DEAN BURNETT

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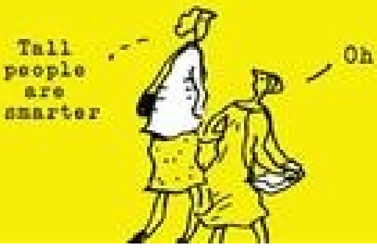
THE IDIOT BRAIN

A Neuroscientist Explains What Your Head Is Really Up To



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The Idiot Brain

A Neuroscientist Explains What Your Head is Really Up To

DEAN BURNETT

Dedicated to every human with a brain.
It’s not an easy thing to put up with, so well done.

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Introduction

This book begins the same way as nearly all my social interactions; with a series of detailed and thorough apologies.

Firstly, if you end up reading this book and not liking it, I'm sorry. It's impossible to produce something that will be liked by everyone. If I could do that, I'd be the democratically elected leader of the world by now. Or Dolly Parton.

To me, the subjects covered in this book, focusing on the weird and peculiar processes in the brain and the illogical behaviours they produce, are endlessly fascinating. For example, did you know that your memory is egotistical? You might think it's an accurate record of things that have happened to you or stuff you've learned, but it isn't. Your memory often tweaks and adjusts the information it stores to make you look better, like a doting mother pointing out how wonderful her little Timmy was in the school play, even though little Timmy just stood there, picking his nose and dribbling.

Or how about the fact that stress can actually *increase* your performance at a task? It's a neurological process, not just 'something people say'. Deadlines are one of the most common ways of inducing stress that provoke an increase in performance. If the latter chapters of this book suddenly improve in quality, you now know why.

Secondly, while this is technically a science book, if you were expecting a sober discussion of the brain and its workings, then I apologise. You won't be getting that. I am not from a 'traditional' scientific background; I'm the first out of everyone in my family to so much as think about going to university, let alone go, stay there and end up with a doctorate. It was these strange academic inclinations, so at odds with my closest relatives, that first got me into neuroscience and psychology, as I wondered, 'Why am I like this?' I never really found a satisfying answer, but I did develop a strong interest in the brain and its workings, as well as in science in general.

Science is the work of humans. By and large, humans are messy, chaotic and illogical creatures (due largely to the workings of the human brain) and much of science reflects this. Someone decided long ago that science writing should always be lofty and serious, and this notion seems to have stuck. Most of my professional life has been dedicated to challenging it, and this book is the latest expression of that.

Thirdly, I'd like to say sorry to any readers who find themselves referencing this book and subsequently losing an argument with a neuroscientist. In the world of brain sciences, our understanding changes all the time. For every claim or statement made in this book, you'd probably be able to find some new study or investigation that argues against it. But, for the benefit of any newcomers to science reading, this is pretty much always the case with any area of modern science.

Fourthly, if you feel the brain is a mysterious and ineffable object, some borderline-mystical construct, the bridge between the human experience and the realm of the unknown, etc., then I'm sorry; you're really not going to like this book.

Don't get me wrong, there really is nothing as baffling as the human brain; it is incredibly interesting. But there's also this bizarre impression that the brain is 'special', exempt from criticism, privileged in some way, and our understanding of it is so limited that we've barely scratched the surface of what it's capable of. With all due respect, this is nonsense.

The brain is still an internal organ in the human body, and as such is a tangled mess of habits, traits, outdated processes and inefficient systems. In many ways, the brain is a victim of its own success; it's evolved over millions of years to reach this current level of complexity, but as a result it has accrued a great deal of junk, like a hard drive riddled with old software programs and obsolete downloads that interrupt basic processes, like those cursed pop-ups offering you discount cosmetics from long-defunct websites when all you're trying to do is read an email.

Bottom line: the brain is fallible. It may be the seat of consciousness and the engine of all human experience, but it's also incredibly messy and disorganised despite these profound roles. You have only to look at the thing to grasp how ridiculous it is: it resembles a mutant walnut, a Lovecraftian blancmange, a decrepit boxing glove, and so on. It's undeniably impressive, but it's far from perfect, and *these imperfections influence everything humans say, do and experience*.

So rather than the brain's more haphazard properties being downplayed or just flat out ignored, they should be emphasised, celebrated even. This book covers the many things the brain does that are downright laughable and how they affect us. It also looks at some of the ways people have thought the brain works that have proved to be way off. Readers of this book should, I hope, come away with a better and reassuring understanding of why people (or they themselves) regularly do and say such weird things, as well as with the ability to legitimately raise a sceptical eyebrow when confronted with the increasing amount of brain-based neuro-nonsense in the modern world. If this book can claim to have anything as lofty as overarching themes or aims, these are they.

And my final apology is based on the fact that a former colleague of mine once told me that I'd get a book published 'when hell freezes over'. Sorry to Satan. This must be very inconvenient for you.

Dean Burnett, PhD (no, really)

1

Mind controls

How the brain regulates the body, and usually makes a mess of things

The mechanics that allow us to think and reason and contemplate didn’t exist millions of years ago. The first fish to crawl onto land aeons ago wasn’t racked with self-doubt, thinking, ‘Why am I doing this? I can’t breathe up here and I don’t even have any legs, whatever they are. This is the last time I play truth-or-dare with Gary.’ No; until relatively recently, the brain had a much more clear and simple purpose: keeping the body alive by any means necessary.

The primitive human brain was obviously successful because we as a species endured and are now the dominant life-form on earth. But despite our evolved complicated cognitive abilities, the original primitive brain functions didn’t go away. If anything, they became more important; having language and reasoning skills doesn’t really amount to much if you keep dying from simple things like forgetting to eat or wandering off cliffs.

The brain needs the body to sustain it, and the body needs the brain to control it and make it do necessary things. (They’re actually far more intertwined than this description suggests, but just go with it for now.) As a result, much of the brain is dedicated to basic physiological processes, monitoring internal workings, coordinating responses to problems, cleaning up mess. Maintenance, essentially. The regions that control these fundamental aspects, the brainstem and cerebellum, are sometimes referred to as the ‘reptile’ brain, emphasising their primitive nature, because it’s the same thing the brain was doing when we were reptiles, back in the mists of time. (Mammals were a later addition to the whole ‘life-on-earth’ scene.) By contrast, all the more advanced abilities we modern humans enjoy – consciousness, attention, perception, reasoning – are found in the neocortex, ‘neo’ meaning ‘new’. The actual arrangement is far more complex than these labels suggest, but it’s a useful shorthand.

So you might hope that these parts – the reptile brain and the neocortex – would work together harmoniously, or at least ignore each other. Some hope. If you’ve ever worked for someone who’s a micromanager, you know how incredibly inefficient this arrangement can be. Having someone less experienced (but technically higher ranking) hovering over you, issuing ill-informed orders and asking dumb questions can only ever make it harder. The neocortex does this with the reptile brain all the time.

It’s not all one way though. The neocortex is flexible and responsive; the reptile brain is set in its ways. We’ve all met people who think they know best because they’re older or have been doing something for longer. Working with these people can be a nightmare, like trying to write computer programs with someone who insists on using a typewriter because ‘that’s how it’s always been done’. The reptile brain can be like that, derailing useful things by being incredibly obstinate. This chapter looks at how the brain messes up the more basic functions of the body.

Stop the book, I want to get off!

(How the brain causes motion sickness)

Modern humans spend a lot more time sitting down than ever before. Manual-labour jobs have ~~largely been replaced by office jobs. Cars and other means of transport mean we can travel~~ while sitting down. The Internet means it is possible to spend practically your whole life sitting down, what with telecommuting, online banking and shopping.

This has its down sides. Obscene sums are spent on ergonomically designed office chairs to make sure people don't get damaged or injured due to excessive sitting. Sitting too long on an aeroplane can even be fatal, due to deep vein thrombosis. It seems odd, but very little movement is damaging.

Because moving is important. Humans are good at it and we do it a lot, as evidenced by the fact that, as a species, we've pretty much covered the surface of the earth, and actually been to the moon. Walking two miles a day has been reported as being good for the brain, but then it's probably good for every part of the body.[1] Our skeletons have evolved to allow long periods of walking, as the arrangement and properties of our feet, legs, hips and general body layout are ideally suited to regular ambulation. But it's not just the structure of our bodies; we're seemingly 'programmed' to walk without even getting the brain involved.

There are nerve clusters in our spines that help control our locomotion without any conscious involvement.[2] These bundles of nerves are called pattern generators, and are found in the lower parts of the spinal cord in the central nervous system. These pattern generators stimulate the muscles and tendons of the legs to move in specific patterns (hence the name) to produce walking. They also receive feedback from the muscles, tendons, skin and joints – such as detecting if we're walking down a slope – so we can tweak and adjust the manner of movement to match the situation. This may explain why an unconscious person can still wander about, as we'll see in the phenomenon of sleepwalking later in this chapter.

This ability to move around easily and without thinking about it – whether fleeing dangerous environments, finding food sources, pursuing prey or outrunning predators – ensured our species's survival. The first organisms to leave the sea and colonise the land led to all air-breathing life on earth; they wouldn't have done so if they'd stayed put.

But here's the question: if moving is integral to our well-being and survival, and we've actually evolved sophisticated biological systems to ensure it happens as often and as easily as possible, why does it sometimes make us throw up? This is the phenomenon known as motion sickness or travel sickness. Sometimes, often apropos of nothing, being in transit makes us bring up our breakfast, lose our lunch, or eject some other more recent but non-alliterative meal.

It's the brain that's actually responsible for this, not the stomach or innards (despite how it may feel at the time). What possible reason could there be for our brains to conclude, in defiance of aeons of evolution, that going from A to B is a legitimate cause for vomiting? In actual fact, the brain isn't defying our evolved tendencies at all. It's the numerous systems and mechanisms we have to facilitate motion that are causing the problem. Motion sickness occurs only when you're travelling by artificial means –when you're in a vehicle. Here's why.

Humans have a sophisticated array of senses and neurological mechanisms that give rise to proprioception, the ability to sense how our body is currently arranged, and which parts are going where. Put your hand behind your back and you can still sense the hand, know where it is and what rude gesture it's making, without actually seeing it. That's proprioception.

There's also the vestibular system, found in our inner ear. It's a bunch of fluid-filled canals (meaning 'bony tubes' in this context) to detect our balance and position. There's enough space in there for fluid to move about in response to gravity, and there are neurons throughout it that can detect the location and arrangement of the fluids, letting our brain know our current position and ~~orientation. If the fluid is at the top of the tubes, this means we’re upside-down, which probably~~ isn’t ideal and should be remedied as soon as possible.

Human motion (walking, running, even crawling or hopping) produces a very specific set of signals. There’s the steady up–down rocking motion inherent in bipedal walking, the general velocity and the external forces such as the movement of air passing you and your shifting internal fluids that this produces. All of these are detected by proprioception and the vestibular system.

The image hitting our eyes is one of the outside world going by. The same image could be caused either by us moving or by us staying still and the outside world going past. At the most basic level, both are valid interpretations. How does the brain know which is right? It receives the visual information, couples it with the information from the fluid system in the ear and concludes ‘body is moving; this is normal’, and then goes back to thinking about sex or revenge or Pokemon, whatever it is you’re into. Our eyes and inner systems work together to explain what’s going on.

Movement via a vehicle produces a different set of sensations. Cars don’t have that signature rhythmical rocking motion that our brains associate with walking (unless your suspension is well and truly shot), and the same usually goes for planes, trains and ships. When you’re being transported, you’re not the one actually ‘doing’ the moving; you’re just sitting there doing something to pass the time, such as trying to stop yourself from throwing up. Your proprioception isn’t producing all those clever signals for the brain to comprehend what’s going on. No signals means you’re not doing anything to the reptile brain, and this is reinforced by your eyes telling it you’re not moving. But you *are* actually moving, and the aforementioned fluids in your ear, responding to the forces caused by high-speed movement and acceleration, are sending signals to the brain that are saying you are travelling, and quite fast at that.

What’s happening now is that the brain is getting mixed signals from a precisely calibrated motion-detection system, and it is believed that this is what causes motion sickness. Our conscious brain can handle this conflicting information quite easily, but the deeper, more fundamental subconscious systems that regulate our bodies don’t really know how to deal with internal problems like this, and they’ve no idea what could possibly be happening to cause the malfunction. In fact, as far as the reptile brain is concerned, there’s only one likely answer: poison. In nature, that’s the only likely thing that can so deeply affect our inner workings and cause them to get so confused.

Poison is bad, and if the brain thinks there’s poison in the body, there’s only one reasonable response: get rid of it, activate the vomiting reflex, pronto. The more advanced brain regions may know better, but it takes a lot of effort to alter the actions of the fundamental regions once they’re under way. They are ‘set in their ways’ after all, almost by definition.

The phenomenon is still not totally understood at present. Why don’t we get motion sickness all the time? Why do some people never suffer from it? There may well be many external or personal factors, such as the exact nature of the vehicle in which you are travelling, or some neurological predisposition to sensitivity to certain forms of movement, that contribute to occurrence of motion sickness, but this section sums up the most popular current theory. An alternative explanation is the ‘nystagmus hypothesis’,[3] which argues that the inadvertent stretching of the extra-ocular muscles (the ones that hold and move the eyes) due to motion stimulates the vagus nerve (one of the main nerves that control the face and head) in weird ways, leading to motion sickness. In either case, we get motion sickness because our brain gets easily confused and has a limited number of options when it comes to fixing potential problems, like a manager who’s been promoted above his or her ability level and responds with buzzwords and crying fits when asked to do anything.

Seasickness seems to hit people the hardest. On land there are many items in the landscape to look at that reveal your movements (for instance, trees going past); on a ship there's usually just the sea and things that are too far away to be of any use, so the visual system is even more likely to assert that there's no movement happening. Travelling on the sea also adds an unpredictable up–down motion that gets the ear fluids firing off even more signals to an increasingly confused brain. In Spike Milligan's war memoir *Adolf Hitler: My Part in His Downfall*, Spike was transferred to Africa by ship during World War II, and was one of the only soldiers in his squad who didn't succumb to seasickness. When asked what the best way to deal with seasickness was, his reply was simply, 'Sit under a tree.' There's no supporting research available, but I'm fairly confident this method would work to prevent airsickness too.

Room for pudding?

(The brain's complex and confusing control of diet and eating)

Food is fuel. When your body needs energy, you eat. When it doesn't, you don't. It should be so simple when you think about it, but that's exactly the problem: us big smart humans can and do *think* about it, which introduces all manner of problems and neuroses.

The brain exerts a level of control over our eating and appetite that might surprise most people.[4] You'd think it's all controlled by the stomach or intestines, perhaps with input from the liver or fat reserves, the places where digested matter is processed and/or stored. And indeed, they do have their part to play, but they aren't as dominant as you might think.

Take the stomach; most people say they feel 'full' when they've eaten enough. This is the first major space in the body in which consumed food ends up. The stomach expands as you fill it, and the nerves in the stomach send signals to the brain to suppress appetite and stop eating, which makes perfect sense. This is the mechanism exploited by those weight-loss milkshakes you drink instead of eating meals.[5] The milkshakes contain dense stuff that fills the stomach quickly, expanding it and sending the 'I'm full' messages to the brain without you having to pack it with cake and pies.

They are, however, a short-term solution. Many people report feeling hungry less than 20 minutes after drinking one of these shakes, and that's largely because the stomach expansion signals are just one small part of the diet and appetite control. They're the bottom rung of a long ladder that goes all the way up to the more complex elements of the brain. And the ladder occasionally zigzags or even goes through loops on the way up.[6]

It's not just the stomach nerves that influences our appetite; there are also hormones that play a role. Leptin is a hormone, secreted by fat cells, that decreases appetite. Ghrelin is released by the stomach, and increases appetite. If you have more fat stores, you secrete more appetite-suppressing hormone; if your stomach is noticing a persistent emptiness, it secretes hormone to increase appetite. Simple, right? Unfortunately, no. People may have increased levels of these hormones depending on their food requirements, but the brain can quickly grow used to them and effectively ignores them if they persist too long. One of the brain's more prominent skills is the ability to ignore anything that becomes too predictable, no matter how important it may be (this is why soldiers can still get some sleep in war zones).

Have you noticed how you always have 'room for dessert'? You might have just eaten the best part of a cow, or enough cheesy pasta to sink a gondola, but you can manage that fudge brownie or triple-scoop ice-cream sundae. Why? *How?* If your stomach is full, how is eating more even physically possible? It’s largely because your brain makes an executive decision and decides that no, ~~you still have room. The sweetness of desserts is a palpable reward that the brain recognises~~ and wants (see Chapter 8) so it overrules the stomach, saying, ‘No room in here.’ Unlike the situation with motion sickness, here the neocortex overrules the reptile brain.

Exactly why this is the case is uncertain. It may be that humans *need* quite a complex diet in order to remain in tip-top condition, so rather than just relying on our basic metabolic systems to eat whatever is available, the brain steps in and tries to regulate our diet better. And this would be fine if that was all the brain does. But it doesn’t. So it isn’t.

Learned associations are incredibly powerful when it comes to eating. You may be a big fan of something like, say, cake. You can be eating cake for years without any bother, then one day you eat some cake that makes you sick. Could be some of the cream in it has gone sour; it might contain an ingredient you’re allergic to; or (and here’s the annoying one) *it could be that something else entirely made you sick shortly after eating cake.* But, from then on, your brain has made the connection and considers cake out of bounds; if you even look at it again it can trigger the nausea response. The disgust association is a particularly powerful one, evolved to stop us eating poison or diseased things, and it can be a hard one to break. No matter that your body has consumed it dozens of times with no problem; the brain says, *No!* And there’s little you can do about it.

But it doesn’t have to be anything as extreme as being sick. The brain interferes with almost every food-based decision. You may have heard that the first bite is with the eye? Much of our brain, as much as 65 per cent of it, is associated with vision rather than taste.[7] While the nature and function of the connections is staggeringly varied, it does reveal that vision is clearly the go-to sensory information for the human brain. By contrast, taste is almost embarrassingly feeble, as we shall see in Chapter 5. If blindfolded while wearing nose plugs, your typical person can often mistake potato for apple.[8] Clearly, the eyes have a much greater influence over what we perceive than the tongue, so how food looks is going to influence strongly how we enjoy it, hence all the effort on presentation in the fancy eateries.

Routine can also drastically influence your eating habits. To demonstrate this, consider the phrase ‘lunchtime’. When is lunchtime? Most will say between 12 p.m. and 2 p.m. Why? If food is needed for energy, why would everyone in a population, from hard physical workers like labourers and lumberjacks to sedentary people like writers and programmers, eat lunch at the same time? It’s because we all agreed long ago that this was lunchtime and people rarely question it. Once you fall into this pattern, your brain quickly expects it to be maintained, and you’ll get hungry *because it’s time to eat*, rather than *knowing it’s time to eat* because you’re hungry. The brain apparently thinks logic is a precious resource to be used only sparingly.

Habits are a big part of our eating regime, and once our brain starts to expect things, our body quickly follows suit. It’s all very well saying to someone who’s overweight that they just need to be more disciplined and eat less, but it’s not that easy. How you ended up overeating in the first place can be due to many factors, such as comfort eating. If you’re sad or depressed, your brain is sending signals to the body that you’re tired and exhausted. And if you’re tired and exhausted, what do you need? Energy. And where do you get energy? *Food!* High-calorie food can also trigger the reward and pleasure circuits in our brains.[9] This is also why you rarely ever hear of a ‘comfort salad’.

But once your brain and body adapts to a certain caloric intake, it can be very hard to reduce it. You’ve seen sprinters or marathon runners after a race, doubled up and gasping for breath? Do you ever consider them a glutton for oxygen? You never see anyone tell them they’re lacking in discipline and are just being lazy or greedy. It's a similar effect (albeit a less healthy one) with eating, in that the body changes to expect the increased food intake, and as a result it becomes harder to stop. The exact reasons why someone ends up eating more than they need in the first place and becoming accustomed to it are impossible to determine as there are so many possibilities, but you could argue that it's an inevitability when you make endless amounts of food available to a species that has evolved to take whatever food it can get whenever it can get it.

And if you need any further proof that the brain controls eating, consider the existence of eating disorders such as anorexia or bulimia. The brain manages to convince the body that body image is more important than food, so *it doesn't need food!* This is akin to you convincing a car that it doesn't need petrol. It's neither logical nor safe, and yet it happens worryingly regularly. Moving and eating, two basic requirements, are made needlessly complex due to our brains interfering with the process. However, eating is one of life's great pleasures, and if we were to treat it as if we were just shovelling coal into a furnace, maybe our lives would be a lot duller. Maybe the brain knows what it's doing after all.

To sleep, perchance to dream … or spasm, or suffocate, or sleepwalk

(The brain and the complicated properties of sleep)

Sleep involves doing literally nothing, lying down and not being conscious. How complicated could it possibly be?

Very. Sleep, the actual workings of sleep, how it happens and what's going on during it, is something people don't really think about that often. Logically, it's very hard to think about sleep while it's happening, what with the whole 'being unconscious' thing. This is a shame because it's baffled many scientists, and if more people thought about it we might be able to figure it out faster.

To clarify; we *still don't know* the purpose of sleep! It's been observed (if you adopt a fairly loose definition) in almost every other type of animal, even the simplest kinds like nematodes, a basic and common parasitic flatworm.[10] Some animals, such as jellyfish and sponges, don't show any sign of sleeping, but they don't even have brains so you can't trust them to do much of anything. But sleep, or at least some regular period of inactivity, is seen in a wide variety of radically different species. Clearly it's important, with deep evolutionary origins. Aquatic mammals have evolved methods of sleeping with only half the brain at a time because if they slept fully they'd stop swimming, sink and drown. Sleep is so important it outranks 'not drowning', and yet we don't know why.

There are many existing theories, such as healing. Rats deprived of sleep have been shown to recover much more slowly from wounds and generally don't live nearly as long as rats that get sufficient sleep.[11] An alternative theory is that sleep reduces the signal strength of weak neurological connections to make them easier to remove.[12] Another is sleep facilitates reduction of negative emotions.[13]

One of the more bizarre theories is that sleep evolved a means of preserving us from predators.[14] A lot of predators are active at night, and humans don't need 24 hours of activity to sustain themselves, so sleep provides prolonged periods where people are essentially inert, and not giving off the signs and cues that a nocturnal predator could use to find them.

Some may scoff at the cluelessness of modern scientists. Sleep is for rest, where we give our body and brain time to recover and recharge after a day's exertions. And, yes, if we've been doing something particularly exhausting, a prolonged period of inactivity is helpful for letting our systems recover and replenish/rebuild where necessary.

~~But if sleep is all about resting, why do we almost always sleep *for the same length of time*~~ whether we've spent the day hauling bricks or sitting in our pyjamas watching cartoons? Surely both activities don't require equivalent recuperation time. And metabolic activity of the body during sleep lowers by only 5 per cent to 10 per cent. This is only slightly 'relaxing' – like dropping from 50 mph to 45 mph while driving because there's smoke coming from the engine is only slightly helpful.

Exhaustion doesn't dictate our sleep patterns, which is why people seldom just fall asleep while running a marathon. Rather, the timing and duration of sleep is determined by our body's circadian rhythms, set by specific internal mechanisms. There's the pineal gland in the brain that regulates our sleep pattern via secretion of the hormone known as melatonin, which makes us relaxed and sleepy. The pineal gland responds to light levels. The retinas in our eyes detect light and send signals to the pineal gland, and the more signals it receives the less melatonin it releases (although it does still produce it at lower levels). The melatonin levels in our body rise gradually throughout the day, and increase more rapidly when the sun goes down, hence our circadian rhythms are linked to daylight hours so we're usually alert in the morning and tired at night.

This is the mechanism behind jet-lag. Travelling to another time zone means you are experiencing a completely different schedule of daylight, so you may be experiencing 11 a.m. levels of daylight when your brain thinks it's 8 p.m. Our sleep cycles are very precisely attuned, and this throwing off of our melatonin levels disrupts them. And it's harder to 'catch up' on sleep than you'd think; your brain and body are tied to the circadian rhythm, so it's difficult to force sleep at a time when it's not expected (although not impossible). A few days of the new light schedule and the rhythms are effectively reset.

You might wonder, if our sleep cycle is so sensitive to light levels, why doesn't artificial light affect them? Well, it does. People's sleep patterns now have apparently changed wildly in the last few centuries since artificial light became commonplace, and sleep patterns differ depending on culture.[15] Cultures with less access to artificial light or different daylight patterns (for example, at higher latitudes) have sleep patterns that have adapted to their circumstances.

Our core body temperature also changes according to similar rhythms, varying between 37°C and 36°C (which is a big variation for a mammal). It's highest in the afternoon, then drops as evening approaches. At midway between the highest and lowest points is when we typically go to bed, so we're asleep when it's at its lowest, which may explain the human tendency to insulate ourselves with blankets while we sleep; we're colder then than when we're awake.

To challenge further the assumption that sleep is all about rest and conserving energy, sleep has been observed in hibernating animals.[16] That is, in animals that are *already unconscious*. Hibernation isn't the same as sleep; the metabolism and body temperature drops much lower; it lasts longer; it's closer to a coma really. But hibernating animals regularly enter a sleep state, so they *use more energy in order to fall asleep!* This idea that sleep is about rest is clearly not the whole story.

This is especially true of the brain, which demonstrates complicated behaviours during sleep. Briefly, there are currently four stages of sleep: rapid-eye-movement sleep (REM) and three non-rapid-eye-movement (NREM) stages (NREM Stage 1, NREM Stage 2 and NREM Stage 3, in a rare example of neuroscientists keeping things simple for the lay person). The three NREM stages are differentiated by the type of activity the brain displays during each.

Often the different areas in the brain synchronise their patterns of activity, resulting in what you might call ‘brainwaves’. If other people’s brains start synchronising too, this is called a ‘Mexican brainwave’.[‡] There are several types of brainwaves, and each NREM stage has specific ones that occur.

In NREM Stage 1 the brain displays largely ‘alpha’ waves; NREM Stage 2 has weird patterns called ‘spindles’, and NREM Stage 3 is predominately ‘delta’ waves. There is a gradual reduction in brain activity as we progress through the sleep stages, and the further you progress the harder you are to wake up. During NREM Stage 3 sleep – ‘deep’ sleep – an individual is far less responsive to external stimulus such as someone yelling, ‘Wake up! The house is on fire!’, than at Stage 1. But the brain never shuts down completely, partly because it has several roles in maintaining the sleep state, but mostly because if it did shut down completely we’d be dead.

Then we have REM sleep, where the brain is as active, if not more so, as when we’re awake and alert. One interesting (or sometimes terrifying) feature of REM sleep is REM atonia. This is where the brain’s ability to control movement via motor neurons is essentially switched off, leaving us unable to move. Exactly how this happens is unclear; it could be that specific neurons inhibit activity in the motor cortex, or the sensitivity of the motor control areas is reduced, making it much harder to trigger movements. Regardless of how it occurs, it does.

And that’s a good thing, too. REM sleep is when dreaming occurs, so if the motor system was left fully operational people would be physically acting out what they’re doing in their dreams. If you can remember anything you’ve done in your dreams, you can probably see why this would be something you’d want to avoid. Thrashing and flailing while asleep and unaware of your surroundings is potentially very dangerous, for you and any unfortunate person sleeping nearby. Of course, the brain isn’t 100 per cent reliable, so there are cases of REM behavioural disorders, where the motor paralysis isn’t effective and people do in fact act out their dreams. And it’s as hazardous as I’ve suggested, resulting in phenomena such as sleepwalking, which we’ll get to shortly.

There are also more subtle glitches which will probably be more familiar to the everyday person. There’s the hypnic jerk, where you twitch suddenly and unexpectedly while falling asleep. It feels as if you’re falling suddenly, resulting in spasm while in bed. This occurs more in children and gradually declines as we age. The occurrence of hypnic jerks has been associated with anxiety, stress, sleep disorders and so on, but overall they seem to be largely random. Some theories state it’s the brain mistaking falling asleep for ‘dying’, so it tries urgently to wake us up. But this makes little sense as the brain needs to be complicit in us falling asleep. Another theory is that it’s an evolutionary holdover from a time when we slept in trees and sudden tilting or tipping sensations meant we were about to fall out, so the brain panics and wakes us. It could even be something else entirely. The reason it occurs more in children is likely to be due to the brain still being in the developing stages, where connections are still being wired up and processes and functions are being ironed out. In many ways we never truly get rid of *all* the glitches and kinks in such complicated systems as those used by our brains, so hypnic jerks persist into adulthood. Overall it’s just a bit odd, if essentially harmless.[17]

What’s also mostly harmless, but doesn’t feel like it, is sleep paralysis. For some reason, the brain sometimes forgets to switch the motor system back on when we regain consciousness. Exactly how and why this happens hasn’t been confirmed, but the dominant theories link it to disruption of the neat organisation of the sleep states. Each stage of sleep is regulated by different types of neuronal activity, and these are regulated by different sets of neurons. It can happen that the differing activity doesn’t alter smoothly, so the neuronal signals that reactivate the motor system are too weak, or the ones that shut it down are too strong or last too long, and as such we regain consciousness without regaining motor control. Whatever it is that shuts down movement during REM sleep is still in place when we become fully alert, so we're unable to move.[18] This typically doesn't last long as once we wake up the rest of the brain activity resumes normal conscious levels and overrides the sleep system signals, but while it does it can be terrifying.

This terror is not unrelated either; the helplessness and vulnerability of sleep paralysis triggers a powerful fear response. This mechanism of this will be discussed in the next section, but it can be intense enough to trigger hallucinations of danger, giving rise to feelings of another presence in the room, and this is believed to be the root cause of alien-abduction fantasies, and the legend of the succubus. Most people who experience sleep paralysis do so only briefly and very rarely, but in some it can be a chronic and persistent concern. It has been linked to depression and similar disorders, suggesting some underlying issue with brain processing.

Even more complex, but likely to be related to sleep paralysis, is the occurrence of sleepwalking. This has also been traced to the system that shuts off motor control of the brain during sleep, except now it's the reverse – that the system isn't powerful or coordinated enough. Sleepwalking is more common in children, leading scientists to theorise sleepwalking is due to the motor inhibition system being not yet fully developed. Some studies point to hints of underdevelopment in the central nervous system as a likely cause (or at least contributing factor).[19] Sleepwalking has been observed as heritable and more common in certain families, suggesting that a genetic component might underlie this central nervous system immaturity. But sleepwalking can also occur in adults under the influence of stress, alcohol, medications and so forth, any or all of which might also affect this motor inhibition system. Some scientists argue that sleepwalking is a variation or expression of epilepsy, which of course is the result of uncontrolled or chaotic brain activity, which seems logical in this instance. However it's expressed, it's invariably alarming when the brain gets the sleep and motor control functions mixed up.

But this wouldn't be an issue if the brain wasn't so active during sleep to begin with. So why is it? What's it doing in there?

The highly active REM sleep stage has a number of possible roles. One of the main ones involves memory. One persistent theory is that during REM sleep the brain is reinforcing and organising and maintaining our memories. Old memories are connected to new memories; new memories are activated to help reinforce them and make them more accessible; very old memories are stimulated to make sure the connections to them aren't lost entirely, and so on. This process takes place during sleep, possibly because there is no external information coming in to the brain to confuse or complicate matters. You never come across roads being resurfaced while cars are still going over them, and the same logic applies here.

But the activation and maintenance of the memories causes them to be effectively 'relived'. Very old experiences and more recent imaginings are all thrown into the mix together. There's no specific order or logical structure to the sequence of experiences this results in, hence dreams are invariably so other-worldly and bizarre. It's also theorised that the frontal regions of the brain responsible for attention and logic are trying to impose some sort of rationale on this ramshackle sequences of events, which explains why we still feel as if dreams are real while they're happening and the impossible occurrences don't strike as unusual at the time.

Despite the wild and unpredictable nature of dreams, certain dreams can be recurring, and these are usually associated with some issue or problem. Indeed, if there's a certain thing in your life stressing you out (like a deadline for finishing a book you've agreed to write) then you're going to think about this a lot. As a result, you'll have a lot of new memories about it that need to be organised, so will occur more in dreams, so it crops up more often and you end up regularly dreaming about burning down a publisher's office.

Another theory about REM sleep is that it's especially important for small children as it aids neurological development, going beyond just memories and shoring up and reinforcing all the connections in the brain. This would help explain why babies and the very young have to sleep a lot more than adults (often more than half the day) and spend a great deal longer in REM sleep (about 80 per cent of total sleep time as opposed to about 20 per cent in adults). Adults retain REM sleep but at lower levels to keep the brain efficient.

Yet another theory is that sleep is essential to clear out the waste products of the brain. The ongoing complex cellular processes of the brain produce a wide variety of by-products that need to be cleared away, and studies have shown that this occurs at a higher rate during sleep, so it could be that sleep for the brain is the equivalent of a restaurant closing down to clear up between lunchtime and evening openings; it's just as busy, but doing different things.

Whatever the true reason for it, sleep is essential for normal brain functioning. People deprived of sleep, particularly of REM sleep, quickly show a serious decline in cognitive focus, attention and problem-solving skills, an increase in stress levels, lower moods, irritability, and a drop in all-round task performance; the nuclear disasters of Chernobyl and Three Mile Island have been linked to overworked and exhausted engineers, so has the *Challenger* shuttle disaster, and let's not go into the long-term consequences of decisions made by sleep-deprived doctors on their third successive twelve-hour shift in two days.[20] If you go too long without sleep, your brain starts initiating 'micro sleeps', where you grab snatches of sleep for minutes or even seconds at a time. But we've evolved to expect and utilise long periods of unconsciousness, and we can't really make do with small crumbs here and there. Even if we do manage to persevere with all the cognitive problems a lack of sleep causes, it's associated with impaired immune systems, obesity, stress and heart problems.

So if you happen to nod off while reading this book, it's not boring, it's medicinal.

It's either an old dressing gown or a bloodthirsty axe murderer

(The brain and the fight-or-flight response)

As living, breathing humans, our survival depends on our biological requirements – sleeping, eating, moving – being met. But these aren't the only things essential to our existence. There are plenty of dangers lurking in the wider world, just waiting for the opportunity to snuff us out. Luckily, millions of years of evolution have equipped us with a sophisticated and reliable system of defensive measures in order to respond to any potential threat, coordinated with admirable speed and efficiency by our marvellous brains. We even have an emotion dedicated to recognising and focusing on threats: fear. One down side of this is that our brains have an inherent 'better safe than sorry' approach that means we regularly experience fear in situations where it's not really warranted.

Most people can relate to this. Maybe you were lying awake in a dark bedroom when the shadows on the walls started looking less like the branches of the dead tree outside and more like the outstretched skeletal arms of some hideous monster. Then you see the hooded figure by the door.

It's clearly the axe murderer your friend told you about. So, obviously, you collapse into a terrified panic. The axe murderer doesn't move though. He can't. Because he's not an axe murderer, he's a dressing-gown. The one you hung up on the bedroom door earlier.

It makes no logical sense, so why on earth do we have such powerful fear reactions to things that ~~are clearly utterly harmless? Our brains, however, aren't convinced of this harmlessness. We could~~ all live in sterilised bubbles with every sharp edge smoothed down, but as far as the brain is concerned death could come leaping out of the nearest bush at any point. To our brains, daily life is like tightrope-walking over a vast pit full of furious honey badgers and broken glass; one wrong move and you'll end up as a gruesome mess in temporary but exquisite pain.

Such a tendency is understandable. Humans evolved in a hostile, wild environment with dangers at every turn. Those humans who developed a healthy paranoia and jumped at shadows (that genuinely may have had teeth) survived long enough to pass on their genes. As a result, when presented with any conceivable threat or danger, the modern human has a suite of (mostly unconscious) response mechanisms providing a reflex that enable them to deal better with said threat, and this reflex is still very much alive and kicking (as are humans, thanks to it). This reflex is the fight-or-flight response, which is a great name as it concisely but accurately describes its function. When presented with a threat, people can either fight it or run away.

The fight-or-flight response starts in the brain, as you'd expect. Information from the senses reaches the brain and enters the thalamus, which is basically a central hub for the brain. If the brain were a city, the thalamus would be like the main station where everything arrives before being sent to where it needs to be.[21] The thalamus connects to both the advanced conscious parts of the brain in the cortex and the more primitive 'reptile' regions in the midbrain and brainstem. It's an important area.

Sometimes the sensory information that reaches the thalamus is worrying. It might be unfamiliar, or familiar but worrying in context. If you're lost in the woods and you hear a growl, that's unfamiliar. If you're home alone and you hear footsteps upstairs, that's familiar, but in a bad way. In either case, the sensory information reporting this is tagged 'This isn't good.' In the cortex, where it's processed further, the more analytical part of the brain looks at the information and wonders 'Is this something to worry about?' while checking the memory to see if anything similar has occurred before. If there's not enough information to determine that whatever we're experiencing is safe, it can trigger the fight-or-flight response.

However, as well as the cortex, the sensory information is relayed to the amygdala, the part of the brain responsible for strong emotional processing, and fear in particular. The amygdala doesn't do subtlety; it senses something might be amiss and initiates a red alert straight away, a response far faster than the more complex analysis in the cortex could ever hope to be. This is why a scary sensation, like a balloon popping unexpectedly, produces a fear response almost instantly, before you can process it enough to realise it's harmless.[22]

The hypothalamus is then signalled. This is the region right under the thalamus (hence the name), and is largely responsible for 'making things happen' in the body. To extend my earlier metaphor, if the thalamus is the station, the hypothalamus is the taxi rank outside it, taking important things into the city where they get stuff done. One of the roles of the hypothalamus is triggering the fight-or-flight response. It does this by getting the sympathetic nervous system to put the body effectively at 'battle stations'.

At this point you may be wondering, 'What's the sympathetic nervous system?' Good question.

The nervous system, the network of nerves and neurons spread throughout the body, allows the brain to control the body and the body to communicate with and influence the brain. The central nervous system – the brain and the spinal cord – is where the big decisions are made, and as such these areas are protected by a sturdy layer of bone (the skull and the spinal column). But many major nerves branch out from these structures, dividing and spreading further until they innervate (the actual term for supplying organs and tissue with nerves) the rest of the body. These far-reaching nerves and branches, outside the brain and spinal cord, are referred to as the peripheral nervous system.

The peripheral nervous system has two components. There's the somatic nervous system, also known as the voluntary nervous system, which links the brain to our musculoskeletal system to allow conscious movement. There's also the autonomic nervous system, which controls all the unconscious processes that keep us functioning, so is largely linked to internal organs.

But, just to make it more complicated, the autonomic nervous system also has two components: the sympathetic and parasympathetic nervous systems. The parasympathetic nervous system is responsible for maintaining the more calm processes of the body, such as gradual digestion after meals or regulating the expulsion of waste. If someone were to make a sitcom starring the different parts of the human body, the parasympathetic nervous system would be the laidback character, telling people to 'chill out' while rarely getting off the couch.

In contrast, the sympathetic nervous system is incredibly highly strung. It would be the twitchy, paranoid one, constantly wrapping itself in tin foil and ranting about the CIA to anyone who'll listen. The sympathetic nervous system is often labelled the fight-or-flight system because it's what causes the various responses the body employs to deal with threats. The sympathetic nervous system dilates our pupils, to ensure more light enters our eyes so we can better spot dangers. It increases the heart rate while shunting blood away from peripheral areas and non-essential organs and systems (including digestion and salivation – hence the dry mouth when we're scared) and towards the muscles, to ensure that we have as much energy as possible for running or fighting (and feel quite tense as a result).

The sympathetic system and parasympathetic systems are constantly active and usually balance each other and ensure normal functioning of our bodily systems. But in times of emergency, the sympathetic nervous system takes over and adapts the body for fighting or (metaphorical) flying. The fight-or-flight response triggers the adrenal medulla (just above the kidneys) as well, meaning our bodies are flooded with adrenalin, which produces many more of the familiar responses to a threat: tension, butterflies in the stomach, rapid breathing for oxygenation, even relaxing of the bowels (you don't want to be carrying unnecessary 'weight' while running for your life).

Our awareness is also turned up, making us extra sensitive to potential dangers, reducing our ability to concentrate on any minor issues we were dealing with before the scary thing happened. This is the result of both the brain being alert to danger anyway and by the adrenalin suddenly hitting it, enhancing some forms of activity and limiting others.[23]

The brain's emotional processing also steps up a gear,[24] largely because the amygdala is involved. If we're dealing with a threat, we need to be motivated to take it on or get away from it asap, so we rapidly become intensely fearful or angry, providing further focus and ensuring we don't waste time with tedious 'reasoning'.

When faced with a potential threat, both brain and body rapidly shift to a state of enhanced awareness and physical readiness to deal with it. But the problem with this is the 'potential' aspect. The fight-or-flight response kicks in *before* we know whether it's actually needed.

Again, this makes logical sense; the primitive human who runs from something that *might* be a tiger was more likely to survive and reproduce than the one who said, 'Let's just wait so we can be sure.' The first human arrives back at the tribe intact, whereas the second is the tiger's breakfast.

This is a useful survival strategy in the wild but for the modern human it's quite disruptive. The fight-or-flight response involves many real and demanding physical processes, and it takes time fo ~~the effects of these to wear off. The adrenalin surge alone takes a while to leave the bloodstream~~, so having our whole bodies enter combat mode whenever a balloon pops unexpectedly is rathe inconvenient.[25] We can experience all the tension and build-up required for a fight-or-fligh response, only to realise quickly that it's not required. But we still have tense muscles and a rapic heartbeat and so on, and not relieving this with a frantic sprint or wrestling session with an intrude can cause cramps, knots in muscles, trembling and many other unpleasant consequences as the tension becomes too much.

There's also the increased emotional sensation. Someone primed to be terrified or angry can' just switch it off in an instant, so it often ends up being directed at less deserving targets. Tell ar incredibly tense person to 'relax' and see what happens.

The demanding physical aspect of the fight-or-flight response is only part of the issue. The brair being so attuned to seek out and focus on danger and threats is increasingly problematic. Firstly, the brain can take account of the present situation and become more alert to danger. If we're in a darkened bedroom, the brain is aware that we can't see as much, so is attuned for any suspicious noise, and we know it should be quiet at night, so any noises that *do* occur get far more attentior and are more likely to trigger our alarm systems. Also, our brain's complexity means humans now have the ability to anticipate, rationalise and imagine, meaning we can now be scared of things tha haven't happened or aren't there such as the axe-murderer dressing-gown.

Chapter 3 is dedicated to the weird ways in which the brain uses and processes fear in our daily lives. When not overseeing (and often disrupting) the fundamental processes we need to keep ourselves alive, our conscious brains are exceptionally good at thinking up ways in which we migh come to harm. And it doesn't even have to be physical harm; it can be intangible things such as embarrassment or sadness, things that are physically harmless but that we still really want to avoid so the mere possibility is enough to set off our fight-or-flight response.

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* It’s not exactly a one-way relationship either. The brain doesn’t just influence the food we eat; it seems the food we eat does (or did) have considerable influence over how our brains work.[4] There’s evidence to suggest that the discovery of cooking meant humans could suddenly obtain a great deal more nourishment from food. Perhaps an early human tripped and dropped his mammoth steak into the communal campfire. The determined primitive maybe got a stick and hooked his steak out, only to find it was suddenly *more* palatable and appetising. Raw food being cooked means it’s easier to eat and digest. The long and dense molecules in it are broken down or denatured, allowing our teeth, stomachs and intestines to get better nourishment from our food. This seemingly led to a rapid expansion in brain development. The human brain is an incredibly demanding organ when it comes to bodily resources, but cooking food allowed us to meet its needs. Enhanced brain development meant we got smarter, and invented better ways of hunting, and methods of farming and agriculture and so on. Food gave us bigger brains, and bigger brains gave us more food, forming a literal feedback.

† This is a joke. For now.

2

The gift of memory (keep the receipt)

The human memory system, and its strange features

The word ‘memory’ is often heard these days, but in the technological sense. Computer ‘memory is an everyday concept that we all understand – a storage space for information. Phone memory iPod memory, even a USB flash drive is referred to as a ‘memory stick’. There’s not much simpler than a stick. So you could forgive people for thinking that computer memory and human memory are roughly the same in terms of how they work. Information goes in, the brain records it, and you access it when you need it. Right?

Wrong. Data and info are put into the memory of a computer, where they remain until needed, at which point they are retrieved, barring some technical fault, in exactly the same state in which they were first stored. So far, so logical.

But imagine a computer that decided some information in its memory was more important than other information, for reasons that were never made clear. Or a computer that filed information in a manner that didn’t make any logical sense, meaning you had to search through random folders and drives trying to find the most basic data. Or a computer that kept opening your more personal and embarrassing files, like the ones containing all your erotic Care Bears fan fiction, without being asked, and at random times. Or a computer that decided it didn’t really like the information you’ve stored, so altered it for you to suit its preferences.

Imagine a computer that did *all* these things, *all the time*. Such a device would be flung out of your office window less than half an hour after being switched on, for an urgent and terminal meeting with the concrete car park three storeys below.

But your brain does *all these things* with your memory, and all the time. Whereas with computers you can buy a newer model or take a malfunctioning one back to the shop and scream at the salesperson who recommended it, we’re basically stuck with our brain. You can’t even turn it off and on again to reboot the system (sleep doesn’t count, as we saw earlier).

This is just one example of why ‘the brain is like a computer’ is something you should say to many modern neuroscientists, if you enjoy watching people twitch due to barely suppressed frustration. This is because it’s a very simplistic and misleading comparison, and the memory system is a perfect illustration of this. This chapter looks at some of the more baffling and intriguing properties of the brain’s memory system. I would have described them as ‘memorable’ but there’s no way to guarantee that, given how convoluted the memory system can be.

Why did I just come in here?

(The divide between long-term and short-term memory)

We’ve all done it, at some time or other. You’re doing something in one room, when it suddenly occurs to you that you need to go to a different room to get something. Along the way, something distracts you – a tune on the radio, someone saying something amusing as you pass, or suddenly figuring out a plot twist in a TV show that’s been bugging you for months. Whatever it is, you reach your destination and suddenly have no idea why you decided to go there. It’s frustrating, it’s ~~annoying, it’s time-wasting; it’s one of the many quirks thrown up by the surprisingly complex~~ way the brain processes memory.

The most familiar division in human memory for most people is that between short-term memory and long-term memory. These differ considerably, but are still interdependent. Both are appropriately named; short-term memories last about a minute max., whereas long-term memories can and do stay with you your whole life. Anyone referring to something they recall from a day or even a few hours ago as ‘short-term memory’ is incorrect; that’s long-term memory.

Short-term memory doesn’t last long, but it deals with actual conscious manipulation of information; the things we’re currently thinking about, in essence. We can think about them because they’re in our short-term memory; that’s what it’s for. Long-term memory provides copious data to aid our thinking, but it’s short-term memory that actually does the thinking. (For this reason, some neuroscientists prefer to say ‘working’ memory, which is essentially short-term memory plus a few extra processes, as we’ll see later.)

It will surprise many to find that the capacity of short-term memory is so small. Current research suggests the average short-term memory can hold a maximum of four ‘items’ at any one time.[1] If someone is given a list of words to remember, they should be able to remember only four words. This is based on numerous experiments where people were made to recall words or items from a previously shown list and on average could recall only four with any certainty. For many years, the capacity was believed to be seven, plus or minus two. This was labelled as the ‘magic number’ or ‘Miller’s law’ as it was derived from 1950s experiments by George Miller.[2] However, refinements and reassessment of legitimate recall and experimental methods have since provided data to show the actual capacity is more like four items.

The use of the vague term ‘item’ isn’t just poor research on my part (well, not *just* that); what actually counts as an item in short-term memory varies considerably. Humans have developed strategies to get around limited short-term-memory capacity and maximise available storage space. One of these is a process called ‘chunking’, where a person groups things together into a single item, or ‘chunk’, to better utilise their short-term memory capacity.[3] If you were asked to remember the words ‘smells’, ‘mum’, ‘cheese’, ‘of’, and ‘your’, that would be five items. However, if you asked to remember the phrase ‘Your mum smells of cheese’, that would be one item, and a possible fight with the experimenter.

In contrast, we don’t know the upper limit of the long-term-memory capacity as nobody has lived long enough to fill it, but it’s obscenely capacious. So why is short-term memory so restricted? Partly because it’s constantly in use. We’re experiencing and thinking about things at every waking moment (and some sleeping ones), which means information is coming and going at an alarmingly speedy rate. This isn’t somewhere that’s going to lend itself well to long-term storage, which requires stability and order – it would be like leaving all your boxes and files in the entrance of a busy airport.

Another factor is that short-term memories don’t have a ‘physical’ basis; short-term memories are stored in specific patterns of activity in neurons. To clarify: ‘neuron’ is the official name for brain cells, or ‘nerve’ cells, and they are the basis for the whole nervous system. Each one is essentially a very small biological processor, capable of receiving and generating information in the form of electrical activity across the cell membranes that give it structure, as well as forming complex connections with other neurons. So short-term memory is based on neuronal activity in the dedicated regions responsible, such as the dorsolateral prefrontal cortex in the frontal lobe.[4] We know from brain scanning that a lot of the more sophisticated, 'thinking', stuff goes on in the frontal lobe.

Storing information in patterns of neuronal activity is a bit tricky. It's a bit like writing a shopping list in the foam on your cappuccino; it's technically possible, as the foam will retain the shapes of words for a few moments, but it's not got any longevity, and hence can't be used for storage in any practical sense. Short-term memory is for rapid processing and manipulation, and with the constant influx of information anything unimportant is ignored, and quickly overwritten or allowed to fade away.

This isn't a foolproof system. Quite often, important stuff gets bumped out of short-term memory before it can be properly dealt with, which can lead to the 'Why did I just come in here?' scenario. Also, short-term memory can become overtaxed, unable to focus on anything specific while being bombarded with new information and demands. Ever seen someone amid some hubbub (such as a children's party, or a frantic work meeting) with everyone clamouring to be heard suddenly declare, 'I can't think with all this going on!'? They're speaking very literally; their short-term memory isn't equipped to cope with that workload.

Obvious question: if the short-term memory where we do our thinking has such a small capacity, how the hell do we get anything done? Why aren't we all sitting around trying and failing to count the fingers on one hand? Luckily, short-term memory is linked to long-term memory, which takes a lot of pressure off.

Take a professional translator; someone listening to long detailed speech in one language and translating it into another, in real time. Surely this is more than short-term memory can cope with? Actually, it isn't. If you were asking someone to translate a language in real time *while actually learning the language*, then, yes, that would be a big ask. But for the translator the words and structure of the languages are already stored in long-term memory (the brain even has regions specifically dedicated to language, like Broca's and Wernicke's areas, as we'll see later). Short-term memory has to deal with the order of the words and the meaning of the sentences, but this is something it can do, especially with practice. And this short-term/long-term interaction is the same for everyone; you don't have to learn what a sandwich is every time you want a sandwich, but you can forget that you wanted one by the time you get to the kitchen.

There are several ways information can end up as long-term memory. At a conscious level, we can ensure that short-term memories end up as long-term memories by rehearsing the relevant information, such as a phone number of someone important. We repeat it to ourselves to ensure we can remember it. This is necessary because, rather than patterns of brief activity like short-term memories, long-term memories are based on new connections between neurons, supported by synapses, formation of which can be spurred on by doing something like repeating specific things you want to remember.

Neurons conduct signals, known as 'action potentials', along their length in order to transmit information from the body to the brain or vice versa, like electricity along a surprisingly squidgy cable. Typically, many neurons in a chain make up a nerve and conduct signals from one point to another, so signals have to travel from one neuron to the next in order to get anywhere. The link between two neurons (or possibly more) is a synapse. It's not a direct physical connection; it's actually a very narrow gap between the end of one neuron and the beginning of another (although many neurons have multiple beginning and end points, just to keep things confusing). When an action potential arrives at a synapse, the first neuron in the chain squirts chemicals known as