is a sentence.

In a 2005 study, Rosemary Varley and colleagues tested three men with major left-hemisphere lesions and severe grammatical impairment. They could still perform the tested calculations, including operations that required sensitivity to mathematical structure. This was evidence that those established mathematical abilities could survive serious language impairment, not proof that language had played no part in acquiring them.

Imaging offers a related distinction. Regions identified for high-level language processing need not respond in the same way to non-linguistic reasoning or working-memory tasks. The networks cooperate without being interchangeable. A spatial relation, a familiar face and the felt direction of a movement need not all be translated into a sentence before they can matter.

The correction has human consequences. Difficulty producing language must not be treated as evidence that thought has disappeared. Nor should a person whose thinking is less verbally narrated be assumed to lack a proper inner life. Language is a powerful resource for thought and communication; it is not a census of everything a mind contains.

“Dopamine is the pleasure chemical”

Dopamine acquired this title because rewards can alter dopamine signalling and because drugs with addictive potential often affect dopaminergic systems. The label then collapsed movement, learning, motivation and pleasure into one marketable fluid.

Dopamine neurons and terminals behave differently across circuits and timescales. Brief changes can resemble reward prediction errors, increasing when an outcome is better than expected and shifting towards cues that predict it. Other dopamine dynamics relate to motivation and the vigour of action. Loss of dopamine neurons in Parkinson's disease impairs movement. Receptor families can have different effects in different cells.

Pleasure itself is not measured by dopamine concentration. Experimental work, much of it in animals, distinguishes wanting, learning and liking, even though they interact. Increasing pursuit does not prove an increase in enjoyment. A cue can become powerful while the outcome delivers less pleasure than expected.

This is more than vocabulary. “Low dopamine” is not a diagnosis of boredom, and a product that raises dopamine somewhere has not supplied motivation in a bottle. Name the circuit, timescale, behaviour and evidence, or admit that the chemical noun is doing all the work.

“The brain finishes developing at twenty-five”

The claim borrows from real developmental imaging. Measures of cortical thickness, white matter, connectivity and task activity continue to change through adolescence and into adulthood. Some trajectories extend into the twenties. None supplies one moment when the entire brain becomes finished.

Large lifespan datasets show different measures peaking, slowing and changing at different ages. Development is not one march towards more tissue: some measurements rise, others fall, and a lower value can reflect refinement rather than loss of capacity. Individual variation is substantial,

and scans are shaped by sampling, equipment and analysis. Maturity is also a judgement about behaviour and responsibility, not one biological variable waiting to be read from an image.

A birthday is convenient for law, parenting and journalism. Convenience does not turn several developmental curves into one finish line. It can be used kindly, to resist expecting teenagers to behave like older adults. It can also deny agency to young adults or imply that later change is impossible. Both uses ask one average curve to settle a social question.

Brains keep changing across life. Developmental change is neither a licence for every action before twenty-five nor evidence of decline immediately afterwards. Specify the capacity, context and population. The organ has many clocks and no graduation ceremony.

“A brain scan shows what the mind is doing”

A structural MRI shows anatomy. Functional MRI commonly tracks changes in blood oxygenation related to neural activity, delayed and blurred across space and time. Researchers compare conditions, model noise and test whether patterns differ reliably. The final colour is an analysis, not light emitted by a thought.

Inference can run in two directions. A task may reliably change activity in a region. Seeing activity there does not prove that the person was performing that one task, because regions participate in several processes. This reverse-inference problem is manageable when evidence is specific and alternatives are tested. It is fatal when a familiar mental label is attached after the fact.

Decoding studies can recover useful information from distributed patterns. A 2023 study with three participants reconstructed aspects of semantic meaning from fMRI during heard or imagined speech. It required extensive individual training and the participant's cooperation. That is a technical achievement, not remote mind reading.

Scans are powerful when the question matches the signal. They can map

anatomy, support clinical planning and test models across groups or within individuals. They become misleading when the image's visual certainty outruns the measurement beneath it.

Use It

Find the operation before naming the trait

“I have no focus” can describe interruption, sleepiness, pain, an unclear task or a difficulty that needs assessment. “I am bad at learning” can mean that practice and the eventual test require different kinds of access. A label may identify a persistent pattern, but it does not automatically identify its mechanism.

Start with an observable difficulty. Is the information missed at first presentation, lost while something else is done, or unavailable when it must be retrieved? Does the problem appear in one setting or several? Does it change with time of day, task, cue or support? These questions do not diagnose a condition. They make the description useful enough for an experiment or a conversation with a clinician.

For an ordinary, non-urgent difficulty, change one manageable condition and observe the result. A written instruction can distinguish forgetting what to do from difficulty doing it. A quieter setting can reduce competing input without proving that distraction caused every previous failure. Treat the result as information, not a verdict on your character. Persistent or worsening changes deserve assessment rather than an endless series of personal productivity experiments.

Design the competition

Attention selects under constraint. Treating it as moral strength leaves competing demands untouched.

When a task matters, reduce the cues that invite irrelevant action. Moving a phone away, closing an unnecessary window or writing down the point at which work stopped are practical experiments. They reduce how much must

be resisted or reconstructed. None is a universal concentration prescription: some people work better with movement, sound or company, and different tasks need different conditions.

External records are especially useful where an intermediate result is fragile. A calculation on paper preserves a step while the next one is performed. A checklist preserves a requirement while attention moves elsewhere. The brain still has to interpret and use the record, but it no longer has to keep every relevant item continuously available.

Selection also creates blind spots. At appropriate intervals, check what has been excluded: an unanswered question, a changed condition or somebody else's need for information. The purpose is not uninterrupted tunnel vision. It is to make the allocation of attention fit the work, including the moments when the work requires looking away.

Train the capability, then test its transfer

Plasticity is too broad a word to specify a useful exercise. Define the result you need. Remembering a name later, understanding an argument and performing a movement reliably are different achievements. Practice should give the relevant operation something to do, rather than merely producing a reassuring score.

Suppose the aim is to explain a page after reading it. Close the page and try. A familiar sentence may be easy to recognise but harder to reconstruct, and a failed explanation can reveal a missing relation rather than a missing word. Return to the passage with that question. The next reading now has a job to do. You are testing the capability you wanted, rather than counting how often you have encountered the material.

Use feedback that distinguishes errors. An outcome tells you that an attempt failed; a useful comparison can show which part needs revision. Then test in the conditions that matter. Improvement on practised examples may depend on those examples, the interface or a narrow strategy. A new example is a more demanding test of what travelled.

Do not infer a general mental upgrade from improvement in a game. Equally, do not dismiss a specific benefit because it fails to improve everything else. Reliable performance on the task that matters can be enough.

Protect the operating conditions

A brain is sustained by a body, not by a collection of brain-branded products. Physical activity, adequate sleep opportunity and appropriate treatment of health problems belong in its care. Vascular health is particularly relevant because the tissue depends on its blood supply. Advice about blood pressure or other medical risks should be followed with a clinician, not replaced by a supplement advertised with a scan.

These are broad health priorities, not promises that a routine will prevent every cognitive illness. Evidence about lowering risk does not supply a guarantee for an individual. Age, disability, medication, caring responsibilities and access to safe activity or sleep all alter what is possible. A sensible plan works with those conditions rather than interpreting them as a lack of discipline.

Check the input as well. In older adults, guidance on cognitive health includes attention to hearing and vision: difficulty receiving information can make conversation and other tasks harder. That does not mean every memory complaint is a sensory problem. It means that maintaining the system includes checking what reaches it and seeking suitable care, rather than concentrating only on what happens inside the skull.

Match confidence to the measurement

When a brain claim appears, ask what changed, what was measured and who supplied the evidence.

A scan can show an anatomical difference without revealing its cause. A task can improve without the study establishing which cells changed. A lesion can show that damaged tissue or its connections mattered, while leaving uncertainty about the precise contribution. A randomised

intervention can strengthen a causal claim about its tested outcome without making that outcome universal.

Keep denominators visible. Cells are not all neurons. Scans are not all different people. Data needed to map tissue are not the tissue's memory capacity. A result from mice can identify a promising mechanism without specifying its importance in human life. These distinctions often do more work than the apparent precision of a headline.

Complete one sentence before accepting the claim: "This measurement supports the conclusion that..." Then compare that conclusion with the promise being sold. An honest inference may be useful and limited. Neither a beautiful image nor an impressive sample count can supply a missing comparison.

Recognise when interpretation must stop

Sudden lost function is different from a familiar lapse during a difficult day.

The stroke reminder FAST stands for face, arms, speech and time. A face may droop on one side; an arm may become weak or numb; speech may become slurred or difficult to understand. In the UK, call 999 immediately for suspected stroke. Do not drive yourself. Symptoms that clear can still require emergency assessment, and NHS advice includes signs within the last twenty-four hours even if they have stopped.

FAST is a recognition aid, not a complete list of possible symptoms or a test that excludes stroke. Sudden visual disturbance, severe imbalance or other abrupt neurological change can also be serious. Follow emergency advice rather than waiting for a self-experiment with food, rest or concentration to work.

The useful knowledge here is modest. You need not identify an artery or decide which kind of stroke occurred. You need to recognise that a rapid new loss of function should not be explained away as behaviour, age or insufficient effort.

The limits

Biology does not exhaust a person's circumstances. Education, language, money, relationships and access to care can change what somebody achieves. A patient is not a lesion, and an explanation of circuitry is not a complete explanation of a life.

This book cannot select medication, diagnose symptoms or predict an individual's future from a group average. It cannot promise recovery through plasticity. Supports that change disability without changing tissue remain legitimate supports. A communication device, an adapted task or another person's time can make a substantial difference without requiring a story about repairing the brain.

The one thing to keep

The glass that looked like a transparent shape became a target for the hand, an event to remember and evidence to reason about. Nothing inside the skull had to watch a private screen and issue all the orders. Different contributions made those different achievements possible.

That changes what failure means as well. A person searching for a word may still have the idea. Someone who needs a reminder may still know what to do once it arrives. A different route can produce a useful ability even when the old one remains damaged. Explanation becomes more humane when it becomes more exact.

The empty chair in the imagined control room is not a missing part of you. There was never a smaller person who could be made to try harder on your behalf. There is the whole person, working through particular capacities under particular conditions. Understanding those conditions gives practice a clearer target and assistance a proper place. A note, an adapted task or medical care can change what becomes possible. The aim is not to find a better operator inside your head. It is to understand more clearly the person whose head it is.

Terms

Neuron

A signalling cell specialised to receive, integrate and transmit influence through electrical and chemical events. Neurons vary greatly in shape, chemistry and firing pattern; the familiar branching diagram represents a family, not one standard component.

Glial cell

A broad class of non-neuronal nervous-system cells with several distinct developmental origins. Astrocytes, oligodendrocytes and microglia support different aspects of chemical regulation, myelin, synaptic function, metabolism, defence and repair.

Dendrite

A branching part of a neuron that receives many synaptic inputs. Dendritic shape, electrical properties, receptor distribution and local chemistry help determine how incoming activity influences the cell.

Axon

The neuronal process that carries action potentials towards target cells, sometimes across long distances. Axons can branch, vary in diameter and acquire myelin that changes the speed and reliability of signal conduction.

Action potential

A brief regenerative change in membrane voltage produced by ion channels. It travels along an axon without carrying a fixed meaning; firing pattern, timing and circuit context supply significance.

Synapse

A junction through which one cell influences another. Most discussed synapses are chemical, using transmitter and receptors, though electrical synapses connect cells directly through specialised gap-junction channels.

Neurotransmitter

A chemical released by a neuron to affect target cells. Its action depends on receptor, location, concentration, timing and circuit, which is why no transmitter has one psychological translation.

Receptor

A protein that responds to a chemical signal and changes cellular activity. Different receptor families for the same transmitter can produce different, even opposing, effects in their target cells.

Excitation

Influence that increases the likelihood or rate of a target neuron's response under given conditions. Excitation drives activity but needs precise timing, feedback and inhibition to remain organised.

Inhibition

Influence that reduces, delays or reshapes neural activity. Inhibition supports selectivity, rhythm, gain control, competition and stability; it is active computation rather than unused signal or silence.

Neuromodulation

A change in how cells or circuits respond, often produced by widely projecting chemical systems. Neuromodulators can alter gain, plasticity, motivation, arousal, attention and action without encoding one fixed message.

Myelin

A layered membrane wrapped around selected axons by glial cells. Myelin enables faster, more reliable conduction and can change with development, injury, disease and patterns of activity.

Grey matter

Tissue rich in neuronal cell bodies, dendrites, synapses and local circuitry. It includes cerebral and cerebellar cortex as well as many deeper nuclei; colour is an anatomical shorthand.

White matter

Bundles of axons, many myelinated, connecting brain regions and the spinal cord. White-matter injury can disrupt a function by disconnecting otherwise intact grey-matter areas from one another.

Cerebral cortex

The folded outer sheet of the cerebral hemispheres. Its regions show specialised gradients and extensive recurrent connections supporting perception, action, language, memory, planning and flexible control.

Hemisphere

One half of the cerebrum. The hemispheres show real functional asymmetries but cooperate through major connections, so lateralisation does not divide people into two personality types.

Working memory

The temporary availability of information for current thought or action. Its limits depend on material, knowledge and interference; it is a working function, not one small storage box inside the cortex.

Brainstem

The midbrain, pons and medulla, linking brain, cerebellum and spinal cord. It contains vital circuits for arousal, breathing, circulation, eye movement, orientation and cranial-nerve function.

Thalamus

A collection of many nuclei with extensive bidirectional cortical and subcortical connections. It routes and transforms much sensory information while helping coordinate attention, state, movement, learning and cortical communication.

Hypothalamus

A small region with large regulatory reach. It links bodily signals, autonomic control, hormones, circadian timing and motivated behaviours such as drinking, feeding and temperature regulation.

Hippocampus

A medial temporal structure important for forming relational and episodic memories, spatial representation and linking events to context. It works with wider cortical systems rather than storing every memory.

Amygdala

Several nuclei in the medial temporal lobe involved in learning and responding to biologically significant events. Threat is important, but reward, novelty and social meaning also recruit it.

Basal ganglia

Interconnected deep nuclei participating in recurrent loops for action selection, movement scaling, habit and learning. Parkinson's disease reveals their importance without reducing them to a start button.

Cerebellum

A densely cellular structure behind the brainstem involved in timing, prediction, calibration and error-based learning. Its contribution extends beyond balance, although motor effects remain the clearest evidence.

Prefrontal cortex

Frontal cortical regions supporting rule maintenance, planning, valuation and flexible control. They influence competition through wider networks and do not contain an independent rational executive.

Network

A set of connected elements whose coordinated activity supports an operation. Network explanations remain useful only when they specify nodes, pathways, direction, timing and the conditions under study.

Plasticity

Change in neural function or structure with development, activity, injury or experience. Plasticity enables learning and adaptation, but it is constrained, often specific and not automatically beneficial.

Episodic memory

Memory for a particular event in its context. It draws on hippocampal and wider systems, and differs from knowing a general fact or performing a skill without recalling how it was learned.

Homeostasis

The regulation of internal variables within ranges compatible with life and action. In a living organism, targets and responses change with context, so homeostasis is active control rather than one fixed thermostat setting.

Connectome

A map of neural connections at a stated scale, from major pathways to individual synapses. It describes possible routes and structural constraints; activity, chemistry, development, task and history determine how those routes are used at any moment.

Go Deeper

These works answer different next questions. The atlas locates structures; the history examines explanatory habits; the clinical paper exposes a functional distinction; the final interpretation challenges where an explanation should begin. They need not be read in that order.

The visual atlas

Rita Carter, *The Brain Book*, fourth edition (DK, 2026).

Begin here when the names still outrun your mental picture. The illustrated format supplies views of structures, cells and systems that prose alone cannot keep continuously in front of you. Use it to revisit the route from cortex through deeper structures, and to place a newly encountered term before reading about its function. An atlas necessarily divides what biology connects, so keep asking which pathways link the labelled parts. This is the most inviting next step for a reader who wants a broad reference rather than an argument with a theory.

The history of the metaphors

Matthew Cobb, *The Idea of the Brain: A History* (Profile Books, 2020).

Cobb follows changing attempts to explain the brain and the technologies that made each account plausible. Mechanism, electricity and computing have supplied questions as well as metaphors. The value is learning to notice what an attractive comparison leaves out, rather than laughing at theories that later failed. Read it for the history of evidence and explanatory ambition. It is a substantial book, and the historical approach asks for more patience than an atlas, but it makes present confidence easier to examine.

The original clinical evidence

William Beecher Scoville and Brenda Milner, “Loss of Recent Memory after Bilateral Hippocampal Lesions” (1957).

This short original paper shows how an apparently single faculty began to

divide under clinical observation. Read for the contrast between severe impairment in new learning and abilities that remained, and for the problem of connecting behavioural loss to surgical anatomy. Its terminology and clinical context are historical; it is not a description of current epilepsy treatment. Later work refined the anatomy and tested additional kinds of learning. The paper is valuable precisely because the foundational observation can be read alongside the limits of what it first established.

An argument from internal activity

György Buzsáki, *The Brain from Inside Out* (Oxford University Press, 2019).

Buzsáki challenges explanations that begin with a passive brain receiving the world. He emphasises internally organised activity and the role of action in giving sensory signals significance. The argument helps expose assumptions hidden inside the familiar perception-then-decision-then-action sequence. It is technically demanding in places and should be read as a developed interpretation, not as a settled theory of everything the brain does. Keep its challenge beside the distinctions in this book: bodily action matters enormously, while memory, language and abstract thought still require explanations of their own.

Notes and Sources

Scope and model

This book treats cellular signalling, specialised networks, bodily conditions, external action and internally generated cognition as connected levels of explanation. It does not claim that one control theory explains every thought. Buzsáki's *The Brain from Inside Out* is an important interpretation, balanced here by distinct treatment of memory and language. Purves and colleagues' *Neuroscience* supplies the reference anatomy and elementary physiology. NINDS material supplies accessible corroboration. The Whole Thing in One Page compresses the claims supported below.

The small cortical specimen

Shapson-Coe and colleagues (2024) uniquely supply the surgical-specimen figures. Volume does not establish shape; cells are not all neurons; image-data storage is not biological memory capacity. The drive comparison uses decimal units. This one clinical specimen cannot represent all regions or people. These distinctions govern the opening example rather than supplying a correction to be applied afterwards.

Physical conditions, cells and signalling

Raichle and Gusnard (2002) give the approximate adult two-per-cent body-mass and twenty-per-cent resting-energy comparison. It concerns whole-brain expenditure relative to whole-body expenditure, not the extra energy needed for difficult thinking. Attwell and Laughlin (2001) explain major signalling costs using an energy-budget model; its component estimates should not be treated as direct measurements of every adult human brain. Elementary ionic gradients, voltage-dependent channels, calcium-triggered chemical transmission and the blood-brain barrier are described in Purves and colleagues. Hodgkin and Huxley (1952) provide the primary squid-axon model, not a claim that all neurons have identical currents.

Golgi's and Ramón y Cajal's 1906 Nobel lectures document their differing interpretations of neuronal structure. Allen and Lyons (2018) review glial functions; Fields (2015) reviews activity-dependent myelination. The manuscript distinguishes non-neuronal cells from glia: vascular cells are included in the former category. Sterling (2012) offers a predictive-regulation framework; anticipatory regulation is retained without making that framework the sole definition of homeostasis.

Counting neurons

The approximate 86 billion figure and the cerebellar share derive from Azevedo and colleagues (2009), who examined four adult male brains. The estimate is neither an exact population constant nor a measure of intelligence. Goriely's article, published online in November 2024 and in a 2025 issue of *Brain*, questions the precision and generalisation attached to such counts. Lent (2025) defends the approximation and method; von Bartheld (2025) stresses methodological interpretation and biological variation. Their dispute does not erase the evidence for tens of billions of neurons. It does rule out treating a small convenience sample as the exact count for every person, age and sex. No incompatible demographic samples are compared here.

Regions, pathways and prediction

The broad anatomical map follows Purves and colleagues. Gajardo-Vidal and colleagues (2021) studied 134 stroke survivors with selected left frontal lesions and relative sparing of posterior language regions. Their persistent speech-production result concerns this lesion distribution and assessment interval. It does not establish that Broca's area never contributes to speech or that a region's role can be inferred from its name alone.

Crapse and Sommer (2008) review corollary-discharge mechanisms. Wolpert, Miall and Kawato (1998) develop cerebellar internal-model accounts. These models organise established observations but are not a completed description of every cerebellar computation. Keller and Mrsic-Flogel (2018) present a broader predictive-processing interpretation. Furutachi and Hofer (2026) examine inconsistent definitions, the evidence for sensory prediction-error signals and alternative computations that could produce similar responses. The manuscript retains circuit-level prediction without presenting one global predictive theory as settled. The latter review appeared online in April 2026 and in the July 2026 volume; those publication dates are not dates for a single newly collected dataset.

Selection, working memory and plasticity

Simons and Chabris (1999) supply the basketball and unexpected-gorilla experiment. Detection depended on the task and display; no universal percentage is claimed. Cowan (2001) concerns working-memory capacity under specified conditions, not a fixed item count for every task. Monsell (2003) reviews task-switching costs; the practical suggestions are applications of those constraints, not claims that one desk arrangement has received a clinical trial.

Maguire and colleagues' taxi-driver study (2000) is cross-sectional and cannot by itself settle whether all observed differences resulted from training. Draganski and colleagues (2004) and Scholz and colleagues (2009) report training-associated MRI changes; the images do not count newly formed neurons or identify one microscopic mechanism. Owen and colleagues (2010) report 11,430 participants who completed a six-week online study. This is a completion count, not the number initially recruited. Their no-transfer result concerns the programmes and untrained measures tested, not every conceivable intervention. Development and adaptation are supported by the reference physiology; recovery is not equated with regrowth of damaged tissue.

The illustrative sequence and prism experiment

The desk, glass, later recollection and conversation form an explicitly illustrative sequence, not a reconstruction of a participant's day. They combine standard mechanisms and do not assert that every component has been measured simultaneously during that exact activity. Conditional examples elsewhere are likewise explanatory illustrations.

Hashimoto and colleagues (2015) supply the prism-adaptation example. Vision of the hand was restricted during movement, with brief endpoint feedback. The study compared specified healthy and clinical groups, not all forms of cerebellar injury. Adaptation and its after-effect support changed sensorimotor calibration without excluding explicit strategies. Zimmerman and colleagues (2016) studied thirst-related circuitry in mice. Their

anticipatory neural responses are not silently presented as direct measurements of the human desk example.

Memory, language and internal thought

Scoville and Milner (1957) supply the foundational clinical report concerning H.M.; Corkin (1968) supplies evidence of selected motor-skill acquisition. The star-tracing task was Milner's: her first-person account is recorded in Julie Barlow's 2019 McGill interview, with the practice-without-recollection contrast also described in Neale McDevitt's 2007 profile. Squire (2009) reviews the distinction between retained abilities, impaired new declarative learning and later anatomical understanding. The operation affected medial temporal structures beyond the hippocampus, and the manuscript does not describe complete removal of both hippocampi, loss of all old memory, or preservation of every kind of learning. Corkin's result is not evidence that medial temporal structures are irrelevant to every motor-learning task.

Addis, Wong and Schacter (2007) compared remembering and imagining events with fMRI. The print year is 2007; the paper was first available online in 2006. Overlap and differences in recruitment support relationships between these activities, not identity of all underlying operations. Varley and colleagues (2005) tested three men with severe grammatical impairment but retained performance on the reported calculations. This concerns established abilities after injury, not the developmental question of whether language helped those abilities emerge. Fedorenko, Behr and Kanwisher (2011) distinguish high-level linguistic processing from several non-linguistic tasks using individually identified regions. Neither result makes language and thought wholly independent.

State, ageing, methods and assistance

NINDS sleep guidance supports the distinction between REM, non-REM and wakefulness, and sleep's involvement in learning and memory. No single-purpose sleep theory or universal brain-cleansing claim is made. NIA's account of ageing supports the distinction between some slower learning or retrieval and a change requiring assessment; it is not a diagnostic checklist.

Willett and colleagues (2021) describe an implanted handwriting-decoding system tested with one participant. The example is explicitly historical, not a claim about the latest performance, general availability or unrestricted thought reading. Logothetis (2003) explains the basis and limitations of BOLD fMRI. Poldrack (2006) explains reverse inference. Tang and colleagues (2023) studied a semantic decoder with three participants, extensive individual training and cooperation. The claim is limited to that system and design, not a forecast that non-consensual decoding will always be impossible.

The misconception corrections

Cesario, Johnson and Eisthen (2020) explain why the layered triune-brain model misrepresents vertebrate evolution. Nielsen and colleagues (2013) analysed 1,011 resting-state scans from people aged seven to twenty-nine and found local lateralisation without the proposed whole-person left-brain/right-brain pattern. This is not a personality test, a census of every age group or a denial of functional asymmetry.

Schultz, Dayan and Montague (1997), Mohebi and colleagues (2019), and Berridge and Robinson (2016) distinguish aspects of dopamine signalling, reward prediction, motivation and pleasure. Much of the mechanistic evidence is animal work; Mohebi's study used rats. These findings do not diagnose an individual's dopamine level from boredom or motivation. Somerville (2016) examines what brain maturity means. Bethlehem and colleagues (2022) combined 123,984 MRI scans from 101,457 participants across more than one hundred studies; scans and participants are different

denominators. That historical release supports varied lifespan trajectories, not one maturity birthday, and is not labelled the newest available chart.

Practical care and reading editions

NHS exercise guidance and NIA's *Cognitive Health and Older Adults* support general activity, health management and attention to sensory input. Risk reduction is not guaranteed prevention, and older-adult guidance is identified as such. NINDS supplies the sleep context. NHS stroke guidance advises calling 999 in the UK for suspected stroke, including symptoms within the last twenty-four hours that have stopped. FAST is not a complete exclusion test. No medication selection or individual diagnosis is offered.

The Go Deeper editions are Carter, fourth edition, DK, 2026; Cobb, Profile Books, 2020; Scoville and Milner, the original 1957 paper; and Buzsáki, Oxford University Press, 2019. The historical clinical paper is recommended as evidence to inspect, not as current treatment guidance.

Bibliography

Original research and primary evidence

Addis, Donna Rose, Alana T. Wong and Daniel L. Schacter. “Remembering the Past and Imagining the Future: Common and Distinct Neural Substrates during Event Construction and Elaboration.” *Neuropsychologia* 45, no. 7 (2007): 1363-1377. DOI 10.1016/j.neuropsychologia.2006.10.016.

Azevedo, Frederico A. C., Ludmila R. B. Carvalho, Lea T. Grinberg, Jose Marcelo Farfel, Renata E. L. Ferretti, Renata E. P. Leite, Wilson Jacob Filho, Roberto Lent and Suzana Herculano-Houzel. “Equal Numbers of Neuronal and Nonneuronal Cells Make the Human Brain an Isometrically Scaled-Up Primate Brain.” *Journal of Comparative Neurology* 513, no. 5 (2009): 532-541. DOI 10.1002/cne.21974.

Barlow, Julie. “The Sensational Centenarian.” Interview with Brenda Milner. *McGill News*, January 2019.

<https://mcgillnews.mcgill.ca/the-sensational-centenarian/>.

Bethlehem, Richard A. I., Jakob Seidlitz, Simon R. White, Joshua W. Vogel, Kaitlin M. Anderson, Chris Adamson, Sophie Adler et al. "Brain Charts for the Human Lifespan." *Nature* 604 (2022): 525-533. DOI 10.1038/s41586-022-04554-y.

Corkin, Suzanne. "Acquisition of Motor Skill after Bilateral Medial Temporal-Lobe Excision." *Neuropsychologia* 6, no. 3 (1968): 255-265. DOI 10.1016/0028-3932(68)90024-9.

Draganski, Bogdan, Christian Gaser, Volker Busch, Gerhard Schuierer, Ulrich Bogdahn and Arne May. "Neuroplasticity: Changes in Grey Matter Induced by Training." *Nature* 427 (2004): 311-312. DOI 10.1038/427311a.

Fedorenko, Evelina, Michael K. Behr and Nancy Kanwisher. "Functional Specificity for High-Level Linguistic Processing in the Human Brain." *Proceedings of the National Academy of Sciences of the United States of America* 108, no. 39 (2011): 16428-16433. DOI 10.1073/pnas.1112937108.

Gajardo-Vidal, Andrea, Diego L. Lorca-Puls, PLORAS Team et al. "Damage to Broca's Area Does Not Contribute to Long-Term Speech Production Outcome after Stroke." *Brain* 144, no. 3 (2021): 817-832. DOI 10.1093/brain/awaa460.

Golgi, Camillo. "The Neuron Doctrine: Theory and Facts." Nobel Lecture, 11 December 1906.

Hashimoto, Yuji, Takeru Honda, Ken Matsumura, Makoto Nakao, Kazumasa Soga, Kazuhiko Katano, Takanori Yokota et al. "Quantitative Evaluation of Human Cerebellum-Dependent Motor Learning through Prism Adaptation of Hand-Reaching Movement." *PLOS ONE* 10, no. 3 (2015): e0119376. DOI 10.1371/journal.pone.0119376.

Hodgkin, Alan L., and Andrew F. Huxley. "A Quantitative Description of Membrane Current and Its Application to Conduction and Excitation in Nerve." *Journal of Physiology* 117, no. 4 (1952): 500-544. DOI 10.1113/jphysiol.1952.sp004764.

Maguire, Eleanor A., David G. Gadian, Ingrid S. Johnsrude, Catriona D.

Good, John Ashburner, Richard S. J. Frackowiak and Christopher D. Frith. "Navigation-Related Structural Change in the Hippocampi of Taxi Drivers." *Proceedings of the National Academy of Sciences of the United States of America* 97, no. 8 (2000): 4398-4403. DOI 10.1073/pnas.070039597.

McDevitt, Neale. "Brenda Milner: Making a Little Noise When She Walks." *McGill Reporter*, 6 December 2007.

<https://www.reporter-archive.mcgill.ca/40/08/milner/index.html>.

Mohebi, Ali, Jeffrey R. Pettibone, Arif A. Hamid, Jenny-Marie T. Wong, Leah T. Vinson, Talia Patriarchi, Lin Tian, Robert T. Kennedy and Joshua D. Berke. "Dissociable Dopamine Dynamics for Learning and Motivation." *Nature* 570 (2019): 65-70. DOI 10.1038/s41586-019-1235-y.

Nielsen, Jared A., Brandon A. Zielinski, Michael A. Ferguson, Janet E. Lainhart and Jeffrey S. Anderson. "An Evaluation of the Left-Brain vs. Right-Brain Hypothesis with Resting State Functional Connectivity Magnetic Resonance Imaging." *PLOS ONE* 8, no. 8 (2013): e71275. DOI 10.1371/journal.pone.0071275.

Owen, Adrian M., Adam Hampshire, Jessica A. Grahm, Robert Stenton, Said Dajani, Alistair S. Burns, Robert J. Howard and Clive G. Ballard. "Putting Brain Training to the Test." *Nature* 465 (2010): 775-778. DOI 10.1038/nature09042.

Ramón y Cajal, Santiago. "The Structure and Connexions of Neurons." Nobel Lecture, 12 December 1906.

Scholz, Jan, Miriam C. Klein, Timothy E. J. Behrens and Heidi Johansen-Berg. "Training Induces Changes in White-Matter Architecture." *Nature Neuroscience* 12 (2009): 1370-1371. DOI 10.1038/nn.2412.

Schultz, Wolfram, Peter Dayan and P. Read Montague. "A Neural Substrate of Prediction and Reward." *Science* 275, no. 5306 (1997): 1593-1599. DOI 10.1126/science.275.5306.1593.

Scoville, William Beecher, and Brenda Milner. "Loss of Recent Memory after Bilateral Hippocampal Lesions." *Journal of Neurology, Neurosurgery and*

Psychiatry 20, no. 1 (1957): 11-21. DOI 10.1136/jnnp.20.1.11.

Shapson-Coe, Alexander, Michał Januszewski, Daniel R. Berger, Art Pope, Yuelong Wu, Tim Blakely, Richard L. Schalek et al. "A Petavoxel Fragment of Human Cerebral Cortex Reconstructed at Nanoscale Resolution." *Science* 384, no. 6696 (2024): eadk4858. DOI 10.1126/science.adk4858.

Simons, Daniel J., and Christopher F. Chabris. "Gorillas in Our Midst: Sustained Inattentive Blindness for Dynamic Events." *Perception* 28, no. 9 (1999): 1059-1074. DOI 10.1068/p281059.

Tang, Jerry, Amanda LeBel, Shailee Jain and Alexander G. Huth. "Semantic Reconstruction of Continuous Language from Non-Invasive Brain Recordings." *Nature Neuroscience* 26 (2023): 858-866. DOI 10.1038/s41593-023-01304-9.

Varley, Rosemary A., Nicolai J. C. Klessinger, Charles A. J. Romanowski and Michael Siegal. "Agrammatic but Numerate." *Proceedings of the National Academy of Sciences of the United States of America* 102, no. 9 (2005): 3519-3524. DOI 10.1073/pnas.0407470102.

Willett, Francis R., Donald T. Avansino, Leigh R. Hochberg, Jaimie M. Henderson and Krishna V. Shenoy. "High-Performance Brain-to-Text Communication via Handwriting." *Nature* 593 (2021): 249-254. DOI 10.1038/s41586-021-03506-2.

Zimmerman, Christopher A., Yen-Chu Lin, David E. Leib, Ling Guo, Erica L. Huey, Gwendolyn E. Daly, Yiming Chen and Zachary A. Knight. "Thirst Neurons Anticipate the Homeostatic Consequences of Eating and Drinking." *Nature* 537 (2016): 680-684. DOI 10.1038/nature18950.

Reviews, methods and interpretations

Allen, Nicola J., and David A. Lyons. "Glia as Architects of Central Nervous System Formation and Function." *Science* 362, no. 6411 (2018): 181-185. DOI 10.1126/science.aat0473.

Attwell, David, and Simon B. Laughlin. "An Energy Budget for Signaling in

the Grey Matter of the Brain.” *Journal of Cerebral Blood Flow and Metabolism* 21, no. 10 (2001): 1133-1145. DOI 10.1097/00004647-200110000-00001.

Berridge, Kent C., and Terry E. Robinson. “Liking, Wanting, and the Incentive-Sensitization Theory of Addiction.” *American Psychologist* 71, no. 8 (2016): 670-679. DOI 10.1037/amp0000059.

Cesario, Joseph, David J. Johnson and Heather L. Eisthen. “Your Brain Is Not an Onion with a Tiny Reptile Inside.” *Current Directions in Psychological Science* 29, no. 3 (2020): 255-260. DOI 10.1177/0963721420917687.

Cowan, Nelson. “The Magical Number 4 in Short-Term Memory: A Reconsideration of Mental Storage Capacity.” *Behavioral and Brain Sciences* 24, no. 1 (2001): 87-114. DOI 10.1017/S0140525X01003922.

Crapse, Trinity B., and Marc A. Sommer. “Corollary Discharge across the Animal Kingdom.” *Nature Reviews Neuroscience* 9 (2008): 587-600. DOI 10.1038/nrn2457.

Fields, R. Douglas. “A New Mechanism of Nervous System Plasticity: Activity-Dependent Myelination.” *Nature Reviews Neuroscience* 16 (2015): 756-767. DOI 10.1038/nrn4023.

Furutachi, Shohei, and Sonja B. Hofer. “Rethinking Predictive Processing.” *Annual Review of Neuroscience* 49 (2026): 471-494. DOI 10.1146/annurev-neuro-102124-031410.

Keller, Georg B., and Thomas D. Mrsic-Flogel. “Predictive Processing: A Canonical Cortical Computation.” *Neuron* 100, no. 2 (2018): 424-435. DOI 10.1016/j.neuron.2018.10.003.

Logothetis, Nikos K. “The Underpinnings of the BOLD Functional Magnetic Resonance Imaging Signal.” *Journal of Neuroscience* 23, no. 10 (2003): 3963-3971. DOI 10.1523/JNEUROSCI.23-10-03963.2003.

Monsell, Stephen. “Task Switching.” *Trends in Cognitive Sciences* 7, no. 3 (2003): 134-140. DOI 10.1016/S1364-6613(03)00028-7.

Poldrack, Russell A. "Can Cognitive Processes Be Inferred from Neuroimaging Data?" *Trends in Cognitive Sciences* 10, no. 2 (2006): 59-63. DOI 10.1016/j.tics.2005.12.004.

Raichle, Marcus E., and Debra A. Gusnard. "Appraising the Brain's Energy Budget." *Proceedings of the National Academy of Sciences of the United States of America* 99, no. 16 (2002): 10237-10239. DOI 10.1073/pnas.172399499.

Somerville, Leah H. "Searching for Signatures of Brain Maturity: What Are We Searching For?" *Neuron* 92, no. 6 (2016): 1164-1167. DOI 10.1016/j.neuron.2016.10.059.

Squire, Larry R. "The Legacy of Patient H.M. for Neuroscience." *Neuron* 61, no. 1 (2009): 6-9. DOI 10.1016/j.neuron.2008.12.023.

Sterling, Peter. "Allostasis: A Model of Predictive Regulation." *Physiology and Behavior* 106, no. 1 (2012): 5-15. DOI 10.1016/j.physbeh.2011.06.004.

Wolpert, Daniel M., R. Chris Miall and Mitsuo Kawato. "Internal Models in the Cerebellum." *Trends in Cognitive Sciences* 2, no. 9 (1998): 338-347. DOI 10.1016/S1364-6613(98)01221-2.

The human-neuron-count exchange

Goriely, Alain. "Eighty-Six Billion and Counting: Do We Know the Number of Neurons in the Human Brain?" *Brain* 148, no. 3 (2025): 689-691. DOI 10.1093/brain/awae390.

Lent, Roberto. "Yes, the Human Brain Has around 86 Billion Neurons." *Brain* 148, no. 5 (2025): e37-e38. DOI 10.1093/brain/awaf048.

von Bartheld, Christopher S. "Understanding and Misunderstanding Cell Counts of the Human Brain: The Crux of Biological Variation." *Brain* 148, no. 8 (2025): e72-e74. DOI 10.1093/brain/awaf136.

Books and reference works

Buzsáki, György. *The Brain from Inside Out*. New York: Oxford University Press, 2019.

Carter, Rita. *The Brain Book*. 4th ed. London: DK, 2026.

Cobb, Matthew. *The Idea of the Brain: A History*. London: Profile Books, 2020.

Purves, Dale, George J. Augustine, David Fitzpatrick et al., eds. *Neuroscience*. 2nd ed. Sunderland, MA: Sinauer Associates, 2001. NCBI Bookshelf edition.

Public-health and clinical guidance

National Institute of Neurological Disorders and Stroke. “Brain Basics: Know Your Brain.” NIH website. Accessed 4 September 2026.

National Institute of Neurological Disorders and Stroke. “Brain Basics: Understanding Sleep.” NIH website. Accessed 4 September 2026.

National Institute on Aging. “Cognitive Health and Older Adults.” NIH website, 11 June 2024. Accessed 5 September 2026.

National Institute on Aging. “How the Aging Brain Affects Thinking.” NIH website, 27 June 2023. Accessed 4 September 2026.

NHS. “Benefits of Exercise.” NHS website. Accessed 4 September 2026.

NHS. “Symptoms of a Stroke.” NHS website. Accessed 5 September 2026.