

Think Before You Think

UNDERSTANDING
AND MASTERING
EXECUTIVE
FUNCTION

Adrian Owen



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*For Emily, who understands my
brain better than I ever will.*

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Introduction

Evolution's Deepest Logic

I had never seen an NFL player in real life before, and somehow I hadn't expected Max to be so *big*. I'm a bit over six feet, but Max towered above me, and he seemed as wide across his shoulders as he was tall. I wondered: Would he fit in the MRI scanner?

Like most NFL players, Max had taken dozens of blows to his head during a long and storied career that included more than a decade in the league, countless games in packed stadiums, and many moments of glory on national television. We were scanning him to investigate whether and how those injuries had affected his brain function. Although Max had been knocked unconscious countless times and cracked his skull open more than once, he was nervous about sliding inside our machine.

"I'm a little bit claustrophobic," he admitted sheepishly.

I tried to distract him. "How did you get most of your injuries?" I asked.

"It's when they get you like this," said Max, placing his huge, clenched fist under my chin, gently pushing upward and effortlessly lifting me until just the tips of my shoes touched the ground. As I dangled, suspended by my chin, the full implications of Max's career choice hit me. I wondered what we were going to find when we got inside his head.

We squeezed Max's considerable frame into the machine. I told him what to expect.

“You’ll hear a loud thunking noise. Ignore it—it’s not dangerous, just loud,” I said, trying to reassure him. “When the scanner starts, we’ll show you words written in different colors on the computer screen. I want you to ignore the word itself and just tell me what color it’s written in.”

We’d designed this test specifically to understand how the sort of brain damage that NFL players like Max acquire affects their behavior. Since retiring, Max had started gambling compulsively—so much so that he barely had anything left to show for his many professional achievements. He’d also started drinking heavily, hanging out in local bars until closing time and regaling anyone who would listen with stories of his sporting victories. Unfortunately, when they wouldn’t listen (which was all too often), his response was to channel the aggression he had once focused on the football field into a barroom brawl. It was almost as if Max had lost his ability to predict, and prevent, the consequences of his actions. Although he would often express regret, especially when he woke up in a police cell the next day, in the heat of the moment Max did exactly what he felt like doing. He threw caution to the wind—along with his reputation, his marriage, and his bank account.

Called “double trouble,” our test was designed to capture the essence of these real-world behavioral catastrophes in a laboratory-controlled setting in order to try to understand why they occur and what might be done to prevent them.

The scanner whirled into action. The word “RED” appeared on a computer screen, which Max could see via a small mirror suspended in front of his face. This was the “target” word, and it was written in a large, bright red font. Moments later, the words “RED” and “BLUE” appeared below the target word; Max’s task was to select the word that corresponded to the *color* of the target word. Max selected “RED,” indicating that he knew the color of the target word was red.

The second trial was more complicated. Again, the word “RED” appeared on the screen, but this time it was written in a bright *blue* font. Max immediately pressed a button. Again, he selected the word “RED,” but this time he was wrong: He should have picked the word “BLUE” because, although the target word was “RED,” it was written in a bright *blue* font. It was as though Max couldn’t stop himself from selecting the obvious first choice based on the word he saw in front of him, even though he knew it was incorrect from the instructions he’d been given. I crossed my fingers,

hoping Max would do better on the next few trials. But he didn't, selecting the wrong word again and again.

On my computer screen in the control room, Max's brain was fully visible, beautifully rendered in three dimensions. At first glance, Max's brain looked fine. All the crests and crevices—or gyri and sulci, as they're called—appeared to be in the right places, and there was nothing obviously missing. But as tiny red and green blobs started to appear on the screen, indicating which parts of Max's brain were active or inactive as he tried to complete the double trouble test, it was clear that something wasn't quite right. One part of his frontal lobes, which are vast regions that account for more than 30 percent of the brain's entire volume, was extremely active—more active than normal, in fact. We'd scanned many healthy brains before and were used to seeing a small burst of activity in this part of the frontal lobe during the double trouble test, but the response in Max's brain was off the charts. I hadn't seen anything quite like it before. It was as though his frontal lobes were working *too hard*. After decades of repetitive injury, a communication breakdown had occurred between Max's frontal lobes and the rest of his brain, leaving them struggling to function effectively. Without the rest of the brain for backup, the frontal lobes needed to work harder to perform even the simplest daily tasks.

I pulled Max out of the scanner and assured him that it had all gone very well. He left cheerily, thanking us for taking an interest in his brain.

Max's inability to inhibit his responses to the words "RED" and "BLUE," his compulsive gambling, his aggression, and his apparent lack of any insight all signaled that his frontal lobes were falling apart—perhaps not literally, but functionally, at least. They were no longer doing their job, communicating with other parts of his brain and coordinating many of the everyday thoughts and actions that we take for granted.

Importantly, Max still knew right from wrong. He could still tell you how long a football field is. He could even accurately report the final score of most of the professional games he'd played during his long career. In most ways, Max's intelligence was unchanged. Yet somehow he was now unable to *use* his intelligence to direct his behavior. He couldn't exercise any inhibitory control—the brain function that prevents us from just doing (or saying) the first thing that pops into our heads without giving it proper consideration. Nor was Max able to effectively solve problems, coherently plan for his future, make sound decisions, prioritize what was important in

his life, and deduce what other people were thinking. Life for him had become a storm of random mysterious incidents that he participated in but over which he had little control.

What was going on in Max's brain to cause all this chaos? While the full answer is undoubtedly complicated, at the heart of it lies a complete and utter failure of his *executive functions*.

A Brief History of Executive Function

These days, the term “executive function” is everywhere—partly because there's no single agreed-upon definition, so a broad mix of mental abilities often gets bundled under the same label. For now, let's think of it as the skills we use to plan, focus, remember instructions, manage impulses, and juggle tasks in pursuit of a goal. These skills emerge as children grow, developing gradually across early and later childhood. Parents and teachers are encouraged to help strengthen these skills—for instance, by fostering self-control, establishing routines, encouraging problem-solving, and guiding children in how to plan ahead.

But the term “executive function” tends to surface most often when things go wrong. Neurologists now routinely describe children and adults with autism, attention deficit hyperactivity disorder (ADHD), obsessive-compulsive disorder, and even Tourette's syndrome as having “compromised executive function.” Early signs of Alzheimer's, Parkinson's, and other neurodegenerative diseases—conditions that affect millions worldwide—are often described as failures of executive function. Neurologists use the same phrase to describe the problems that beset survivors of strokes, cardiac arrests, brain injuries, and a long catalog of other insults to the brain. Even without these major conditions, many elderly adults seem to be slipping cognitively, and more often than not, declining executive function gets the blame. They get lost, they get confused, they blurt out whatever comes to mind, however crass or offensive, and they tell the same story again and again (and again).

Even those who are young and healthy can experience regular failures of executive function. Some days, we are inexplicably beset by “brain fog,” hardly a scientific term but descriptive of a kind of confused muddle, a discombobulated inability to think clearly—to reason, plan, and make

decisions. We can't seem to formulate a single coherent thought. We scour the house for our car keys only to find we've been holding them in our hand all along. We enter a room to do something important, then can't remember what it is. At such moments, the organ in our skulls, widely considered the most complex entity in the known universe, may strike us as fickle, even willful. What is going on in our brain on days like these, when the lights dim and the fog rolls in? And why on other days do we feel sharp and laser focused?

The difference has to do with how well our executive functions are working, which in turn depends on the efficiency and capacity of different parts of our frontal lobes and their subtle interconnections and interactions with other brain regions. Scientists first began to postulate a link between the frontal lobes and our executive functions as early as the mid-1800s. In 1861, the renowned French zoologist Louis Pierre Gratiolet referred to the frontal lobes as the site of the "regulating mind" or the "supreme organ of the brain." Later, in the twentieth century, both the Soviet neuropsychologist Alexander Luria and the British experimental psychologist Donald Broadbent referred to the frontal lobes as playing a key role in the hierarchical regulation or "control" of behavior, using many of the managerial metaphors that we now use to describe our executive functions. However, the term "executive" itself was not used in relation to the frontal lobes until 1973, when Karl Pribram, an Austrian-born pioneer in the field of neuropsychology, wrote that "the frontal cortex appears critically involved in implementing executive programs when these are necessary to maintain brain organization in the face of insufficient redundancy in input processing and in the outcomes of behavior." In other words, when the brain gets overloaded with information, making it difficult to make clear decisions about what to do next, the executive functions of the frontal lobes step in to take control.

Such early descriptions of executive function—often borrowed from the computer jargon of the time and loosely tied to the frontal lobes—were vague and imprecise. By the late 1980s, however, they had begun to sharpen as new evidence increasingly pointed to the frontal lobes as central to the brain's ability to coordinate, manage, organize, and carry out basic tasks, such as remembering a list of numbers or planning the day's activities. Gradually, the term "executive function" started to become more commonplace among psychologists and neuroscientists as a convenient way

of describing what had until then been a rather disconnected and jumbled set of scientific observations. Theoretical models were developed with fancy names like “the supervisory attention system” and “the central executive” to describe the processes that scientists surmised were going on in the black box inside our heads.

But these models still had serious limitations. Early attempts to investigate them involved studies of people who had sustained brain damage and a careful documentation of what they could and could not do as a result—a field known as *neuropsychology*. The overarching theory was that the frontal lobes are largely responsible for how we control our behavior and organize our lives, and this hypothesis was then tested through numerous investigations that sought to refine, clarify, and document this relationship between structure (the brain) and function (how we behave). But scientific progress was almost entirely dependent on exactly the right patient, with exactly the right kind of brain damage, coming along at exactly the right time.

Thus, it was not until the advent of neuroimaging (or “brain scans”) in the late 1980s that neuroscience really started to come to grips with our executive functions and how they arise from the neural machinery of our brains—neural machinery born of eighty-six billion neurons working together in a multitude of ways to create our individual selves. Neuroscientists could now take healthy participants and actually see their brains in action while they tackled complex tests of executive function, like the double trouble task we gave Max. Functional magnetic resonance imaging (fMRI) has been particularly influential in this regard, in part because it is completely harmless, relatively easy to do, and can provide real-time pictures of the human brain while it carries out the most intricate of cognitive operations. Tens of thousands of fMRI studies have been published in the last thirty years, and they have truly revolutionized our understanding of human brain function.

I was fortunate enough to be part of this neuroscientific revolution. When I was an undergraduate student of psychology in the mid-1980s, few of us even had a desktop computer to play with. Within a decade, my scientific colleagues and I were using a new generation of supercomputers and brain scanners to visualize brains—living human brains—as they solved problems, made plans, and dreamed of the future.

In the thirty-five or so years since, my lab has completed dozens of studies of executive function—what it is, how it works, and what happens to us when it doesn't. We've scanned the brains of thousands of people, some with brain injuries and many without. We've tested the executive abilities of almost twenty million volunteers via our web-based cognitive assessment platform at Creyos.com. Creyos is an online tool that measures how your brain is working with short, gamelike tasks that assess memory, attention, reasoning, and self-control. It was developed in my lab because we wanted to take the kinds of assessments once locked inside research labs and neuropsychologists' offices and make them accessible to anyone with a computer or phone.

It's one of the many tools we've used to map the frontal lobes: how they plan, remember, make decisions, and solve problems. Through these studies, we've learned that executive function drives every single conscious decision we make, determining the shape of our lives and defining our successes and failures. Who we are, how we behave, and the impact that each of us makes on the world are very much the sum total of our executive functions, underscoring why it's so important that we understand how to make the most of them.

Executive Function Versus IQ

Considering our mental capacities through the lens of executive function, rather than more traditional concepts like IQ, allows for a much more nuanced understanding of how our brains actually work and what goes wrong when they don't. Tests of IQ were developed long before the modern era of neuroscientific understanding and the advent of incredible tools like fMRI, so they don't "fit" much of what we now know to be true about the brain. And despite many attempts over the years, study after study has repeatedly failed to reveal any one brain area or circuit that can explain why one person's IQ is higher than another's—whereas our executive functions have been carefully characterized, measured, and mapped through thousands of neuroscientific studies using a variety of complementary techniques.

In 2012, my team carried out the largest study of intelligence and the brain ever conducted. In collaboration with Roger Highfield, then editor of

New Scientist magazine, we placed a series of craftily worded ads in high-profile media outlets such as the Discovery Channel and the *Daily Telegraph*, offering to provide volunteers with a free and comprehensive analysis of “how intelligent they were.” Rarely have I seen such enthusiasm for a scientific study as when 44,600 excited participants rushed to a website we’d created to test their brains—so many, in fact, that our server overloaded on the first day and we had to restart the whole study! Every participant completed a series of cognitive tests—presented as games—at Creyos.com to assess their memory, concentration, problem-solving, planning, verbal abilities, and much more. Indeed, we tried to capture as many aspects of human “intelligence” as we could to give us the best chance of finding that one special quality that made some people appear smarter than others. We found nothing of the sort. Regardless of how we carved up the data, we could find no evidence at all that there was a single measurable quality (an IQ score) that made some people better at our neuroscientific tests than others.

To explore this further, we put some of the participants into our fMRI scanner and had them perform all our cognitive tests while we scanned their brains. fMRI works by measuring changes in oxygenated and deoxygenated blood in the brain. Blood that is carrying oxygen to brain tissue behaves differently in a magnetic field than blood that has already delivered its oxygen. In other words, oxygenated blood and deoxygenated blood have different magnetic properties. More active areas of the brain receive more oxygenated blood, and the fMRI scanner can detect this and pinpoint where the activity is occurring.

When we analyzed the fMRI data from our global IQ study, it turned out that no one brain area or circuit was generally associated with good performance across all of the cognitive tasks.

In short, by examining a whopping sample of 44,600 people, we showed that their cognitive abilities could not be reduced to a single number (an IQ score), nor was there any trace of an “IQ spot” in the brain. To put it bluntly, we had shown that the whole concept of IQ is neuroscientifically meaningless. That’s not to say there were no differences between people; quite the contrary. But while one person may have excelled at one particular type of task (say, memory), they often performed more poorly at another (problem-solving, for example). More importantly, our fMRI data showed that these different mental abilities relied on quite

separate brain networks, offering a clear neuroscientific explanation for why some people may be stronger in one particular area of cognition than another.

Mental fitness comes in many forms, just like physical fitness. Who is fitter, an Olympic 100-meter champion or a Boston marathon winner? Who is more athletic—a discus champ or a cross-country ski racer? Each of us may excel in one area while performing poorly in others. Our cognitive abilities are no different. Is a person who can remember a sequence of thirty digits smarter or less smart than a person who can solve a Rubik's Cube in thirty seconds? Both require a certain degree of mental acrobatics, but trying to decide whether one is smarter than another makes no sense at all, because the two activities involve entirely different sets of brain processes.

Framing our extraordinary cognitive capabilities in terms of executive function reflects a contemporary neuroscientific understanding of the brain that takes physiology, biology, anatomy, *and* psychology into account. More importantly, it allows us to begin to unlock the secrets of many other aspects of our mental armory that evade more traditional measures of intelligence: curiosity, creativity, imagination, inspiration, drive, perseverance, ambition. None of these has ever been explained by measures of IQ, yet they all have a lot to do with our executive functions and the human brain. And they are often at the core of genius, achievement, and success.

Einstein once remarked, "Imagination is more important than knowledge." That is, the solution to a problem is not necessarily embedded in the information (knowledge) that may already be inside our heads; rather, finding the solution may also require us *to think about it* in a particular way—strategically, reflectively, and by focusing on those aspects of the problem that are critical to finding the best solution while identifying and ignoring distracting information that will hinder our progress. Einstein didn't come up with his great theories by simply regurgitating what he already knew. He didn't find the solutions to the questions that kept him awake at night by searching through his mental database of facts and figures, nor did he do it by reading what was already written in books and scientific papers. Instead, he used his scientific training to figure out *how* he could answer those questions, what process would lead him to a solution. He may have needed to gather more information as part of that process, but

it was imagining how he might solve each problem that led him to the solution.

This is why imagination and executive function are intrinsically linked: Our executive functions let us imagine how we might solve a problem, giving us a focus and direction that can lead to creative solutions, helping us figure things out. It's our mental "mission control," and it allows us to assess, reassess, and refine our own thought processes—finding new meaning from within and yielding insights that show the true potential of our brains.

Once Upon a Time

My first investigations into executive function began in the late 1980s when I was a PhD student at the world-renowned Institute of Psychiatry in Camberwell, South London, which was the leading center for mental health and neuroscience research in Europe. My early studies involved testing people with shotgun wounds, survivors of traffic accidents, and surgical patients who had had parts of their brains removed for one reason or another.

One young patient, Stephen, had undergone surgery to have a type of rare tumor removed from his orbitofrontal cortex—the underside of the front part of the brain. It gets its name from its position immediately above the "orbits" (the bony cavities or sockets in the skull in which the eyes and their appendages are located). Unfortunately, like many surgeries of that sort, some "good" pieces of brain had to be removed along with the "bad." That's often the grim nature of brain tumors; they physically displace and compress healthy brain cells, interrupting the connections between them that are essential for communication, leaving them functionally useless and prone to future malignant growths. Stephen's neurosurgeon, a delightful white-haired gentleman called Mr. Polkey (to this day male surgeons are always addressed as "Mr." in the United Kingdom), had made this exact point to me about Stephen's surgery.

Before his injury, Stephen had been described as a "shy and intelligent young man." Afterward, he was wildly disinhibited and anything but shy. Dressed from head to foot in denim and with a livid surgical scar bisecting his brow, he stalked the streets, abusing complete strangers and wielding a

canister of paint with which he defaced any public or private surface he could get his hands on. His speech was littered with expletives, angrily spat out at anyone he encountered, including me. He had completely lost control of many of his executive functions. He couldn't reason; he couldn't inhibit his outrageous behaviors; and his lack of any remorse or insight suggested that he'd become completely detached from his own emotions. His wild behavior escalated. One day, he persuaded a friend to hold his ankles while he hung out of the window of a speeding train, a lunatic activity by any measure. His skull and most of the front part of his brain were crushed when he crashed headlong into a tunnel. By some cruel, circular twist of fate, his lifesaving frontal lobe surgery had led directly to major damage to the same part of his brain.

What struck me most about him, more than his disfigurement or constant cursing, was his runny nose. Through the entire testing session his nose constantly dripped, which he dealt with every few moments by wiping it on the right sleeve of his denim jacket. This grotesque action was accompanied by a muttering of choice expletives.

It was only later, when discussing the case with Mr. Polkey, that I came to understand that what was running from this patient's nose was something far more disturbing than snot—it was cerebrospinal fluid, a colorless, watery liquid that flows in and around your brain and spinal cord to help cushion them from injury and provide nutrients. Usually that's where it stays, but sometimes cerebrospinal fluid “leaks” occur, and they require medical attention. Along with everything else he had going on, Stephen's brain injury had left him with a continuous trickle of brain fluid dripping from his nose, which was then transferred, almost habitually, to his jacket's sleeve.

Cases like this fascinated me. It wasn't the brain damage per se that I found so interesting, but rather the peculiar effects it had on my patients' behavior—and the more peculiar the better as far as I was concerned. Up until that point, my understanding of brain damage had been rather black and white; your brain takes a major hit, and the result is a debilitating physical or mental disability, utter dependence on others, or maybe even death. But here was something quite different. Despite his horrendous brain injury, this young man was not physically or mentally disabled in the traditional sense, and he was not dependent on anyone else to survive. In fact, he continued to live his life pretty much as he pleased. Of course, to

the outside observer there was nothing “normal” about this life. But as far as the patient was concerned, he was continuing to function effectively, barreling through life like the proverbial bull in a china shop.

Another of Mr. Polkey’s referrals was an older gentleman whose frontal lobe surgery had led to “perseveration,” a repetitive pattern of behavior that is impossible to stop once started. I asked the gentleman to name as many words as he could beginning with the letter S, which was a standard test of frontal lobe function in those days. “Six,” he said, followed by “sixteen, sixty, sixty-one, sixty-two, sixty-three . . .” I stopped him at sixty-eight, hoping I could break him out of his ceaseless repetitive behavior, and said, “Let’s try the letter F.” Quick as a flash he began “Five, fifteen, fifty, fifty-one, fifty-two . . .” There was nothing I could do to stop his repetition.

I also tested an elderly female patient with frontal lobe damage who had an entirely different type of perseveration, combined with a complete lack of inhibition. As she sat bolt upright, apparently concentrating on the simple memory test I had given her, I suddenly felt her hand sliding up my thigh to my crotch. I handled it as best I could, gently removing her hand and saying, “Please concentrate on the test.” “Oh, I had no idea what I was doing!” she said. Nevertheless, within a couple of minutes, the hand was back, sliding purposefully up my leg.

I wasn’t looking only at patients with frontal lobe damage. I met patients with damage to the temporal lobes, the parietal lobes, the occipital lobes, and various other parts of the brain. Only some of these patients struck me as truly bizarre, and what I started to notice was that all of the most interesting patients had some kind of damage to their frontal lobes. Strange behaviors differed from patient to patient; yet in every case, frontal lobe damage was the culprit, and an impairment of one or more of their executive functions was the result.

Since those early days at the Institute of Psychiatry, I’ve spent much of my career trying to understand executive function, asking questions about how and why our executive functions are such an integral and important part of who we are. Are they woven into our DNA, or are they skills that we can learn and sharpen over time? What happens when a blow to the head disrupts this intricate system or when age starts to wear it down? Do other animals, in their own ways, have executive functions? And what about AI? Do systems like ChatGPT have executive functions—or even consciousness itself?

This book will dive into these questions and more. Together, we'll explore how our executive functions drive everything from a child's first steps in learning self-control to the feats of human innovation that built skyscrapers and sent us to the moon. We'll look closely at how these mental processes help us create, plan, remember, and dream—and how, when they falter, it can change everything. We will see that the frontal lobes act like the brain's control center, constantly coordinating, adjusting, and guiding us through the complexities of life. These crucial parts of the brain push our cognitive capacity beyond simple thought into the realm of what we neuroscientists call “metacognition”—our incredible (and perhaps unique) ability to think about what we are thinking.

By the end of this book, you will understand that optimizing your executive functions is the best thing you can do to take control of your life and that the best way to optimize your executive functions is to *think about how you use them*. In doing so, you will gain a clearer view of who you are—your strengths, your limitations, and the vast potential within.

How Many Executive Functions Are There?

Recent literature lists a cornucopia of executive functions: planning, problem-solving, reasoning, self-restraint, working memory, emotional control, focus, task initiation, organization, time management, goal setting and implementation, flexibility, observation, stress tolerance, cognitive control, self-regulation, creativity, attention, inhibitory control, task switching, and mental flexibility. Executive function can often seem to mean everything and therefore absolutely nothing. But there is at least widespread agreement about what is *not* an executive function. Vision (seeing), audition (hearing), olfaction (smelling), gustation (taste), movement control, and emotions in their most basic forms (anger, fear, happiness, and so on) are just some of our sophisticated brain processes that are not generally considered executive functions.

One way of deciding what is and what is not an executive function is to consider whether it involves managing, regulating, and coordinating our thoughts and actions in order to achieve goals. In other words, executive functions are what enable us to think before we act. For example, most of us cannot easily change or control our immediate emotional response to

being slapped in the face by a stranger; it would likely make us angry or sad or both. Hence, most emotions are not generally considered executive functions because they do not involve managing, regulating, and coordinating our thoughts and actions. But deciding what *action* to take in response to that slap is another matter entirely. It depends on the coordination of many different brain processes, including memory (what happened the last time I got into a fight with a stranger?), attention (is this stranger alone, or does he have several accomplices hiding in the shadows?), planning (if I hit back, do I have a good exit route lined up?), and more. Thus, *emotional regulation* is a good candidate for an executive function of the brain, because, by definition, it involves regulating our feelings and behavior through the coordination and integration of various other brain processes (memory, attention, planning, and so on).

With these considerations in mind, I have had to make some tough decisions about which abilities to include on my roster of executive functions. My choices draw on more than thirty years of research, focusing on the areas where neuroscience has given us the clearest answers. My choices may disappoint some, and my omissions may irritate others, but what follows is a comprehensive account of human executive functions, grounded firmly in science.

First, there is *working memory*: our ability to memorize and hold a piece of information for as long as we need it, which might be a few seconds or several days. Working memory supports many of the other executive functions—including *planning*, which comes next. Planning is our ability to schedule and order events that have not yet occurred. Many of our everyday activities require working memory and planning to work seamlessly together to achieve our goals. Next we'll look at *inhibitory control*, the mental force that allows us to resist temptation, suppress impulsive actions, and maintain focus on our long-term goals. This is the executive function that was most affected in our NFL retiree, Max. Then we'll examine *attention*, including *cognitive flexibility*, *selective* and *sustained attention*, and *divided attention*. What we pay attention to—whether it's a conversation, a red light, or a missed email—largely determines how our lives unfold. Next we'll explore *theory of mind*—that mysterious mental faculty that allows us to guess what another person is thinking. It's the skill that lets us navigate everything from playground politics to business negotiations, and without it, human relationships would be almost

impossible. Finally, we'll examine *emotional regulation*, which is an umbrella term that describes our ability to look inward, think about our thoughts, feelings, and actions, and, when necessary, change them. It's what keeps us from snapping at the boss, crying in the supermarket, or saying something we'll regret in the heat of the moment.

Throughout these chapters, it will become clear that many aspects of executive function intersect with issues relating to consciousness and free will. For example, executive function is all about control—choosing what to focus on, what to remember, what reaction to suppress. But if we are not conscious of a thought or action, can we really be said to be “controlling” it? Executive functions also give us the feeling of agency—the sense that it's “us” deciding between options, inhibiting impulses, and weighing consequences. But neuroscience often shows these processes unfolding before we're aware of them, raising questions about how much free will we truly have.

Then we'll consider the pros and cons of what some call the *extended mind*—the ways our executive abilities stretch beyond the brain. Smartphones, computers, and even watches now hold our memories, schedule our days, remind us what to do, and sometimes even decide what we should pay attention to. These technologies, frequently driven by artificially intelligent (AI) systems, can feel like superpowers when they augment our abilities or like shackles when they erode them, forcing us to ask where the boundary lies between our own conscious choices and the quiet influence of machines.

From there the journey becomes more personal. We'll see how understanding executive function is not just a matter for neuroscientists or philosophers, but something that touches every corner of our lives. When you grasp how your brain plans, remembers, resists, and regulates, you begin to see why you sometimes make choices you regret, why habits are hard to break, why you feel so easily distracted, or why some days you feel unstoppable.

This book is about learning to take that knowledge and use it: to think *before* you think; to spot when your executive functions are working against you, and to train them so they work in your favor. It's a practical tool kit for becoming more focused, more intentional, and more resilient in the face of everything modern life throws at us.

My hope is that you'll see executive function for what it truly is: not a dry scientific term, but the invisible scaffolding that supports our decisions, our relationships, our ambitions, and our sense of who we are. It is the set of skills that lets us take control of our lives, rather than being pushed and pulled by habit, impulse, or circumstance. It is, quite simply, an extraordinary constellation of mental tools that guide us through the everyday business of being human.

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Working Memory

The Power of Short-Term “Tags”

The art of remembering is the art of thinking.

—WILLIAM JAMES

A few years ago, I was invited to give a science talk at the Latitude Music Festival in England. Established in 2006, Latitude has become a prominent cultural event, celebrated for its diverse programming, including music, theater, literature, comedy, the arts—even *science*. The year I was invited, I was delighted to see that Thom Yorke, from Radiohead, was playing, and I replied yes to the invitation before I really knew what I was getting myself into.

I was scheduled to speak in the so-called “science tent”—local code for the tent where strung-out music lovers would go to lie down after a hard night in the mosh pit to listen to scientists like me tell them horror stories about what various drugs might be doing to their addled brains. I was quite excited about all this. A captive audience, a summer speaking gig in a tent in Henham Park, Suffolk, and a *free ticket to see Thom Yorke!* This is what I live for!

In the days beforehand, I carefully prepared my talk. The truth is, back then I didn’t know a whole lot about how recreational drugs affect the brain, but I was keen to get on top of the literature. So I studied hard and came up with some interesting facts and figures that I thought would catch the attention of my audience, however stoned they might be. Maybe I came up

with too many facts and figures, because by the time I went on stage, I was struggling to keep it all in my own mind.

As I stood there among the empty beer cans and bales of hay, I was happy to see that at least two hundred people had turned up to hear my lecture about “drugs and the brain,” and at least half of them were wide awake and appeared to be listening. I launched into my talk, touching on all the main cornerstones of the topic. Drugs: marijuana, cocaine, alcohol, crystal meth! Neurotransmitters: dopamine, norepinephrine, serotonin, glutamate! Brain regions: the frontal lobe, the hippocampus, the thalamus! I was hitting all the bases, and they seemed to be taking it in—or at least they stayed awake. I wondered whether I had packed too much information into a forty-five-minute talk. At the end I got a round of applause and left the stage satisfied that I had achieved something. At the very least, I could say I had performed at one of England’s most prominent music festivals on the same bill as that bloke from Radiohead.

Afterward, I hung around to hear the next speaker, who was introduced as an award-winning memory champion. This intrigued me, because much of what I had just talked about involved how some street drugs can affect people’s memories. Richard Bowdler turned out to be a lovely guy and not what I imagined a memory champion to be at all. I had grown up watching memory gurus on Saturday night talent shows on British television, and they all seemed to be old white men in black dinner suits with beards. Richard was young and hip, dressed more like a surfer dude than a traditional magician.

I was stunned by what happened next. “I am going to give Dr. Owen’s talk again!” Richard announced. “I’m not a neuroscientist, and I understand very little of what he said, but I will repeat his lecture as best I can to demonstrate the power of my memory.”

I sat back with a self-satisfied smirk: I couldn’t wait to see how badly it would go. But over the next eight minutes, Richard repeated my lecture at breakneck speed, not word for word, but certainly touching all of the main topics as he went—marijuana, cocaine, alcohol, crystal meth . . . dopamine, norepinephrine, serotonin, glutamate . . . the frontal lobe, the hippocampus, the thalamus . . .—it was all there, not just in some perfunctory, vaguely connected way but absolutely on point, in exactly the right order, and with the same narrative arc that I had so carefully crafted back in my office days earlier. I was gobsmacked. I’d seen memory maestros before, and I was

used to seeing them memorizing lists of words or numbers, but this was something quite different. Richard had regurgitated neuroscience facts and figures, oddly named brain areas and unpronounceable neurotransmitters like norepinephrine (try pronouncing it for yourself and you'll see what I mean).

As a neuroscientist who had studied how memory works in the brain for many years, I had some sense of how Richard was able to do what he did, but I had never seen such a graphic demonstration of the power of this particular executive function—*working memory*. How could Richard repeat my lecture when I, the neuroscientist, could barely keep it in mind?

Working to Remember

When most people hear the word “memory,” they tend to think of long-term memory—that vast and enduring storehouse of information about past experiences, knowledge, skills, and concepts that we acquire throughout our lives. Long-term memories are thought to be stored in networks of interconnected neurons distributed across different brain regions (mostly outside of the frontal lobes). The capacity of long-term memory is virtually limitless, and all those deeply embedded facts, names, and episodes can often be recalled days, years, even decades after we experience them.

But while extremely interesting and important in its own right, long-term memory is not an executive function. It is not one of those flexible, adaptable neural tools that we can use to solve problems, control our behavior, and navigate our way through the ups and downs of everyday life. Rather, long-term memory is more like a library that our executive functions can dip into, when they need to, in order to grab the particular fact or figure that is required to solve the problem at hand.

Psychologists have known for decades that not all memories endure for a lifetime, like that phone number we hold on to for just long enough to dial it, or the face of the person whose pen we borrowed at a crowded conference. The term “short-term memory” emerged to describe this mental clipboard, where information could be held temporarily until it is no longer useful (you’ve finished dialing the phone number or returned the pen to its owner). But it wasn’t long before scientists realized that this clipboard metaphor was missing something crucial: We don’t only hold information

in mind—we often *work* on it. As a result, the concept of *working memory* was born, popularized by pioneering British psychologist Alan Baddeley and his colleague Graham Hitch in the 1970s. They proposed a much more active system—not merely a place to *store* information temporarily, but a dynamic set of specialized tools that allows us to manage and manipulate memories on the fly to aid decision-making, planning, and problem-solving. Over time, the concept of short-term memory was largely subsumed into this richer, more dynamic idea, and in modern neuroscience, “working memory” is the go-to term for describing the brain’s ability to temporarily hold and manipulate information in real time.

As one of our most frequently used executive functions, working memory has several different components that make it immensely powerful. For example, when you intentionally decide to remember something, neuroscientists refer to it as working memory *encoding*. We’ll go into detail a little later about how the brain does this, but for now think of working memory encoding as the mechanism by which we intentionally put a new piece of information into temporary storage. It’s like putting an expensive piece of jewelry into the bank’s safe deposit box until it’s needed for the next wedding. When we intentionally decide to go back and get a piece of information out of storage, we refer to it as working memory *retrieval*—like returning to the bank to retrieve the piece of jewelry from the safe deposit box.

Working memory encoding and retrieval give us considerable control over what we remember and what we don’t. But the true power of working memory lies in the fact that its contents can be *reorganized* over time. It’s not a static process by which a piece of information is encoded and then, after languishing in the recesses of our brain for a while, is retrieved. Quite the contrary. While held in working memory, information can be monitored and manipulated in all sorts of fascinating ways that allow us to perform extraordinary feats, almost effortlessly.

Imagine you are cooking a complicated recipe for the first time. You encode the first few instructions into working memory (“chop onions, sauté garlic, add spices”). As you progress, you need to hold this information in mind while simultaneously updating it with new instructions (“fry the onions, stir in tomatoes, let simmer for 15 minutes”). Throughout this process, your working memory is dynamically working to “tick off” steps that have been completed, add new steps to the process as their turn comes,

and integrate any unexpected new information as it occurs (“I’ve burned the onions, so I need to go back and do that part again”). This continuous mental juggling act illustrates how working memory allows us to maintain and adapt information in real time, ensuring that the dish is prepared correctly and as efficiently as possible.

But what’s the difference between a task like this and all the other tasks we do every day, like driving, watching TV, or reading a book? The difference has to do with how much “work” we have to do on whatever it is we are holding in memory at any given time. We lay down new memories hundreds, perhaps thousands, of times each day. However, most of these memories are encoded automatically and do not require *working* memory: the strange face of the man at the gas station or the electric blue Lamborghini revving its engine in front of you at the traffic light. These are details and facts that you effortlessly encode as you go about your day, whether you want to or not, and they do not generally involve working memory because they are remembered automatically. Working memory only comes into play on those occasions when you actively set out to remember something, whether it’s a recipe, a telephone number, or a shopping list that is too short to bother writing down.

We don’t usually need our working memories to recall something, such as a face or an event, because it occurs automatically. When you see that man from the gas station again the following day, you instantly recognize him. You don’t have to *decide* if he’s someone you’ve seen before; it just happens automatically (or if you’ve forgotten him, it doesn’t). In situations like this, working memory is not required because no decision is involved for you to recognize his face—it happens whether you want it to or not.

It’s good that we don’t have to think about what to remember all the time, because if we did, we’d open ourselves up for all sorts of trouble. Imagine meeting your mother-in-law for the first time and failing to store a memory of her face. It would be very embarrassing when you didn’t recognize her the following day. It’s great that our brains remember things like that automatically, because then we don’t have to remember to do it ourselves. It’s efficient: Much of what we remember, even much of what we *need* to remember, doesn’t need to be consciously and meticulously filed away. Information like our new mother-in-law’s face gets remembered automatically, and, for the most part, that’s a very good thing.

On the other hand, we don't want our memory to always work on autopilot, making us remember absolutely everything all the time. We want to have some capacity for *selecting* what we need to remember and what we don't; that's where more intentional, working memory comes in. Imagine that when being introduced to your mother-in-law, she is surrounded by a whole gaggle of similar-looking aunts and distant cousins who you are also meeting for the first time. Now the stakes are a little higher because there's a chance you'll get mixed up, and that would be disastrous. You need to steal yourself away for a moment, activate your working memory, and make a special and intentional effort to remember your mother-in-law's face above all others, because there's little doubt that the penalty for forgetting it will be highest.

When we do not fully utilize our working memory in this way, we leave what we remember and what we don't to chance. For instance, imagine wandering through an art gallery. You see hundreds of paintings, some unique, some similar in terms of color, subject matter, or style. Imagine also that you make no particular effort to remember any of them. The next time you visit that same art gallery, you'll probably recognize some of the paintings but not others. Some may look familiar, but you won't be absolutely sure that you've seen them before; you may be confusing them with other paintings that you saw that were similar in some way. Others you won't recognize at all, despite having seen them previously.

This is what happens most of the time; there's loads of information out there in the world to remember, and real life is not a memory test, so we don't go around using our working memory to try to remember what we experience in an effortful, intentional way. We just live our experiences, and some of it sticks and some of it doesn't. Generally, what sticks is unusual or distinct, like that man at the gas station with the strange face or the electric blue Lamborghini. What doesn't stick is the information that's less distinct or more common (like every white sedan we pass on our drive home), and therefore it's less easily recalled later. Memories that stick do so because they stand out in some way. For the most part, we exert little control over what sticks and what doesn't, and so we have little control over what we remember and what we don't.

Working memory is the mechanism we can use to influence this process, intentionally making some memories stickier and therefore more likely to be remembered. By consciously deciding to encode something into

working memory, we assign it special significance, increasing our chances of remembering it.

Imagine yourself back in the art gallery. You have been told to remember a painting of your choice so you can describe it in detail later. As you wander through the exhibits, you choose a painting and make a conscious decision to remember it, committing it to working memory as you do so. Much later, when you revisit the gallery, you'll have a very good chance of remembering that particular painting and less of a chance remembering the others. By assigning special importance to that particular piece of art and encoding it in your working memory, you made it stickier—just as you did with your mother-in-law's face.

Working Memory and the Brain

I first became interested in working memory as a PhD student, traveling around South London in the late 1980s, visiting Mr. Polkey's neurosurgical patients. I was testing these patients on a computerized test that was actually just a human version of a task that had been developed to study rudimentary forms of this executive function in mice and rats. The so-called "radial arm maze" was developed by the American psychologist David Olton and his colleagues in the 1970s. The original apparatus consisted of eight equidistantly spaced arms, each about four feet long, and all radiating from a small circular central platform, where a mouse or rat would start the test. At the end of each arm a little morsel of food was placed, something tasty that would appeal to the rodents. Their task was to visit each arm in turn, collecting all eight pieces of food one by one.

Just like humans, rats like to be efficient when they can, and so they naturally try to avoid revisiting any arm where food has already been found. To do this, they must keep a running tally in working memory of where they have already been, constantly updating their stored record as each new piece of food is found (yes, rats and mice have excellent working memories too!). The radial arm maze is a classic working memory task and is still used in labs all over the world to study this executive function in rodents. It's analogous to one of the most famous and extensively studied puzzles in the field of computer science, known as the "traveling salesman problem," which requires computing the most efficient route for a salesman to take to

visit a number of cities exactly once and then return to the starting city, minimizing the total distance traveled.

Much as I would have liked to put my participants in a maze and reward them with tasty treats, that wasn't going to fly with the university's ethics committee. Our version of the task involved a series of square boxes presented on a touch-sensitive computer screen. I would ask participants to touch each of the boxes in turn to search for a "reward" (when they found the right box, it would open to reveal a small, colored token hidden inside—that was their "reward"). Once it was found, they had to search for the next token, which would always be hidden in one of the boxes that had not been used to hide a token previously. Just as in the rodent version of the task (and the traveling salesman problem), the participants had to visit each box looking for a reward while avoiding boxes where a reward had already been found. And just like the rodents, the human participants had to maintain and update a running tally in their minds of which boxes they had already visited and, crucially, pay special attention to where rewards had already been found. It was all that updating that made this such a good test of working memory; there was constant *work* involved in keeping all that information up to date for the duration of the test.

In one early study, I found that patients with damage to their frontal lobes were impaired on this test of working memory. Even when they had found a token in a box, they would return to it time and time again, despite being explicitly told that they were to avoid doing so. In fact, sometimes they even seemed to forget which boxes they had visited at all, returning to open a box just a few seconds after visiting it and establishing that it contained no reward. Their basic memory seemed to be intact—they could remember the rules of the game and what they were supposed to be doing—but as soon as they had to juggle a few items around in working memory, they quickly became confused and made errors.

Our study had firmly established that frontal lobe damage affects working memory. But what part of the frontal lobes? They're huge, accounting for almost one-third of the entire cerebral cortex. It is not a homogeneous region—one big blob of the brain that does the same thing. The frontal lobes comprise distinct areas that differ in terms of their connections with other parts of the brain. The problem was that no two of my patients had exactly the same frontal lobe damage, so it was impossible to work out if one part was more important for working memory than

another. We needed a different approach—a new neuroscientific method to allow us to go further. We got just that with the advent of functional brain imaging technology.

I was positioned to take full advantage of these powerful new imaging technologies when, in 1992, I moved to Canada and began working with Michael Petrides, an intellectual giant of Greek descent who headed the Department of Cognitive Neuroscience at the Montreal Neurological Institute (or “the Neuro,” as it was affectionately known). Both of us were keen to map how the frontal lobes work and to understand how different areas contribute to various executive functions.

Positron-emission tomography (PET) activation studies had just taken off and were showing us for the first time how thinking happens in the healthy brain—that is, in those of us who do not have any damage to our frontal lobes. No longer would we have to wait for a special patient to come through the door with damage to one specific part of the brain in order to deduce what that brain area did. Now we could simply put healthy people in the scanner and ask them to perform our cognitive tests while we watched their brains spring to life. The process was delightfully simple: Volunteers for PET activation studies would lie in the scanner and be injected with small amounts of a radioactive tracer that attached itself to oxygen molecules in the blood. Those parts of the brain that were working hardest required more oxygen, which was delivered in the blood. Thus, blood flow increased to areas involved in the task, a change we could detect by measuring the amount of radioactivity in those areas. We could literally map the movement of blood around the brain with our PET scanner and see which parts of the brain were contributing to performance of the task.

I can’t stress how revolutionary this was and how much it challenged what we thought we knew about how the brain works. We understood fundamental brain functions like seeing, hearing, and movement, but we knew surprisingly little about how thoughts happen, what determines the direction they take, and where they occur in the brain. In short, we knew very little about what *thinking* actually is.

In one early PET study at the Neuro, Michael and I found that as the participants worked through the boxes on the computer screen, an area of the brain known as the ventrolateral frontal cortex was activated. This region of the frontal lobe appeared to be responsible for two crucial

components of working memory: *encoding* information (in this case, box locations) and then *retrieving* it for use later on.

The word “ventrolateral” combines “ventral” (meaning “toward the belly”) with “lateral” (meaning “toward the side”). The human brain sits on the base of the skull, which is made up of five bones that directly support four of its main parts—the frontal lobe, the temporal lobe, the brain stem, and the cerebellum. To get a feel for where the ventrolateral frontal cortex is located, rest your right palm flat on your forehead, and spread your fingers out so that your pinky finger touches your left temple, your thumb touches your right temple, and your middle three fingers are spread roughly equally across the front and top of your head. The area under your whole hand more or less corresponds to the frontal lobes of the brain, which are split down the middle into two halves that look roughly identical. The ventrolateral part of each frontal lobe stretches upward from where your pinky finger and thumb are located (on the left and right temples, respectively), toward the top of the head for a couple of centimeters or so. Think of it as a broad strip on the lower outer flank of each frontal lobe, mirrored on both sides of the head.

But our neuroimaging study also revealed something interesting about a third component of working memory: how we *reorganize* and *manipulate* information while it’s held in storage. As our participants tried to keep track of which boxes had already contained a reward and which had not, constantly updating and reworking the contents of their working memories as they did so, an area known as the dorsolateral frontal cortex was activated.

Place your right palm back on your forehead, exactly as you did previously. The dorsolateral frontal cortex extends from the top of the ventrolateral frontal cortex (approximately where your index and ring fingers are located), all the way to where the two hemispheres of the brain meet, directly below your middle finger.

Our study showed that working memory involves a carefully choreographed collaboration between two different regions of the frontal lobes, the ventrolateral frontal cortex (or lower part) and the dorsolateral frontal cortex (the upper part). If you just need to make sure you hold some stuff in working memory and regurgitate it verbatim a little later, then your ventrolateral frontal cortex will get you by. But if you have to do something

with that memory, like update it or reorganize it, that's where your dorsolateral frontal cortex kicks in.

This apparent hierarchy between the lower (ventrolateral) and upper (dorsolateral) parts of the frontal lobes tells us a lot about how the various components of working memory operate together and are required in different measures (and at different times) for many everyday tasks. Imagine you have a plan to pick up the kids from school, do the shopping, and be home in time for dinner. The plan puts a substantial load on working memory as you assemble and remember the sequence of events, mentally tick them off your list as they're accomplished, and update or change the plan when necessary (skip the shopping, because it's almost dinner time!). Everyday tasks like this require all the subcomponents of our working memory to work together seamlessly as we encode, retrieve, and manipulate information in real time. And that requires two closely connected parts of our frontal lobes—the ventrolateral and dorsolateral frontal cortices—dipping in and out, making their specialized contributions as they're needed.

Everyday Fluctuations in Working Memory

Like many of our executive functions, our ability to exercise our working memory effectively can wax and wane. Fortunately, there are things we can do to help preserve and enhance working memory. And, perhaps more importantly, there are things we should avoid if we want to keep this particular executive function firmly in hand.

Let's start with the bad news. Studies consistently show that even a single night of poor sleep impairs our ability to hold and manipulate information in mind the next day. In one study conducted by cognitive neuroscientists in Singapore, fourteen undergraduate volunteers were given tests of working memory encoding, retrieval, and manipulation both before and after being deprived of sleep for twenty-four hours. After sleep deprivation, the speed at which the volunteers responded in all the tasks was significantly slower, although their performance was less affected in the more complex (manipulation) task.

Similarly, stress is no friend to working memory. In one Swiss study, thirty-five young adult male students were randomly assigned to one of two

groups. The researchers induced stress in one of the groups by asking the participants to give a speech and perform a complex mental arithmetic task in front of a live audience. The second (control) group were spared the ordeal. The researchers found that levels of the hormone cortisol in the participants' saliva (a physiological measure of stress) were significantly elevated in the stress group within fifteen minutes of starting the task. Compared with the control group, the stress group also exhibited profound impairment on a word-based working memory test following their stress tasks. The authors interpreted their results as indicating that stress reduces the efficiency of frontal lobe processing, leading to deficits in working memory performance.

But it's not all doom and gloom. Physical exercise, especially aerobic activity, has been shown to improve working memory. In one recent German study, three groups of healthy individuals either performed a high-intensity aerobic workout for fifteen minutes, completed a simple walking exercise over the same period, or remained physically inactive reading a book. Immediately after the intervention, the high-intensity aerobic exercise group outperformed both of the other groups on a test of working memory manipulation.

Exercise enhances blood flow to the brain, promotes neurogenesis (the formation of new neurons), and boosts the release of brain-derived neurotrophic factor—a sort of Miracle-Gro for your neurons. Nevertheless, it's important to point out that these improvements in working memory may be short-lived. In 2025, my lab used our large-scale testing platform at Creyos.com to examine the effects of a lifetime of physical exercise on cognitive function in more than a thousand healthy participants between eighteen and eighty-seven years of age. We were motivated by a statement from the World Health Organization (WHO) that regular moderate-to-vigorous physical activity has “beneficial effects on cognition” for adults, older adults, and adults living with disability. Around 75 percent of our sample reported meeting the WHO's recommendation of 150 minutes of physical activity per week and so were, as a group, generally fit. Nevertheless, the amount of physical activity taken on a regular basis was not significantly related to any measure of cognitive performance, including working memory.

Importantly, our findings do not dispute the established benefits of physical activity on physiological health. Regular exercise undoubtedly

improves physical fitness and has well-documented beneficial effects for general health, but in the long term it does not appear to improve working memory. If you want an instant boost, however, a quick session of high-intensity aerobic exercise may do the trick.

Finally, if you want to preserve your working memory as you age, keep using it. Cognitive activities such as learning a new language, playing a musical instrument, or reading regularly build what neuroscientists call “cognitive reserve.” It doesn’t necessarily stop working memory decline, but it can delay its consequences by making your brain more efficient at compensating for changes. It’s the neurological equivalent of backing up the data on your computer regularly, so you’re not stuck if your hard disk crashes.

Working memory capacity certainly changes with age, but it doesn’t just evaporate. If you want to keep it in tip-top condition well into old age, sleep well, move often, keep your stress levels under control, and keep your mind busy with things that interest you.

But you might be wondering: Can I go further than just maintaining or optimizing what I already have? Can I actually *upgrade* my working memory?

How to Become a Working Memory Champion

Watching memory maestro Richard Bowdler redeliver my Latitude Festival lecture intrigued me. How had he done it? Fortunately, for the second half of his presentation, Richard let us in on the secret, known to memory aficionados as the method of loci.

The method of loci, often referred to as “the memory palace technique,” is a mnemonic strategy that leverages our ability to navigate in physical or mental space to enhance our ability to retain information in working memory. Spatial navigation (as psychologists often call it) is your brain’s built-in GPS—the mental process that helps you find your way through the real world or imagine your way through an environment you are familiar with. Whether you’re tracing your steps back to the car in a crowded parking lot or mentally rehearsing the route you are going to take to your favorite restaurant across town, your brain is creating, updating, and using mental maps to guide you.

Spatial navigation is an extremely well-developed and largely innate cognitive ability, reliant on a small seahorse-shaped structure in the middle of the brain known as the hippocampus. As we explore our surroundings, either physically or mentally, so-called “place cells” in the hippocampus generate “cognitive maps” by activating in specific spatial locations, effectively “marking” those spots to create a mental snapshot of the environment—just like a Roomba forming its map of your house. Each place cell is tuned to a particular location, so as we move through a space such as a room, different place cells fire in a sequence that reflects the path and layout of that room. By encoding these spatial relationships, place cells enable us to navigate and remember the structure of the world around us, forming the foundation of our cognitive maps. In 2014, the American-British neuroscientist John O’Keefe was awarded a Nobel Prize for the discovery of these place cells.

Users of the method of loci exercise their spatial navigation abilities to mentally associate the information they want to remember with specific locations within a familiar space, such as a house or a street. By mentally navigating this familiar environment, individuals can recall the information in a specific order. For instance, if someone needs to remember a list of items, they might mentally place each item in a distinct location in their house. When the time comes to recall the information, mentally retracing their steps through their house helps trigger the memories that were associated with each location.

In Richard’s case, he had used the festival tent as his familiar space. To pull off his mnemonic feat, he had planned a route around the tent, imagining that specific items, or terms, from my lecture were placed in various locations. For example, there was a fridge in one corner of the tent, and as Richard listened to my lecture, that’s where he “arrived” in his mental journey at the exact point that I mentioned the part of the brain that is crucial for spatial navigation—the hippocampus. To make sure he remembered this, Richard visualized a hippopotamus sitting on top of the fridge before moving on to the next location and the next part of my talk. He told me that the more bizarre his mental imaginings were when using the method of loci, the better he was able to remember, because—as mentioned earlier—we are much better at remembering quirky and unusual things (like hippopotamuses sitting on fridges) than the familiar and the

bland. I'd read about the method of loci before, but it was something else to see it used in such an imaginative way to remember my own lecture.

The method of loci is a strategy that Richard employed to reduce the pressure on his working memory system, organizing the material to be remembered using spatial cues. Other strategies can also boost working memory performance; the most widely studied is one known by the unprepossessing name of "chunking." Chunking was first described in 1956 by cognitive psychologist George A. Miller, who argued that it is a key cognitive process that involves the recoding of a set of data into a more compressed, efficient form, thus extending working memory capacity.

This principle was taken to new heights by K. Anders Ericsson, a prominent Swedish psychologist who worked with a college student named Steve Faloon to see if he could expand Faloon's memory capacity by practicing specific memory techniques. Faloon was an ordinary college student with an average memory at the beginning of the study. Ericsson trained Faloon to group information together in meaningful ways to make it easier to remember. For example, instead of trying to remember a long string of numbers, Faloon learned to group them into smaller, more manageable chunks. Over the course of twenty months of training (more than 230 hours of laboratory testing!), Faloon's digit span (the number of digits he could remember) ballooned from a decidedly average seven to a record-breaking eighty. What's more, Faloon's improvement wasn't just temporary; he retained his enhanced memory abilities even after the study had ended.

The key to understanding Faloon's remarkable memory improvement comes from an analysis of his own description of how he did it. His secret was to categorize three- and four-digit groups as running times for various races. For example, the sequence 3492 was recoded as "3 minutes and 49 point 2 seconds," which he remembered as "very near the world record mile time." By focusing on a benchmark that he was familiar with ("very near the world record mile time"), the expression "3 minutes and 49 point 2 seconds" came to mind, from which Faloon was able to retrieve the remembered sequence 3492. Put simply, Faloon was boosting his working memory by ordering the new material to be remembered into chunks that reminded him of information he had stored years ago in his long-term memory, like the world record for running a mile. By lining up each of

these remembered “chunks” of information and retrieving them one by one, Steve Faloon was able to increase his working memory capacity tenfold.

To be fair, the race-times method only got him so far. As the sequences he was required to remember got longer and longer, Faloon supplemented his initial method with other versions of the same system. For example, once he’d exhausted his method of familiar race times, he turned to ages (893 was coded as “89 point 3—very old man”) and dates (1944 was coded as “near the end of World War II”). Curiously, when Ericsson presented Faloon with sequences that could not easily be associated with running times (before he’d started to use ages and key dates in world history to help him), his performance dropped back to his beginning level. This underscores the fact that Faloon wasn’t actually improving his memory *per se*, despite the fact that he was increasing the number of digits he could recall. Without his strategy there to prop up his working memory, he was right back where he had started.

Faloon’s ability to recode sequences of digits according to concepts he was familiar with makes complete sense, but it doesn’t explain everything. How did he manage to string them all together? How did he remember which race time, followed by which age, followed by which date?

Ericsson’s detailed accounts of his landmark studies provided some early clues, even decades before the advent of functional neuroimaging. In 1980, he wrote, “The next important advance came when [Faloon] introduced organization into his retrieval structure.” What Ericsson meant is that Faloon began to further categorize and organize what he had remembered into ever more complex chunks, or “supergroups,” as Ericsson called them. In practice, this meant that instead of recalling a string of unrelated race times, ages, and dates, Faloon grouped them into larger, structured units—like a cluster of three race times followed by two ages, which then pointed him to a particular date. These supergroups acted like mental filing cabinets, letting him keep track of dozens of digits by storing them in an orderly system rather than as isolated fragments. Given recent advances in neuroscience, we now understand how Faloon’s brain achieved this. Encoding information into working memory and retrieving it later (as Faloon had done with each individual race time) is the purview of the ventrolateral frontal cortex. But once we start reorganizing that information while it is in working memory (which Faloon had to do as he assembled ever more complex supergroups), we need the dorsolateral frontal cortex to

take control. By using these two parts of his frontal lobe to efficiently encode, reorganize, and then retrieve the information in exactly the right order, Faloon had inflated his working memory capacity from seven to eighty items.

In another interesting study, Ericsson and his colleague William Chase tried to work out how experts remember information compared with novices. In simple terms, they wanted to figure out why experts in a particular field, like chess players, are so much better at remembering complex patterns compared with people who aren't experts. To do this, they worked with both a chess master named A. D. de Groot and some amateur chess players. They asked the players to look at a chessboard with pieces arranged in a particular game setup for just a few seconds. Then they took the board away and asked the players to re-create the positions of the pieces on a blank board. They found that the chess master, de Groot, was able to remember the positions of the pieces on the board much better than the amateur players. Even though the board had a lot of pieces and seemed chaotic to most people, de Groot could remember where almost all the pieces were.

Chase and Ericsson found that de Groot used a chunking method much like Faloon, so he didn't have to remember every single piece individually, but rather groups of pieces that formed meaningful patterns to him as a chess expert. They established that de Groot didn't have a better memory in general. Rather, he was only really good at remembering things in the context of his area of expertise—real games of chess. But when the same pieces were placed on the board in random, impossible positions (configurations that could never occur in a real game of chess), de Groot lost his advantage and performed no better than the amateurs. This is another example of how we can give our working memories a helping hand by relating them to knowledge that we already have stored in our long-term memory.

Ericsson's studies help us to understand that experts aren't just born with better memories—they develop them through years of practice and experience in their particular field. Indeed, one of Ericsson's most famous collaborations led to the popularization of the "10,000-hour rule," which suggests that it takes roughly 10,000 hours of deliberate practice to achieve mastery in a particular domain. While the exact number of hours required may vary depending on the complexity of the skill and individual

differences, Ericsson's research underscored the critical role of sustained and focused practice in skill development.

You might be wondering whether, through all this practice and training, memory experts like Faloan and de Groot had increased their working memory capacity for other types of material. Well, the evidence suggests not. After three months of practicing digits, when Faloan was already well on his way to being able to recall eighty of them, Ericsson switched him to letters (A, D, K, L, and so on), and Faloan's memory capacity for the new material was exactly as it had been for digits before he started training (that is, seven or eight letters). This was early evidence that while we can make improvements to our memory capacity through training or developing strategies, those improvements are also tightly linked to the material that we are training on. Put simply, while Faloan could remember eighty digits after twenty months of training, it didn't make him better at remembering anything else.

Train in Vain

"Upgrade your brain in just ten minutes a day!" "Age-proof your mind!" "Unlock your inner genius!" The promise of brain training is appealing. Just complete a few online working memory games and sharpen your mind, lift the brain fog, and become laser focused in minutes—all from the comfort of your own living room. With claims like these, it's no surprise that the brain training industry has grown at such a remarkable rate in recent years. Indeed, it has been estimated that there are now almost seventy million active users of various brain training programs, driving a multibillion-dollar industry. However, has the promise of brain training gone beyond the science that supports it?

In 2010, I decided to investigate this question. At that time, a Nintendo game known as *Brain Age*, developed by Japanese neuroscientist Ryuta Kawashima, was all the rage, and people everywhere were tapping away at their portable devices in an effort to make themselves smarter.

In a collaboration with a popular BBC science show called *Bang Goes the Theory!*, we recruited more than 11,400 volunteers and assessed them on our tests of working memory, planning, problem-solving, and reasoning at Creyos.com. Then, after six weeks of brain training, mainly using games

that engaged their working memory, we tested them again to look for improvements. For our scientific audience, we published the results in the journal *Nature*, but for the general public we revealed them on primetime British TV with as much fanfare as we could muster.

“Dr. Owen,” said the host, “How much smarter were our participants after six weeks of brain training?”

I paused briefly for dramatic effect. “Funnily enough,” I said, enjoying the moment, “they didn’t improve at all!”

And that was the truth. We had brain trained 11,400 volunteers for six weeks and they hadn’t got better at a single one of our cognitive tests. Sure, they had improved at the brain training games themselves, but that’s just practice: Keep trying to ride a bicycle and you will get better at it, but it won’t make you a better violin player. And now we had shown through our massive online study that the same is true where commercial brain trainers are concerned: Train on one thing, like remembering sequences of digits, and you might get a little better at that over time, but don’t expect to get better at anything else, including activities that appear, on the face of it, to be quite similar. In fact, as had been the case with Steve Faloan, in our huge study even training on one working memory task (for example, remembering sequences of digits) did not improve performance on another working memory task (for example, remembering sequences of letters).

One day, years later, my wife Emily, who is also a neuroscientist, turned to me and asked, “Why do you think your massive brain training study didn’t work?”

“I dunno,” I replied, “Because brain training just doesn’t work?”

“No,” she said. “*Why* didn’t it work?” In other words, why is it that when we train on one cognitive task we don’t get better at other cognitive tasks?

“Perhaps it’s like going to the gym?” I ventured. “If you spend all your time lifting weights, you don’t get any faster at the 100m sprint.”

We mulled over this. Perhaps mental “fitness” really is like physical fitness. After all, you rarely see an Olympic athlete competing in more than one sport, except in exceptional circumstances; and even then, there’s usually almost complete overlap between the two events (the 100m and 200m sprints, for example). And it’s pretty obvious why that’s the case, isn’t it? Throwing a javelin, for example, involves a lot of upper-body training, particularly to increase arm strength. All that training does very

little to improve the strength of your legs, which is what's really required to run the 100m. Perhaps brain training is the same?

Based on that conversation, Emily and I set about designing a study to understand why brain training doesn't work. We recruited sixteen willing volunteers to brain train for four weeks on either a working memory task or "double trouble," our test that Max, our NFL hero, had performed so poorly on. Every few days we would bring them back into the lab and perform a special kind of MRI scan called "diffusion tensor imaging."

Diffusion tensor imaging, or DTI as it is more commonly known, measures the strength of the physical connections (white matter tracts) connecting different parts of the brain. White matter in the brain is like a vast network of highways, transmitting signals between different regions at speeds of up to about 230 feet per second—that's as fast as a Shinkansen bullet train racing across Japan and considerably faster than a tennis serve by Novak Djokovic. Gray matter, which makes up most of the rest of the brain, contains the brain's neurons and processing centers, the "cities" of our mental landscape. Like major highways, white matter connects these cities, integrating each mental "neighborhood" into a unified whole.

Diffusion tensor imaging works by measuring how water molecules move around in the brain. In white matter, water tends to move along the length of the fiber rather than across it. By sending out harmless signals that bounce off these water molecules, DTI takes advantage of this directional movement of water to create a "map" of the brain's structure and connectivity. The technique can also show areas where there might be damage or changes due to injury, disease, or other conditions.

Some years ago, neuroscientists at Oxford University used DTI to show that as people learn to juggle, the white matter tracts that connect those parts of the brain that are crucial for motor coordination get stronger, and that is likely how improvement occurs. Your brain literally rewires itself to strengthen those physical connections between the parts of the brain that are most important for whatever it is that you are practicing. Could the same be true of cognition?

Sure enough, after four weeks of training on our working memory task, certain white matter tracts in the brain were noticeably stronger on the DTI scans of our participants. Practice had strengthened the physical connections between the parietal cortex in the back of the brain and the frontal lobes, which we know are crucially important for working memory.

White matter tracts had also been strengthened in our participants who had trained on double trouble. The crucial finding, however, was that it was a totally different set of tracts. These participants had strengthened their connections between the frontal lobe and the temporal lobe and between the frontal lobe and the occipital cortex.

In short, there was very little overlap in the DTI changes between the two training groups. And so, cognitive training really is like physical training. Train one part of your brain and it will get stronger (or rather, connections between different brain areas will get stronger), but it won't change your performance on tasks that are dependent on other areas of the brain (or connections between those areas). It turns out that this general principle is true even if the tasks are, on the face of it, quite similar. Just as K. Anders Ericsson had shown with Steve Faloony years before, we showed that with enough training and realistic expectations, you *can* improve your ability to remember one type of information, but it won't improve your ability to remember anything else. But now, finally, we had a neuroscientific explanation for it.

You *Can* Teach an Old Dog New Tricks

Most of what I have told you so far about working memory and brain training involves research that was conducted with young, healthy volunteers. But it's important to draw a distinction between these participants and older folk or people who are already struggling with cognitive challenges. Just because young, healthy volunteers cannot get any smarter by training their brains does not mean that those who are not currently operating at their absolute best cannot do anything to improve their cognitive function. And that's where mnemonic strategies like the method of loci or chunking may come into play.

Although most people associate Alzheimer's disease with impaired long-term memory (distant memories and experiences from early life, for example), there is increasing evidence that executive functions are also impaired. For example, impairments in working memory have been reported in the earliest stages of Alzheimer's disease. Indeed, cognitive deficits unrelated to long-term memory can emerge up to fourteen years prior to a formal Alzheimer's diagnosis.

A few years ago, I was introduced to Jonathan Huntley, a young British doctor. Jon wanted to know whether patients with Alzheimer's disease could also benefit from the sort of chunking strategies that Steve Faloony had mastered several decades earlier. Jon recruited thirty patients with relatively mild Alzheimer's disease and randomly split them into two groups. He presented both groups with increasingly long sequences of digits, which they would have to repeat back after a short delay. In some trials, the digits were mathematically structured (246975, for example) to encourage working memory strategies, while in others there was no such structure (816294). Over the course of eighteen thirty-minute training sessions across eight weeks, Jon trained one of the two groups to use the mathematical strategy to boost their working memories for digits, while the other group had no such training.

Remarkably, the trained group improved significantly in their ability to remember the mathematically structured sequences, relative to the nonstructured sequences, whereas no such effect was observed in those patients who had not been trained. That is, training patients with Alzheimer's disease to use a strategy to boost their working memory performance actually worked. What was even more amazing was that the training also seemed to provide some level of "protection" in these patients against the global cognitive deterioration that is common in conditions like Alzheimer's. Specifically, over the course of the study, the untrained patients dropped almost two points on the Mini Mental State Examination, a widely used general measure of cognitive performance. In contrast, the trained patients' performance stayed exactly where it was at the beginning of the trial, suggesting some preservation of their cognitive abilities.

The really clever feature of Jon's training study was that he put all the patients into an fMRI scanner before the trial began and also after it had ended, scanning them both times while they performed the digit span task. Curiously, for patients who had been trained, activity in the frontal lobes *decreased* relative to that of patients who had not been trained. Put simply, as the training boosted the patients' working memory performance by teaching them to use strategies, the frontal lobes had to work less hard to keep up. As Jon wrote at the time, "These results provide evidence of the potential for functional plasticity following training in Alzheimer's disease." *Functional plasticity* refers to the brain's ability to adapt to change, to rewire itself as new coping strategies are developed in the face of

the relentless downward spiral of disorders like Alzheimer's. Jon's study had shown that despite the numerous cognitive challenges, working memory training in mild Alzheimer's disease could, at least temporarily, put the brakes on that downward spiral.

Currently, there are more than 55 million people in the world living with Alzheimer's disease and other forms of dementia, and that number is projected to rise to 139 million by 2050. Any tool that could help this growing population of patients would have a profound positive effect on society. Chunking-based cognitive training could be one such tool for maintaining cognitive function in early Alzheimer's disease.

Imagine a future where, even in the face of Alzheimer's, memory loss can be slowed and cognitive resilience bolstered with simple, targeted strategies. Using visual associations, creating storylines for facts, or using spatial cues (the method of loci) could be a game changer for those with early Alzheimer's. We now know from our studies with MRI that these methods can reduce the mental load by anchoring new information to stronger neural pathways, effectively providing "memory crutches" that help people recall essential details longer and more reliably.

While these strategies won't cure Alzheimer's, they offer a way for patients to navigate their world more confidently and independently, giving them precious time to preserve cherished routines, relationships, and some level of independence. Studies like Jonathan's promise that with consistent training in these memory techniques, patients can not only retain more, but may even experience a spark of cognitive empowerment, showing us that a diagnosis of Alzheimer's doesn't have to mean giving up on all of life's mental richness.

Whether you want to become a memory champion like Richard Bowdler or stave off the inevitable cognitive deterioration of diseases like Alzheimer's, we've seen that there *are* things you can do to make the best use of your working memory. Make a mental note of what matters most, relate it to information you already know, and refresh it regularly. Push everything else out of your head space by writing it down, setting cues, and silencing distractions. And treat context as part of the system: Regular sleep, regular exercise, and keeping calm will all give your working memory system room to work. In practice, that might mean the difference between half-finishes ten things and fully finishing three. Just thinking about working memory and how you use it will make it more effective—

whether you're recalling numbers onstage or just getting dinner, meeting deadlines, or bundling the kids into the car.

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2

Planning

Memory for the Future

A goal without a plan is just a wish.

—ANTOINE DE SAINT-EXUPÉRY

On a crisp August morning in 2009, Aman Kassaye walked into a makeup studio in London's Covent Garden and explained that he needed to be made to look much older than his twenty-five years for a video he was shooting. Excited by the challenge, for the next four hours the makeup artist pulled out all the stops, applying latex prosthetics and toner to Kassaye's face and covering his thinning dark hair with a more voluminous professional wig. The transformation was absolute, so much so that Kassaye looked in the mirror and commented that his own mother wouldn't recognize him.

A few hours later, Kassaye and several male accomplices, some dressed as women, entered the Graff Diamonds flagship jewelry store in London's opulent Mayfair district and walked out with a fortune in jewelry. The largest ever gems heist in Britain at the time had been executed to perfection, the culmination of months of meticulous planning.

Ethiopian-born Kassaye—a drug-dealing college dropout—masterminded the operation. Months of surveillance, disguised reconnaissance, and shrewd observation preceded the heist. Like a patient chess player, Kassaye studied the store's layout, security systems and

personnel, and the behavior of customers and staff, noting patterns that he used to his advantage.

The brilliance of the Graff Diamonds heist wasn't just in the loot—nearly \$65 million worth of diamond-encrusted rings, bracelets, necklaces, and wristwatches—but in the precision with which it unfolded. Outside the store the robbers made their getaway in a waiting blue BMW. Several hired vehicles, including an eight-ton truck, had been strategically parked to block police from following the getaway car. Kassaye and his gang switched vehicles twice before disappearing.

Yet, despite his months of planning, one tiny oversight proved to be the fatal error that eventually linked Kassaye to the heist. In their haste to transfer between getaway cars, one of the thieves left his burner phone wedged between the hand brake and driver's seat. Numbers stored on the phone allowed police to discover the identity of Kassaye and his accomplices. After all the planning and preparation, and a successful heist carried out without a hitch, a mislaid cell phone led to the gang's capture.

Although Kassaye and his gang were caught, only one item of the forty-three pieces of stolen jewelry has so far been recovered. Authorities speculate that the gems from the rings, bracelets, and necklaces were recut and sold for a fortune. Kassaye was sentenced to twenty-three years in prison.

The heist's precise choreography demonstrated Kassaye's mastery of one key executive function—planning. Planning, as we'll see, involves coming up with an overall goal (a successful heist) and then breaking it down into its component parts in order to get there. Despite its criminal nature, I'm sure I'm not the only one to view the Graff Diamonds heist as an example of human ingenuity at its finest.

What makes some of us better at planning than others? We all know people who seem to have a better understanding of what might be possible and how to make it happen. The most brilliant of us are dreamers as well as planners, fantasists and schemers, planning savants like Kassaye who can both envision and execute. We may wish for a better future, but what good is that if we can't construct a clear plan for how to get there?

When I began my early investigations into frontal lobe function more than thirty-five years ago, how our brains construct plans was a subject that many neuroscientists were starting to talk about, so naturally I wanted to get involved. At the time, I was working toward my PhD, assessing Mr.

Polkey's patients at the Institute of Psychiatry in London. One such patient sticks in my memory: a middle-aged man who had had a large tumor removed from his left frontal lobe. The surgery required that some "good" brain tissue be removed with the "bad," leaving little of his left frontal lobe intact. Prior to the operation, the gentleman in question had owned and run a textile company in South London that employed several hundred people. After the surgery, he made a full physical recovery and went back to work.

Almost immediately, his colleagues noticed changes in his behavior and attitude. He fired people on a whim and squandered large sums of money chasing deals that he could never hope to close. In one case, he had signed an enormous contract with a materials supplier but had neither the staff nor storage space to process the material when it was delivered to his factory. Textiles worth a fortune rotted outside his company headquarters. Unfortunately, because the business was his, it was very difficult to stop him making these poor decisions and plans. When questioned by his colleagues about his behavior, he claimed to have no idea what they were talking about.

I visited him at his home in South London and was struck by his absolute lack of self-awareness or insight. He lived in a Victorian-era semidetached red-brick cottage with a pitched roof and immaculate front and back gardens. His prim wife served us tea. He was a short man, round-faced and balding, dressed in business attire (a slightly shumpy blue suit and mauve tie), though he was not going into the office that day. We sat on either end of a small sofa. As I questioned him, it became clear that he had no idea at all that the demise of his business, which was almost absolute by then, had come about through his poor planning. Indeed, when I questioned him directly about the cause of these events, he struggled to find alternate explanations, citing bad luck and a turn in the economy as contributory factors. He willingly acknowledged making all of the key decisions and was able to describe the plans he had made to grow the business, but he could not see any link between those plans and their repercussions.

His marriage broke up soon after I interviewed him. When I later asked his wife what, ultimately, had led to the separation, she said simply, "He wasn't the man I married." In some ways, the effects of the patient's brain damage were subtle (he could still see, hear, move, and talk), yet they were sufficient to lead his wife to describe him as not being "the man I married." In some intangible way, he was no longer *him*.

What was it that had gone so terribly wrong in this gentleman's brain that had ruined his business and left his marriage in tatters? And what was so different about Aman Kassaye's brain that had enabled him to pull off (for a while at least) one of the largest diamond heists in history? To answer those questions, I needed to do a bit of reading.

A Slice of Life

The Institute of Psychiatry was situated in what was in those days a seedy South London neighborhood and provided exactly the retreat I needed from the urban hellscape outside. Its library was about as peaceful a place as you could imagine. I would regularly spin through its rickety aluminium turnstile and escape for hours at a time. I had recently devoured *The Man Who Mistook His Wife for a Hat* by neurologist Oliver Sacks, and I was on the hunt for similar cases of the curious and the peculiar and what they could tell us about how our brains work. Although my strategy at the library was simply to browse randomly with no expectations, I often found myself transfixed by hidden gems.

One evening I came across a brief scientific paper published in 1935 by the celebrated American-Canadian neurosurgeon Wilder Penfield that helped me organize my then-scattered thoughts about executive function and changed the course of my career.

Penfield described a young housewife with a large tumor in her right frontal lobe, which he successfully removed. After recovering, the patient began to display an unusual set of behaviors. For example, she was completely unable to plan and prepare a family meal. She was perfectly capable of cooking the individual dishes, but *only one at a time*. She had to complete the cranberry sauce before beginning the sweet potatoes. The green beans had to be fully cooked before the salad could be made. She had completely lost the ability to multitask, and even relatively simple meals took forever to prepare and were often ruined. Prior to surgery, she was a busy housewife with an active family and could pull off this kitchen work without a hitch; yet after having part of her frontal lobe removed, complex tasks like cooking a family meal became unsurmountable. What really floored me was the fact that the patient, Ruth, was Wilder Penfield's *sister*. Can you imagine? Performing neurosurgery on your sister?

Reading the Penfield story immediately made me think of the patients I'd been seeing: patients who couldn't come up with a simple strategy for remembering a sequence of numbers or generating a few animal names. Preparing a family meal requires planning, mental organization, and a fair bit of problem-solving. Like my frontal lobe patients, Penfield's sister had retained the basic behaviors required to get by in life, but she had lost the high-level strategies required to plan and simultaneously carry out many complex daily tasks.

I left the library that night buzzing with excitement. How could we study the brains of people like Wilder Penfield's sister or my south London textiles magnate in a more scientific way? How could we get to the bottom of what planning really is and which parts of the brain are responsible? I'd find the answers to those questions through what was then a little-known cognitive test called the Tower of London.

The Tower of London Test

The Tower of London test was developed in 1982 by the great British neuropsychologist Tim Shallice, and it quickly became the gold standard for testing planning ability. It requires patients to move a red ball, a blue ball, and a green ball between three vertical rods of different lengths in order to match a goal arrangement displayed on three similar rods. The difficulty of the problem can be manipulated by varying the starting position of the initial arrangement of the balls. Shallice had developed the test to try to understand why patients with frontal lobe damage run into difficulties when they have to make plans.

One lunchtime, I arranged to meet Tim in Cambridge, where he was then working, and we picnicked on "the backs," a long stretch of gardens and wild pastures beside the River Cam that weaves behind many of Cambridge's grandest colleges. Tim told me how he had come to understand what goes into making a plan. Formulating a plan typically consists of a number of distinct phases, he said. First, you need an overall assessment of the problem and a high-level appraisal of what must be done to solve it. You need to "see" the problem, looking for clues to a solution. Each step of the plan can be thought of as a subgoal, and every subgoal

needs to be identified in advance if the plan is to succeed. The subgoals have to be ordered, which often involves mental trial and error.

Tim and I discussed how tests like the Tower of London could help us work out the relationship between the frontal lobes and planning—which parts of the frontal lobes are really crucial for our ability to plan and how planning is affected by damage to those regions. If we could understand those relationships, we might begin to answer all sorts of really fundamental questions, such as how is it that humans can plan minutes, days, even years in advance and why this remarkable ability to think ahead is barely evident in other species. Why do young children, and even teenagers, rarely seem to make any plans at all, living in the moment with scarce regard for life beyond today? We pondered how we could investigate what happens in the brain as we travel backward or forward in mental time. I came away from the conversation inspired by Tim's enthusiasm for trying to tackle what is surely one of the most complex feats of human brain function—our ability to plan. More importantly, I was in awe of Tim's incredible ability to *think*. A lot of what Tim Shallice had achieved, many of his great contributions to scientific understanding, had come from just thinking very carefully about a problem, breaking it down into its constituent parts, and solving each part until answers to the bigger questions started to come into sharper focus. I took the train back to London that night convinced that I, too, could tackle some of the biggest questions in neuroscience. I just had to think about it.

From Bad Planners to Rad Scanners

Although understanding what happens in the brain as we travel back or forward in mental time was the grand idea, as always in science the question was how to get there. Using a version of Tim's Tower of London test, I carried out a study assessing a group of twenty-six patients with frontal lobe damage, trying to figure out what had impacted their ability to plan. Twenty-six patients might not seem like many, but in this field, finding more than a handful of people with the same kind of brain damage is not easy. Besides, you can often learn more from the unusual behavior of a single patient who has the “right” type of brain damage than you can from a hundred of those who do not.

My twenty-six patients had damage to either one or both frontal lobes. Sometimes a sliver of brain tissue had been taken and sometimes the entire frontal lobe on one side was gone or a part of both frontal lobes had been removed. Using a computerized version of the Tower of London test, I assessed all twenty-six patients, along with a group of healthy control volunteers who were of a similar age and education level. My frontal lobe patients took significantly more moves to solve the Tower problems than the control group. If a problem could be solved by moving the balls five times, my patients typically took between seven and eight moves. Also, the harder the problem, the more poorly they performed. They knew what they had to do because eventually they were able to solve most problems; they just took more moves to get there. Through further studies, we established that the key problem our frontal lobe patients had was that they were *impulsive*; that is, they began to make moves before they had successfully generated an appropriate solution to the problem. In essence, they hadn't got all the subgoals identified and assembled in the right order before they began. So they were not really planning at all but rather setting out on a path toward a solution without quite knowing where they were headed.

I thought back to the textile business owner whom I'd tested. The way his behavior had changed postsurgery started to make more sense. Signing an enormous contract for a textile delivery without the staff or the storage space to process it sounded a lot like setting out on a path toward a solution without quite knowing where he was headed. I realized that through this simple little Tower puzzle, we had managed to capture the very essence of a key challenge facing frontal lobe patients: their failure to plan effectively.

Now I understood why their lives often fell apart. Imagine going through life day by day, moment by moment, and making decision after decision without ever thinking ahead. You'd decide to stop by the post office before the school pickup, which might turn into grabbing a coffee, which then might turn into browsing dog Halloween costumes for reasons even you don't fully understand. Before you know it, school's out and there's no one there to pick up the kids. Or you'd start making dinner but neglect to defrost the chicken, or you'd boil the water without checking if you even have the pasta. Your life would be chaos!

But more than that, our ability to plan effectively is fundamental to who we are. It makes us "us"; without it, the very essence of who we are would likely change beyond recognition. For example, imagine if you were

suddenly unable to make any plans—or the plans you made were just not very good ones. First, you'd become very unpredictable; you'd say one thing and then do something else. You'd also become unreliable because you'd make promises that you couldn't keep when your terrible plan went off the rails. Some of your behavior might even be interpreted as deceitful, because after making your plans clear, you wouldn't follow through with them. All of these mysterious alterations in your behavior would start to look like a complete change of personality—to an unpredictable, unreliable, and deceitful version of yourself. Yet, as inexplicable and unconnected as they may seem on a psychological level, they all stem from what is a tractable problem for neuroscience—an impairment in your ability to make plans. Now I could see why our textile magnate who went bust really *wasn't* the same person his wife had married.

To further explore the relationship between planning and the frontal lobes, I needed to take advantage of the new generation of brain scanners that were becoming available in the early 1990s, and moving to the Montreal Neurological Institute in 1992 allowed me to do just that. There were less than half a dozen institutions in the world back then performing PET activation studies, and the Neuro was one of them.

I scanned healthy volunteers while they performed both easy and difficult versions of our Tower of London planning task, observing significant activation in the dorsolateral frontal cortex. We've encountered this region before, when discussing working memory.

The change in blood flow we observed while our volunteers were planning was located in the lower part of the dorsolateral frontal cortex, on the outer surface of the brain, close to where it meets the ventrolateral frontal cortex. We had identified which part of the frontal lobe is crucial for planning and why patients with damage to this region struggle with tests like the Tower of London. The fact that this was almost exactly the same region of the frontal lobe that we knew by then was crucial for developing strategies to solve complex working memory problems wasn't lost on me. As I've already said, a plan is a strategy we develop for organizing our behavior in pursuit of a specific goal and that places a significant load on our working memories as we consider, accept, or reject various possible paths that might lead to that goal. The link between planning and one crucial component of working memory was starting to make sense.

Nevertheless, it didn't mean that this is the only function of the dorsolateral frontal cortex. Nor did it mean that it acts alone.

Planning and Parkinson's Disease

Parkinson's disease, which affects millions of people worldwide, is a degenerative and ultimately fatal neurological disorder. It was first described in 1817 by English physician James Parkinson as a "shaking palsy." Until the mid-1980s, patients were usually described in terms of movement difficulty: bradykinesia (slowness of movement), rigidity (stiffness), or tremor (shaking limbs). But then studies started to appear suggesting that patients with Parkinson's disease might also experience problems with executive function, and in particular, their ability to plan effectively. Back in my Cambridge days, we'd shown that, curiously, their planning difficulties were subtly different from patients who had had surgery to remove part of the frontal lobe. Unlike frontal lobe patients, people with Parkinson's didn't head off impulsively when attempting to solve problems like the Tower of London puzzle. In fact, their behavior was quite the opposite; they would spend up to twice as long as healthy people planning a solution, but when they eventually came up with one, it was often right on target. So, they were slow planners, very slow in fact.

In Montreal, I wondered whether patients with Parkinson's disease also had a problem with their dorsolateral frontal cortex. Or was their problem elsewhere? Could we also study that question with positron-emission tomography? We knew that if we put Parkinson's patients into the scanner and had them perform our Tower of London planning task, we would be able to see for the first time which parts of their brains activated and which parts were not responding normally to the challenge.

The results were surprising. Solving the Tower puzzles activated the dorsolateral frontal cortex in our Parkinson's patients, just as it did with the healthy controls. Clearly, then, frontal lobe damage was not at the root of their problems. Where they did differ, however, was in terms of brain activity in a bundle of structures deep within the brain known as the basal ganglia: structures that are strongly connected to the frontal cortex through a network of neural pathways that passes information between the two.

The basal ganglia lie more or less at the brain's center, which means they are not visible from the surface and can only be seen through very invasive neurosurgery or with modern neuroimaging techniques like MRI. The basal ganglia are ancient brain structures. It is likely that they first emerged in the most primitive vertebrates, helping to coordinate basic movements long before complex cognition was even a glimmer in evolutionary history. As animals grew in complexity, so did their brains, and with the eventual rise of mammals—especially primates—the frontal lobes expanded, adding layers of sophisticated planning, impulse control, and higher thought. While the basal ganglia are found in a wide range of species, including birds, reptiles, and fish, the extent of their interactions with the relatively recent frontal lobes in humans represents a significant evolutionary leap. Together, these brain regions form an essential feedback loop that is behind everything from basic movements to the most intricate of human thoughts, making possible our capacity for learning, innovation, and the richness of human experience.

Indeed, the frontal lobes and the basal ganglia form part of a sophisticated network of neural circuits that shape much of how we think, feel, and act. These circuits are primarily composed of dense white matter tracts of the type we discussed earlier. Signals shoot along these neural high-speed cables in rapid bursts, like messages zipping through a complex network of highways. Information from the frontal cortex, like a grand idea (“Let’s go to the Galápagos Islands!”) or a simple thought (“I’m hungry, what can I eat?”), gets funneled down to the basal ganglia for further processing before it is pushed back up to the frontal lobes and the rest of the brain, ultimately giving rise to more detailed thoughts, decisions, and actions.

This system allows us to not only think through our choices and plans but also follow through with them, with each electrical pulse bridging the gap between thought and action. It’s this dynamic interaction, this invisible symphony of electrical rhythms, that helps us achieve everything from simple movements to the most complex feats of creativity and self-control.

To be fair, much of the detail about how the information in our brain is processed through this network remains a mystery, but what we do know is that damage to any part of it has serious consequences for how we think and move. And Parkinson’s disease is one of those consequences.

Our discovery that many patients with Parkinson's disease struggle with planning because of issues relating to their basal ganglia was one of the first clues that executive functions are not solely the purview of the frontal lobes—they arise through interactions *between* the frontal lobes and other areas of the brain. And that was likely why the exact nature of the planning problems we saw in patients with Parkinson's disease was different from that of our patients who had undergone surgery to remove part of the frontal lobe itself. The problem seen in Parkinson's patients was not with the frontal lobes per se, but with another area deep in the brain that provides information *to* the frontal lobes in order for them to plan effectively.

But why, exactly, was that information not coming through as loud and clear as it should?

The Dopamine Connection

Parkinson's disease is caused by the degeneration of brain cells that produce the neurotransmitter dopamine. More than one hundred different neurotransmitters have been identified in the human brain, and dopamine is one of the most famous.

Although it's commonly assumed that neurotransmitters are fluids, they are in fact microscopic molecules that transmit signals between neurons. These molecules are ridiculously small, around 23 octillion times smaller than the adult human brain (that's 23, followed by 27 zeros, by the way). Imagine them as tiny chemical droplets, far too small to see with the naked eye, suspended in the cerebrospinal fluid that surrounds and cushions the brain and spinal cord. This so-called extracellular fluid is a clear, watery solution rich in ions (like sodium, potassium, and calcium) and other molecules necessary for maintaining the delicate balance required for neural communication. The fluid acts almost like a conductive gel, facilitating rapid communication while protecting the brain's fragile structures.

When a neurotransmitter is released from a neuron, it travels across the synaptic cleft (the small gap between neurons) to attach itself to receptors on a neighboring neuron, thereby transmitting the signal between the two. Think of neurotransmitters as miniature keys, each designed to fit perfectly into their corresponding locks on the surface of neighboring cells.

Our nervous system controls everything, from the way we think to the way we move, as well as the functioning of all our organs. Dopamine is an important neurotransmitter in that process, one that is essential for the neurons in our brains and bodies; without it, they simply can't communicate with each other.

Your brain holds a mere few milligrams of dopamine, yet this small amount is vital for regulating mood, attention, and even movement. Dopamine is produced by the brain through a two-step process. First, it changes the amino acid tyrosine (which occurs naturally in soy products, chicken, turkey, fish, peanuts, almonds, avocados, bananas, milk, cheese, yogurt, cottage cheese, lima beans, pumpkin seeds, and sesame seeds) into a substance called dopa and then into dopamine. These tiny molecules of dopamine are released from specialized structures deep in the brain with fancy names like the substantia nigra and the ventral tegmental area; from there they are pumped across synapses—those narrow, microscopic gaps between neurons—before docking onto receptors on the receiving neuron.

The primary problem in Parkinson's disease is that cells in the substantia nigra begin to die and so they stop producing dopamine, starving the basal ganglia (and, to a lesser extent, the frontal lobes) of the very chemical they need to function effectively. As a result, problems with movement and thinking start to occur. We often think of thought and movement as two separate things, but Parkinson's disease reminds us how interrelated they are; both arise from the brain's complex networks of neurons and neurotransmitters.

As Parkinson's disease progresses, more and more cells in the substantia nigra die and less and less dopamine ends up in the basal ganglia. We don't know exactly why this happens, although many now believe that Parkinson's disease results from a combination of genetic and environmental factors, such as exposure to toxins. As the degeneration continues, symptoms worsen. And one of those symptoms is impaired planning ability.

Until 1960, there was very little that could be done to help patients with Parkinson's disease. But in 1960, a pharmacologist of Ukrainian-Austro-Hungarian origin named Oleh Hornykiewicz changed all that. With his colleague Herbert Ehringer, Hornykiewicz collected and dissected the brains of six patients who had died of Parkinson's disease and discovered that they all had a profound loss of dopamine in the basal ganglia.

The next obvious step was to try to find a drug that would increase dopamine levels in the brain. In November 1960, Hornykiewicz suggested to neurologist Walther Birkmayer that they try injecting Parkinson's patients with levodopa (or L-Dopa as it is often called) to see if it would replace the missing dopamine in the patients' basal ganglia and ameliorate their symptoms. Amazingly, bedridden patients were suddenly able to sit up, other patients were able to stand unassisted, and patients who had been unable to walk all started to move under the influence of levodopa. Eventually, an oral form of the drug was developed and sold under the brand name Sinemet. In the six or so decades since then, tens of millions of patients with Parkinson's disease have benefited from Sinemet and other forms of levodopa therapy.

Reading about all this in scholarly journals provided me with some important clues as to why Parkinson's patients have difficulties making plans and why those difficulties differ from those experienced by patients who have had parts of their frontal lobes removed. Tim Shallice had taught me that even relatively straightforward executive functions like planning were actually fiendishly complicated, and I was now starting to realize just what he meant.

What was the relationship between the frontal lobes, the basal ganglia, and dopamine that could produce this myriad of different planning impairments in different patient populations? In the case of Parkinson's disease, a shortage of dopamine in the basal ganglia seemed to be at the root of the problem. Dopamine depletion was causing bradyphrenia (slowed thinking), which in turn put the brakes on the ability to make plans and execute them. As we grandly stated at the time, "Accuracy and efficiency of planning may be mediated largely by mechanisms within the frontal lobes themselves, whilst speed of thinking may be modulated by neurotransmitter systems of subcortical origin." To put that in lay terms, we were suggesting that planning, as complicated as it is, can be disrupted in different ways by different types of brain damage.

Think back to my description of the Tower of London task and how solving even a simple puzzle involves many different cognitive processes, from scoping out the problem, to identifying subgoals, to deciding in what order to carry out those subgoals, to actually executing the entire plan. Our studies had shown that each of these different stages of planning is controlled by a different brain mechanism, or set of mechanisms, and so

different kinds of brain damage will likely interfere with planning in quite different ways. While surgical damage to the frontal lobes seems to lead to a failure to identify appropriate subgoals, or a tendency to execute them in the wrong order, the neurochemical imbalance that occurs in Parkinson's disease seems to simply slow down the planning process by interfering with the cognitive machinations that allow it to happen at all.

Genes, Smart Drugs, Implants, and Planning

How do these findings improve our understanding of executive function for the general population—those of us who are lucky enough not to have a brain injury or a neurodegenerative disorder like Parkinson's disease? Before I offer some answers to that question, it's important to note that your planning abilities probably depend in part on your genes. As part of our genetic makeup, we all have a gene that is an important contributor to how much dopamine we have in our central nervous system, including our brain. Whether the gene is “turned on” or not is controlled by what is called a polymorphism—a specific DNA sequence that can occur among different individuals or groups. One of these polymorphisms, or “variants,” leads to more activity in the gene that controls dopamine levels, meaning that some people naturally have a genetic makeup that leads to more dopamine in their brains than others. This has a particularly important effect on dopamine levels in the frontal lobe. Many studies have shown that either too little or too much dopamine is bad for planning, working memory, and many other processes that depend on the dorsolateral frontal cortex—for most of us, a middling level of dopamine is optimal. And whether you have this middling level of dopamine is based on your genetic makeup.

In our studies, Parkinson's patients who had more dopamine swishing around in their brains as a result of their genes did better on the Tower test than those with less dopamine. While the disease process had undoubtedly reduced their dopamine levels, the genes they were born with had gone some way to mitigating against this reduction, bringing them closer to that optimal middling level. Luck of the draw. Regardless of whether we are healthy or in the throes of a debilitating neurodegenerative disease, there is a fine balance going on in the brain, driven by genes, that influences how good or how bad we are likely to be at planning.

Could we change the odds to improve our chances of being a great planner? We already live in an age when genetic modification is possible and specific areas in human DNA have already been identified that seem to control our cognitive functions. Are we heading toward a future where so-called “smart genes” could be manipulated to make us better planners? While most scientists agree that it will probably be a long time before we can bioengineer cognitively enhanced human beings, the idea has certainly become more feasible with the recent development of CRISPR (clustered regularly interspaced short palindromic repeats). CRISPR is a new technology that enables geneticists to edit parts of the genome by removing, adding, or altering sections of the DNA sequence.

In the here and now, smart drugs may provide a more short-term solution to how we can optimize our mental selves. Barbara Sahakian, at Cambridge University, has recently reported that as many as one in five people are using performance-enhancing drugs for common tasks ranging from taking exams to giving presentations and conducting important negotiations. Drugs like dextroamphetamine (Adderall), methylphenidate (Ritalin), and modafinil (Provigil) improve cognitive performance, including planning. All of these drugs affect levels of dopamine in the brain.

It’s an ethical minefield, but as usual there are two sides to every story. While it may seem unfair for one undergraduate to get a pharmacological “leg up” in their final exams by taking a dose of modafinil, wouldn’t you prefer your brain surgeon to optimize her ability to plan your tumor removal by doing the same? And what about the military? Or air traffic controllers? All these people have jobs that impact our lives in one way or another. Wouldn’t we prefer them to be at the top of their game when it comes to their work?

Sooner or later, we will also have to consider the efficacy and ethics of brain implants. Companies like Elon Musk’s Neuralink are working to develop new ways of stimulating the brain from the inside with arrays of electrodes that can be controlled with the flick of a switch. While this has obvious therapeutic possibilities for patients with disabilities, it’s no secret that a secondary agenda is brain augmentation through cognitive enhancement. While it may be some years before any of us are able to sign up for a voluntary brain implant to improve our ability to plan effectively, the possibility is certainly in the offing. Implanting a tiny chip loaded with

millions of lines of code into a healthy brain to optimize our ability to make plans is not as far off as it may seem.

It's been more than twenty-five years since IBM's supercomputer Deep Blue beat Garry Kasparov at chess, which is one of the most complex planning problems ever created. In another twenty-five years, we may all be able to do the same by simply turning on that little chip in our heads. Let us hope that our enhanced planning abilities will not only help us to live more fruitful and successful lives, but, more importantly, help us to tackle the many seemingly intractable issues facing the planet, from global warming to poverty to the quest for world peace.

And if you don't want to take cognitive enhancing drugs, have your genes manipulated by CRISPR, or have electrodes planted in your brain by Musk and Co., you still have options. Planning, like any cognitive skill, can be strengthened with the right habits and mental scaffolding. One of the most robust findings from psychology is that simply *making a plan*—and ideally writing it down—can dramatically increase the odds that you'll follow through on your goals. These “implementation intentions” act as cognitive triggers, priming your brain to act when the right moment arises. Regular physical exercise, particularly aerobic activity, has also been shown to enhance prefrontal function and improve planning ability, even in older adults. Sleep is another nonnegotiable. We know from neuroimaging studies that sleep deprivation reduces activity in the dorsolateral prefrontal cortex—the very region that is critical for planning. Likewise, high levels of stress can compromise your ability to forecast, sequence, and regulate behavior, so carving out even brief moments of mindfulness or reflection in a busy day is not a luxury—it's brain maintenance. The truth is you don't need to be a superhuman to plan like one. You just need to give your executive brain the basic conditions it thrives on: structure, rest, movement, and a bit of strategic foresight.

In short, whether you can plan effectively doesn't just depend on whether you still have your frontal lobes or sufficient dopamine swishing around in your basal ganglia; it depends on how well you use what you *do* have. We all know people who'd like to achieve great things, but drift through life with no clear plan for how to realize their dreams. One minute they're set to begin a career-changing course in clothing design and the next they've canceled the course and nipped off to Ibiza for a once-in-a-lifetime beach party. Likewise, we've all met people whose lives seem so on track

that it can't have happened without a carefully thought-out plan. Where do each of us lie on that spectrum? Are you a dreamer or a planner? In my opinion, you need a bit of both. Even Aman Kassaye's ostentatious heist began as a dream, and if you can't dream, you can't scheme.

Planning and dreaming are two sides of the same creative coin, intimately connected in ways that make both imagination and human innovation possible. When we plan, we mentally simulate possible futures, considering steps, obstacles, and outcomes—engaging the same neural circuits that allow us to dream. Dreams, whether they're the kind we encounter when we sleep or the hopes we have for our lives, are mental rehearsals for what could be, opening a realm of possibilities that fuel our motivation to shape and plan our future. Whether it's a great artist sketching out the next masterpiece or an accomplished inventor mapping out an idea for a new technology, dreams drive their plans, shaping reality with their minds before they ever pick up a brush or a blueprint. Without our ability to dream and plan, our capacity for imagination and creativity would be far more limited, bounded by the here and now instead of the infinite expanse of what might be.

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3

Inhibition

Taking Control of Your Brain

Remember not only to say the right thing in the right place, but far more difficult still, to leave unsaid the wrong thing at the tempting moment.

—BENJAMIN FRANKLIN

When I was a young child, my family had huge Christmas gatherings. My grandfather, Bert, was notorious for having a little too much whisky after dinner. Bert, a brilliant grandfather, was always funny. Ensconced in an armchair, pipe in hand, he giggled at his own jokes, which were, for the most part, family friendly. After a couple of whiskies, however, the jokes would turn a little risqué—delighting us kids, but often horrifying our parents.

Bert's naughty jokes didn't have any discernible effect on his behavior or on his life in general; if anything, they just made us adore him more. But that isn't always the case. Our inability to inhibit ourselves can have a disastrous effect on our lives. Inhibition allows us to resist temptation, suppress impulsive actions, and maintain focus on our long-term goals. But when it goes wrong, all that falls apart.

Inhibition (or “inhibitory control,” as it is often called by neuroscientists) is widely considered one of our most important executive functions because it's key to almost every decision we make and almost everything we do. It shapes our destiny. It can be immediate and focused on a short-term goal (“I could eat that last piece of cake, but I'm going to resist

the desire to do so”), or it can be a pattern of behavior that, over time, yields a desired outcome (“If I inhibit my tendency to spend money every time I enter a clothing store, eventually I will save enough for a vacation”). When we inhibit a response, we are generally aware that we are doing so; that is, it is a component of our *conscious* behavior and something that, for the most part, we have some control over (hence “inhibitory control”).

Understanding and honing this mental superpower is key to mastering the delicate art of self-discipline and achieving the goals that matter to us. It is crucial for helping us navigate difficult situations, and it gives shape, agency, and purpose to our lives.

A Freudian Slip

It’s worth noting that this view of inhibition is relatively new. A long tradition in psychology, promoted by influential thinkers such as Sigmund Freud, Carl Jung, and Wilhelm Reich, cast inhibition as a wholly negative contributor to the human psyche. According to Freud, inhibition is a defense mechanism that our minds use to deal with conflicting desires or uncomfortable emotions; in particular, he saw it as our way of dealing with conflicts between what we want and what society expects from us. Freud believed that these inhibitions often stem from our unconscious, where memories are stored that we’re not fully aware of or may not want to confront. Freud’s disciple, Carl Jung, thought that inhibition comes from hiding parts of ourselves, such as our deepest fears or desires, in our subconscious minds. Wilhelm Reich, on the other hand, believed that inhibition is linked to how tense or relaxed our bodies are. He thought that holding back our energy and emotions could make us tense, causing problems in our bodies and minds. So, while they all had different ideas, Freud, Jung, and Reich all agreed that inhibition can negatively affect how we feel and behave, whether it’s about our desires, our minds, or even our bodies.

Dial forward a hundred years or so, and contemporary neuroscience has a very different take on the matter. While Freud and his peers correctly saw inhibition as a crucial part of how our minds work, shaping our behaviors and personalities in ways we might not always understand, in many instances these influences can be positive, as well as negative. Inhibiting the

urge to buy a lottery ticket when you know the chances of winning are a million to one will save you ten bucks. Inhibiting the urge to get into a fight with the aggressive idiot who's goading you on the street may even save your life. Not responding to the flirtatious come-on from a stranger will keep you out of the divorce courts. The truth is, in most (though not all) instances, inhibitory control is a *good* thing. Our brains have evolved to have some inhibitory control over our more basic instincts, habits, and desires because it is evolutionarily advantageous to have this control. Freud, Jung, and Reich weren't completely wrong, but I do think their collective moral compass may have been a few degrees off true north.

Inhibiting Instincts

Broadly speaking, there are three types of actions that we need to inhibit in life: instincts, habits, and desires.

Historically, psychologists have often discussed and investigated inhibition as a voluntary or involuntary "brake" that we use to control our instinctive responses. An *instinct*, if taken literally, is an innate, typically fixed pattern of behavior in response to certain stimuli. Many fears and phobias are instinctive. Ophidiophobia, or fear of snakes, is a good example of an instinctive fear; faced with even the friendliest-looking snake in the wild, many of us will turn and run without even thinking about it. Our instinct is to run away. But to a large degree, part of being human involves inhibiting our instinctual responses, whether it's resisting the urge to grab an enticing snack or the temptation to interrupt a colleague with your next big idea, and we are able to do that because of our exceptional frontal lobes.

Human beings are somewhat unique in this regard. Reptiles like Scale, my son Jackson's pet bearded dragon, don't have much of a frontal lobe (in fact, Scale has none at all). If you put food in front of him, assuming he isn't already sated, he can't stop himself from eating it. Scale is more or less a slave to his instincts. Now travel up the phylogenetic chain a little bit and consider Ronnie, our family dog. She also doesn't have much in the way of a frontal cortex—only around 10 percent of her brain is frontal lobe, compared with one-third in humans. Ronnie wasn't able to stop herself chasing squirrels until she had been quite well trained, and even now you

can see she has to use every last ounce of whatever mental control she has to stop herself from tearing off her leash to pursue them.

In apes, there is good evidence for some inhibitory behavior, but it is still not well developed in the way it is in (most) humans. Indeed, it is only when you get to humans (with our relatively huge frontal lobes) that you see this executive function in all its glory. In fact, some people are almost superhuman in their capacity to inhibit. Think about protesters who go on hunger strike—they will not eat, even though they know that starvation will kill them. Yet somehow the value they are able to assign to whatever cause they are striking for overrides their biological (instinctual) need to eat.

The modern study of instincts began in the 1930s with the emergence of ethology (the academic name given to the study of animal behavior). When advanced technologies such as fMRI became available in the 1990s, neuroscientists began to be able to chart the complex neural circuits that underlie instinctual behavior. Instinctual reactions often involve the rapid processing of sensory information (what I am seeing, hearing, touching, tasting, or smelling) and the initiation of an appropriate motor response. Sensory areas of the brain gather information from the environment, and motor areas execute the required response, often bypassing higher cognitive processes for swift action. This is exactly what happens when we catch a ball that is thrown at us unexpectedly. Although in other circumstances (throwing a ball around with friends) we may be able to consciously *decide* to catch a ball, when it's thrown at us unexpectedly, we sacrifice conscious control for speed and efficiency (if we stopped to think about it, we'd get it in the face before we had time to act).

Instincts are often hardwired, meaning that they are innate, or genetically programmed, rather than learned through experience and over time.

Inhibiting Habits

Not all types of inhibition are in response to something that is instinctive; we often have to inhibit ourselves to overcome something that is simply a force of habit. My wife and I recently moved my son Jackson, who is eleven years old, to the spare room for a few weeks while we redecorated his bedroom. Night after night he would climb the stairs at bedtime and turn

right toward his bedroom rather than left toward the spare room. “Duh!” he would say when he realized his mistake, slapping himself, open-palmed, on his forehead. In fact, one night he became so frustrated with his repeated error that he announced at the bottom of the stairs, “This time I’m going to concentrate and get it right!” Lo and behold, by the time he reached the top of the stairs he’d forgotten his pledge and failed to inhibit the habitual urge to turn right.

Unlike instincts, habits (like turning right at the top of the stairs) are not innate. They are formed through behavioral repetition and can become immensely powerful to the point that they may feel hardwired. From a neuroscientific point of view, habits are the brain’s way of saving energy—shortcuts forged through repetition that allow us to act without thinking. Deep in the brain, patterns of behavior are stored in the basal ganglia, which we encountered in the previous chapter on planning. When we brush our teeth, drive to work, or automatically reach for our phone, it’s often this system quietly calling the shots. Habits are wired into circuits designed for speed and efficiency, not reflection. Once a cue triggers a habitual routine, the desire can feel automatic, even primal. In many ways, habits are the domesticated cousins of instincts: learned behaviors that can run on autopilot, unless actively interrupted by our brain’s inhibitory system.

Inhibiting Desires

Inhibition is required to overcome instincts and habits, but it is also essential for effective day-to-day decision-making, which frequently involves inhibiting our desires. For example, we routinely make decisions that involve inhibiting what might be the most desirable short-term outcome in favor of the most practical, or advantageous (“I could respond to the guy who’s flirting with me at the bar, but that might put my marriage in jeopardy”).

Whether it’s a response to an instinct, a habit, or a desire, our inhibitory system works tirelessly to guide and coordinate other more automatic brain responses, ensuring that we emerge unscathed as the very best version of ourselves.

The Marshmallow Test

Like many of the brain's executive functions, inhibition comes into play rather late in development. As every elementary teacher knows, many kids under the age of ten have difficulty following classroom rules; they forget to raise their hands before speaking and have trouble staying seated even when repeatedly asked to do so. They impulsively grab toys from other children, act without thinking during a game, or make decisions without considering the potential outcomes. In childhood, this is completely fine and part and parcel of typical child development—as with my grandfather Bert, these minor inhibitory slips hardly alter the course of our lives. They do, however, offer a window into how our ability to control our actions and thoughts develops over time, showing us that our ability to inhibit our behavior is not innate and fixed at birth.

This phenomenon was beautifully illustrated by Walter Mischel's famous marshmallow test. Mischel, an Austrian-born Stanford University professor, developed the test in the 1960s, perhaps in response to the zeitgeist of a generation of young people who seemed bent on a level of instant gratification and self-indulgent behavior that appalled their elders. Mischel had been testing children's self-control through a series of experiments with treats like pretzel sticks or animal cookies. By 1972, marshmallows had become the reward of choice in his studies, and the marshmallow test was born.

Children around four years of age were placed in a room by themselves where they were presented with a choice: They could either eat the solitary marshmallow on the table in front of them immediately, or they could wait for the experimenter to return, at which point they would be rewarded with a second marshmallow. The results were fascinating. Some children gobbled down the marshmallow seconds after the experimenter left the room, while others displayed remarkable self-control, waiting up to fifteen minutes for the promised second marshmallow.

What made this experiment truly groundbreaking was its ability to predict future success. In follow-up studies, Mischel and his team found that the children who could resist the immediate temptation of the marshmallow went on to exhibit better academic performance, have healthier relationships, and do better in their careers. This tantalizing twist, connecting a child's ability to resist a single marshmallow with future accomplishments, unleashed a storm of public interest, and the

marshmallow test quickly found its way into parenting manuals, television shows, and stand-up comedy routines.

The marshmallow test has not been without its controversies. Some critics argued that it oversimplified complex human behavior, reducing it to a simple test of willpower. Yet, in my opinion, that is exactly the point. “Willpower” is just a colloquial term for our ability to exert inhibitory control, and studies like this show us that much of our everyday behavior results from a tug-of-war between our instincts, habits, and desires on the one side and our ability to exert inhibitory control on the other. When we inhibit a response, we are generally aware that we are doing so; we *feel* that we are in control. Inhibitory control (or willpower) enables us to override our immediate desires, emotions, and impulses in favor of more meaningful objectives, even in the face of obstacles or distractions.

In any case, the marshmallow test continues to be a cornerstone in the ongoing debate about nature versus nurture and the importance of teaching self-regulation to children. What began as a simple experiment has transformed into a symbol of the human struggle to resist temptation and delay gratification, offering us a much deeper understanding about the importance of inhibitory control.

Inhibition in the Brain

We’ve already seen some of the consequences of throwing caution to the wind. Some of us are prone to this type of behavior, while others appear much better at managing the primitive urges that drive them. We also saw what happens to football players like Max who, following a lifetime of repeated blows to the head, lose their ability to inhibit themselves in many situations.

Early in my career, I studied many patients whose brains had been damaged through surgery to try to understand these forms of disinhibited behavior. Although the picture wasn’t clear back then, evidence was already starting to emerge for the involvement of one particular part of the frontal lobes in inhibitory control. This region is known as the *inferior frontal gyrus*. Perhaps the best example was the elderly female patient I worked with who couldn’t keep her hands away from my crotch. Mr. Polkey had

recently removed her inferior frontal gyrus, suggesting a reason for her obvious failure to inhibit herself.

The inferior frontal gyrus is part of the ventrolateral frontal cortex, which, as we've seen, is a broad strip on the lower outer flank of each frontal lobe. It is a ridged area that extends from the bottom "corner" of the frontal lobe to approximately one-third of the way up the brain, where it ends at a deep groove known as the inferior frontal sulcus. Importantly, the inferior frontal gyrus is closely connected with many other brain regions, suggesting that it is intricately involved in multiple aspects of how we think and feel.

Four decades after Walter Mischel's marshmallow studies, the brains of several of those children, now in their midforties, were scanned using fMRI. Instead of waiting to eat a marshmallow, the adults had to press a button as quickly as they could when they were presented with a happy face and resist pressing the button when they were presented with a sad face (or vice versa). The experimenters assumed that marshmallows would no longer be a lure for forty-year-olds. The findings were remarkable. Resisting (or inhibiting) a response was associated with brain activity in the right inferior frontal gyrus. Moreover, participants with consistently low levels of inhibitory control, measured from their childhood performance on the marshmallow test, had diminished activity in this area of the brain compared with those who had shown high levels of inhibitory control as children.

This long-term follow-up study was important for three reasons. First, it showed that resistance to temptation (inhibitory control) is a relatively stable individual difference that is evident in early childhood and persists through to adulthood. Second, it provided compelling fMRI evidence for which part of the brain is responsible for inhibitory control—the inferior frontal gyrus. Third, it showed that this region is less active in individuals who (as both children and adults) have difficulty resisting alluring rewards.

Indeed, we now know from numerous fMRI studies in healthy humans that the inferior frontal gyrus allows us to put the brakes on in any situation that requires it. The double trouble task we gave to Max, our NFL superstar, is a perfect example. When we see the word "RED" written in a red font, it's relatively easy to name the color of the font (red in this case), because there's nothing to inhibit. But when we see the word "RED" written in blue, it's much harder to name the color of the font correctly because we have to

suppress (inhibit) the urge to just read and respond to the word we see before us (“RED”). This is because we are very practiced at reading words; we do it all the time, many hundreds of times a day. But how often do we have to name the color of a font? Hardly ever. Over time, our brains have become rewired to automatically read words (and we do this in milliseconds), and so to not do so requires effort. And that effort, where double trouble is concerned, requires inhibition. Unsurprisingly, therefore, this task also activates the inferior frontal gyrus when healthy participants attempt to do it in the fMRI scanner.

There are a couple of small caveats to address here. Although the inferior frontal gyrus does appear to provide the “brake” that allows us to inhibit unwanted actions and thoughts, that’s just one example of what this part of the brain is capable of. fMRI studies from my own lab have shown that the inferior frontal gyrus helps us to enact any kind of conscious response, from selecting among scrumptious desserts, to intentionally committing a favorite moment to memory, to pulling that memory back into consciousness so it can be enjoyed again much later. And as we have seen, one specific example of this is our ability to suppress or inhibit those same actions and thoughts.

A second issue—which will come up throughout this book—is that, like other regions of the frontal lobe, the inferior frontal gyrus does not act alone; it is heavily connected to many other brain regions, sending and receiving signals in the service of our executive functions. One of the most important connected regions is the orbitofrontal cortex, a cortical region that is literally the underside of the front of the brain, immediately behind the eyes. The orbitofrontal cortex plays a fundamental role in understanding the “rewards” and “punishments” associated with different behavioral choices. This role is a crucial part of inhibitory control, because knowing when to inhibit and when to just let go depends on how important any particular choice is to us, and that depends on the “value” we place on our choice.

The term “value” crops up in many neuroscientific studies and refers to the perceived worth or importance of a stimulus, action, or outcome, often in terms of the reward it promises or the risk it carries. This can be a simple pleasure, like the value of a favorite food, or more abstract, like the long-term value of a career goal or a political idea. Importantly, the value of any stimulus can change with the circumstances. For example, the value we

place on a hamburger might be quite different when we are hungry than when we are not.

As someone who is lactose intolerant, I am constantly picking and choosing what I can and can't eat, and often, when faced with a tray of delicious desserts, I have to weigh the pros (a yummy dessert) versus the cons (stomach cramps and a gassy night in the spare bedroom) of eating them. Put simply, my orbitofrontal cortex assigns a value to each dessert I encounter, and because stomach cramps and a gassy night won't actually kill me, on some occasions the "reward" associated with a particularly tasty dessert will trump the "punishment" associated with it, and I'll tuck right in, despite the consequences. If I'm very hungry, the reward value associated with eating a lactose-laden dessert more easily outweighs the punishment I will endure as a result, and inhibiting the urge to eat it becomes harder. The orbitofrontal cortex does not store these values in the way that data are stored in a computer, but calculates them based on the here and now by integrating information from the outside world (does this contain lactose?), my current state of being (hungry or not), and my previous experiences (stomach cramps).

Let's consider again the case of Stephen, the young man who had a rare tumor removed from his orbitofrontal cortex. Much of his subsequent behavior, from his abuse of complete strangers to his defacing of every public surface he could get his hands on, can be understood in terms of a failure to weigh the pros and cons (rewards and punishments) of his actions. For example, the reward associated with spraying a clean wall with explicit graffiti (the pleasure in knowing that his piece of "art" would catch the eye of a passerby perhaps?) had greater value to him than the punishment associated with his behavior (he might get caught, fined, or even thrown in jail). In essence, he couldn't inhibit his tendency to behave this way, not because it was irresistible per se, but because he had assigned a value to the behavior that was different from the one most of us would give it.

So while the inferior frontal gyrus is the main area of the brain responsible for inhibitory control, it does this by working closely with a neighboring part of the frontal lobe called the orbitofrontal cortex to make on-the-fly decisions about when to put the brakes on and when to just go with the flow. This close relationship between these two areas of the frontal lobe is crucial when it comes to making decisions, because knowing the

value of potential outcomes can change a situation from one in which inhibition is required to one in which it is not.

Imagine you are in your car and approaching a yellow traffic light, and you know it will turn red before you can make it safely across the intersection. If stopping has no consequences (perhaps you are in no particular hurry to get anywhere), it's a low-value decision, and pulling up at the light is effortless. But imagine approaching the same light while your wife is in the back seat about to give birth to your first child. Now running the red light has a higher value (you'll make it to the hospital in time), whereas stopping comes with a considerable penalty (she might end up giving birth in the car). Because the orbitofrontal cortex has associated each possible outcome with a value, one much more positive than the other, running the red light becomes much more attractive and thus harder for your inferior frontal gyrus to inhibit.

Whether we are tempted or not to play the lottery is another good example. As the potential winnings increase week by week, the urge to buy a ticket goes up for most of us; it's harder to inhibit blowing a few dollars because *the value of the potential outcome has increased*, even though we are well aware that our chances of winning have not changed (in fact, they have often got worse, because more people have bought tickets). But if our orbitofrontal cortex assigned no value to monetary gain, then our inferior frontal gyrus would have no problem inhibiting our urge to buy a ticket based solely on our meager odds of winning.

Failures of Inhibitory Control

If the inferior frontal gyrus is the brake that allows us to inhibit automatic or undesirable actions and thoughts, what happens when it goes wrong? Problems with response inhibition have been associated with conditions such as ADHD, the most common neurodevelopmental disorder, affecting around 9 percent of children between the ages of two and seventeen. Cognitive challenges are a defining symptom of ADHD, and in some patients, serious deficits in intellectual function that accompany their attentional difficulties contribute to problems at work, at school, and at home.

In 2022 alone, 41.4 million prescriptions were dispensed for the ADHD drug Adderall in the United States, a 10 percent increase from 2021. This apparent rise in the incidence of ADHD has not gone unnoticed by regulators. Indeed, there have been numerous recent crackdowns, particularly among digital telehealth companies, who have come under significant scrutiny regarding the processes they employ to diagnose ADHD; some have even been forced to shut down entirely. The methods used to diagnose ADHD range from simple and subjective approaches like questionnaires and clinical interviews to full-blown neuropsychological examinations that can take many hours. There really appears to be no “industry standard,” which is frustrating for patients, parents, and physicians alike.

To solve this problem, Conor Wild, a research associate in my lab, recently looked at whether tests like double trouble might provide a more accurate and objective way of spotting the early signs of ADHD. What he found was remarkable.

Conor examined over one hundred scientific publications that reported a statistically significant difference between individuals diagnosed with ADHD by a health care professional and individuals from a healthy control population. Across studies, it was clear that there were a number of key “markers” of the condition—that is, changes in cognitive performance that distinguished people diagnosed with ADHD from the general population.

One of those markers was how quickly ADHD patients responded on the double trouble task: They were slower, specifically when confronted with one of the more difficult problems (the word “RED” written in a blue font, for example). In other words, they were slower whenever response inhibition was required but responded at a normal pace when it was not.

Conor then took this marker along with several others he had identified in a similar way and combined them into a new cognitive tool for identifying ADHD. To validate the new tool, he then examined the performance of almost eleven thousand adults who had taken the tests on our online cognitive assessment platform at Creyos.com and found that it could reliably discriminate between those who had been diagnosed with ADHD and those who had not. A similar difference was also found in a smaller group of kids with ADHD.

Through the sheer power of numbers, Conor had developed a simple twenty-minute test for ADHD that could potentially replace the months of

questionnaires, clinical interviews, and neuropsychological examinations that are typically required to reach the same conclusion.

The exact reason why kids and adults with ADHD are impaired on tests like double trouble is not known, although a dysfunctional right inferior frontal gyrus might contribute to these problems. Interestingly, the drug methylphenidate (Ritalin) significantly improves the ability of adults with ADHD to inhibit behavioral responses on similar tasks. Another ADHD drug, atomoxetine (Strattera), when given to healthy participants for testing purposes, increases brain activity in the right inferior frontal gyrus when they attempt to inhibit a response. These observations suggest that drugs like Ritalin and Strattera exert their beneficial effects on inhibitory control in patients with ADHD by temporarily “repairing” their dysfunctional right inferior frontal gyrus.

The inferior frontal gyrus is also one of the last brain regions to emerge in both developmental and evolutionary terms. In one study, fMRI was used to compare kids aged eight to twelve with adults on a test similar to our double trouble task. Not only were the kids less able to inhibit an incorrect response but, unlike adults, they also failed to activate the inferior frontal gyrus when doing so. This suggests an explanation for my eleven-year-old son’s forehead-slapping “Duh!” moments, as yet again he heads off toward his half-decorated bedroom. His inferior frontal gyrus has yet to fully mature. Indeed, immature development of this part of the frontal lobe in children likely explains why they have so much more difficulty controlling their impulses than adults.

Concussion is another common condition that has been strongly associated with failures of inhibitory control. According to the Center for Disease Control and Prevention, an estimated 1.7 million traumatic brain injury (TBI) cases arise every year, with 75 percent receiving a diagnosis of concussion or another form of mild TBI.

As we saw in Max’s case, retired NFL players may be particularly vulnerable due to the impact of repetitive head injuries sustained during their football careers. Retired NFL players have been found to exhibit difficulties in regulating behavior, controlling impulses, and maintaining attention, which are core components of inhibitory control. These deficits may manifest as impulsivity, disinhibition, and difficulties with decision-making, affecting many aspects of their daily functioning and quality of life.

I first became interested in this relationship several years ago when we scanned Max, although it was only more recently that I got to investigate it on a much grander scale. In 2020, we launched an online study to investigate the long-term cognitive effects of concussion in the general population. We ran a few ads on social media, and I was pleasantly surprised to find that almost twenty thousand people signed up from all walks of life and from many different countries around the world.

We asked our participants whether they had ever had a concussion, and if so, how many. We then gave them twelve cognitive tests from our online cognitive assessment platform at Creyos.com. The tests have been taken more than twenty million times, so we have a very good understanding of the difference between a typical, healthy performance and one that is outside the norm. One of those tests was double trouble, the test of inhibitory control that Max had struggled with several years previously and the same test that kids and adults with ADHD have particular difficulty solving.

Other tests in the battery looked at memory, problem-solving, reasoning, and verbal skills, providing a well-rounded assessment of each participant's cognitive performance. Amazingly, 3,750 of our participants reported having had at least one concussion—that's almost 20 percent of our test population. Moreover, the number of concussions reported ranged from just one to an incredible eighteen.

When we examined the cognitive performance of our participants, we were surprised to find no impairments whatsoever on eleven of our twelve tests among those who claimed to have sustained a concussion. Their memory, problem-solving ability, and reasoning were all fine. What wasn't fine was their inhibitory control. In those who had sustained a concussion, a significant impairment was found in just one test—double trouble. What's more, the severity of the impairment was directly related to the number of concussions reported: The more concussions a person had incurred, the worse they performed on double trouble.

We wanted to go one step further than simply documenting the incidence of concussion in the general population and its effects on inhibitory control: We wanted to make a *prediction*. We predicted that our simple little test of inhibitory control—double trouble—would be able to detect the long-term effects of a blow to the head, even in people who hadn't reported, or simply weren't aware of, having had a concussion in the

first place. To test this, we needed a group of volunteers who routinely banged their heads together—and what better place to turn than the varsity football team at my own institution, Western University. In exchange for beer and pizza, seventy-four football players signed up to the study along with a smaller group of varsity rowers. The rowers served as a perfect control group because, like the football players, they were young and fit, yet unlike the football players, they rarely sustained any blows to their heads.

Our prediction was spot on. The varsity football players were impaired on just one test—double trouble—while the rowers were not impaired on any test at all. In fact, during the test, the footballers were making an inhibitory error approximately every eight seconds! Despite these measurable impairments in one of their key executive functions, most of the players continued to deny that they had ever been concussed, probably because their return to the field (and in some case, their professional careers) depended on it.

We had again used the power of numbers to accumulate yet more evidence that those of us who participate in activities that involve regular blows to the head are more likely to experience problems with inhibitory control. Of course, this goes well beyond football. Impairments of inhibitory control have been reported in retired soccer players, hockey players, boxers, wrestlers, and individuals who indulge in other activities that commonly involve repetitive mild head trauma (“head banging”).

The importance of these findings is not only what they indicate about inhibitory control. It has been understood for decades that participation in certain sporting activities may increase an athlete’s risk of developing a neurodegenerative disease later in life. This relationship was first noted in boxers. By the 1970s, signs of dementia were evident in significant numbers of retired boxers, but studies of their brains after death revealed a specific pattern of neurodegeneration that differed from other dementing conditions such as Alzheimer’s disease. Over the next few decades, similar findings were reported for other sports, but the effects were often most pronounced in those who had sustained more blows to the head during their sporting careers. In soccer, for example, the severity of neurodegeneration has been related to the number of times a professional player has headed the ball, so defenders (who head the ball frequently) are more prone to this disease than forwards or goalies (who hardly head the ball at all).

Eventually, the term “chronic traumatic encephalopathy,” or CTE, became commonplace for describing these disturbing brain changes and the cognitive degeneration that accompanies them. CTE usually appears in midlife, after the athlete has retired from the sport, and often begins with the family noticing cognitive changes, including problems with inhibition. Some individuals with early CTE develop problems with drug abuse as a consequence of their loss of inhibitory control caused by the neurodegenerative disease. Later on, these problems worsen, and difficulties with movement and speech emerge, followed, in many cases, by full-blown dementia. Alarming, the average age of onset is around forty-three years, much earlier than other forms of dementia. Scientists at Boston University recently announced that they had found evidence of CTE in the brains of all twelve deceased NFL players they had studied. Like Max, many of these players had experienced problems with thinking and memory, mood swings, aggression, and failures of inhibition. And as with Max, the problems gradually worsened and the lives of these players mysteriously fell apart.

Unfortunately, I lost touch with Max some months after we scanned him. Given his behavior on our double trouble task and the extent of his apparent failures of inhibitory control, it’s likely he is no longer with us. In advanced stages, CTE can result in significant brain shrinkage and loss of neurons. This extensive neurodegeneration leads to severe cognitive impairment, including memory loss, dementia, and profound behavioral changes such as aggression and depression. Max was already showing signs by the time we scanned him. The disruption of critical brain functions eventually impacts basic life-sustaining processes. Patients may suffer from difficulties in coordination, swallowing, and breathing. These complications can result in fatal outcomes, often due to infections, respiratory failure, or other health conditions exacerbated by deteriorating brain function.

Inhibitory Control and Dementia

We’ve recently investigated whether our double trouble test of inhibitory control can also predict the onset of dementia in the rest of us—that is, even those of us who haven’t made careers out of banging our heads together.

Specifically, we wanted to know whether we can predict dementia before there are any obvious physical or mental signs of the disease.

Why is spotting the earliest signs of dementia so important? Perhaps you are thinking: There's no cure, so what can be gained from knowing what's to come? Many lifestyle choices have been linked with brain health and specifically with the risk for dementia. Blood pressure and diabetes, for example, are known risk factors for dementia that are modifiable, either with drugs or smarter lifestyle choices. Detecting the likelihood of dementia early maximizes the chances that such interventions might be effective in preventing, or at least holding back, this awful disease. More than one hundred anti-Alzheimer's drugs are currently in clinical trials worldwide, and many of the results suggest that early intervention is going to be most effective.

On the flip side, recent FDA-approved drugs for conditions like Alzheimer's present many challenges, not least of which is their considerable cost and potential for unwanted side effects. Treating a patient for Alzheimer's disease could have disastrous effects if that patient is simply showing the natural signs of cognitive wear and tear. So correctly predicting who will *not* go on to have Alzheimer's disease is just as important as predicting who will. If double trouble, our little test of inhibitory control, could play any role in that, it would be a huge step forward because unlike blood tests, genetic screening, or expensive brain scans, a simple five-minute online test of executive function costs almost nothing and can easily be administered to huge numbers of people.

In 2023, it was again Conor Wild working in my lab who took this idea and ran with it. Conor is an expert at machine learning, a technique that allows computers to learn from data and improve their performance on a task over time without being explicitly programmed. Instead of writing specific instructions for every possible scenario, machine learning algorithms can analyze large amounts of data, identify patterns, and make predictions or decisions based on those patterns.

Using our cognitive tests at Creyos.com, Conor trained his machine learning algorithm to spot the difference between a group of twenty-two thousand healthy participants and a group of almost four thousand patients who had attended a neurology clinic worried about their cognitive health. Once the algorithm had been trained, Conor could then test it on different populations to see how well it could make the classification when all it had

to go on was their cognitive scores. Remarkably, the classifier was able to accurately spot dementing patients more than 80 percent of the time using the results of just two of our tests. One of those tests was double trouble, suggesting that early failures of inhibitory control in the general population may predict the onset of dementia further down the line. If so, it will be a game changer in the race to detect, prevent, and treat neurodegenerative conditions like Alzheimer's disease.

What About the Rest of Us?

We've discussed how clinical conditions like ADHD, concussion, and dementia can all involve failures of inhibitory control, but even those of us fortunate enough to remain healthy throughout our lives will experience the occasional inhibitory lapse. We began this chapter with Bert, my grandfather, who would delight my family with a few risqué jokes after one too many whiskies at Christmas time. Alcohol has well-known disinhibitory properties, and fMRI studies have shown that it can dampen activity in the inferior frontal gyrus, which we have seen is crucial for inhibitory control. This neural dampening helps explain why, after a few drinks, we might find ourselves saying things we'd usually keep to ourselves or making decisions we'd later regret.

Benzodiazepines, prescribed for anxiety and insomnia, are also known to cause disinhibition in some individuals. While they have a calming effect for many, a subset of users may experience paradoxical reactions, including increased impulsivity and risk-taking behaviors, indicative of a failure of inhibitory control.

Cocaine, a powerful stimulant, has been shown to impair inhibitory control significantly. Functional imaging studies reveal that individuals with cocaine use disorder exhibit altered activation in brain regions responsible for impulse control, including the inferior frontal gyrus. This impairment can lead to a cycle of compulsive use and difficulty resisting the drug, even in the face of negative consequences.

In summary, even small amounts of substances like alcohol, benzodiazepines, and cocaine can impair our brain's inhibitory control mechanisms, reminding us of the delicate balance our brains have to maintain to keep our impulses in check—where even a minor disruption of

our frontal lobe executive system can tilt our behavior toward risk, impulsivity, and poor judgment.

Improving Inhibitory Control

As we have seen, good inhibitory control is valuable for various aspects of life—including making decisions, breaking bad habits, and achieving our goals. It is one area of executive function that has been studied extensively with respect to possible ways to improve it, including mindfulness meditation, which can make us more aware.

Practicing mindfulness can help some people become more aware of their thoughts, emotions, and impulses; by observing them without judgment, they are able to develop the ability to pause and choose their responses more deliberately, rather than reacting impulsively. Had Max only stopped and thought for a minute about whether getting involved in yet another bar fight would improve or worsen his current situation, he might have decided to stay home and not go to the bar.

Cognitive behavioral therapy (CBT) can also help individuals improve their inhibitory control by teaching them how to recognize impulsive thoughts and behaviors before they take over. At its core, CBT encourages a pause—a brief moment of awareness between impulse and action—which is where self-control lives. For example, someone prone to angry outbursts might learn to identify the early warning signs of frustration, such as racing thoughts or muscle tension, and use practiced strategies like deep breathing or reframing the situation before reacting. Similarly, a person trying to resist the urge to overeat might be taught to distinguish between actual hunger and emotional triggers, such as stress or boredom, and to substitute the habitual snack with a short walk or a call to a friend. By making these internal processes visible and deliberate, CBT effectively strengthens the brain's "braking system"—the mechanisms of executive function that allow us to override automatic responses in favor of more thoughtful, goal-directed behavior.

I also have a few suggestions of my own on how we might better control our counterproductive and destructive impulses, beginning with setting clear goals. In one randomized trial of eighty-five undergraduates who were experiencing academic difficulty, an online structured goal-

setting program that required them to articulate their academic objectives and reflect on how to achieve them significantly improved their grades that term. In the chapter on planning, we saw that identifying goals and constructing a path to achieve them through a series of well-defined subgoals is one key to achieving what we want in life. It can also provide us with a sense of purpose and direction, making it easier to resist distractions and temptations (inhibitory control!) that divert us from our objectives.

Numerous psychological and neuroscientific studies, including the marshmallow test, have shown that those of us who are able to delay gratification are better able to exert inhibitory control when we need to. We can practice delaying immediate rewards for larger, long-term benefits.

Consistent routines can also reduce the need for constant decision-making and reliance on willpower. As we saw earlier, context is important for inhibitory control; when we are “hangry,” we are less able to make sensible food choices; when we are poor, the value we place on winning the lottery may change, affecting our ability to inhibit placing a bet.

We’ve also seen that our environment can affect how easily we are able to inhibit actions and thoughts. Alcoholics don’t do well in bars, and gamblers often fall off the wagon after a chance visit to a casino. Try removing or reducing temptations from your surroundings. For example, if you’re trying to eat more healthily, keep unhealthy snacks out of your home, making it less likely that you’ll give in to impulsive cravings. If the “penalty” associated with the “reward” of binge eating chocolate cake is that you simply have to open the fridge, then it will be harder to inhibit. But if you have to get dressed, get in the car when it’s minus twenty outside, and drive three miles through driving snow to the grocery store, you’ve tipped the balance in favor of successful inhibition. Improving inhibitory control is a skill that can be developed over time with practice and consistency.

I often think back and remember my grandfather Bert with considerable affection. His slightly unfiltered sense of humor, unleashed by a post-Christmas dinner whisky or two, was a gentle reminder that occasional lapses in inhibitory control aren’t always disastrous—sometimes they’re even endearing. But in other moments, and in other people, those same lapses can derail conversations, complicate relationships, or ruin entire lives. Inhibitory control, as we’ve seen, is the quiet mental brake that lets us steer rather than skid through our daily challenges. Without it, we interrupt,

we overreact, we act before we think. And yet, when it's too rigid, when we suppress too much, we risk missing opportunities for spontaneity, creativity, or connection.

Like all executive functions, inhibition isn't about perfection; it's about balance. Bert, thankfully, had found that balance and landed somewhere in the sweet spot—just risqué enough to raise eyebrows, but never so far gone that anyone took away his whisky.

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4

Attention

How We Stay Focused

The simple act of paying attention can take you a long way.

—KEANU REEVES

As I write this, I am sitting on an Air Canada Airbus A330, traveling from Heathrow in London, England, to the place that I now call home—the “other London” in Ontario, Canada. It’s a noisy flight, full of excited kids heading to Canada for their first taste of a North American vacation. But I am distracted, lost in thought about recent events. Just yesterday, I was back at Cambridge University—the place where I had done most of my research up until late 2010, when I moved permanently to Canada. It had been an emotional return.

Much of what we know about executive function today we know because of work conducted in Cambridge at the Medical Research Council’s Applied Psychology Unit (now called the Cognition and Brain Sciences Unit). We’ve already met former unit member Tim Shallice, who defined the entire field of research on planning and the frontal lobes. His colleagues at the unit were also responsible for the idea of “working memory,” overthrowing what was until then a long-held belief that all memories were either long term or short term. Another critical executive function—attention—has also been the subject of multiple groundbreaking

discoveries from the unit; my friend and colleague John Duncan was behind many of them.

I was at Cambridge to attend John Duncan's Festschrift—celebrating his retirement after forty-five years with the unit. Despite its name, a Festschrift is a very British kind of affair. Once your time for retirement comes, all those who have worked with you and admired you throughout your career turn up and give lectures in your honor, go out for a lavish dinner, and generally celebrate your greatness.

The word *Festschrift* is borrowed from the German, translating roughly to “celebration writing.” Originally, a Festschrift referred to a collection of essays written in honor of a scholar, typically marking a milestone like retirement or a significant birthday. The word's Teutonic roots give it a kind of intellectual gravitas—after all, it's hard to imagine something called “a booklet of complimentary scribbles” commanding much respect in academic circles. However, it was the British who took the concept and added tea, awkward speeches, and the occasional badly photocopied program into the mix. Yet it remains one of those words that feels unnecessarily serious for what often amounts to a glorified excuse for colleagues to reminisce and speculate about how much happier the honoree will be without departmental meetings.

At John's Festschrift, his well-known work on attention was the topic of many of the papers presented. Attention may seem like a rather niche subject for one scientist to base an entire career on, but it is in fact a sprawling area of scientific inquiry and a key executive function.

One thing that made John's Festschrift so memorable and moving was that it was held at the very place that he had done most of his research, a place that I had been a part of and that had made such a big impression on me as a young researcher. The unit began life in 1944 as part of Cambridge's psychology department. In 1952, its third director, Norman Mackworth, a British psychologist known for his work on boredom and vigilance, found it had outgrown the space available within the department. He noticed a pleasant Edwardian manor house on the city's outskirts, complete with steeply pitched tile roofs, red-brick chimneys, and a huge, beautifully landscaped garden. Mackworth immediately purchased the manor with his own money and informed the university that this was to become the Applied Psychology Unit (APU). I'm sure such things only happen in Cambridge.

For the next half a century, the unit had a very British influence on psychology. As its name implies, its speciality was *applied* psychology, generating psychological theories and tools that could be used to solve real-world problems, such as how much alcohol someone should be allowed to drink before they were deemed unfit to drive. When I worked at the APU, I tested an elderly local woman who had been participating in studies there for several decades. Evidently, she hadn't visited recently because she remarked that what I was asking her to do (complete the same double trouble task that Max, our NFL hero, would fail some years later) wasn't half as interesting as the activity she'd been asked to do during her last visit. Naturally, I was curious and asked her about the earlier study. "Oh," she said, rather excitedly, "a nice young gentleman made me drive around the block in his car while he sat in the back seat taking notes. And then he gave me two glasses of sherry and asked me to do it again!"

Some things about the APU haven't changed at all in the years since I left. In my day, the unit's payroll included an elderly gentleman called Brian, stooped and with thinning white hair, whose principal job was to make tea and coffee, which was ceremoniously served up on an equally ancient cart universally known as "the tea trolley." In 2024, Brian was long gone, replaced by a trendy new coffee machine; but a younger, keener version of Brian still swooped in to clean up the tea and coffee cups the moment they were set down.

The unit's Christmas pantomime was legendary—a very British tradition in which men seize the opportunity to slip into a dress, lipstick, and a wig and become their favorite female bombshell. Having spent my formative years at a boy's grammar school in the South of England, where such events were commonplace, nothing about the unit has ever seemed in the least bit strange to me. The pantomimes are still going strong and, I fear, will be until long after we are all gone. Indeed, almost every lecture at John's Festschrift began with a photo of him, usually dressed in drag, or channeling Ziggy Stardust—era David Bowie. It was a glorious celebration of his career, attitude, and life.

By the mid-1990s, purely psychological accounts of human behavior were starting to fall out of favor as more neuroscientifically motivated studies became the norm. Terms like "applied psychology" also fell out of fashion, and so, to move with the changing times, the Applied Psychology Unit was renamed the Cognition and Brain Sciences Unit, and its focus

shifted firmly from traditional psychology to what we now call *cognitive neuroscience*—a field that still embraces the core pillars of psychological theory, like working memory and attention, but investigates, refutes, or refines them through the lens of neuroimaging and other neuroscientific techniques. Many of the unit’s key scientists didn’t embrace this fundamental change in how they were required to go about the daily business of trying to understand human behavior and either left to find work at another institution or were gently nudged out by the unit’s new director, William Marslen-Wilson. What I have always admired about John Duncan is that rather than flee, he chose to adapt and used this revolution in neuroscientific methods to revisit some of his greatest discoveries in attentional research, but now using PET and fMRI. Indeed, John’s work is one of the main reasons why the unit has continued to be internationally renowned, making major contributions to our understanding of how every aspect of human behavior—including attention—emerges from the neural machinery of our brains.

Attention is one of the brain’s most dazzling superpowers—an intricate symphony of processes that lets us focus on what’s important while the rest of the world fades into the background. Imagine it as the mental spotlight you shine on what matters most in any given moment, helping you tune into a conversation at a noisy party, focus on a book in a crowded café, or filter out irrelevant details while driving down a busy road. But this spotlight isn’t one-dimensional; like several of the executive functions we’ve already considered (such as working memory), attention comes in multiple different flavors, each serving its own purpose and involving unique mental maneuvers.

Selective Attention and Your Attentional Spotlight

Ordinary, everyday attention of the sort you might be using as you read this book or watch a film happens automatically. A good movie grabs your attention and keeps a tight hold on it. Let’s use the popular family movie *Despicable Me*, as an example. As you watch *Despicable Me*, your attention darts around all over the place; it might be on Gru, the main protagonist, one minute as he explains his plot to restore his former status as the world’s

greatest villain, but then your attention moves to focus on his Minions as they wreak havoc on the other side of the screen.

For many years, psychologists and neuroscientists have referred to this phenomenon as our “attentional spotlight”—a metaphor to describe how our attention can be directed to specific locations, objects, or features, much like a spotlight illuminating particular areas on a stage. Whatever it is that we are attending to at any given moment has fallen within our attentional spotlight. And it doesn’t have to be something out there in the world, like a Minion on a movie screen; it can be something inside us, such as a thought, feeling, or desire. We have all had the experience of suddenly realizing we are hungry—our thoughts immediately turn to our growling stomach. This is how our attentional system works most of the time, flicking between the sights, sounds, and smells of the real world out there or the thoughts and feelings going on in the world inside our heads.

In 1995, John and American neurophysiologist Robert Desimone came up with a theory about how the brain accomplishes this type of everyday attention, which has become known as the “biased competition model.” This model suggests that our brains are constantly flooded with information, and attention acts like a filter, helping us focus on what’s most relevant or important at any given moment. Imagine your brain as a bustling marketplace where different stimuli compete for your attention. Stimuli that are more meaningful are like vendors with flashy signs, grabbing your attention first. However, other stimuli still have a chance to be noticed if they’re relevant to your current goals—like a vendor offering exactly what you’re looking for. This model helps explain how we prioritize and process information in a world full of distractions, allowing us to stay focused on what matters most.

One aspect of the biased competition model that’s important to grasp is the relationship between “bottom-up” influences (or biases, as they are referred to in the model) and “top-down” influences on attention. Bottom-up influences are like the vendors with flashy signs; the term refers to aspects of the environment that *bias* your attention toward them. Where vision is concerned, bright colors, sudden movement, and objects that are surprisingly big (or surprisingly small) may all bias your attention in their direction. Your hearing, on the other hand, might be grabbed by the sudden blast of a car’s horn or a baby crying. The same is even true of smells and tastes—that foul odor as you enter a room immediately grabs your

attention, as does the taste of biting into a rotten piece of fruit. We don't *choose* to attend to these things; they automatically grab our attention.

Bottom-up influences can even influence our behavior against our will. Imagine running for a bus, determined to get there before the doors close, when a loud explosion occurs behind you. Before you know it, you've stopped and turned toward the source of the blast, missing your bus in the process. That's because explosions are unusual and typically signal something bad that we might need to avoid. Biased competition saves you the time and effort that would be required if you were to consciously *decide* to choose between attending to the blast or catching the bus. What makes the blast more important? Over time, our brains learn what is commonplace and unlikely to pose much of a threat (a bus leaving without you) and what is unusual and best to be avoided at all costs (an explosion). The explosion grabs your attentional spotlight because that is the aspect of your environment that needs to be attended to. If you change the scenario and imagine yourself in a war zone running for the last bus that can take you to safety, biased competition may push your attentional spotlight in the opposite direction. The bus is now your only chance of survival, whereas explosions have become everyday occurrences and can largely be ignored.

In a nutshell, bottom-up biases grab our attention whether we like it or not—we don't decide to attend to them, and they are largely outside of our conscious control. Of course, you can consciously decide to ignore your baby's cry *after it's grabbed your attention*, just as you can decide to ignore the explosion behind you; but you can't consciously decide to not attend to either sound in the first place, because by then it's already well within your attentional spotlight.

Although most of the time our attention system is running in this kind of autopilot state, quietly responding to bottom-up influences, it's when we consciously choose to take control of our attention that its true executive powers kick in. These instances are top-down influences, also known as "selective attention." For example, if you're searching for your friend in a crowded room, your brain uses top-down signals to prioritize looking at people's faces over other aspects of the environment, because that's probably the fastest strategy to find your friend. Similarly, if you're preparing your tax returns, your brain might prioritize the documents on the desk in front of you, while filtering out distractions such as the radio playing in the background. Top-down influences direct our attention to

what's most relevant or meaningful to us at any given moment, whether it's listening to someone speak, reading a book, or driving a car.

Imagine you are back in the theater watching *Despicable Me*. Instead of sitting back and letting the film control your attentional spotlight, you decide to direct your attention. You might set yourself a simple task, like counting how many times a Minion appears on-screen. Assuming you could keep this up, the task would essentially hijack your entire attentional system, and the chances are you would recall very little about the movie's plot. That's attention messing with our memories. As we saw with working memory, what we choose to attend to stands a better chance of being remembered, and by extension, what we don't attend to stands less chance of being remembered.

This relationship between selective attention and working memory is best illustrated through studies in nonhuman species, many of whom show rudimentary forms of both types of executive function. For example, a rat in a rodent testing box can easily be trained to selectively attend to a stimulus (such as an abstract shape presented on a computer screen) in order to store it in working memory. Later, that same rat will show that it remembers the stimulus by selectively attending to it again, receiving a food pellet as a reward for its efforts. Likewise, monkeys can selectively attend to objects, faces, and locations in order to store them in working memory.

In 2024, Robert Desimone and his colleagues at MIT published a fascinating experiment that used a new methodology known as *optogenetics* to try to understand the brain's role in attention versus its role in working memory. The term "optogenetics" combines "opto," referring to light, and "genetics," pertaining to genes and heredity. Optogenetics is a cutting-edge technique used in neuroscience to control and manipulate the activity of specific neurons in the brain using light. Scientists achieve this by inserting light-sensitive proteins called opsins into the neurons they want to study or manipulate. The sizes of these components of neural hardware are impossibly small to imagine and vary a lot: Proteins are typically between 2 and 10 nanometers across, and the main part of neurons are a thousand times bigger, between 4 and 10 micrometers (about one-tenth the diameter of a human hair). How they get one inside the other is beyond me (although genetic tools are used to insert these proteins into the DNA of neurons, hence the "genetics" in "optogenetics"), but there have been many calls for a Nobel Prize for the neuroscientists who first worked out how to do this.

The opsins act as switches, allowing researchers to turn the neurons on or off with precision using pulses of light. By selectively activating or inhibiting neurons in this way, scientists can uncover the underlying neural circuits and mechanisms that govern certain behaviors, such as attention or working memory.

While optogenetics holds great promise for understanding and treating neurological disorders, it cannot yet be used in humans for practical and ethical reasons. In animal studies, fiber-optic cables can be implanted directly into the brain to deliver light, but this invasive approach is not feasible (or ethical) in humans. Additionally, the potential long-term effects of introducing light-sensitive proteins into neurons are not well understood, raising concerns about unintended long-term consequences or risks. Yet, the potential is there. In neuroscience circles there is much talk of using optogenetics to cure neurodegenerative diseases, psychiatric disorders, and more, hence the call for Nobel Prizes all round; but to be fair, many techniques in the history of neuroscience have been touted as the ultimate panacea, only to fade into obscurity once the next big thing comes along.

Desimone and his colleagues trained monkeys to perform a task that required both attention and working memory, but at different times. After seeing a set of dots move across a computer screen, the monkeys had to use their *working memory* to remember the direction in which the dots were moving. Then the animals were shown more moving dots, this time traveling in multiple directions. By selectively focusing their *attention* on the dots that were moving in the same direction as the first set they had seen, the monkeys earned a juice reward. Of course, none of this is easy for a monkey, and it can take months to train them to successfully accomplish such a task. Using a reward (like juice), each step in the process is taught, one at a time, until the monkey is able to combine them all together to complete the entire task.

While the monkeys performed this task, Desimone and his team monitored neurons in several brain regions, including the frontal lobe, and, using optogenetics, switched them off for a few hundred milliseconds at a time. They found that they could switch off neurons toward the back of the frontal lobe early, when the monkeys needed their working memory, without interfering with their ability to complete the task. But when they turned the same neurons off later in the trial, when the monkeys needed to focus their attention, the animals performed poorly.

In studies like this, where neuroscientists measure the electrical activity in neurons when something happens, like attention or working memory, the question that is always asked is “Did that change in activity *cause* the behavior or are the two events just *correlated* (that is, they occurred at the same time but neither *caused* the other)? Understanding the difference between correlation and causation is crucial in psychology and other sciences because it helps prevent erroneous conclusions. Imagine a school principal who notices that students who eat breakfast perform better academically than those who skip breakfast. She might conclude that eating breakfast directly causes higher academic performance. Yet, this is a correlation between two variables—eating breakfast and academic performance—and has no bearing whatsoever on causality. Perhaps smarter students know that eating breakfast is a good thing. Perhaps students who eat breakfast come from families with higher incomes, who can afford nutritious food and other educational resources, such as tutoring or a quiet study environment. Typically, where correlations are observed, there are many other explanations that do not require *causality*. But, if every time you flick a particular light switch the bedroom light comes on, you would be well within your rights to claim that your flicking of the switch was *causal*.

Commenting on his findings, Desimone said: “Optogenetics allows us to distinguish between correlation and causality in neural circuits. If we turn off a circuit using optogenetics, and the animal can no longer perform the task, that is good evidence for a causal role of the circuit.”

The discovery that at least one part of the frontal lobe is critical for attention, but not for working memory, reaffirms that these processes are different executive functions, dependent on different parts of the brain. Indeed, together they perform many tasks that push our executive powers way beyond what would be possible if they worked alone. Imagine the job of an air traffic controller who has to rely heavily on working memory to remember the positions, speeds, and altitudes of various planes under their control. That’s a whole bunch of four-hundred-ton bullets hurtling through the sky at around five hundred miles per hour. At the same time, they must maintain sharp attention to rapidly changing information, such as new instructions from pilots, weather updates, and incoming flight data through precise exchanges that leave no room for misinterpretation. An air traffic controller might need to quickly recall the exact location of a plane they

guided moments ago, while simultaneously monitoring and directing a new plane entering the same airspace. And they're doing all of this with split-second timing, knowing that even a tiny error could be catastrophic. The mental machinery required to handle these constant streams of data, anticipate movements, make quick decisions, and pivot from one task to another is staggering—and yet it's something a trained brain can do, almost seamlessly.

This has got to be the human brain's most incredible conjuring trick. When you consider the immense cognitive load involved in being an air traffic controller (and many other demanding jobs, for that matter), the brain's attention system truly starts to feel like magic. Underneath every split-second decision lies a vast network of interconnected neurons working in perfect synchrony, each firing off electrical impulses to relay tiny bits of information that will ultimately influence the final outcome. But our neurons aren't just sending these signals; they're making thousands of connections with other neurons across the brain, generating one enormous network of activity that gives rise to the laser-focused, quickly adapting, and infinitely flexible type of thinking that being an air traffic controller demands. Meanwhile, neurotransmitters like dopamine and norepinephrine feed the network, ensuring that signals are timely, precise, and on point.

Whether we're landing ninety planes an hour at Hartsfield-Jackson Atlanta International Airport or juggling the demands of three screaming kids and the daily grocery run, it's mind-boggling to think that this highly coordinated performance, honed over millions of years of evolution, can take place inside our heads. Each one of our eighty-six billion neurons has its own job, yet they work together in perfect harmony to create our experience of the world. And just as an entire orchestra generates a single listening experience for the audience, the actions of these billions of neurons coalesce into a single stream of consciousness for each of us, bringing order, focus, and clarity to the chaos of incoming sensory information.

Inattentional Blindness

While top-down influence, or selective attention, is an immensely powerful executive function, it can also lead to failures or lapses that can be both

amusing and disturbing. The now-famous basketball and gorilla experiment was first described by psychologists Christopher Chabris and Daniel Simons in their 2010 book *The Invisible Gorilla*. In the original experiment, participants were asked to watch a video of a crowd of people passing basketballs back and forth and count the number of passes. A person in a gorilla suit walks into the scene, pounds his chest, and exits. Astonishingly, many participants fail to notice the gorilla because they are focused on counting passes.

This phenomenon is known as “inattention blindness,” which can be devastating and sometimes fatal. In 2012, Matthew Grissinger, reporting on medical errors in Pennsylvania, described a case in which a nurse pulled a vial of the anticoagulant drug heparin from an automated dispensing cabinet, read the label, prepared the medication, and then administered it intravenously to an infant. The infant received heparin at one thousand times the intended concentration and died. The nurse had followed all the recommended procedures that are in place to avoid such catastrophes, but her attention was elsewhere as she mixed the drug, leaving her “blind” to the crucial detail that would have saved a young child’s life. In another case described in the same paper, a pharmacist entered a prescription for the anti-inflammatory drug methotrexate into the pharmacy computer. A dose warning appeared on the screen. The pharmacist saw the warning, bypassed it, and dispensed the medication as entered. As a result, the patient died. Because the warning was actively bypassed, we can be sure that it was acknowledged by the pharmacist, but because his attention was elsewhere, it didn’t register as important. These and other real-life errors are commonplace, both in health care and other industries, often with dire consequences.

In 2019, workplace injuries caused 105 million lost workdays in the United States alone, at a cost of \$171 billion. Amazingly, 95 percent of these accidents were attributable to cognitive slipups, many of them lapses of attention. We recently set out to investigate whether these lapses of attention could be predicted based on a person’s cognitive performance. Our reasoning was that if these lapses can be predicted, then they can be prevented. Before heading to work, a group of employees at a large public transport company who work in positions that could put others at risk (train drivers, bus drivers, and so on) were asked to complete three of our quick and engaging tasks at Creyos.com that measured different aspects of

attention. In one test, they were asked to spot the difference between two abstract shapes that got more and more complex as the test went on, pushing their attention to its limits. In another test, we asked the workers to decide whether two triangles presented on a computer screen were the same or different. Small changes in size and orientation required increasingly close scrutiny, testing their selective attention. In a third task, two similar or identical complex patterns were presented on a computer screen, one rotated relative to the other. Our participants had to mentally manipulate the two patterns in their mind's eye to decide if they were the same or different.

Only 38 percent of the people we tested performed well on all three tests, confirming that their attention was in good working order. The fact that 62 percent did not suggests that the majority of us do have occasional lapses of attention and that these can be detected with the right cognitive tools.

The people involved in these types of attentional lapses are often labeled as careless and negligent because they failed to see what should have been obvious and plainly visible; yet mistakes like this are often made by intelligent people who simply cannot explain the lapse afterward. Being able to predict the circumstances under which lapses are most likely to happen is therefore of paramount importance and could save lives.

Susceptibility to inattentional blindness varies between individuals—some of us hardly suffer from it at all, while for others it occurs frequently and shapes their days. People differ in their attentional capacity, or how much attention they need to complete a task. An expert pianist can play while having a conversation with a friend, but beginners have to devote every ounce of their attentional capacity to hit the right notes. When all of your attentional capacity is occupied in this way, it is more likely that you will miss things.

Relevance is another factor that likely accounts for individual differences in inattentional blindness. In a noisy, crowded room, you are more likely to notice when your own name is mentioned rather than a stranger's. Indeed, if there is enough going on, you would likely not notice the stranger's name at all. The stranger, on the other hand, would notice her name but be inattentionally blind to yours.

A final factor that may account for individual differences in inattentional blindness is expectation, and this is where selective attention really doesn't work in our favor. Imagine trying to spot your friend Peter in

a crowd at a football game. When he left you at the bar to return to his seat, he was wearing a red jacket. You carefully search the crowd, selectively attending to red jackets, but it's a hot day, and unbeknownst to you, Peter has now removed his red jacket to reveal a blue shirt. In this situation, you would be extremely unlikely to spot Peter and would experience all sorts of "false alarms" as other people wearing red jackets jump into your attentional spotlight. Another friend, however, who has arrived late to the game and so did not see Peter in his red jacket, would stand a much better chance of spotting him in the crowd because he would not be influenced by a prior expectation about what Peter was wearing.

Inattention blindness highlights the limitations of our attentional system and shows how we can miss the obvious when our focus narrows. Because we can use selective attention to bias our attention in a top-down manner, it often leads to inattention elsewhere.

Change Blindness

Selective attention can also let us down in other strange and mysterious ways. "Change" blindness is a fascinating phenomenon where people fail to notice significant changes in their environment, even when they occur right before their eyes. In another famous study by Daniel Simons, a psychologist at the University of Illinois, Urbana-Champaign, an experimenter asked a random pedestrian for directions. As the naive pedestrian provided directions, two people holding a wooden door walked right between the pedestrian and the experimenter, momentarily blocking the pedestrian's view. In that moment, the experimenter was switched to a new person who looked completely different and had a distinctly different voice.

Remarkably, nearly 50 percent of pedestrians failed to notice that they were talking to a different person after the door had passed! Like inattention blindness, change blindness highlights the limitations of our attentional system, showing that we don't always notice changes in our environment, especially when our attention is engaged elsewhere. This phenomenon also reminds us that our perception of reality is not as detailed or accurate as we might think.

What happens in the brain when we fail to notice obvious changes happening right in front of our eyes has been studied in humans using

fMRI. While they performed one task on a computer screen (looking for the letter X in a series of other letters), healthy participants had to monitor for any changes in pictures of faces presented toward the edge of the screen. Because the participants in the scanner were so focused on looking for the X, they often failed to notice when one face was swapped out for another. When a change was detected, brain activity was observed on the outer surface and toward the back of the right frontal lobe—more or less the same region that Desimone and colleagues were able to switch off using optogenetics in monkeys, thereby causing attentional deficits. This was more evidence, then, that this area of the brain helps us maintain selective attention, monitoring our environment and spotting whether any changes occur. On trials where the participants failed to notice when the face changed, no activity was observed in this region of the frontal lobe, revealing what is happening (or not happening!) in the brain when change blindness occurs.

Another fMRI study of change blindness, conducted at the National Institute of Mental Health in Bethesda, Maryland, revealed that activity in this part of the brain can trick us into thinking that something has changed when it hasn't at all. Participants had to judge whether two subtly different arrays of lines presented sequentially on a computer screen were the same or different. As in the previous study, when they got it right and spotted a change, brain activity was observed on the outer surface of the frontal lobes. The researchers then looked at what happened on those trials in which the participants reported seeing a change when one had not actually occurred. Surprisingly, the pattern of activity in the frontal lobes looked very similar, showing us that when this part of the brain is triggered, we are led to believe something has changed even when it hasn't. This is an excellent example of how our experience of the world isn't necessarily real—it is what our brains make of it. Think about cloud formations. When you see a face in the clouds, or a pig riding a unicorn for that matter, it is because your brain sees a pattern and tries to make sense of it. It effectively connects the dots, filling in the missing parts, and adds a dose of imagination to create an image of something that might be there, but isn't. I've lost count of the number of times I've told my wife I can see a guitar in the clouds and then have to spend half an hour explaining which end is which. The entire field of astrology is built on similar principles!

The point is this: Our ability to focus our attention is both our biggest executive strength and our biggest executive weakness. On the one hand, it allows us to focus on what we think is most important, but on the other hand, in doing so we may miss really important stuff going on that hasn't quite made it into our attentional spotlight. And that's where another property of our attention system, cognitive flexibility, really comes into its own.

Cognitive Flexibility

The fact that we can selectively attend to whatever we like gives rise to another executive component of attention—*cognitive flexibility*. Cognitive flexibility is like having a mental gymnast in your brain. It's the ability to quickly switch between different tasks, ideas, or ways of thinking in response to changing demands or situations. Picture yourself navigating through a bustling city, seamlessly shifting from following directions on your phone to chatting with a friend to deciding where to grab lunch. That's cognitive flexibility at work. Cognitive flexibility also helps us pivot when the unexpected comes our way. For instance, if you're working on a project and suddenly encounter a problem, cognitive flexibility allows you to shift gears, brainstorm alternative solutions, and adapt your approach accordingly. Similarly, when learning a new skill, like playing a musical instrument, cognitive flexibility enables you to adjust your technique in response to feedback and improve over time. This mental agility is crucial for problem-solving, creativity, and effectively navigating the complexities of everyday life. In this sense, cognitive flexibility overlaps with some of the executive functions that we have considered in previous chapters, like planning and working memory.

Cognitive flexibility is often assessed using tests that require attentional switching; as the name implies, these tests involve shifting our focus of attention from one aspect of a task to another. I first became interested in attentional switching as a PhD student working with Mr. Polkey's frontal lobe patients. We weren't the first to point out that patients with damage to their frontal lobes were not very good at switching attention, but we wanted to understand exactly why.

The story of this discovery begins back in the 1940s when two University of Wisconsin–Madison scientists, David Grant and Esta Berg, developed the Wisconsin Card Sorting Test, which remains one of the most widely used cognitive tasks in use today. Imagine you’re given a deck of cards, and each card varies in terms of the number, color, and type of shape on its face (two blue stars, three yellow triangles, and so on). Your task is to sort the cards into piles according to a rule that you have not been told. At first, you might sort them by color, putting all the red cards on one pile, all the blue cards on another pile, and so on. The experimenter gives you feedback after each card (“right” or “wrong”), and so very quickly you will learn whether or not you are sorting according to the correct rule. However, what you’re not told is that the sorting rule can change without warning. So, just when you think you’ve figured it out after piling a few cards of the same color on top of one another, the rule switches, and you will find yourself being told that you are now sorting the cards incorrectly. At this point, the way forward is to try a different sorting rule—perhaps putting all the stars on one pile regardless of their color and all the triangles on another pile. Eventually, you will work out the new rule until suddenly, without warning, it changes again. The test challenges cognitive flexibility because it requires you to shift your attention from sorting according to one rule (color) to sorting according to another (shape).

In the 1960s, the celebrated neuropsychologist Brenda Milner was working at the Montreal Neurological Institute with the institute’s founder, Wilder Penfield. I worked with Brenda many years later at the Neuro when she was well into her seventies (she is now 106 years old and still going strong). In 1964, Brenda published a paper showing that patients with damage to their frontal lobes were impaired at the Wisconsin Card Sorting Test. Their problem seemed to be one of impaired cognitive flexibility. Once they had learned one rule—say, to sort the cards according to color—they found it very difficult to switch to a different rule (shape, for example) and continued sorting the cards according to color despite being repeatedly told that they were now wrong. At the time, and in many subsequent replications of this famous study, the deficit in the frontal lobe patients was referred to as “perseveration,” meaning that once their attention had become focused on one particular aspect of the cards, such as color, they simply couldn’t “unlock” or “detach” their attention in order to focus elsewhere.

Many years later, working with Mr. Polkey's surgical patients, I also saw signs of perseveration among my frontal lobe patients. One sunny day, I pulled up outside a house in South London. I could see my patient's agitated husband waiting on the doorstep to greet me. "Thank goodness you're here!" he said. "You need to see what Beryl has been doing. She's been at it for days!" I entered the house and followed him down a short corridor into the living room. On one wall was a floor-to-ceiling bookcase filled with all sorts of books—books about nature, books about space, books by popular novelists, such as Wilbur Smith and Fredrick Forsyth. More striking than the sheer number of books displayed was their meticulous arrangement, almost as if the size and color of every book had been taken into account. This made for a highly unusual sight. In libraries or bookstores, books are usually arranged alphabetically or by author. These books seemed to be arranged *visually*, the result being a beautiful collage of colors that reminded me of an enormous, embroidered quilt of the sort my grandmother used to make.

Beryl stared at the shelves, quietly pondering her handiwork. We'd met some months earlier, just after a tumor had been surgically removed from her orbitofrontal cortex. Her hair had fully grown back, and she looked fit and well for a woman in her sixties who just a few months earlier had undergone major brain surgery. She gave me a big smile "Good afternoon young man, how are you?"

"Very well," I replied. "How are you?"

"Oh, you know, getting on with life," said Beryl. "But I wish I could sort out these ruddy books!"

As we sat on the brown sofa sipping tea, Beryl's husband explained the problem. "She decided to start sorting the books about a week ago and now she doesn't seem able to stop," he said. "Every day she gets up, has breakfast, and then starts sorting. And just when I think she's finished, she starts all over again!" I asked Beryl what she thought the problem was. "Oh, I don't think there's a problem," she said, "These books won't sort themselves!"

To see perseveration play out in real life in this way was a real eye-opener for me. I had read about it in scientific articles and books many times, but to see how it could affect someone's everyday activities to the point where they really couldn't accomplish much else was startling.

“There’s nothing in the fridge because we haven’t been shopping for days,” Beryl’s husband muttered as I stood up to say goodbye.

Curiously, my patients with Parkinson’s disease also seemed to have problems with cognitive flexibility, although their problems seemed to be subtly different from those experienced by patients like Beryl, who actually had damage to their frontal lobes. None of my Parkinson’s patients became fixated on sorting books to the point that they went hungry. Yet, they would fail the Wisconsin Card Sorting Test. What was the difference? It took a special kind of study using an entirely new task to answer that question.

Our reasoning in constructing the study went something like this. When the rule changes on a test like the Wisconsin Card Sorting Test, you can fail to switch rules for two quite different reasons. First, you can be so focused on the rule you are using that you just can’t stop yourself using it. It wouldn’t matter how many other rules there are in the world, this is the one you are using, and you are never going to stop. Why a damaged brain would do this is unclear, but my best guess is that it reflects a type of overly rigid rule learning; as the rule is learned, groups of neurons that remember that rule become dominant to the point that they are the only way that information about that particular task can flow. To use a suitable analogy, let’s return to our friend Peter at the football stadium, who leaves the bar wearing a red jacket. Throughout the time that you are chatting with him over a beer, your brain is learning information about his physical state—specifically, that he is wearing a red jacket. Once he leaves the bar, that representation (that he is wearing a red jacket) dominates all other thoughts, and that is all you can focus on.

In neuroscientific parlance, we also use terms like “cognitive rigidity” to describe this type of behavior, and it can happen occasionally to any of us. When it happens frequently, the assumption is that those parts of the brain that are required to “unlearn” something are damaged or missing. This looked like a reasonable description of Beryl’s problem. She knew there were other issues that she should take care of (like shopping), but she was so stuck on sorting books that those alternative chores didn’t enter her head.

But there is a second reason for failing the Wisconsin Card Sorting Test. All the while you are sorting according to one rule (say, color), your brain is also learning that all other possible rules are to be ignored, to the point that, in your head at least, they cease to become relevant to the problem. And

once you have learned that those other rules are irrelevant, it's harder to unlearn *that* fact, so those alternate options are less likely to be considered.

To return to our analogy, the whole time you were chatting to Peter at the bar, a memory representation was forming of him in his red jacket. But at the same time, your brain was also learning that he was *not wearing* a different-colored jacket. When you search for him later in the crowd, your attention is drawn to people in red jackets because that's what you believe he is wearing, but you also tend to ignore people in blue or yellow jackets (even if they look exactly like him), because you have previously learned that he is *not* wearing those colors.

Neuroscientists refer to this as *learned irrelevance*. Learned irrelevance is exactly what it sounds like; you have learned that something (in this case, a yellow or blue jacket) is irrelevant, and that makes it more difficult for you to consider it as relevant in the future. By contrast, perseveration is the process by which you have learned that something is relevant (the jacket Peter was wearing was red), and that alone makes it harder for you to consider anything else as relevant.

Learned irrelevance didn't look like Beryl's problem at all. It was not that she thought grocery shopping with her husband was irrelevant, it was just that sorting books was *more important*—she was perseverating on sorting books! On the other hand, some of my Parkinson's patients did show a type of cognitive inflexibility that looked a lot more like learned irrelevance. For example, after he had failed the Wisconsin Card Sorting Test, I asked one Parkinson's patient why he had not switched from color to one of the other rules, like shape or number. "Oh!" he replied, "I didn't know there *were* other rules." Despite the fact that he'd been sorting cards for several minutes that varied in terms of color, shape, and number, somehow, he'd learned to disregard shape and number completely to the point that when it came to making a rule switch, he didn't even consider these as possibilities.

I set out to investigate this attentional difference between patients with frontal lobe damage and patients with Parkinson's disease by designing a new cognitive test to tease these things apart. As in the Wisconsin Card Sorting Test, the participants had to make selections between options presented on a computer screen by discovering and then following a simple rule based on shape (squares, circles, or triangles), color (red, blue, or yellow), or number (one, two, or three). By surreptitiously manipulating the

rules of the game, I was able to determine whether any failures were due to perseveration, learned irrelevance, or a combination of the two. Sure enough, in the laboratory, the result turned out exactly as we'd predicted. When frontal lobe patients were required to shift their attention from one type of rule (say, color) to another (shape), they got stuck—fixated, if you will—on the rule they had already been focusing on. It didn't matter what other options we gave them, they just continued to perseverate according to whatever rule they had previously been using to guide their choices. Parkinson's patients, however, behaved quite differently. When the rule changed, they could switch easily, but only when the new rule was *entirely* new—that is, when it was offered up as an option they had not experienced before rather than as a rule they previously had to ignore. For example, they could stop responding according to shape (for example, always picking the square) and start responding according to color (picking the blue object, regardless of its shape) *only* if color had not been a distinguishing feature previously; to achieve this, in some trials I made all the stimuli the same color. The problem the Parkinson's patients were experiencing was one of learned irrelevance. Once again, we had shown that it is possible to fail a traditional cognitive task (like the Wisconsin Card Sorting Test) for two quite different reasons, and this provided important clues about the different brain regions involved.

You might be wondering why this is important. In the last few years, the term “executive dysfunction” has become a catch-all phrase for pretty much anything to do with cognitive or behavioral issues, a “diagnosis” that tells you almost nothing because it can mean almost anything. Yet every patient is different. While they might all show failures of executive function, patients with ADHD, obsessive-compulsive disorder, Parkinson's disease, Alzheimer's disease, concussion—the list is truly endless—exhibit markedly different patterns of behavior.

The study we have just explored shows how neuroscience can elevate us beyond broad behavioral categorizations like “executive dysfunction” and help us understand the precise challenges that any particular group of individuals is facing and what the underlying brain mechanisms are likely to be. This is not just an interesting academic exercise—it has fundamental implications for society and how we view each other.

For example, if you are someone who is prone to perseveration—determinedly sticking to one type of behavior even when you know that an

alternative course of action might be more effective or efficient—our study suggests that your frontal lobes may not be performing optimally. And while this may not seriously affect your life, it could help shape who you are, how you behave, and the decisions you make. But if learned irrelevance is your problem—not noticing that there are alternative courses of action available to you—our data from patients with Parkinson’s disease suggest that it is more likely related to the levels of dopamine in your brain. And even among those of us who do not have Parkinson’s disease, levels of dopamine in the brain vary between individuals and from one time to another, and this can certainly produce measurable changes in our behavior.

This subtle, but important, distinction has implications for interventions designed to address these various behavioral differences. For example, understanding perseveration—the brain’s relentless, sometimes absurd insistence on repeating a thought or action—has shaped approaches in various fields. In neurorehabilitation, therapists now create structured exercises to help retrain flexibility in thinking. Meanwhile, recognizing perseveration in education has led to techniques to gently steer students with learning disabilities out of repetitive cycles. And in technology, machine learning experts have even taken cues from studies of human perseveration (and cognitive flexibility) to improve AI’s adaptability. In the workplace, understanding learned irrelevance has helped create environments that support better attention switching and responses to changing information, incorporating varied, flexible cues to ensure that people can update their focus as conditions change. For many, this has turned what once seemed an insurmountable series of mental hurdles into a manageable part of daily life.

By studying perseveration and learned irrelevance, we’ve learned that cognitive flexibility isn’t just a feature of a nimble mind—it’s a fundamental component of mental health and adaptability, proving that sometimes the brain’s limits teach us more than its strengths.

Sustained Attention

Pay attention! We’ve all heard those words before, most likely beginning as young children, when our ability to resist distraction and focus on the task at hand was still developing. But how exactly are we supposed to pay

attention to something when it might not even be the most interesting thing in the room? This is where *sustained attention* comes in, and it really does demonstrate the extraordinary powers of our executive functions. When it works, that is.

Sustained attention refers to our ability to maintain concentration on a task or activity over an extended period of time. Imagine reading a captivating book for hours, fully engrossed in the story without becoming distracted—that's an example of sustained attention at work. Sustained attention keeps us focused and productive. However, it can easily falter when distractions are abundant or the task is monotonous. Driving long distances on a familiar route may require sustained attention to stay vigilant, but the monotony of the road can lead to lapses in attention, increasing the risk of accidents. Similarly, in today's digital age, with constant notifications and interruptions from smartphones and other devices, sustaining attention on important tasks can be challenging. This is where the full powers of our executive brain come in. Sustaining attention on even the most monotonous task can be done, but it requires willpower and concentration.

Our sustained attention system is far from perfect and everyday slips are common: pouring cream in your friend's coffee even though she requested it black; or nodding along to a lecture and then realizing you haven't heard a word of it. I've lost count of the number of times I've been driving on the highway when the car ahead of me stops short and for a split second I don't even notice. Luckily, I've always managed to pull myself back from my daydreams just in time.

At John Duncan's Festschrift, I was delighted to see that Professor Ian Robertson, from Trinity College, Dublin, was another of the invited speakers. Ian is a world expert on sustained attention, and one of his many claims to fame is that he invented what has become the go-to task for assessing it.

The Sustained Attention to Response Task (SART) is a brief (4.3-minute) behavioral measure of sustained attention failures. In the center of a computer screen, 225 digits are presented in random order, and the participant's task is to press a key as quickly as possible in response to every digit except 3.

Aha! you may be thinking to yourself. Piece of cake. Well, let me tell you, this test sounds much easier than it is. The SART test is, in fact, one of

those exquisitely devised forms of torture that Ian designed during his time at Cambridge, specifically to make the shortcomings of our brains abundantly clear. Typically, people start off well, pressing a key to every digit they see (except 3), but very quickly the repetitive nature of the task means they succumb to the monotony and fail to inhibit a finger press when a 3 appears. “Oops!”—I’ve heard this uttered countless times while giving this test (or occasionally something less polite). It’s no surprise that the title of Ian’s first scientific paper about the task begins with the word “Oops!”

The test has been used to assess sustained attention in many different patient groups, including those with mild Alzheimer’s disease. Alzheimer’s patients make more than three times the number of errors as healthy controls on the SART test. The severity of this impairment correlates with performance on other cognitive assessments, suggesting a strong link between sustained attention deficits and overall cognitive decline in Alzheimer’s. Having developed and used a variety of cognitive tests over the last thirty years or so, I can readily attest to the fact that many are tedious and boring and therefore highly susceptible to lapses in attention.

The good news is that certain drugs may be effective in improving these types of attentional deficits in early Alzheimer’s disease. For example, donepezil is an ingenious little substance that works by inhibiting the activity of acetylcholinesterase, an enzyme that breaks down the neurotransmitter acetylcholine in the brain. Acetylcholine is one of the most ubiquitous neurotransmitters, known for its widespread distribution and crucial roles in various brain functions. By blocking acetylcholinesterase, donepezil helps to enhance communication between neurons in the brain because it leaves more acetylcholine available to transmit those crucial signals between neurons. This, in turn, improves cognitive function and has been shown to improve sustained attention in some patients with dementia. This provides an important clue about how the brain helps us to sustain attention and what might be going on when we experience those inevitable slips.

Unlike other aspects of attention that we have discussed, such as selective attention and cognitive flexibility, a core requirement of sustained attention is that we must keep doing it for a long period of time, and that’s hard to do. Indeed, it’s an odd paradox of sustained attention that maintaining focus during tedious, monotonous tasks feels demanding. And this is where the neurotransmitter acetylcholine comes in.

One likely possibility is that acetylcholine acts in the brain like gasoline—allowing us to remain focused on one task for long periods of time, even in the face of endless tedium. Indeed, studies have shown that acetylcholine levels fluctuate during tasks that require sustained attention, with increases in acetylcholine activity associated with improved performance. When we're fully engaged in a challenging task, such as studying for an exam or working on a project at home, our brains release more acetylcholine to help us maintain focus and concentration. And medications such as donepezil, an acetylcholinesterase inhibitor, also increase acetylcholine levels in the brain by blocking the enzyme that breaks it down, and that, in turn, also improves sustained attention. Certain dietary and lifestyle factors can also influence acetylcholine levels in the brain, although the effects are likely to be very small. For example, consuming foods rich in choline, such as eggs, fish, and nuts, might confer small benefits. Similarly, engaging in regular physical exercise has been shown to enhance acetylcholine release in the brain, potentially promoting cognitive function, including sustained attention.

In short, acetylcholine is an important neurotransmitter that supports our ability to sustain attention over time, and disruptions in acetylcholine levels in the brain can lead to difficulties in sustaining attention. The best example of this is Alzheimer's disease, which affects the brain's acetylcholine-producing neurons, leading to a broad pattern of cognitive deficits that may stem from an impairment in sustained attention.

Divided Attention

The last type of attention we'll look at is *divided attention*. We all believe we can effectively divide our attention between multiple tasks. We chat with our passenger while driving, scroll through our phones while waiting for the light to turn green, prepare dinner while helping our children with their homework. How does the brain do this, and is it really doing what we think it's doing?

It's widely acknowledged that when you try to divide your attention between two tasks, neither is performed quite as well as when it is performed on its own, which has been referred to as the "divided-attention deficit" or "dual-task deficit." Nobel Prize winner Daniel Kahneman tried to explain this in terms of a limited "attentional resource"—that is, there is

only so much attention to go around, and spreading it thinly between multiple tasks means that none of the tasks gets quite as much attention as they should. However, this idea can't explain why some task combinations are easier than others. For example, chatting while driving is easy, but chatting while reading a book is hard.

Christopher Wickens, a psychologist at Colorado State University, has, I think, a better theory. He acknowledges that attentional resources are finite, but they draw on different parts of our brain—auditory versus visual, for example. The reason you can drive and chat at the same time is because driving and chatting do not overlap in terms of their cognitive requirements. Chatting is not part of driving and driving is not part of chatting. One is mainly vocal, and the other is mainly manual. However, if you were to try to read a book and listen to a podcast at the same time, it would be impossibly difficult because both draw on the same brain function (comprehending language). Wickens's model is not perfect, however, because other factors can also affect how easily we can divide our attention between two tasks. For example, fatigue tends to increase the magnitude of the dual-task deficit, while familiarity or practice with the two tasks tends to decrease it.

Professor Earl Miller, at MIT, thinks that divided attention is just an illusion. As he said recently, "Your brain can only produce one or two thoughts in your conscious mind at once. That's it." What Earl means is that we cannot, in fact, divide our attention at all. All we can do is go back and forth between different thoughts, and that's inevitably going to have an impact on how well we perform any one task. "We have fallen for an enormous delusion," he says. "The average teenager now believes they can follow six forms of media at the same time. When neuroscientists studied this, they found that when people believe they are doing several things at once, they are actually juggling. They're switching back and forth. They don't notice the switching because their brain sort of papers it over to give a seamless experience of consciousness, but what they're actually doing is switching and reconfiguring their brain moment-to-moment, task-to-task and that comes with a cost."

Earl's view makes much more neuroscientific sense than the possibility that you can actually divide your attention between two tasks and expect performance of neither to be affected. Think of it like the plumbing in your house. There's a finite flow of water coming from the city. If you take a

shower and run the dishwasher simultaneously, each might receive a little less water, but you'd barely notice the difference. But attempt both of those things at the same time that you water the lawn and run the washing machine, and you'd likely start to notice that the water pressure in your shower is getting a bit lackluster. Attention is no different. Perhaps you *can* drive while chatting and not notice any effects, but as soon as you have to navigate your way through an unfamiliar town while driving, chatting becomes much more challenging. In truth, there is a cost to driving and chatting; it's just too small for you to really notice.

In 2015, Cary Stothart and colleagues at Florida State University looked at these small effects, specifically in relation to cell phone usage. More than 90 percent of American adults own a mobile phone, and many of these devices can also be used to access email and social media, download music, and watch videos. In their study, Stothart and colleagues asked their participants to perform the SART test twice, once without distraction and a second time with varying levels of cell phone distraction. One-third of them received random text notifications during their second session, one-third received a random call to their phone, and one-third had no interference (exactly like their first session). Participants who received no distraction on the second session performed exactly as they had on their first, but the participants who received random notifications (either text or call) made significantly more errors.

Overall, the scientific literature supports this pattern; cell phone notifications impair cognitive performance by forcing you to switch your attention between whatever it is that you were doing and the incoming notification. As Earl Miller put it, "Focus on one thing at a time. If I am writing a paper and working and I am checking my email every minute, I am incurring a switch cost every minute. If I check every hour, it is less. The less the better." What Earl means by "switch cost" is the negative effect on performance that we incur when we shift our attention between multiple activities. Using his own example, the scientific paper he is writing will not be as good or will take a lot longer to write if he's constantly checking his email while he's doing it.

I agree with Earl that divided attention is just an illusion—a clever conjuring trick that our brains play on us to make us think we can perform multiple tasks at once, when in fact all we are doing is shifting back and forth so fast we barely notice. In that sense, while it features prominently in

many accounts of executive function, I don't regard divided attention as an actual cognitive process—and therefore not really part of our executive armory at all.

ADHD and the Attention Spectrum

ADHD (attention deficit hyperactivity disorder) is often portrayed as childhood chaos involving kids who are unable to sit still and who are perpetually distracted. But the reality is far more complex than that. First, ADHD is not a disorder that only affects children. Plenty of adults are diagnosed with ADHD, too, sometimes decades after they first begin to show symptoms. In addition, along with impairments of inhibitory control, ADHD often involves a constellation of attentional challenges that combine difficulties with staying focused over time, tuning out distractions, and managing multiple things at once; that's sustained attention, selective attention, and attentional switching. These issues stem from both biological and developmental factors, not lazy habits or moral failings. Studying ADHD through a neuroscientific lens allows us to understand (and sometimes treat) these symptoms, but it teaches us plenty about the healthy mind as well.

Where sustained attention is concerned, both children and adults with ADHD often struggle to maintain focus over extended periods, particularly on mundane or repetitive tasks. One ADHD patient I assessed recently remarked, "Any task that takes more than a few minutes makes me feel like I'm wading through treacle." Functional MRI studies have shown that during tasks that require "vigilance," individuals with ADHD have lower levels of activity in multiple areas of the brain, including the frontal lobes. In one influential study by Katya Rubia, my former colleague at the Institute of Psychiatry in London, the frontal lobes consistently showed reduced activation in people with ADHD during tasks requiring sustained effort.

Selective attention is also frequently affected by ADHD. Imagine trying to read in a noisy café while every other conversation subtly draws your gaze. We've all experienced this on occasion, but for people with ADHD, that can be what life is like *all the time*. Studies using auditory distractions, like sounds that are irrelevant to the task being performed, show that adults

with ADHD struggle to ignore them, suggesting that their ability to selectively attend to what is most important in the here and now is impaired. These aren't just little quirks; as we've seen, they're rooted in how the brain's selective attention system juggles bottom-up and top-down influences to guide our focus of attention.

Switching between different tasks (multitasking) also requires a bit of attentional juggling—for example, when we're listening to a speaker while taking notes or comparing data across two spreadsheets. These activities are hard enough for most of us, but for someone with ADHD they can be insurmountable. Exactly why this is so is not well understood, but some studies have suggested it is related to sluggish coordination between different brain networks, making fluid multitasking feel messy and effortful.

What's going on here in neuroscientific terms? Why do people with ADHD struggle so much at what are routine daily tasks for the rest of us? Well, genetics certainly plays an important role. ADHD is 70 to 80 percent heritable, meaning that for many people, differences in the brain circuits that regulate attention and inhibitory control are there from birth. Neurochemically, ADHD has been associated with impaired dopamine and noradrenaline activity in the frontal lobes, critical for various aspects of attention. That's why stimulants (for example, methylphenidate, or Ritalin) and nonstimulants (atomoxetine, or Strattera) tend to improve symptoms: They help normalize these neurochemical imbalances, reducing the symptoms most commonly associated with ADHD.

Medication isn't the only instrument in the ADHD tool kit. In fact, a growing body of research suggests that behavioral and lifestyle interventions can meaningfully enhance attention in both children and adults with ADHD. Cognitive-behavioral therapy (CBT), for example, helps individuals build routines, manage distractions, and reframe unhelpful thought patterns, all of which support better executive control. Mindfulness training, too, has shown real promise. In one randomized controlled trial, eight weeks of mindfulness-based cognitive therapy led to significant improvements in attentional regulation and a reduction in ADHD symptoms among adults, even months after the intervention ended. And something as seemingly mundane as structured daily scheduling, using planners, reminders, and time-blocking strategies, can reduce the mental load of everyday decision-making, freeing up cognitive resources for sustained and

selective attention. None of these strategies are magic bullets, but together they offer some hope for the millions of children and adults worldwide who have been diagnosed with ADHD.

From ADHD to Everyday Brains

The science of ADHD shines light on the fragile scaffolding of attention: how it depends on the seamless orchestration of brain chemistry, structure, and network coordination. But what does it say about the rest of us and what we might do to keep our attention systems in tip-top condition? As we've seen, attention isn't a single thing so it's no surprise that there is no single ideal approach for maintaining or optimizing every aspect of this complex set of executive processes. The good news is that whether you want to be able to stay focused over time in order to proofread your tax forms (sustained attention), keep an ear out for your name in a crowded room while ignoring distractions (selective attention), or improve your multitasking abilities (switching attention), there are things you can do.

Most of us routinely attempt to divide our attention between different tasks, conversations, and thoughts, maybe hundreds of times a day, which, as we have seen, results in us performing every task a little more poorly than if we were to give it our undivided attention. Perhaps, then, one easy way to improve your attention might be to stop trying to do this—selectively attend to the most important information, reduce distractions, and stay focused on the task at hand. There is scientific evidence that maintaining attention on a single task enhances productivity and that focused attention can be trained, with measurable benefits for cognitive performance and efficiency. For example, Michael Mrazek and colleagues at the University of California showed that participants who received mindfulness training (which enhances sustained attention) showed a significant improvement in working memory and reduced mind wandering. Katherine MacLean, also at the University of California, studied participants undergoing intensive attention training over three months and found improvements in perceptual sensitivity and sustained attention, and crucially, these gains persisted over time. And even if you don't have three months to devote to improving your attention, there's still hope for you: One study of forty undergraduate Chinese students showed that with just

twenty minutes of practice over five days, attention could be significantly improved.

On the downside, a single night of poor sleep can degrade your ability to stay focused the next day. If you've ever found yourself rereading the same sentence ten times after a bad night, this is why. Keeping to a consistent sleep schedule (even on weekends) is one of the most powerful ways to preserve your mental stamina.

When we're stressed, anxious, or feeling low, our ability to switch between different tasks really suffers. These emotional states demand cognitive resources, leaving fewer available for juggling multiple streams of information. Chronic stress, in particular, can impair attentional switching by changing the physical structure of neurons in the frontal lobes. In fact, even quite mild stress can cause a rapid and dramatic loss of prefrontal cognitive abilities. Practicing stress management through mindfulness, moderate exercise, or just taking regular breaks can help keep your attentional system more flexible and less brittle under pressure.

Finally, the brain's attentional networks are surprisingly trainable. Focused attention meditation, where you repeatedly return your focus to a single thing (like your breath), has been shown to improve both selective and sustained attention over time.

In short, attention isn't just about willpower. It's shaped by biology, environment, habits, and mood. We can't expect perfect focus in a world designed to interrupt us, but we can stack the odds in our favor. Sleep well, move your body, and stay relaxed. And don't beat yourself up for being distracted because it's all part of being human. The trick is learning to nudge your attentional spotlight back, gently but consistently, to where it really matters.

Of Mice and Men

Are any of these components of attention uniquely human? Unlike some of the other executive functions we've discussed, such as planning and inhibition, the attentional abilities of many other species are incontrovertible. I've seen firsthand that polar bears will lie motionless for days at a time, silently monitoring a hole in the ice until an unfortunate seal pops its head up, only to meet its bloody end. I would wager that few

humans can sustain attention, uninterrupted, for anything close to that amount of time. Our family dog, Ronnie, can selectively attend to her food, or a toy, or my son Jackson if he's in the mood to chase her around the house. Likewise, she can shift her attention from one source of joy (the treat cupboard) to another (Jackson waving her favorite toy) and back again; perhaps she, too, is able to fool herself into thinking that she's able to multitask. Even Scale, Jackson's bearded dragon, will loiter motionless by a log for hours, waiting for that one cricket who hasn't received the memo about the local reptile and his insatiable appetite for members of the Gryllidae family. Indeed, the footprints of attention can be seen all over the animal kingdom, which suggests that it is an evolutionarily ancient process, or set of processes, that have existed in various forms for millennia.

What then, if anything, is special about the human brain? Its attentional powers are extraordinary, for sure, but are we truly unique or just a modest upgrade from an earlier model? We'll turn to this question in the final chapters of the book, but for now it suffices to say that what I think makes humans different is our ability to consciously decide how we deploy our executive functions, rather than being slaves to our more primitive impulses, needs, and desires. And attention is an excellent example of that.

Earlier in this chapter, I suggested that you could, if you wished, decide to watch the entire *Despicable Me* movie by selectively attending to the number of Minions on-screen instead of following the plot. I wouldn't recommend it (I've tried). It's intensely tedious and places a serious load on sustained attention, but it's a choice you have, and if you want to, you can do it. Likewise, you can choose to travel to Churchill, Manitoba, and sit by a hole in the ice and wait several days for a seal to pop its head up. I *would* recommend doing that, if you have the means, but take a very warm blanket and be prepared for a long wait.

My point is that humans generally have choices about how to think and act, and our executive functions are critical tools we can use to guide those choices. Other species also have choices, but arguably, most species are more restricted and more closely constrained by their needs and desires. The polar bear by the ice hole in Churchill can probably decide that she's had enough five days in, and she can pack up and go home. But can she resist the urge to go there in the first place? Ronnie has her off days—days when she doesn't want to play—but she really can't resist attending to a potential treat, even when she's feeling under the weather. And what about

Scale and his clueless cricket? I think he'll probably still be sitting there long after the cricket has shuffled off her mortal coil if something tastier hasn't come along.

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5

Theory of Mind Knowing What Someone Else Is Thinking

I'm playing the audience like a piano.

—ALFRED HITCHCOCK

One damp Tuesday afternoon some years ago, I was called back to the Institute of Psychiatry at short notice to assess another of Mr. Polkey's postoperative patients. I had been told very little, only that this gentleman's surgery had involved the removal of a large tumor on the medial surface of the right frontal lobe.

As we've seen, the brain (and the frontal lobes) consists of two roughly symmetrical halves, or "hemispheres." The surface where the two hemispheres meet is flat compared with the rest of the brain so that the two sides nestle neatly against one another. At the front of the brain, these two flat surfaces are where the medial frontal cortex is located.

The patient, Colin, was in his midforties and had previously worked as a regional manager for B & Q, a British chain of DIY stores. He met me in the outpatient clinic waiting area wearing a beige hoodie and holding a lukewarm sausage roll in one hand and a dripping umbrella in the other. "Dr. Owen," he said, "You seemed *much* taller on the phone." This immediately made no sense to me, especially as I had never spoken to Colin on the phone. But before I could clear that up, he gestured toward the clinic

doors. “Shall we get cracking? I’ve cleared my whole day for this. Canceled my dental check-up and everything.” That didn’t make much sense either—Colin had no way of knowing that he was going to see me that day, as our meeting had been scheduled at the last minute following one of his routine follow-ups with Mr. Polkey.

We settled in one of the small testing rooms, and I began leading Colin through our battery of cognitive tests to assess his working memory, planning, inhibitory control, and attention. He performed reasonably well on everything. It wasn’t until we moved on to a more conversational interview that the strangeness resurfaced.

“So, Colin,” I asked, “do you know why I am here?”

“You’re here to witness the brilliance,” he said, gesturing at himself. “To bask in the radiant intellectual glow of a man who can name every make of cordless power drill sold in B & Q.”

His response was odd to say the least. I tried to bring things back to earth. “Actually, I’m here to understand how your brain’s doing after the surgery. Just to ask a few questions, get you to do a few of our computer tests. Nothing too demanding.”

Colin nodded. “Of course. I’ll help you *feel smart*. That’s important, in your line of work.”

At first, I took that as an awkward joke. But then things got even stranger. “Your wife has said you’ve had a few issues at home,” I said.

“She’s oversensitive,” he replied. “She got upset yesterday when I told her friend Karen that she’s boring.”

“Did you say that *to* Karen?” I asked.

“Of course! Otherwise, how would she know?” he replied.

I continued to probe. “Did it occur to you that saying that might hurt her feelings?”

Colin shrugged. “Well, she *is* boring. Isn’t it better to be honest? I mean, your tie is boring, but I wouldn’t expect you to cry if I pointed it out.” He paused, frowned, then added helpfully, “Not *boring* boring—just boring in a sort of *plain navy* way.”

I pretended to make a note in my file and tried a different tack. “If I told you I was cold, and I crossed my arms like this . . .”—I mimed a shiver—“. . . how do you think I’d be feeling?”

“Annoyed,” he said. “Because you’re making *me* cold.”

Later, as we walked back through the corridor, I held the door open for an elderly woman coming the other way. Colin walked straight through the door, almost ramming into her, totally oblivious. As I caught up with him, he turned to me and said, “I don’t get why people do that. She’s old, not invisible. Let her push the door for once.”

By the time we parted, it was clear that Colin’s surgery had left him with a striking inability to put himself in anyone else’s shoes. He could talk, plan, reason, and recall perfectly well. But he couldn’t grasp how his behavior affected others. It wasn’t rudeness exactly—more like an emotional blind spot. He simply didn’t seem to realize that other people have minds too.

This ability to understand what others are thinking, to imagine their beliefs, intentions, feelings, and desires, is something psychologists call *theory of mind*. It’s called a “theory” because we can never really know with certainty what someone else is thinking—it’s our theory about what’s on their mind. From everyday social exchanges to the world’s most complex negotiations, from first dates to jury trials, understanding what someone else is thinking shapes how we interact with them. Without it, we are left like Colin, bumbling through life, totally oblivious to anyone else’s feelings, points of view, personal circumstances, or challenges.

Not all neuroscientists think that theory of mind is an executive function. I have included it because it fulfills my criteria: It helps us manage, regulate, and coordinate our thoughts and actions in order to achieve our goals. Because he lacked theory of mind, Colin failed to take into account any feelings I might have had when he referred to my tie as boring. You might be thinking that that’s just a failure of inhibitory control, which we have already discussed. There are certainly some similarities, but the devil is in the details. If Colin had simply failed to inhibit a genuine belief that my tie was boring, he would likely have had some sense of failing to suppress his opinion and, as is so often the case, regretted it immediately afterward. In fact, Colin seemed perfectly comfortable mocking my rather plain tie and showed not the slightest hint of regret. He just didn’t seem to understand that I would *care*. Interestingly, it was *my* theory of mind that allowed me to understand that it was not Colin’s explicit intention to hurt my feelings, allowing me to move the conversation politely on.

Unlike other executive functions, theory of mind really does grease the wheels of every single social interaction we have, making it one of our most useful weapons when it comes to shaping and controlling the narrative of our lives: It allows us to interpret and (importantly) *predict* the intentions behind others' actions.

Imagine a negotiation between two business partners, Alice and Bob. Alice proposes a new project and sees Bob frown slightly. Recognizing that Bob is finding the proposal risky, Alice uses her theory of mind to infer that he might have concerns about the project's feasibility. She adjusts her approach, addressing potential risks and highlighting safety measures. Bob notices Alice's detailed explanation and uses his theory of mind to infer that she anticipated his concerns, and he appreciates her thoroughness. This mutual understanding and adjustment based on inferred thoughts and feelings facilitates a productive and cooperative negotiation between the two partners.

This example demonstrates that attribution of intentions involves inferring what someone else is thinking or feeling and understanding that person's motivations for behaving in a certain way. This executive superpower is essential for effective social communication, as we saw in my unorthodox conversation with Colin. It's easy to imagine how socially awkward life would be if, like Colin, we could never take anyone else's perspective or guess what they might be thinking based on their behavior. Theory of mind enables us to interpret verbal and nonverbal cues, infer meaning from others' expressions and gestures, and engage in reciprocal exchanges of information and emotions.

This is why theory of mind is such an important executive function. Although we wouldn't perish without it, we'd be hollow versions of ourselves, unable to understand our place in the world, unable to understand how our behavior influences others, and unable to understand how other people's beliefs about us have a direct bearing on our lives.

Cheeky Monkey

Theory of mind develops gradually over the course of childhood and continues to be refined throughout adolescence and adulthood. Chat with any young child and you will realize that while they are very well versed in

many aspects of how the world works, taking another person's perspective is not their forte.

A few years ago, when my son Jackson was about four, he developed a habit of hiding things. Not valuable things, just whatever happened to be in his hand when the impulse struck: a spoon, a sock, the remote control. One afternoon, I was getting ready to take him to a birthday party and I couldn't find my car keys. After five increasingly frantic minutes of searching, I asked, "Jackson, have you seen my keys?" Without hesitation, he said, "They're in the fridge." I opened the fridge, and there they were, right next to a half-eaten banana and one of his Lego creations. "Did *you* put them there?" I asked. "Yes!" he said proudly. "Okay . . . but how was I supposed to know that?" He looked at me, completely unfazed. "Well, *I* knew."

In Jackson's four-year-old mind, that was enough. The fact that *he* knew where the keys were meant that *I* should know, too. It simply hadn't occurred to him that someone else might see the world differently or be missing information that he had, because his theory of mind was still developing.

In the 1980s, the so-called "false belief" task was introduced as a measure of children's understanding of others' beliefs. In the classic version of the false belief task, children are told a story in which Sally puts her marble in one location, leaves the room, and while she's gone, someone moves the marble to a different location. The key question is: Where will Sally look for her marble when she returns? Children who have developed a mature understanding of false beliefs recognize that Sally will search for the marble where she originally left it, even though the children watching know it's in a different place now. In contrast, younger children who haven't fully grasped the concept of false beliefs will often say that Sally will look for the marble in the new location it was moved to when Sally was out of the room. Research using the false belief task suggests that the basic components of theory of mind emerge around the age of four or five, although full development of the system continues well into adolescence. For example, it is often not until the early teenage years that children learn to interpret complex mental states—like sarcasm, irony, or double bluffs—and can manage multiple perspectives at once (for example, "I know that she thinks that he believes . . .").

Even in adults, when our theory of mind has fully matured, there continues to be considerable variability between individuals in how

effectively it is deployed in different situations. The reasons for these differences are undoubtedly multifaceted, but factors like culture, language, and social experience all play a role. For example, individuals from different cultures often construe social stimuli differently, and as a result, their style of analyzing social situations is also different. Imagine an American manager who assumes that a colleague from Japan agrees with their proposal because they nodded politely and didn't voice objections. But in fact, the Japanese colleague strongly disagrees, and their silence is a culturally appropriate way for them to express disapproval without confrontation. Without cultural context, the American manager might fail to attribute the correct mental state.

Language also plays a central role in how easily we apply theory of mind, because it's often through language that we access other people's thoughts, beliefs, intentions, and emotions. In fact, language doesn't just convey someone's mental state; it shapes how we interpret it. Sarcasm, for example, depends heavily on context, tone of voice, and shared knowledge. Without these cues, the literal meaning of words can completely override the intended meaning. Imagine a colleague who says, "Great job on that presentation" in a flat tone after a disastrous meeting. A native speaker might pick up on the sarcasm, but someone unfamiliar with subtle tonal cues, or a non-native speaker, might interpret it as genuine praise, misreading the speaker's real intent.

Finally, theory of mind is also improved through social experience. The more opportunities we have to interact with other people, especially in diverse, emotionally meaningful, or challenging ways, the better we become at interpreting their thoughts, beliefs, and intentions. Children with siblings tend to develop theory of mind earlier and more robustly than those without. For these kids, daily sibling squabbles, pretend play, and negotiation provide early lessons in how others think and feel. Conversely, children who grow up in socially deprived environments, such as institutions with minimal caregiver interaction, often show delays or impairments in their theory of mind.

Yet, even when external factors like culture, language, and social experience are taken into account, healthy adults still vary widely in their ability to effectively exercise theory of mind. Some people just seem to have a knack for guessing what others are thinking, whereas other people remain clueless and go through life assuming that everybody sees the world

exactly as they do. While those at one end of the spectrum, like Colin, tell us a lot about how badly life can go with little, or no, theory of mind, those at the other end may provide some valuable insights about the roots of creative genius.

Indeed, some of the most creative individuals in history appear to have had a remarkable ability to tune into the mental states of others. William Shakespeare, for example, wrote about characters whose motivations and beliefs were not only psychologically rich, but often contradictory and elusive in exactly the way real people can often be. Iago, from *Othello*, is a perfect example. He is one of Shakespeare's most psychologically complex characters precisely because his motives are contradictory, elusive, and hard to pin down. In one well-known line, he tells the audience, "I am not what I am," a confession of his own duplicitous nature that captures both his cunning and the psychological opacity that makes him so disturbing. In creating Iago's character, Shakespeare proved that he had a deep understanding of how human minds can deceive, second-guess, and outmaneuver one another. The fact that audiences are still debating Iago's true intentions more than four hundred years later is a testament to the extraordinary theory of mind that went into crafting him.

Jane Austen also built entire novels on the premise that her protagonists were constantly, and sometimes disastrously, misinterpreting what others were thinking. For example, early in *Pride and Prejudice*, Elizabeth Bennet quickly forms a strong dislike for Darcy, interpreting his reserved and awkward behavior as arrogance and disdain. At the same time, she trusts Wickham, who is charming and seemingly honest, when in fact he's lying about his history with Darcy to win her sympathy. As with William Shakespeare, the creative genius of Jane Austen doesn't lie only in having special knowledge of human behavior, but in being able to imagine what it's like to be someone else and then communicate that to the rest of us.

Along similar lines, Alfred Hitchcock's mastery as a director can be attributed in large part to his profound understanding of human psychology and his excellent theory of mind. Hitchcock had an unparalleled ability to delve into the depths of the human psyche, crafting characters with intricate motivations and inner turmoil. Through his films, he tapped into universal fears, desires, and anxieties, captivating audiences with suspenseful narratives that resonated on a deeply psychological level. Hitchcock's keen insight into the complexities of the human brain—his personal theory of

mind—allowed him to manipulate emotions and perceptions, creating tension and suspense that lingered long after the credits rolled. Moreover, his ability to anticipate audience reactions and play upon their expectations shows that he had an astute understanding of how viewers interpret and empathize with characters on the screen. By harnessing his theory of mind, Hitchcock transcended mere storytelling, leaving an indelible mark on cinema, and is rightfully seen as one of the greatest directors of all time.

Indeed, a well-developed theory of mind shows up not only in novelists, playwrights, and great directors, but in comedians, diplomats, screenwriters, therapists, and anyone else whose job depends on understanding people and predicting their actions from the inside out. Whether it's a stand-up comic predicting how an audience will interpret a punchline or a negotiator anticipating what an opposing party *really* wants, these skills rest on a highly tuned ability to infer what others know, believe, feel, or intend—even if they never say it out loud.

So, what is it that allows some people to step so effortlessly into the minds of others, while other people seem constitutionally unable to do so? Given what you now know about some of our other executive functions, you won't be surprised to learn that theory of mind depends on our old friend, the frontal lobes.

The Dark Side of the Brain

In a study conducted at the Baycrest Centre and Hospital in Toronto by Canadian neuropsychologist Donald Stuss, nineteen patients with frontal lobe damage were given a task that tested their ability to infer that someone was deceiving them. During the test, the patients sat facing the experimenter in a small room, separated by a table. On the table between the examiner and the patient was a small wooden frame twenty-nine inches high and thirty-three inches wide. The frame held a curtain such that the subject could not see over or around the frame when the curtain was closed.

Two cups were placed on the table in front of the patient but hidden from view by the curtain. A quarter was hidden under one of the two cups. The patient was told that on each trial they had to choose the cup under which they thought the quarter had been hidden. Also in the room was an onlooker, who was in a position to watch the coin being placed under one of

the cups. When the curtain was raised, the onlooker pointed to one of the cups and the patient then had to guess where the quarter was hidden. The key point was that the onlooker *always pointed to the wrong cup* and so consistently gave a false clue. Most of us would very quickly work this out and select the cup that the onlooker was not pointing at, but patients made more errors on this task, particularly those with damage to the medial surface of the frontal lobe.

The term “medial” is from the Latin *medialis*, meaning “middle.” Picture two flat walls of brain tissue about the height of a typical coffee mug, mostly hidden from view because each hides the other from sight. It really is the dark side of the brain because only neurosurgeons, those of us with access to sophisticated brain imaging machines like MRI, and a few forensic pathologists ever get to see the medial frontal lobes in all their glory.

The human medial frontal cortex is responsible for a variety of cognitive functions, particularly those related to social behavior and self-awareness. Essentially, it acts as a control center for navigating complex social interactions and understanding the intentions and perspectives of others. It is not surprising, therefore, that patients with damage to the medial frontal cortex were particularly impaired at realizing that they were being deceived, because to know that they would have to understand the intentions and the perspective of the onlooker in the room.

This is a crucial point. Imagine a situation in which you ask a colleague which of two cups conceals a coin. He gives you the incorrect answer and you select the empty cup. Based on this, two scenarios are possible; either the colleague is deceiving you or he, like you, has no idea where the coin is hidden and has simply made a (wrong) guess. How can you determine which is which? One obvious way is to ask the colleague to repeat the task multiple times. Your colleague could only consistently suggest the wrong cup if he knew which was the correct cup; repeated errors would be a clear indication that he was lying.

The frontal lobe patients in the study had an additional piece of information that should have allowed them to deduce that they were being deceived after a single trial; they knew that the onlooker had watched the coin being hidden, and so when the curtain was raised and the onlooker pointed to the wrong cup, the patients should have correctly inferred that they were being duped. By analogy, if you knew that your colleague was

the one who placed the coin under the cup and he pointed to the wrong cup, you would know immediately that he was lying. This is where your medial frontal cortex comes in—in situations when you need to deduce what other people's intentions are based on the outcome of their actions.

Humans are (mostly) social animals. Much of what we learn, and certainly much of what we achieve every day, occurs as a result of some kind of social interaction. Whether it's watching the face of the other driver at the intersection and realizing that he has no intention of blowing through a stop sign or understanding that the expression on your friend's face when she takes a bite of your homemade chili means that she hates it, much of our own behavior is governed by interpreting and understanding the behavior of others.

Brain scanning studies in healthy participants have also shown that the mostly hidden medial wall of the frontal lobes is important for theory of mind. In one positron-emission tomography study by Paul Fletcher, a former colleague of mine at Cambridge University, healthy participants were read stories like the following: "A burglar who has just robbed a shop is making his getaway. As he's running home, a policeman sees him drop his glove. He doesn't know the man is a burglar, he just wants to tell him he dropped his glove. But when the policeman shouts out to the burglar, the thief turns round, sees the policeman, puts his hands up, and admits that he did the break-in at the local shop."

They were then asked, "Why did the burglar do this?" The obvious answer is that the burglar thought he was being apprehended for the crime and had no idea he had even dropped his glove. But to reach that conclusion you would have to understand the perspective of the burglar—that he didn't know that he had dropped his glove. Compared with similar vignettes that did not require the participants to understand the perspectives of others, these stories activated the medial frontal cortex.

Other functional neuroimaging studies have shown that predicting another person's next movement, judging others' knowledge of a situation, assessing whether another person understands a story, and correctly interpreting the intentions behind the speech of others all activate the medial frontal lobe regions, and all of these tasks and activities require an active theory of mind.

Other Kinds of Minds

It used to be thought that only humans and a few species of great apes may be capable of true theory of mind, although over the years such claims have been made about other animals, including dolphins, elephants, corvids (ravens and crows), and some parrots.

However, investigating theory of mind in nonhuman species presents unique challenges. Observation is one, albeit limited, approach. You may have seen YouTube videos of monkeys in zoos blowing raspberries at the crowd or appearing to try to coax onlookers into sharing their ice cream. It's very hard *not* to interpret these behaviors as evidence that monkeys know what we're thinking. In many cases, however, it seems that what we are observing is simply learned behavior. Every time the monkey has spontaneously blown a raspberry in the past, it has been "rewarded" by the laughter and applause of the crowd; so over time it has learned to associate this behavior with positive feedback. It doesn't need to *know* what we're thinking right now; it simply needs to remember what it has done in the past that led to the reward and do it again.

For decades, scientists have argued back and forth about the remarkable behaviors of other species, with one seemingly convincing demonstration being debunked after another. But all that has changed in the last couple of years, based largely on the fascinating work of one of my colleagues at the Canadian Institute for Advanced Research (CIFAR), Christopher Krupenye.

Chris is a professor in the Department of Psychological & Brain Sciences at Johns Hopkins University. By comparing humans with our closest primate relatives, chimpanzees and bonobos, his work seeks to identify the shared traits that were present millions of years ago in our common evolutionary ancestors. He uses many clever approaches, from eye tracking to behavioral tasks, to understand the cognitive abilities of other species.

In one recent study that garnered worldwide media interest, Chris and his colleagues presented chimpanzees, bonobos, and orangutans with a series of short films, scripted to pique the apes' interest and keep them watching. The apes could choose, or not, to enter a specially designed viewing room where they could (again, their choice) take a seat, positioned to allow them to sip on juice from a straw while they directed their eyes

toward a screen on which skits played out. A computer tracked the apes' eye movements as they watched, indicating where their attention was focused.

In one film, a man dressed in a gorilla suit snuck up behind a human actor and for no apparent reason aggressively whacked the actor on the back. The human actor startled and became incensed. The gorilla-suited assailant scurried away in full view of the aggrieved human actor and hid behind one of two bales of hay. The human actor then ran off-camera. While he was gone, the gorilla-suited assailant switched his hiding place, moving from one bale of hay to the other. The aggrieved human actor returned with a swordlike stick, wielding it as if he wanted to clobber his assailant. But to which bale of hay would he go to seek revenge?

Tracking the apes' eye movements, Chris could infer what the apes understood about what the actors knew and believed. The apes knew that the gorilla-suited actor had changed his hiding place while the human actor was gone. But the human actor didn't know this. The big question was: Would the apes know that the human actor didn't know this? In almost all instances, the apes looked to where the aggrieved man had last seen his assailant, suggesting that they knew what was in the human actor's mind: He had a *false belief* that his assailant was behind the bale of hay where he had seen him hide, rather than the bale of hay where the apes knew the gorilla-suited actor was now situated. That's theory of mind! The apes took the human's perspective—they *knew* what the human was thinking, even though they also knew it was wrong!

Although this seems like convincing evidence that apes have theory of mind, not all scientists were convinced by these findings. Chris and his colleagues designed further studies that proved impossible to refute. In another version of the false belief task, he and his colleagues presented forty-seven chimpanzees, bonobos, and orangutans with filmed scenes that involved two types of barriers, opaque and see-through. In one film, a human entered the scene and watched while another actor dressed as an ape hid an object in one of two boxes. The first human then stood behind the barrier while the costumed human moved the object, first to the second box, and then from the second box, fleeing the scene with it. The human then came out from behind the barrier and looked quizzically at the two boxes. The experimenters monitored the real apes' eyes to see whether they looked toward the first box (where the object had been hidden in full view of the human), the second box (where it had been moved when the human was

behind the barrier), or elsewhere completely (after all, the real apes knew the object was long gone).

Amazingly, the apes tended to gaze at the first box that the object had been placed in more often when the barrier looked opaque to them than when it looked to be transparent. That is, when they thought that the human couldn't see through the barrier, they assumed the person would believe the object was right back where they had seen it placed to begin with. But when the apes thought that the human could see through the barrier, they assumed that the human would have seen the object being taken away, and they appeared to have no expectation that the human would search in either of the boxes. In short, the study showed conclusively that chimpanzees, bonobos, and orangutans will reliably predict that a human will search for an object where the person has last seen it and therefore believes it to be, even if the apes themselves know that it is no longer there. They understand that the human has different knowledge and therefore different beliefs than they do. In other words, they have theory of mind!

Understanding which other animals have theory of mind is important because it helps us identify the building blocks of cognition that were already present millions of years ago at the start of our unique evolutionary journey—in short, how we came to develop the executive superpowers that we, as humans, possess today. For example, by demonstrating that some of our closest ape relatives have theory of mind, as Chris and others have done, they introduce the intriguing possibility that our uniquely human language and cultural capacities were built on evolutionarily ancient mechanisms of social cognition. That is, our ability to communicate through language and our well-developed sense of culture may have emerged on the back of our ability to understand the thoughts and actions of others, rather than the reverse. To put it another way, it may not have been the *emergence of language* in humans that led to the development of some of our extraordinary executive powers, as many people think. Rather, some of these advanced cognitive abilities—like theory of mind—may have started to emerge early on in humans, eventually leading to the development of language and other culturally critical cornerstones of modern society.

Imagine our early ancestors beginning to grasp that each individual had a mind of their own, with desires, beliefs, and intentions that might differ from theirs. This newfound awareness would have created an intense need for communication. To coordinate hunts, to share stories, to express danger,

or to forge alliances, they needed a way to express complex ideas and share mental states. And so, language may have blossomed: a tool for shaping invisible thoughts into shareable sounds. With each new word and gesture, early humans didn't just communicate; they built bridges between minds, allowing knowledge, culture, and empathy to freely flow. This leap in social cognition—driven by the emergence of theory of mind—may be what unlocked language and set us on the unique evolutionary path that has defined our species.

Understanding this connection brings us closer to the origins of what makes us human, revealing how deeply intertwined language is with our innate desire to understand one another. Not everyone will agree with this, of course—neuroscientists can't agree *when* human language emerged, let alone *why*—and all we can do is connect the dots we already have and come up with a plausible account for how we think we as a species evolved. For me at least, the need to find a language to connect our rapidly evolving but disconnected minds seems a more likely force for change than the spontaneous emergence of language simply looking for a place to hang its hat.

Autism and Theory of Mind

Although theory of mind emerges early on in life, for some of us, it doesn't develop at all. In 1985, my Cambridge colleague Simon Baron-Cohen was among the first to suggest that many children with autism lack theory of mind, their problems stemming from a lack of understanding what those around them are thinking. Although not universally accepted, it does appear that many individuals classified as autistic—both children and adults—have difficulty assigning mental states to others, lacking theory of mind capabilities. They may struggle to interpret the emotions of others, understand sarcasm or irony, or predict other people's behavior. However, autism is a spectrum disorder, meaning that individuals with autism can vary widely in their abilities and challenges, and that includes theory of mind.

In Baron-Cohen's original study, twenty autistic children aged six to sixteen took part in the classic version of the false belief task, in which they were told the story about Sally: Sally puts her marble in one location and

then leaves the room; while she's gone, someone moves the marble to a different location. Then, when Sally returns, the children are asked: "Where will Sally look for her marble?"

If the children pointed to the marble's new location, they failed the question by not taking into account Sally's belief. Sixteen of the twenty autistic children failed the test, pointing to where the marble really was, rather than to where Sally would believe it to be. This failure was not due to random pointing. Nor was it due to any failure to understand and remember the demands of the task or the narrative, because the autistic children all knew the location of the marble when asked, as well as where it had originally been hidden. Baron-Cohen and his colleagues therefore concluded that the autistic children did not appreciate the difference between what they knew and what Sally knew.

More recently, scientists have started exploring theory of mind among adults with autism using new tools designed specifically for the job. One of the most popular is the Reading Mind in the Eyes Test, also developed by Simon Baron-Cohen and his colleagues. In this test, the participant is presented with a series of thirty-six photographs of the eye region of the faces of different people and asked to choose which of four words best describes what the person in the photograph is thinking or feeling. For example, if the eyes are scrunched with abundant crow's feet, one might conclude that they belong to someone who is "serious," rather than someone who is "bewildered." If the eyes are open and relaxed, they might belong to someone who is "reflective" rather than someone who is "aghast." Importantly, the test does not include emotions that are obvious, such as happiness, sadness, anger, or fear, because they can be recognized easily from facial expressions alone, without the need to attribute a belief to the person. Adults on the autistic spectrum were significantly poorer than healthy control participants at identifying what the people in the photographs were thinking or feeling.

Recently, one of my graduate students, Kathleen Lyons, decided to see what goes on in the brains of children on the autistic spectrum when they try to interpret the feelings and intentions of others—not real people, but the characters and creatures that appear in a popular and engaging movie. Again, we turned to a scene from *Despicable Me*. More than twenty years ago, neuroscientists in Israel showed movies to healthy participants in an fMRI scanner and noticed that as the plot unfolded, everybody's brain

synchronized, with the same regions turning on and off at the same points in time. On the face of it, this makes perfect sense. When a gun goes off in a movie, our auditory cortex, the part of the brain that detects sound, will activate; and because every person in a movie theater hears the gunshot at the same instant, all their auditory cortices will activate at exactly the same moment.

The same is true of many other events that are common in movies. For example, when a face looms large on the screen, an area on the underside of the brain and toward the back called the fusiform gyrus will activate. That region, which is often referred to as the “fusiform face area,” is particularly responsive to faces and will activate in synchrony in every person looking at the same face. An area located more toward the center (but also on the underside) of the brain, known as the parahippocampal gyrus (or “parahippocampal place area”) plays a similar role where places or locations are concerned. As the camera takes us through a scene, perhaps moving from street to street in a speeding car, this region will fire in perfect synchrony across people, as each of our brains maps and encodes every location we pass through. Thus, during a movie, countless brain regions will switch on and off in unison across a group of people, reflecting their shared conscious experience of unfolding events.

Kathleen’s idea was to use this phenomenon to examine whether the brains of kids diagnosed with autism spectrum disorder respond differently from those of typically developing children when watching *Despicable Me*. Although *Despicable Me* is a relatively simple movie, following its plot still requires understanding and interpreting the intentions of many of its key players. For example, a central theme in the plot is that Gru, the movie’s main protagonist, wants to steal the moon in order to restore his former status as the world’s greatest villain. Meanwhile, he starts a family by adopting three orphan girls, and he must decide where his commitments lie. Understanding this dilemma (between being the world’s best villain and the world’s best dad) requires that you understand Gru’s perspective and the emotional difficulties he has brought upon himself.

From a publicly available database kindly provided by the Child Mind Institute in New York City, Kathleen examined the data from twenty-eight children ages seven to twelve diagnosed with autism spectrum disorder and twenty-eight controls without autism. All of the participants had been fMRI scanned while watching a ten-minute clip of *Despicable Me*. The results

showed that the brains of typically developing children were highly synchronized in areas associated with theory of mind, including the medial frontal cortex. In contrast, the autism spectrum group had very little synchronization in these regions, suggesting that the children in this group were experiencing the movie differently than the typically developing children.

Interestingly, in several recent studies, the brains of adults with autism spectrum disorder have also been shown to be less synchronized than those of typical adults while watching a movie, suggesting that they, too, have differences in the way they understand the intentions and feelings of others. It also suggests that these challenges do not resolve as kids grow into adulthood but continue to contribute to their difficulty interpreting verbal and nonverbal cues, inferring meaning from others' expressions and gestures, and engaging in social relationships throughout their lives.

Improving Theory of Mind

Can we actually get better at reading minds? Not in the telepathic sense, of course, but in the psychological one? Theory of mind was once thought to be a fixed capacity, something that matured in childhood and then simply stayed with us. But more recent research suggests that it isn't just a developmental milestone—it's a skill that can be refined, trained, and in some cases rehabilitated.

One of the most intriguing findings comes from the world of fiction. A 2013 study by psychologists in New York City found that reading fiction, specifically fiction that focuses on complex characters and rich emotional narratives, can boost performance on theory of mind tasks. Their interpretation was that immersing yourself in other people's mental lives, even fictional ones, fine-tunes your social radar and improves theory of mind. Interestingly, this effect didn't hold for nonfiction or even genre fiction, suggesting that it's not about reading itself, but about *empathic engagement* with ambiguity and mental nuance.

Beyond the bookshelf, training programs have shown some promise, especially in children and individuals with conditions like autism spectrum disorder, where theory of mind development can be delayed or atypical.

There's also growing interest in how mindfulness and compassion-based training might enhance theory of mind. Therapeutic programs like mindfulness-based stress reduction (MBSR) have been associated with increased empathic accuracy, particularly in emotionally charged or ambiguous situations. Indeed, one neuroimaging study found that compassion meditation led to structural and functional changes in brain regions associated with theory of mind, including the medial prefrontal cortex.

None of these approaches will turn you into an expert lie detector overnight, but they do support the idea that theory of mind isn't a static ability etched in neural stone. Like most cognitive skills, it can be shaped by experience, practice, and even by the stories we choose to immerse ourselves in. If you want to get better at understanding the thoughts and feelings of others, you could do worse than picking up a good novel.

Bang! You're Dead

Whether or not you have theory of mind also proves to be a very useful way of determining whether you are conscious or not. On the face of it, it's obvious—if you are completely unconscious, you aren't in any position to develop a theory about what anyone else is thinking. But the idea runs much deeper than that. Can demonstrating that you *have* theory of mind be used to demonstrate that you *are* conscious in circumstances where there is considerable doubt?

This is the question that one of my colleagues, Lorina Naci, and I tackled as part of our research to understand the brains of patients who are in vegetative states. The vegetative state is a condition that usually follows a serious brain injury. Patients may open their eyes, grunt and groan, occasionally utter isolated words, but they do not respond to stimulation. Ask them to squeeze your hand or blink their eyes and they will do nothing. They appear to live entirely in their own world, devoid of thoughts or feelings.

It turns out that many people in vegetative states really are oblivious and incapable of thought. But in 2006, we were the first to demonstrate that a sizable number—up to 25 percent, in fact—are experiencing something quite different: intact minds adrift within damaged bodies and brains.

How do you detect these people? How can you find those who are conscious and trapped within their lifeless bodies and tell them apart from those who are truly vegetative, with no awareness of who they are, where they are, or the predicament they're in? Surprisingly, Alfred Hitchcock provides one answer.

The remarkable phenomenon discussed earlier—that our brains synchronize when we watch the same movie—may be part of the appeal of Alfred Hitchcock movies, because they are carefully constructed to make us think, fear, anticipate, expect, and react. Hitchcock's movies are designed to give viewers a shared conscious experience driven, in large part, by the recruitment of similar brain processes as each viewer observes the events unfolding and seeks to understand their relevance, leading to an ongoing involvement in the plot. Hitchcock creates suspense through the plot's twists and turns, rather than through a series of fast-moving bangs and flashes that are the central components of so many films today. Bang-flash movies also drive the brain, but not to the same extent as the subtle changes in direction—and misdirection—that are Hitchcock's trademarks.

In 2013, Lorina and I scanned a group of healthy participants watching a short black-and-white 1960 made-for-TV Hitchcock episode called “Bang! You're Dead.” The episode depicts a five-year-old boy who finds his uncle's revolver, partially loads it with bullets, and plays with it at home and in public, unaware of its power. The extremely engaging plot gradually unfolds, with the viewer becoming more and more convinced that the gun will be fired and kill someone.

To truly appreciate this story—to understand the plot—requires a very well-developed theory of mind: You have to realize that although you (the viewer) know the gun is real, the young boy thinks that it's a toy. You have to be able to see the unfolding scenario from his perspective. That is why the situation is so suspenseful—the boy loves playing shoot 'em up with his little cowboy friends. This time he doesn't know it's for real. But you do!

As adults, we have a particularly elaborate theory of mind about children: They don't understand guns; they don't understand that they kill people. This knowledge is fundamental to our sense of suspense when we watch “Bang! You're Dead.” An unloaded gun in the hands of a child is not scary. A gun, loaded or unloaded, is less scary in the hands of an adult (particularly a responsible one) than in the hands of a child. Thus, in “Bang! You're Dead,” theory of mind is also required to understand the point of

view of others in the plot, such as the boy's parents. *They* know it's a real gun and you have to know that they know it's a real gun to understand why they might not be happy to see him waving it around.

As expected, when we scanned our participants watching "Bang! You're Dead," their brains became highly synchronized, including the medial frontal cortex, which is required for theory of mind. That's because when Hitchcock guides our brains toward understanding the thoughts of others ("Oh, the boy thinks it's a toy gun!"), we all have that thought at the same time. The episode, then, or more specifically the synchronized brain activity during the episode, can be used as an indicator that we are having conscious thoughts, including those that are required for theory of mind.

In August 1997, an eighteen-year-old named Jeff was assaulted outside a friend's house in Lloydminster, Alberta, a small city about two hours east of Edmonton. (Names and details in this account are used with permission and have not been changed.) According to his father, Paul, an operations coordinator for Husky Energy, Jeff was an outgoing teenager with plenty of friends, a hard worker who was saving money, but he wasn't sure what he wanted to do after he had graduated from high school that spring.

The evening that changed the family's life forever started out at a nightclub. Jeff was getting friendly with the ex-girlfriend of a former bouncer for the club, who was also there that night. Jeff and the girl left the club to go to a friend's house to watch a movie. Paul told me that the ex-bouncer followed them and "called Jeff out," knocking him to the ground and, as Jeff was getting up, kicking him in the chest. The kick caused a cardiac arrest and Jeff collapsed. He was taken to the local hospital in Lloydminster and then airlifted to Edmonton.

Paul, who was out of town for work, learned about the incident the morning after it happened and immediately flew to Edmonton. He found his son comatose and on life support. Jeff emerged from his coma after three weeks and began to breathe on his own. But he was nonresponsive, and he was diagnosed as vegetative. "He looked glazed," said Paul. "There was no life in his eyes. No expression. Nothing."

In 2012, fifteen years after Jeff's assault, Paul came across a story online about the research in my lab and immediately fired off an-email: "I would very much like to have Jeff tested for his awareness. It would make both Jeff's brother and me extremely happy knowing Jeff understands what we are saying to him. I believe it would make Jeff feel better as well. I am

certain that Jeff understands what I say to him but I have no way of knowing for sure. I want to know if he knows how loved and missed he is. I would be willing to do whatever it takes to get this test to happen.”

Something about the email really struck me. Paul wanted to know if Jeff had any awareness, whether he understood the conversations going on around his bedside; but what he *really* wanted to know is whether Jeff knew how loved and missed he was. To put it another way, what Paul wanted to know was whether Jeff still had any theory of mind. To understand that you are loved and missed requires that you understand what others think about you; that is, you need to be able to take their perspective.

While this wasn’t our central question at the time—all we were really looking for were some residual signs of consciousness in Jeff—Paul’s quest illustrates just how important having theory of mind is for our own sense of personhood and the sense of personhood that we have about others.

We agreed to evaluate Jeff, and Paul arranged for his son to be transported two thousand miles via commercial aircraft in July 2012 from Edmonton to Hamilton, Ontario, which is about eighty miles from London. An ambulance brought them to Parkwood Hospital in London, Ontario, where Paul made Jeff comfortable before retiring to the Best Western Plus Lamplighter Inn, located right across the street.

The following day, my team began to assess Jeff. We asked him to look at a pen—nothing. We asked him to look at a mirror—still nothing. We asked him to stick out his tongue. No response. We found no evidence of awareness, nor any indications that Jeff was able to communicate.

We sent another ambulance to Parkwood to pick up Jeff and Paul the following day and bring them to the scanning center. Paul, a tall good-looking man with a full head of dove-gray hair, stood beside the gurney as Jeff was wheeled in through the secure heavy door that separates the scanner from the rest of the world. Jeff had a lean face and closely cropped hair. He was wide-awake, his head cocked to one side as he sat propped up on the gurney’s pillows. I thought about how much love and commitment it must have taken for Paul to make this journey with his son, and I hoped that we might be able to send them both home with some good news. I told Jeff about the fMRI scan and the film he was about to see, not knowing whether he understood, or even heard, anything I said.

As Jeff slid into the scanner, I stepped outside to the waiting room where Paul was patiently waiting. “We’re just showing Jeff an Alfred

Hitchcock movie,” I told him, “to see whether we can activate his brain.”

Back in the fMRI room, “Bang! You’re Dead” was playing on the screen above Jeff’s head. We knew that the screen would be visible to him via a mirror mounted in front of his eyes, but we couldn’t be sure he was watching. When it was over, we pulled Jeff out of the scanner and sent him back to Parkwood for the night.

When we looked at the results, I was stunned. Although Jeff’s brain activity was a little reduced compared with that of our healthy controls, as he watched the episode, all the appropriate brain areas had activated *at the right time*. In response to sounds, Jeff’s auditory cortex sprang to life. When the camera angle changed or the young boy ran across the screen, Jeff’s visual cortex activated. But most important, at all the critical twists and turns in the plot—those places where a clear understanding of the story unfolding on screen is essential—Jeff’s brain responded exactly like those of a person who was conscious and aware, including the medial frontal cortex! Jeff still had theory of mind!

To this day, being able to tell Paul that Jeff was still aware of just how loved and missed he was remains one of the most satisfying moments of my scientific career. It also had a particular effect on Jason, Jeff’s brother, and it changed their relationship in some ways. “I talk to him with more passion now,” Jason said when I spoke to him sometime later. “I want him to know how much he means to me. When you’re eighteen and twenty-one, you don’t say things like ‘I love you.’ Your tests reaffirmed all those talks I had with him in private. To know that he’s heard me—it does feel good.”

Somehow, through showing that Jeff still had theory of mind, we had restored a part of his personhood, a whole part of his being. Those around him loved him dearly, and now we had shown them that Jeff knew that—because Jeff had theory of mind.

6

Emotional Regulation Navigating Tumultuous Seas

You can't help what you feel, but you can help how you behave.

—MARGARET ATWOOD

Every year, thousands of people around the world conquer their fears and jump out of an airplane with only a parachute for company. Most of us say we would never do such a crazy thing—it sounds terrifying—yet many of us manage to overcome those fears and do it anyway. I was put in this exact position a few years ago when one of my postdocs, Ola, a seasoned skydiver with more than five thousand jumps under her belt, insisted that I have a go. “Why not?” I thought “How scary can it be?”

I soon found out it is very scary indeed. As the plane’s rear door opened at ten thousand feet, the wind roared. Far, far below me I could see the airstrip—a tiny target that I had to try to aim for as I plummeted earthward at 120 miles per hour. It’s called “terminal velocity” for a reason, I thought. I started to shake my head vehemently back and forth. “I’m having second thoughts,” I sputtered. All smiles and enthusiasm, Ola held her hand to her ear, pretending she couldn’t hear me. I tried again, determined to make myself heard over the roaring wind. “This isn’t happening!” I yelled. “I’ve changed my mind!” Right then, Ola’s smile turned to a wicked grin, and with a deft martial arts maneuver, she sent me flying through the plane’s open door into the abyss.

The wind caught me immediately and I started to spin through the air gracelessly, like a sock in a clothes dryer, hopelessly out of control. The only emotion I felt was absolute terror. I couldn't decide if this was the most exhilarating moment of my life or if it was the exact scenario my brain had evolved for millions of years to avoid. Either way, I had to quickly take control of my emotional state because too much was at stake if I didn't. I needed to focus: check my altimeter every few seconds, keep an eye out for other skydivers in my vicinity, and—most crucially—deploy my parachute at exactly the right moment. Luckily, I managed to pull myself together and landed safely, but face down, in a muddy field beside the airstrip.

Curiously, this need to regulate my fears did not change with each subsequent jump. Indeed, after twenty or more jumps, the feeling was exactly the same—utter terror every time the plane door opened and I stared down at the earth's surface almost two miles below. I asked Ola if this feeling ever goes away—after all, she'd jumped five thousand times, and surely she'd have stopped much earlier if the fear, and the need to regulate it, was the same every time. “It never goes away,” she replied, “but that’s why I do it!”



Much of psychology is about understanding our emotions—where they come from and how they shape us. How many emotions are there? Do they differ across cultures? What is the best way to classify them (the so-called “taxonomy” of emotions). How do individual differences, such as personality traits or genetic factors, affect emotional experiences? How do emotions influence interpersonal relationships and social interactions?

I learned about all this as a psychology undergraduate in the 1980s, and to be honest, none of it really interested me because no one seemed to care much about how the brain affects our emotional lives. Emotions are far more than fleeting feelings; they are the brain's way of adding color to our lives, turning black-and-white thought into a masterpiece of color through a dynamic interplay of neurotransmitters, networks, and structures that shape every conscious experience we have. Neuroscience allows us to peek into the unseen world within us and examine the biological roots of joy, fear, anger, and love, helping us to understand that emotions aren't just “in the mind” but deeply woven into the very fabric of our nervous system.

Decoding the nature of emotions at a neuroscientific level isn't just about understanding why we think the way we do—it's a quest to understand the neural bedrock of the human condition.

With the arrival of functional neuroimaging in the early 1990s, it finally became possible to study the neuroscience of emotions—what happens in our brains when we are happy, sad, angry, or afraid. Much of the earliest work using techniques like fMRI focused on an area of the brain known as the amygdala.

Tucked away deep within the brain, the amygdala is a small, almond-shaped structure that plays a vital role in our emotional experiences and responses. It's not only shaped like an almond, but also about the size of a ripe almond, the kind you might find in a bag of mixed nuts. I have always thought of the amygdala as the celebutante of brain areas—famous for being famous—yet it's hard to know exactly why. The amygdala is recognized for its role in creating fear, but it does far more than that. It is our brain's emotional sentinel, constantly receiving and interpreting information from our senses for potential threats or rewards. When it detects something of significance, whether it's a frightening situation or a pleasurable experience, the amygdala springs into action, triggering a cascade of physiological and emotional responses through the release of hormones like adrenaline: Our heart rate increases, our muscles tense, and we become more alert. These changes influence our emotional reactions, causing feelings of fear or excitement. This process happens almost instantaneously, helping us respond quickly to important situations.

But what happens when we want to exert some *control* over our emotional responses? How do we jump out of that airplane when every neuron in our amygdala is yelling "Don't do it!"? The answer is through *emotional regulation*. Emotional regulation is our ability to monitor, evaluate, and modify our emotional response to situational demands or personal goals. It's the guiding hand, allowing us to navigate the tumultuous seas of our inner lives. From controlling our fears when we are dangling almost two miles above planet earth to skillfully negotiating every social situation, mastering emotional regulation is not merely a handy skill to have, it is an essential aspect of everyday life. This is why I consider it to be a key executive function.

Emotional regulation should not be confused with what has been called "emotional intelligence"—our ability to recognize, understand, and

navigate our own emotions, as well as to understand and respond to the emotions of other people. Emotional intelligence involves skills such as empathy, self-awareness, and social awareness. For instance, if you notice a friend looking upset, and you're able to empathize with her feelings and offer support, you're demonstrating emotional intelligence.

Emotional regulation, on the other hand, is the executive mechanism we use to consciously manage our own primary emotions, which are often defined as natural, instinctive states of mind that derive from our circumstances, mood, or relationships with others. A widely accepted theory developed by American psychologist Paul Ekman suggests that we have six basic emotions—sadness, happiness, fear, anger, surprise, and disgust—although other theories include emotional states such as envy, gratitude, guilt, jealousy, love, and pride. Regardless of how many emotions you think there are, emotional regulation refers to the ability to control and modulate our responses to any of them in various situations.

While regulating our emotional response to fear allows us to indulge in sports and pastimes we might not normally have the courage to do (like jumping out of a plane), regulating our emotional response to anger has more practical day-to-day advantages. Imagine you're stuck in traffic on your way to an important meeting. Another driver cuts you off, triggering a surge of anger. Instead of pounding your horn or bellowing in frustration, you take a deep, calming, soothing breath and remind yourself that getting angry won't change the situation. You decide to "let go" of your anger and focus on more important things, like mentally preparing for your meeting. By consciously choosing to regulate your immediate emotional response (in this case, anger), you are optimizing the situation and avoiding the negative consequences (in this case, getting distracted from your meeting preparation).

Happiness is another emotion that is nice to be able to regulate. Hundreds of pop-science books have been written over the years about the science of happiness, claiming to use the power of positive psychology to uncover the secrets to leading a happier and more fulfilling life. From the power of gratitude and positive thinking to the importance of meaningful relationships and personal growth, they describe actionable strategies to cultivate well-being and happiness. The recommendations that many of these books make—whether it's "savoring life's simple pleasures," "finding purpose and meaning," or "fostering social connections"—are, in essence,

forms of emotional regulation. The message they are all sending is, “You may not be feeling the way you want to feel right now but do this thing or that thing and you will begin to feel better in the future.” Perhaps “finding purpose and meaning” in your life isn’t quite as straightforward as, say, suppressing your immediate fear in order to jump from an airplane, but it still requires you to take control of your emotions in order to experience life the way you want to.

To exert its effects, emotional regulation leans heavily on other executive functions, including selective attention, working memory, theory of mind, and inhibition, because the strategies we typically use to control our emotions often require these additional executive processes. By moving our focus of attention toward or away from the source of the emotion, we can control how we respond to it. For example, when engaged in public speaking, we might minimize our anxiety by focusing on the person in the front row who is beaming at us, rather than the person behind him who has a menacing glare. Alternatively, we might shift our focus of attention internally to information we have brought into working memory (perhaps a previous occasion when our public speaking received a rave review).

We can also use theory of mind to change the way we feel about an emotionally evocative event by reinterpreting its meaning. Imagine receiving a text from an old friend, canceling plans to meet. Initially, you may feel disappointed and slightly annoyed—you were looking forward to your time together. However, you then decide to reframe your interpretation of your friend’s behavior to change your emotional response. Instead of assuming she canceled because she doesn’t value your friendship, you consider alternatives. You recall that your friend has been experiencing some stress at work, and she has an elderly parent in the hospital. Through theory of mind, you surmise that she must be feeling pressured. Your disappointment transforms into empathy and understanding, and you respond to the message in a supportive and encouraging tone, offering to reschedule the date. By consciously changing your interpretation of your friend’s behavior, you have effectively shifted your emotional response from negative to positive, strengthening your friendship in the process.

Emotional regulation is also linked to inhibitory control. For example, resisting the impulse to lash out in anger when we are provoked involves both controlling the emotional reaction itself (making sure we remain calm internally) and inhibiting our immediate behavioral response (resisting the

urge to respond in kind). Nevertheless, emotional regulation and inhibition are distinct executive processes involving different psychological processes and neural circuitry. Emotional regulation is all about managing our feelings, and in many situations that does not involve inhibition at all—situations where the goal isn't necessarily to suppress a reaction but to modulate, redirect, or reframe emotions in a constructive way. For example, after a frustrating argument, you hit the gym or go for a run, using your emotional energy to fuel a productive workout instead of letting it boil over into a tantrum or resentment. In cases like that, emotional regulation doesn't involve holding emotions back or suppressing (inhibiting) impulses but skillfully redirecting, reinterpreting, or amplifying emotions in a way that serves your well-being. It's more like steering a car than hitting the brake.

Conversely, as we've seen, inhibition is also required in many situations that do not involve emotional regulation—like not eating the cookie dough before baking it or resisting the urge to doom-scroll your phone at 2 a.m. So, while emotional regulation and inhibition often work hand in hand, they are not interchangeable. Working together, however, these two pillars of executive function help us navigate complex social situations and maintain focus in the face of emotional challenges.

The Development of Emotional Regulation

By experiencing what happens when we regulate our emotions successfully, we learn about the beneficial effects that emotional regulation can have on our lives, which then increases the probability that we will respond in a similar way in the future. Over time, these small changes accumulate, shaping our behavior to be more advantageous to ourselves and eventually shaping our entire lives.

Indeed, we begin learning to regulate our emotions in early childhood and continue through adolescence, and into adulthood. As emotional regulation develops, infants progress from near-complete reliance on their caregivers for regulation to independent self-regulation. In the early months of life, infants find it difficult to deal with their emotions and begin to develop basic self-regulation skills, such as the ability to soothe themselves by sucking their thumbs or cuddling with a comfort object like a blanket. By preschool, they become more capable of identifying and labeling their

emotions, as well as recognizing the emotions of others. By interacting with adults and other children, they learn to understand their feelings and rationalize them, gradually starting to make more reasonable behavioral choices in response to the emotions they feel.

Between the ages of six and eleven, children start to use cognitive strategies to regulate their emotions, such as reappraising a situation or problem-solving to find solutions. At this stage, different regions of the frontal lobe are developing rapidly, and selective attention, working memory, theory of mind, and inhibition all become available to assist with emotional regulation. Adolescence is marked by further developments in emotional regulation, although it is often complicated by increased emotional volatility due to hormonal changes.

I recently asked one of my colleagues who has two teenage daughters whether she'd noticed any problems with emotional regulation. Her eyes went to the ceiling as she replied, "How much time have you got?" I pressed her for specifics. "Like when they explode at someone who has absolutely nothing to do with what they are annoyed about," she said. This immediately struck me as a perfect example of emotional regulation—rather than emotions themselves—running amok. We all get annoyed, sometimes quite legitimately, by events in our lives. But to transfer that irritation to someone who has nothing to do with its source is a classic failure of emotional regulation, and with social consequences. Fortunately, once their hormones stop banging about, most teenagers come out of this phase relatively unscathed, although for some, emotional regulation continues to be a problem well into adulthood.

Effective emotional regulation is often considered an early marker for later successes. A recent study of 325 kindergarteners in the United States found that emotional regulation was positively associated with children's later academic success, classroom productivity, literacy, and math achievement scores. In 2020, a review of 150 studies involving more than 215,000 participants concluded that "self-regulation in childhood can predict achievement, interpersonal behaviors, mental health, and healthy living in later life." Many of these studies were longitudinal, meaning that they followed the same kids across time, sometimes for several decades. The results showed that good emotional regulation in preschool (around age four) was positively associated with social competency, school engagement, and academic performance in early school years (around age eight).

Furthermore, good emotional regulation in early school years was positively related to academic achievement (math and literacy) in later school years (around age thirteen) and employment prospects in adulthood.

Why would learning to regulate emotions in childhood set the stage for success and well-being? The simple answer is that children who develop effective emotional regulation skills become better equipped to handle the ups and downs of life, leading to improved academic achievement, healthier relationships, and overall mental health. Successful emotional regulation in children also lays the foundation for positive interpersonal behaviors, such as empathy, communication, and conflict resolution. As these children grow into adults, they are more likely to form supportive relationships, navigate social situations effectively, and have a positive attitude. The ability to regulate emotions is closely linked to taking care of oneself. Nurturing emotional regulation in childhood paves the way for a happier, more successful, and more fulfilling life in years to come.

Inside the Control Room

Given the fundamental role that emotional regulation plays in our lives, it's not surprising that many neuroscientists have sought to understand the brain systems involved. As we have already seen, the amygdala is involved in processing many different emotions, and these include fear, joy, sadness, and anger. For example, when we recall a happy memory from childhood or feel a surge of anger in response to an injustice, our amygdala is at work, creating our emotional responses. But when we need to *control* those emotional responses, it's our frontal lobes that spring into action.

In one fMRI study, twenty-four female participants were asked to try to either increase or decrease the negative emotions they felt in response to unpleasant images, such as pictures of sickly-looking patients in their hospital beds. To improve their (understandably negative) emotional responses, some of the women were encouraged to adopt an objective perspective, viewing the pictures from a detached, third-person stance, or imagining the pictured situation improving (a quickly recovering patient). In contrast, to increase how negatively they responded to the pictures, some of the women were encouraged to imagine that they themselves or a loved one was the person in the hospital bed or imagine that the person pictured

was in great pain and tragically likely to die. Experiments that use psychological manipulations of this sort may seem unnecessary, cruel even, but they have been the key to our understanding of how emotional regulation occurs in the brain.

The strategies given to the participants worked. Those who were encouraged to remain detached from the depicted events or imagine that the situation was not as grave as it first appeared rated their overall feelings as less negative, and activity in the amygdala decreased, reflecting their change in emotional state. In contrast, those who were asked to increase their negative emotions by either imagining themselves in the scene or imagining the worst-case scenario for the patient rated their overall feelings as more negative, and amygdala activity increased.

But what was happening in the frontal lobes while all this was going on was the most interesting. First, *both* increasing and decreasing negative emotions activated an area of the frontal lobe known as the anterior cingulate cortex, which is part of the medial frontal cortex. We learned about the medial frontal cortex in the previous chapter on theory of mind. Its two flat surfaces nestle against one another at the front of the brain. The anterior cingulate cortex is a section of brain tissue about halfway up those two flat surfaces, arching gracefully around the corpus callosum—the bundle of nerve fibers that connects the brain’s two hemispheres. It is about as broad as a couple of pencils laid next to each other and extends backward for a few inches from just behind the forehead.

One function of the anterior cingulate cortex is to monitor for differences between our automatic emotional responses to events in the world and what we would ideally like those responses to be—what neuroscientists call “conflict monitoring.” The twenty-four women in the scanner were experiencing an automatic negative emotional response to the pictures they were being shown, yet they knew that they were required either to suppress their response or to enhance it using the strategies they had been given. The anterior cingulate was keeping track of this mismatch (or “conflict”), monitoring changes in the women’s emotional state until they came into line with the instructions they had been given.

Other parts of the frontal lobe were also involved in regulating the negative emotions to the pictures but differed depending on whether they were being enhanced or suppressed. For the women who were trying to improve their mood, the inferior frontal gyrus was activated. As we’ve

already seen, this part of the frontal lobe is crucial for inhibiting, or suppressing, thoughts and behaviors we would rather avoid. In contrast, in those who were seeking to worsen their emotional response, activity was observed in an area of the frontal lobes known as the dorsal medial prefrontal cortex—that’s a region lying just above the anterior cingulate cortex, on the flat surface of the brain between its two hemispheres. This region crops up in all sorts of brain imaging studies, but in this context, it appeared to be keeping track of the negative emotions generated by the amygdala and helping to amplify them.

This continuous dialogue between the frontal lobes and the amygdala is the neural basis of emotional regulation. The amygdala automatically sounds the alarm, and the frontal cortex decides whether or not to act on that alarm. To do this, the frontal cortex draws on its vast network of connections to other brain regions, carefully considering past experiences, social norms, and possible consequences. That’s why emotions themselves feel *automatic* (you don’t decide to get angry at the driver who cuts you off at the lights, it just happens spontaneously), yet how we respond to our emotions feels more conscious and controlled (do I hit the horn to register my anger or remain calm and drive on?). It’s a sophisticated dance of electrical impulses and neurotransmitters that tells us that the brain isn’t just a machine processing inputs and outputs—it’s a dynamic, self-regulating marvel, capable of bending its own emotional responses to better fit our goals and aspirations.

Angry Birds

There is good evidence that animals other than humans have the capacity for emotional regulation, although the extent and mechanisms of this vary widely across species. While I’m sure that birds do get angry, do they have the capacity to temper that anger and even channel it into something more productive than an emotional maelstrom in the way that many humans can?

You might find the answer surprising. Birds, like ravens and crows, which are known for their high intelligence, show signs of emotional awareness and control. For example, ravens have been observed calming themselves after social stress by preening or engaging in “kiss and make up” behavior with others. These birds also display signs of frustration in

competitive scenarios but have been seen to redirect their irritation in socially adaptive ways, such as adjusting posture, vocal tone, or movement to signal reconciliation, rather than responding impulsively. Even rats and mice have shown that they are capable of exercising control over their emotional behavior. For example, rats trained to avoid impulsive actions to get rewards show an ability to “wait” or “pause” that resembles a rudimentary form of emotional control. Of course, all this has to be trained, and it’s debatable whether an animal that is trained to wait for a reward is making that “choice” or simply knows that in order to survive it needs food, and in order to get food it has to wait. Human emotional regulation, on the other hand, feels much more flexible and under our own control. Jumping out of an airplane is hardly a survival instinct (although, to be fair, statistically it is not as dangerous as many people think).

Nevertheless, studies in primates, particularly chimpanzees and bonobos, provide even stronger evidence for emotional regulation in nonhuman species. For example, chimpanzees have been observed restraining aggression in social settings, apparently to maintain group harmony (although this is hard to prove). They also exhibit behaviors like reconciliation after conflicts, which may indicate an awareness of the emotional states of others and an effort to manage those states to preserve social bonds. Wolves also show behaviors that may suggest some emotional control. Dominant wolves in a pack sometimes “walk away” from conflicts instead of engaging, which is thought to help stabilize the pack’s social structure, although this is also difficult to prove.

Overall, the evidence suggests that other species may not regulate emotions in the same complex way that humans do, although they do exhibit behaviors consistent with basic emotional regulation. They may control impulses, adjust behavior for social harmony, or calm themselves in stressful situations. This hints at the evolutionary roots of emotional regulation, which may not be unique to humans at all, but rather a fundamental aspect of social life across many species.

Hunger and Emotional Regulation

Like many of our executive functions, emotional regulation can be easily affected by relatively small changes in our personal situation or

environment, including hunger, anxiety, lack of sleep, and sickness. We've all experienced "hanger"—when we have less control over our temper when we are hungry.

In 2018, neuroscientists at the University of North Carolina at Chapel Hill asked 236 American college students to either fast or eat normally before coming into the lab. After some of the students were given a simple exercise designed to direct their focus of attention to their emotions, all the participants were asked to complete a tedious exercise on a computer that, unbeknownst to them, was devilishly programmed to crash just before it could be completed. One of the researchers then came into the room and blamed the student for the computer crash. Some of the hungry participants rated the experience as more stressful (and the researcher conducting the experiment as more judgmental) than those who had eaten normally beforehand, but only those who had not previously been taught to focus their attention on their emotions. In other words, "hanger" only occurred in the students who hadn't been explicitly encouraged to make a link between their hunger and their emotional state, suggesting that "hanger" can be controlled as long as we recognize it for what it is.

Whether we recognize it or not, "hanger" is a real thing, rooted in the immense energy requirements of the human brain. The brain, despite its relatively small size compared with other organs, voraciously consumes energy, accounting for about 20 percent of our total energy use. This is due to its complex, active nature. The brain constantly processes information, regulates bodily functions, and coordinates movements. Even when we're at rest, our brains are busy maintaining vital functions like breathing, circulating blood, and controlling body temperature. Additionally, activities such as thinking, learning, and problem-solving require even more energy. The brain burns calories to fuel these activities.

Unlike many other organs and tissues in the human body that can use a variety of nutrients to do their jobs, the brain is critically dependent on glucose to deliver those essential calories. When you eat, carbohydrates, proteins, and fats are digested into simple sugars, including glucose, which pass into your bloodstream before being distributed to your tissues and organs, including your brain. As time passes after your last meal, your blood glucose levels drop, which can have a direct effect on the functioning of your brain. Although not everyone agrees on the precise details, one theory about "hanger" is that the brain responds by reserving its stock of

glucose for essential brain functions like seeing, hearing, and moving, while less critical functions (like behaving within socially acceptable norms) get temporarily shut down.

Sleep Deprivation and Emotional Regulation

Poor sleep can also interfere with our ability to regulate our emotions. Take the example of everyday irritations. After a full night of restful sleep, a missed bus or a spilled coffee might be a minor annoyance, easily brushed off. But with only a few hours of shut-eye, that same incident can feel like a catastrophe, as if the world is conspiring against you. Many studies have shown that sleep-deprived people are not only more reactive but are also less able to interpret facial expressions accurately, sometimes mistaking neutral or even friendly expressions as threatening. This “emotional dysregulation” can lead to more conflicts, heightened anxiety, and a distorted view of social situations.

In 2017, my team again partnered with the BBC to launch what would become the world’s largest study of sleep, executive function, and the brain. To kick things off, Fergus Walsh, the BBC’s medical editor, flew to my lab in London, Ontario, to try the experiment for himself. One evening, after most people had left the lab, we assessed Fergus’s cognitive abilities using the tests we’d developed as part of the Creyos.com platform. We then kept him engaged by having him play a game of Monopoly with some other volunteers until 4 a.m. before sending him off to bed in one of our five sleep labs, which are small, comfy, bedrooms equipped with discretely placed reconnaissance equipment that allows us to monitor people, ensuring they are asleep. At 8 a.m., just four hours later, I cracked open the door to the sleep lab and cheerfully announced my arrival: “Good morning, Fergus! Time to get up!” From the outset, it was obvious that Fergus was irritated and not easily able to control his feelings, despite knowing this would all be captured on camera for the BBC evening news. “I’m feeling . . . ugh . . . like I haven’t had enough sleep,” Fergus said wearily.

When we tested his cognitive abilities again, the effects of having only four hours of sleep were obvious. Fergus performed more poorly on almost all the tests of executive function we gave him, but what was more noticeable was the marked change in his mood. While he’d been cheery and

enthusiastic when we tested him the night before, now he was much quieter and easily irritated as he struggled through the cognitive tests. We also put Fergus in our fMRI scanner before and after his four hours of sleep, and the results showed us why both his cognitive abilities and his ability to regulate his emotions had been so badly affected. Many areas of the brain were less active during the second scan, but particularly those in the frontal lobe, including the anterior cingulate cortex, the dorsal medial frontal cortex, and the inferior frontal gyrus, which we know all contribute to emotional regulation.

When we formally launched the study a few days later, seventeen thousand people from all over the world signed up, and the results were fascinating. Although the perfect amount of sleep for optimizing executive function was between seven and eight hours, around half of our sample did not get that much sleep regularly, reporting less than 6.3 hours of sleep per night on average. In fact, many people reported sleeping for only four hours per night, which may be one reason why so many of us struggle with regulating our emotions.

Although not fully understood, it is thought that sleep deprivation alters the balance of neurotransmitters in the brain, such as dopamine, serotonin, and acetylcholine, which play crucial roles in regulating cognitive functions. Sleep deprivation also increases levels of stress hormones like cortisol, which can further impair cognitive function and exacerbate mood disturbances.

The Effects of Physical and Mental Health on Emotional Regulation

Our ability to regulate our emotions can also be affected by the stress associated with physical or mental illness, although the precise way this happens likely varies from illness to illness. At the beginning of 2020, most of us had little idea that the entire world was about to be turned upside down by the COVID-19 pandemic. In fact, back then, most of us didn't even know what COVID-19 was. Notwithstanding the awful toll on human lives, the economy, and the livelihoods of millions of people worldwide, the pandemic offered some of us the chance to study the relationship between a viral illness, cognition, and mental health on a scale like never before.

We were already running our online cognitive assessment platform at Creyos.com, which had been visited by millions of participants, so we were in a good position to carry out neuroscientific research online—which was the only option once the lockdowns began. Even by the end of that first year, as the number of COVID-19 cases surpassed one hundred million worldwide, it was becoming increasingly clear that many survivors were experiencing both ongoing cognitive challenges and issues with emotional regulation.

In Canada, the SARS-CoV-1 outbreak of 2002–2003 had hit hard, so we already understood a lot about how viruses can lead to long-term physical, cognitive, and mental health issues, but COVID-19 (caused by the SARS-CoV-2 virus) was something different. The cognitive and emotional issues being reported could have been the result of the virus directly affecting the brain through inflammation, strokes, or autoimmune responses. Indirect effects of the virus were also a possibility, including those caused by blood clots, low oxygen levels, sedation, or ventilation.

It was a complex set of issues for science, and we wanted to try to understand them. As the pandemic dragged on, terms like “brain fog” entered common parlance, along with “long COVID” and descriptions of COVID “long haulers.” But none of this meant much in neuroscientific terms, and so we designed a study to try to make sense of it all. We studied 485 patients whose diagnosis had been confirmed by a positive COVID-19 test. They all completed our online battery of executive tasks at Creyos.com as well as an extensive questionnaire to fully document their COVID-19 experience, infection severity, extent of recovery, physical health status (including levels of pain, energy, and fatigue), and mental health status, assessed using standard measures of anxiety and depression.

The results unequivocally confirmed the existence of executive function impairments in the aftermath of COVID-19 infection. How quickly people could think was markedly impaired, with reasoning and global cognition scores also affected. However, the results also showed that rates of depression, anxiety, and self-reported limitations in emotional well-being were through the roof among our COVID-19 survivors. We cannot know for sure whether this was due to the sickness itself—factors such as inflammation, an autoimmune response, blood clots, or low oxygen levels—or whether environmental influences, such as job insecurity, financial instability, homeschooling, social isolation, and an elevated sense of

community fear, were to blame. Regardless, the results confirmed that our ability to regulate our emotions is easily affected by external stressors, whether they arise because of personal illness or a global international catastrophe like the COVID-19 pandemic.

Learning to Regulate Your Emotions

As we have already seen, emotional regulation is a set of skills that we acquire gradually as we go from toddlers to children and then on into adulthood. But while we all have the neural machinery for effective emotional regulation, its efficiency varies widely from individual to individual. Some of us have a natural knack for controlling our emotions, a well-tuned frontal cortex that swiftly tamps down the flames of anger or anxiety thrown at it by the amygdala. For others, this process is more challenging. The question is, can we do anything to change that?

Until recently, efforts to improve emotional regulation focused on time-consuming and costly psychotherapeutic, psychopharmacological (drugs), and invasive neurosurgical approaches, such as deep brain stimulation (DBS). DBS involves implanting electrodes into specific brain regions to modulate neural activity and potentially restore normal emotional processing. Understandably, highly invasive surgical techniques like DBS are reserved for severely impaired neuropsychiatric groups of patients whose lives are compromised by their disabilities.

In 2013, however, several of my former colleagues at Cambridge University published a paper entitled “Training the Emotional Brain” that might help the rest of us. In it, they make the point that many tests of emotional regulation rely on the same frontal lobe regions as tests of other executive functions, including working memory. They reasoned that systematic working memory training performed in an emotional context may have the potential to improve emotional regulation.

To test this theory, they put thirty-four healthy participants into an fMRI scanner, then showed them three types of film footage containing either neutral information (a weather forecast); emotionally charged information (documentary footage of war scenes, accidents, terrorist atrocities, famine), during which they were asked to attend without attempting to regulate their

emotions; and the same unpleasant film clips, but with the instruction to attempt to cognitively regulate their emotional distress as much as possible.

Some of the participants then underwent twenty-one days of training on a task that combined emotional information with a working memory test. They would see pictures of faces, some of which had emotionally negative expressions (fearful, angry, sad, or disgusted), while others were neutral. At the same time, they would hear words through their headphones, some of which were negatively charged (“evil,” “rape”), while the rest were emotionally neutral. The working memory component was simply that the participants had to say whether or not the face or the word was the same as one presented a few trials earlier.

At the completion of their training, the participants were fMRI scanned again while watching neutral and emotionally evocative films and asked to try to reduce their negative feelings. Remarkably, the participants who had been trained were better able to regulate their emotional responses to the disturbing films than a separate group of participants who had not been trained on the emotional working memory task. And the fMRI data showed that this improvement in emotional regulation was accompanied by changes in brain activity in several regions of the frontal lobes.

These results show that just three weeks of training on a working memory task that involves emotional stimuli can improve emotional regulation, because the same frontal lobe brain regions are involved in regulating both types of executive function. That is, there is enough overlap in the neural machinery that training one type of executive function (working memory) is sufficient to improve another, unrelated executive function (emotional regulation).

As far as I know, this is the first (and best) example of cognitive training working beyond the obvious (you get better at whatever you train at). Training with one type of emotionally evocative stimulus can improve the ability to regulate negative responses to an entirely different type of emotionally charged stimuli. Moreover, it provided a neuroscientific explanation for these effects.

But for me, the most interesting part of this study is that the participants were taught how to *think* about their emotions. Again, this feels like the key to understanding how we take control of our thoughts and actions before they take control of us. Neuroscientific studies like this show us that the path to emotional regulation might be simpler—and more powerful—than

we ever thought: taking a moment to actually think about our emotions before they turn into actions.

It sounds almost too easy, but this pause, this brief second of contemplation, engages our brain's executive functions and puts us back in the driver's seat of our behavior. In that fraction of a second, the frontal lobes—the brain's chief executive—can assess the impulse bubbling up from the more ancient emotional centers, like the amygdala, and ask, “Is this really how I want to respond in this situation?” By calling on our “inner referee,” we can tame our raw, instinctive emotional responses and steer them toward something more balanced, more deliberate.

Imagine the chaos our lives would descend into if we simply acted immediately on every emotional response: fights with loved ones, impulsive emails we'd regret, that moment of road rage we can't take back. But with just a moment of reflection, we can transform knee-jerk reactions into responses that align with who we want to be. It's almost as if our brains are constantly holding a lively debate, with input from here and there constantly pushing and pulling our emotions this way and that. But we should get to decide the outcome, we should take control. With each conscious decision, each small act of emotional self-control, we sculpt not only our behavior, but the very essence of ourselves.

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7

Executive Function, Consciousness, and Free Will

We do not see things as they are, we see them as we are.

—ANAÏS NIN

When I first met Carol, I was shocked by her condition. It's never easy meeting victims of a traumatic brain injury, but Carol's accident was still relatively recent, and she looked awful. It was August 2005, and I was about to embark on an fMRI study that would change my life forever.

A month or so earlier, Carol had been multitasking—crossing a busy road while talking to her husband on her cell phone. That decision would change *her* life forever. Two cars hit her, one after the other, inflicting terrible injuries to her brain and causing multiple limb fractures. Like Max, Carol was another shocking reminder of how vulnerable we are and how quickly our lives can change.

Carol was tested repeatedly by experienced neurologists and diagnosed as being in a vegetative state. That means it was assumed she had no awareness of who she was, where she was, or the predicament she was in. But I had a different idea. In the fMRI scanner, I was going to ask Carol to *do something*. Patients who are diagnosed as vegetative cannot move intentionally; they won't squeeze your hand or blink their eyes if you ask them to. But my hunch was that if there was any part of Carol still in there

—a conscious mind inside a lifeless body—then she might just be able to make a conscious decision to activate her brain if we asked her to.

While she lay in the scanner, we asked Carol to imagine playing tennis. We asked her to think about swinging her arm back and forth, a volley here, a drop shot there, and perhaps an occasional smash. We did this for one simple reason: We already knew that thinking about playing tennis activates a part of the frontal lobe that is involved in planning movements, a region known as the premotor cortex.

We haven't yet encountered this part of the frontal lobe in our journey through the executive functions of the brain, but if you place your finger on what you would typically think of as the top of your head, that's more or less where the premotor cortex sits—about halfway between the front and back of your brain. Think of it as the brain's "movement planning bench," watching the game unfold and choreographing the perfect play for every one of your movements. It's not the star of the movement show—that's the primary motor cortex—but without a premotor cortex, your actions would be as chaotic as a marching band performing on an ice rink.

If Carol could activate her premotor cortex exactly when we asked her to, we would know that she could understand us, and we would know that she was conscious. In one way it felt like total madness. We were asking a vegetative-state patient to imagine playing a game of tennis! But inside the scanner, something amazing was happening. Whenever we asked Carol to imagine playing tennis, she would activate her premotor cortex exactly as we had asked her to do! And when we asked her to stop—to just relax and "empty her mind"—the activity in the premotor cortex disappeared.

Since that day in 2005, more than a thousand "vegetative" patients worldwide have been asked to imagine playing tennis in an fMRI scanner. About one in four of them can do it. Like Carol, they are not vegetative at all, despite their appearance. They are trapped inside their bodies, unable to move or speak, but able to control their brain activity voluntarily. And this was the secret we discovered to unlocking their consciousness.

Conscious Control

A recurring theme throughout this book has been that our executive functions are available to us to deploy consciously—we can *decide* when

and where to use them. For example, when we make a plan to solve an everyday problem, we frequently *decide* to make that plan, and then, as we consider our options, we decide to accept (or reject) various solutions. Similarly, while basic emotions like anger or sadness are not something we typically decide to experience (a punch in the face from a stranger makes you angry whether you like it or not), how we regulate those emotions (ignore it or punch back) is something that we have control over. This is what neuroscientists often refer to as “conscious control,” and in Carol’s case, it was the one thing she could do to tell us she was still in there. She consciously controlled her premotor cortex by deciding to imagine playing tennis, which required that she utilize several of her residual executive functions, such as working memory (for her imaginary game of tennis), attention (to our instructions and to her own thoughts), and even some planning (where to imagine hitting the ball next).

Just because we *can* consciously control our executive functions doesn’t mean we do it all the time. For example, you don’t have to consciously decide to selectively attend to the faces at a party if you are trying to find your friend Molly. More likely, you will simply find yourself doing it because spotting Molly in a crowd is a familiar problem and you have a tried and tested solution (scan faces until you recognize Molly). That’s you putting your executive functions on autopilot, freeing up resources for you to think about something else, like what you are going to say to Molly when you find her. However, you don’t *have* to stay on autopilot, because, like our other executive functions, selective attention *can* be controlled consciously. For example, if you wished, you could adopt a completely different strategy and attend to everybody’s shoes until you find Molly’s signature purple Doc Martens. It may not be as fast or effective as looking for her face, but it would probably work eventually.

This level of flexibility can be incredibly powerful in situations where the goal is less familiar, allowing us to devise novel and efficient strategies for solving difficult problems. For example, imagine you are looking for your white Toyota RAV4 in a crowded parking lot and you don’t know where to start because it was parked there earlier in the day by your husband. Selectively attending to each white car until you found your own is likely to be a very inefficient strategy because 25 percent of all cars in North America are white. Looking for all the Toyota RAV4s will also take a while as it’s one of the best-selling cars on the continent. Then you

remember that last year you installed a bike rack on the roof of your car. Bike racks are relatively uncommon, and chances are there is only one white Toyota RAV4 with a bike rack on its roof in that parking lot. Making a conscious decision to selectively attend to white RAV4s with bike racks will therefore rapidly locate your vehicle.

To summarize, one important characteristic of executive functions is that we can consciously choose when to use them and when not to, and that imbues us with a tremendous amount of control over our lives. In some circumstances, it's fine to just go with the flow, but on other occasions stepping in and taking conscious control can make all the difference. Imagine taking a trip to the grocery store and working through the items on your shopping list in alphabetical order because that's just how you wrote them down. You'd search for an avocado at one end of the store, then go to the other end for butter and then back to where you'd started for a cucumber, and so on. Even a simple shopping trip would be an exercise in frustration and wasted time. But because we are able to consciously categorize and sort items (both avocados and cucumbers belong to the category "fruits and vegetables"), most of us are able to mentally rearrange our list so that we focus on one section of the store (fruits and vegetables) and then move on to another section (dairy) for the next category of items, and so on. Everyday strategies like this involve several executive functions working together, including planning, attention, and working memory, and so multiple regions of the frontal lobe have to chip in to make sure everything runs smoothly. It's not surprising, therefore, that many of the frontal lobe patients I was seeing in the late 1980s stumbled whenever a task required them to exercise this sort of conscious control over their behavior. For example, in one test, I would ask them to remember the numbers 2, 5, 8, and 11—not a particularly difficult memory task when you notice that the numbers keep increasing by 3. But instead of using this simple strategy, my frontal lobe patients would often try to remember the four items individually, and not always in the right order (8, 2, 5, 11, for example). By failing to use what is a simple and obvious mathematical strategy, they made the task harder for themselves and invariably failed. In contrast, if the numbers to be remembered were not linked by an obvious strategy (7, 2, 4, 17), my frontal lobe patients would perform just as well as people with no damage to their brains at all, even though, on the face of it, it was exactly the same task!

Another test they routinely failed involved naming as many different animals as they could in one minute. It sounds easy, but it's more difficult than you might think: dog, cat, lion, elephant, cow, . . . after a dozen or so animals, many of us run dry. But people who are really good at this task typically boost their performance by using a simple conscious strategy to organize their mental fumbling into a number of distinct categories, such as “pets” (dog, cat, hamster, guinea pig, mouse), “safari animals” (tiger, lion, elephant, giraffe, monkey, cheetah, wildebeest, snake), “farmyard animals” (cow, sheep, goat, horse, pig). Unlike people without brain damage, my frontal lobe patients almost never adopted this strategy and were left wracking their brains after just five or six animals had come to mind. And it turned out that this general principle proved to be the case for most of the tasks with which my frontal lobe patients struggled. What the “difficult” tasks had in common was that they could all benefit from the patients stepping in and taking conscious control. Instead of stopping to think about the task for a second, they would just go with the flow, making it a whole lot harder to complete.

Who Is *Really* in Charge Here?

If our executive functions are available for us to control, then what (or who) is doing the controlling? It almost feels that there is something in our brain that is even more executive than our executive functions! Who is *really* in charge here? This is an age-old philosophical question that has puzzled thinkers for centuries. If our executive functions control much of our behavior, then what controls them?

From a neuroscientific perspective, the interactions between different parts of the frontal lobe and between the frontal lobe and the rest of the brain are crucial here. Until recently, it was thought that different areas of the brain perform different cognitive “functions” that more or less map on to how our abilities appear to us—an approach known as *localization*. Memory is a great example of this. We know we are able to store facts and figures in our heads, so for many years it was assumed that there must be an area of the brain where all those facts and figures are stored. With the explosion of functional neuroimaging methods like PET and fMRI in the 1990s, we have come to understand that memory storage is not the purview

of one part of the brain at all but, like all complex cognitive feats, is the result of many different areas of the brain working together. As it turns out, *there is no one memory location in the brain.*

Executive functions are no different. While the frontal lobes play a central role in orchestrating executive behavior, they do so through dynamic interactions with many other brain regions that shape how these functions influence our thoughts and actions. For example, as we have seen, the limbic system, including the amygdala, manages many of our basic emotions, and it is through interactions between various regions of the frontal lobe and the amygdala that we are able to regulate our emotions effectively. The parietal cortex toward the back and top of the brain is also intimately involved in carrying out many executive processes, including attention and working memory. John Duncan, whom we met in the chapter on attention, describes the frontal and parietal lobes as a “multiple demand network” that works to support many executive functions. Rather than being specialized for just one process, the multiple demand network is activated whenever we need to tackle difficult or novel tasks. For example, if you’re trying to solve a complex puzzle or learn a new skill, this network kicks in to help you organize information, shift strategies, and stay on task. The prefrontal cortex might help you decide on the steps (or “subgoals”) needed to complete the puzzle, while the parietal cortex keeps track of spatial relationships between puzzle pieces.

John Duncan’s research suggests that this network doesn’t just handle one specific type of problem but rather serves as a general-purpose system that our brain relies on whenever we need to apply effortful, controlled thinking. By drawing on a common set of cognitive resources, the multiple demand network allows us to respond flexibly to a wide variety of situations, from problem-solving and decision-making to maintaining attention and managing working memory.

So, to return to our earlier question—Who is *really* in charge here?—this is where the question of control becomes murky. While the prefrontal cortex might be the CEO of your brain’s operations, it’s not an all-powerful dictator. It’s more like a mediator, negotiating between different departments (such as the amygdala, the parietal lobes, and the basal ganglia) to reach a consensus. A lot of the time, autopilot is just fine, and the best decision will be made without you needing to give it much thought. But on other occasions, the views of several different parts of the brain need

to be considered before a decision is made, and that is where the frontal lobes come in.

But if our executive functions are just parts of a complex machine that operates largely on autopilot, where does free will fit in? Is it just an illusion, a story we tell ourselves to make sense of our actions? Some philosophers and neuroscientists think so. They argue that our decisions are shaped by factors we're not even aware of, from genetic predispositions (including instincts) to unconscious biases (including habits). The idea of a completely free, unbounded will might simply be a comforting myth, they say. There is certainly some truth to that; many of our behaviors do seem predestined to occur, whether we like it or not, based on our prior experiences, our expectations, our preferences, habits, and traits.

Some have taken this idea to extremes, such as Stanford neuroscientist and primatologist Robert Sapolsky, author of *Determined: A Science of Life Without Free Will*. Sapolsky argues that all human behavior is the result of prior causes, including biology, genes, hormones, life experiences, and environmental triggers. Everything we do, from ordering a salad to starting a revolution, is the inevitable result of what came before. Your frontal lobes may be running the show, but they're doing so on the back of processes you didn't choose: your dopamine levels, your trauma history, and whether your mother smoked while pregnant. To put it another way, if you could fully understand a person's brain, developmental history, and current context, you could, in principle, predict all their choices. That leaves no room for true free will.

It's an attractive argument to some, not least because it allows us to absolve each other of any moral responsibility. Imagine a middle-aged man who, after years of law-abiding behavior, suddenly starts to shoplift regularly. He's caught and charged for his crimes. But then he has an MRI and a tumor is discovered pressing against his orbitofrontal cortex, which, as we have seen, plays a crucial role in understanding the rights and wrongs associated with different behavioral choices. After the tumor is removed, the shoplifting stops completely.

Most of us would agree that the man's bizarre and impulsive behavior was most likely caused by his tumor. Those who believe there is no free will might then ask: Why should we think things are any different for people who behave badly *without* a tumor? Is there really a clear line between biological malfunction and "normal" behavior, or is that line just

one of visibility? After all, every action we take is the result of a brain state, and every brain state is the result of something: genes, stress, trauma, hormone levels, a sleepless night, or too much caffeine. What difference does it make if we can see it on a scan?

It's a powerful argument. It is also, according to the late, great philosopher Daniel Dennett, missing the point. Dennett's view was that free will is about having the ability to act according to our desires and reasoning, even if those desires and reasons are products of our brain's intricate, behind-the-scenes processes. The mistake, according to Dennett, is assuming that if our choices are influenced, they must be meaningless.

He argued that we do, in fact, have free will, but it's the kind that emerges from our incredible ability to reflect, plan, and consider alternatives—what Dennett called “the freedom to choose in a rational way.” We can be both a product of our circumstances and an agent in our own lives. In fact, said Dennett, being influenced by reasons, consequences, and deliberation is *what makes us free*. Our brains are constantly juggling possibilities, simulating outcomes, and weighing potential risks and rewards. In this intricate dance, free will is simply the product of a finely tuned system that allows us to choose among options with a degree of flexibility unparalleled in the animal kingdom. Those choices are not inevitable and predetermined—they reflect our executive functions doing their thing.

Consider a simple everyday example—the act of deciding to exercise. Your frontal lobes might weigh the benefits against the effort, but this decision is also influenced by your identity as someone who values health. Meanwhile, other areas of the brain might subtly nudge you toward, or away from, exercising based on past experiences (you broke your ankle last time you played squash), emotional states (you just don't feel like it today), or even your assumptions about the weather (it's going to rain, and I'll get wet walking home from the gym). Sapolsky is likely to say that whichever option you pick, it was always going to be that way—you were destined to forget the gym and stay at home based on an intricate chain of neural antecedents.

Dennett, on the other hand, would say that *how* you deliberated matters. Did you pause, consider the health benefits, but then remember the time you broke your ankle exercising? For Dennett, that is free will. You used

your executive functions—working memory, inhibition, emotional regulation—to act with intention rather than instinct.

Of course, Sapolsky might respond that reasoning is just more biology. Your ability to decide not to go to the gym was determined by the wiring in your prefrontal cortex, shaped by your upbringing and your genetic profile. You didn't choose your executive functions. And you didn't choose whether they do the job they are designed to do well, or not.

The problem with these sorts of debates is that the proponents on each side are coming at it from entirely different biological levels and therefore talking past each other. Sapolsky zooms in to the molecular level of causation; ultimately, everything that happens is caused by something that came before it. Dennett zooms out to the level of social and psychological complexity; our ability to make complex choices only makes sense when we look at the full human experience, not just the chemical soup inside our skulls.

From the perspective of executive function, this distinction matters because whether or not we can trace every aspect of our behavior back to the molecular milieu that allowed it to happen, we certainly do have the ability to plan, inhibit, shift focus, and reflect—the core ingredients of self-control and goal-directed behavior. Granted, we aren't *entirely* free—we're bound by our neural circuitry, shaped by our experiences, and limited by the physical world. But within that framework, our brains are able to give us a remarkable kind of agency. And while the philosophical debate will rage on, that's probably as much free will as any of us need to live meaningful, morally responsible lives—and to decide whether to go to the gym tonight or not.

Free Will(y)

If we accept that we have free will and that this allows us a good degree of control over how and when we deploy our executive functions, could this provide some clues about the differences between the human brain and those of other species? There's no question that many other animal species have some executive functions, like simple decision-making. For example, when she's tired, Ronnie, our family dog, will take herself off for a nap. Sometimes she'll choose the sofa and sometimes she'll choose her bed.

That's decision-making right there! But what is less certain is how much control she has over her decisions. Could she, for example, decide to go to sleep on the dining room table just for the heck of it (as my niece once did at a family wedding)? When we feed Ronnie, she keenly munches down her food. But can she arbitrarily decide not to eat a meal in a way that most humans can, regardless of whether they are hungry or not?

It doesn't seem so. Unlike dogs, humans can decide not to eat even when they are starving, particularly if there is some greater calling behind their decision. When Ronnie gets up in the morning, I am quite sure she doesn't plan out her day like we do ("first I'll have breakfast, then I'll go for a walk, and then I'll decide whether to play fetch in the garden or have a nap on the sofa"). But that is not to say her life is devoid of any plans. Like most dogs, Ronnie can formulate and carry out simple plans, like running to the bottom of the garden to fetch the frisbee that she remembers she left there earlier. But that's about it. Ronnie's planning ability is limited to what she knows and what she is quite familiar with. It seems highly unlikely that she can plan much beyond the here and now or decide when a new plan is needed versus when it's best to just go with the flow, like most humans can.

As you ascend the phylogenetic scale beyond dogs to examine more evolved species, like apes, this distinction between having some executive capabilities and being able to control them at will becomes blurrier. It really does feel as though Chris Krupenye's orangutans must be *deciding* to keep track of which box has been used to hide an object and who knows where it is hidden. If not, why would they bother doing it in the first place? They don't gain anything by having that knowledge beyond understanding a little more about what is going on in the world around them. Assuming they do these things intentionally, do they have the same experience of having control over their executive functions, the same sense of free will that we have?

Neuroanatomical differences between species may provide some clues. Humans and chimpanzees split from their common ancestor more than six million years ago, and during that period, the human frontal lobes grew disproportionately relative to that of our primate cousins. Many believe that this rapid expansion of frontal lobe tissue allowed our sophisticated executive functions to emerge, which would suggest that such functions might also exist in chimpanzees and other great apes, but likely in more primitive forms. In 2024, a group of neuroscientists in Germany used MRI

to compare the amount of gray matter in the brains of 480 people between the ages of twenty and seventy-four and 189 chimpanzees between the ages of nine and fifty. By comparing the brains of humans and chimps of equivalent age and sex, they were able to show that most of the difference—a measure of where in the brain most evolution had occurred—was in the frontal lobes. These new results from Germany suggest that rapid evolutionary expansion of the frontal lobes in humans may well underpin our extraordinary executive powers. This mirrors what is known about the developing brain; as we have seen, the frontal lobe is one of the last parts of the human brain to fully mature, and in line with this same pattern, our executive functions are also some of the last to fully come online.

If the brains of our closest genetic relatives suggest some, albeit more primitive, control over their executive functions, what about species that are further away from us in evolutionary terms? As you *descend* the phylogenetic scale to look at insects and other bugs, it starts to feel less likely that they have much control over their thoughts, even though they may exhibit some behaviors that suggest they have some primitive executive functions.

Nevertheless, it's important to distinguish between our sense about such things and the available scientific evidence, and here, neuroscience continues to unearth some real surprises. For example, New Caledonian crows have been shown to exhibit sophisticated problem-solving abilities, such as using and modifying tools to access food in ways that suggest a level of conscious deliberation and foresight. Octopuses can solve puzzles and display other complex behaviors that suggest they can make flexible decisions and adapt their behaviors based on goals they have set themselves. Most interesting to me are honeybees. Recent research has shown that they consider factors such as distance, predator risk, and nectar quality when deciding where to forage, even communicating these factors to other bees. These are all behaviors that suggest various levels of executive functioning and, more surprisingly perhaps, some level of conscious control over those functions.

These remarkable examples push us to rethink our understanding of consciousness, free will, and executive function—not only in humans, but across species. If a crow or an octopus can plan, problem-solve, or make adaptive decisions based on their past experiences, where do we draw the line? Is human consciousness unique, or is it a more evolved version of

processes that exist across the animal kingdom? The possibilities are dizzying. Perhaps future research will reveal that what we once thought of as uniquely human traits are simply more refined versions of what nature has been tinkering with all along.

As we continue to explore the minds of our evolutionary relatives, the mystery deepens, drawing us ever closer to acquiring more complete answers to questions about the true nature of consciousness, how free our “free will” really is, and the incredible neural machinery that drives both our instincts and our aspirations. The answers might change not only how we understand ourselves, but also how we understand our place in the world.

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8

The Rise of Machines

Executive Function and the Extended Mind

Anything that is in the world when you're born is normal and ordinary and is just a natural part of the way the world works. Anything that's invented between when you're fifteen and thirty-five is new and exciting and revolutionary and you can probably get a career in it. Anything invented after you're thirty-five is against the natural order of things.

—DOUGLAS ADAMS

Unless you've been living under a rock, you cannot have missed the fact that new technologies, driven in large part by artificially intelligent (AI) systems, are rapidly infiltrating every aspect of our lives. From that smartphone in your pocket to the Netflix and Amazon algorithms that make recommendations about what you should watch or buy, these influences are everywhere. In many cases, they have been created specifically to support our executive functions: We have digital calendars to plan our lives, social media directing our attention here, there, and everywhere, and endless gadgets and apps to keep track of shopping lists, projects we're in the middle of, and pretty much anything we don't want to hold in our working memories. This evolution in artificial intelligence has raised new fears—that this new technology will boggle our minds and the minds of our children and that by using these devices we will somehow lose some of the cognitive abilities that we currently possess. Just as a sedentary lifestyle can

lead to muscle atrophy, will handing over some of our executive functions to a machine lead to brain atrophy?

Some scientists seem to think it might. In 2025, a team at MIT investigated how using ChatGPT to write an essay affected both cognitive performance and brain function measured directly using electroencephalography (EEG). Fifty-four participants were assigned to three groups: One group was encouraged to use ChatGPT to write; the second group could use any website to help them, but ChatGPT or any other large language model (LLM) was explicitly prohibited; and the third group could only use their brains and was forbidden from using either ChatGPT or any website for assistance. Participants completed three sessions over the course of four months without changing their group assignment, but in a fourth session the rules were switched such that the ChatGPT-assisted participants were asked to use no tools, while the brain-only group was asked to switch to ChatGPT.

Unsurprisingly, perhaps, after the first session, the ChatGPT group was significantly poorer in their ability to quote from the essays they had written just minutes earlier. Indeed, 83.3 percent of participants in that group failed to provide a single correct quotation, whereas only 11 percent in both the search-engine and brain-only groups had the same difficulty. More surprising (and worrying), this pattern spilled over into session four, when the roles were reversed; that is, most of the participants who switched from using ChatGPT to their brains were still unable to reproduce a single quote from their essays, whereas most of those who switched from their brains to ChatGPT did just fine.

The EEG results mirrored these behavioral findings, showing that brain connectivity was systematically reduced as the amount of external support increased. The students who wrote essays using only their brains showed the strongest and most wide-ranging connectivity between different brain regions and had more activity going from the back of their brains to the all-important frontal lobes, while the ChatGPT group showed the weakest connectivity.

One, perhaps obvious, interpretation of this study is that the brains of people writing essays with the assistance of ChatGPT and similar LLMs are less engaged than those of people using just their brains, and over time, this leads to a decrease in their cognitive abilities. However, intriguing as these results are, they should not be overinterpreted; the study involved a

relatively small number of participants over a short time period and so does not tell us whether regular use of systems like ChatGPT affects cognition in the long term.

Overall, the scientific evidence that modern technology is meddling with our brains is at best equivocal. For example, a recent review of the scientific literature examining how performance of various tests of executive function is affected by technology use in healthy adults between eighteen and thirty-five years of age found that no clear pattern emerged across the board. In one study of inhibition, there were no differences between “excessive” and “normal” smartphone users; yet in a different study, “high” smartphone users were reported to be more impulsive (and therefore less able to inhibit) than “low” users. Other studies have shown that planning and problem-solving do not appear to be affected by smartphone usage, while in several other studies, working memory has been shown to be better in regular video game players than in non-gamers.

In 2025, my lab examined the effects of video game playing on executive function in more than a thousand healthy participants between eighteen and eighty-seven years of age. One-third of our sample were non-gamers, one-third were infrequent gamers (less than three hours per week), and one-third were frequent gamers (more than three hours per week). Frequent gamers were significantly better at working memory and reasoning tasks than infrequent gamers, who were, in turn, significantly better than non-gamers. Indeed, those who frequently played video games performed, on average, like people who were 13.7 years younger than themselves who did not play video games at all! The exact cause of this relationship is unclear, although neuroimaging studies have demonstrated that video games are associated with increased gray matter in the frontal lobes, among other regions. Playing video games has also been found to increase the release of the neurotransmitter dopamine, which, as we have seen, is crucial for planning and other executive functions. In addition to these structural and chemical changes, video games are well known to enhance visual attention and processing speed through repetition and practice, presumably stemming from the rapid and dynamic visual demands of many of these games.

Although it is impossible, based on these results, to conclude that regular gaming exerts a direct effect on executive function (after all, it’s possible—theoretically at least—that people with better executive functions

are more drawn to playing video games), the results do suggest a strong association.

It's very easy (and common) to cherry-pick from these and other studies to argue for—or against—the effects of modern technology on our executive functions. But it's important not to lose sight of the big picture and understand that the real answer is likely to be a very nuanced one. Perhaps some types of modern technology are better for our executive functions, while others aren't so good; while we have shown in my lab that video games may improve working memory, scientists in Greece have found that using a mobile phone for just five minutes can significantly *impair* working memory performance.

It is also likely that some aspects of executive function are augmented by modern technology, while others are impaired. For example, although our 2025 study showed that regular video gaming improved working memory and reasoning abilities, a 2022 study by Dutch scientists showed that inhibitory control was worse in adolescents who regularly played violent video games.

Finally, the effects of modern technology on both our cognitive and mental well-being are likely to be age and situation dependent. In *The Anxious Generation* (2024), social psychologist Jonathan Haidt argues that the dramatic rise in anxiety, depression, and self-harm among adolescents since around 2010 can be traced, in large part, to the replacement of a play-based childhood with a phone-based one. According to Haidt, this generational shift has rewired social development, depriving young people of in-person interaction, unstructured outdoor play, and even adequate sleep, while saturating their lives with curated and addictive social media feeds. The data he presents are persuasive to some: In the United States, United Kingdom, and Canada, mental health issues among teens began climbing just as smartphones and social media became universal.

But not everyone agrees with Haidt's ideas. Developmental psychologist Candice Odgers has pushed back, pointing out that while social media use is widespread, the strongest predictors of adolescent distress are still rooted in *offline* experiences—poverty, abuse, family instability—not screen time per se. She notes that many teens report using their phones to find support, connection, and creative outlets—particularly those who may lack these in real life. And the picture gets even more nuanced when you look at the brain. Emma Duerden, my colleague at

Western University, has used neuroimaging to explore how screen time affects brain development and cognitive control. Her work suggests that the impact of technology on executive function is subtle and highly dependent on context; moderate, structured use may be neutral or even beneficial, while excessive, unregulated use might hinder the development of brain networks that support self-regulation and flexible thinking.

The Extended Mind

Fears about the detrimental effects of new technologies are as old as technology itself. In the late nineteenth century, as the electric light bulb began to replace gas lamps and candles, many worried about its potential dangers and societal impact. Some feared that light generated by electricity was “unnatural” and could cause harm to human health. There were concerns that constant exposure to artificial light might disrupt sleep cycles or even lead to blindness. Religious and moral concerns also surfaced, with some questioning whether humanity should meddle with nature by creating light after dark, a realm previously thought to belong to the divine.

In truth, we’ve been using devices of various kinds to augment our executive functions for hundreds of years. Before the iPhone there was the Filofax, and before the Filofax we had address books and calendars stuck to the fridge door. Before computers there were calculators, and before calculators there were the abacus, slide rules, and log tables, or we would just rely on a pen and paper to help us solve a math problem. These are all methods that humans have used down the years to take the mental load off their brains when dealing with challenging tasks. Arguably, modern technologies like computers, smartphones, and LLMs like ChatGPT are no different. A smartphone app that tracks appointments and deadlines simply enhances our ability to plan and organize our activities. Instead of relying solely on memory, we offload these tasks to a digital assistant, reducing the cognitive load and freeing up mental resources for other tasks.

These are all examples of what British philosopher Andy Clark calls “the extended mind.” Imagine you’re trying to remember your grocery list: apples, bread, milk, and the ever-elusive quinoa. You might jot it down on a piece of paper or, more likely these days, pop it into your phone. According to Clark, when you do this, your mind is extending itself into the world—

your brain is outsourcing some of its cognitive load to a piece of paper or a smartphone app. Clark has argued that the gadgets we use can become as much a part of our thinking as the neurons firing in our heads. For example, when you're navigating through a new city, your phone's GPS doesn't just give you directions; it becomes an extension of your sense of direction. But it also extends your executive powers by providing instant access to information about your destination, such as alternate routes, thereby enhancing your problem-solving capabilities and allowing you to adapt to changing conditions while exerting minimal mental effort. You're no longer just relying on your brain to get from point A to point B—you've become a hybrid being, part human, part smartphone, cruising through the urban jungle.

If we take Clark's idea seriously, then the tools we use in our daily lives—our phones, our calendars, even those scraps of paper in our back pocket, allow us to extend our executive functions beyond our own brains. They are more than mere accessories; they're part of this whole executive team.

Let's take a concrete example. Numerous project management apps now allow teams to track progress, assign tasks, and set deadlines. These tools support executive functions such as planning and problem-solving by extending them into a collaborative digital space. Team members can see the big picture and the individual steps required to complete a project, facilitating better organization and coordination. Likewise, at home, digital calendars and to-do lists make it easier for us to keep track of appointments, deadlines, and tasks that we need to accomplish. These external aids reduce the mental burden of remembering and organizing information, allowing for more efficient and effective planning.

Working memory is another executive function that can be boosted significantly by technology, and whether you know it or not, you already do it many times every day. Whenever we use external devices like notebooks, sticky notes, or digital note-taking apps on our phones or computers, we are offloading information from our brains and freeing up mental resources for tasks we'd rather be doing instead. Spreadsheets, mind-mapping software, and decision support systems also augment our executive brains by providing platforms on which to organize, analyze, and visualize information. These tools enable us to tackle complex problems and make informed decisions more effectively than by relying on our brains alone.

Even emotional regulation can benefit from a little bit of extra help from technology. Apps that track habits, mood, or productivity provide feedback and reminders that can help us to regulate our actions and maintain focus.

This idea—that technology can extend our mental powers—also has implications for education and for those who struggle with their executive functions. For example, children with ADHD often have trouble paying attention and performing everyday tasks. Tools such as visual schedules, timers, and task management apps can support their cognitive abilities by providing external structures that help manage time and tasks effectively. While distracting in some contexts, these tools, when used appropriately, can act as external aids that bolster the brain’s executive functions and help students do better in school.

In short, by integrating technologies like smartphones or computers into our cognitive lives, we can support and enhance our capacity to remember, plan, and make decisions more effectively. In the words of Andy Clark, we are “supersizing” our executive capacities.

The beauty of the extended mind concept is that it reframes how we think about executive function. We’re not lone operators, marooned inside our heads, but rather highly adaptable creatures who are constantly extending our minds into the world around us. And while this might sound like science fiction, it’s actually happening every time you Google a fact, use a calculator, or glance at your Fitbit to check your daily quota of steps.

User Error?

That, I think, is the best answer for those who worry unduly about the “problem” of modern technology and its effects on our brains. The problem may not be the technology itself, but how and why we use it.

When I began my scientific career as young PhD student, the only way I could learn about something, like the frontal lobes, was to visit the university library, find a book that broadly covered the subject matter, and start reading. That book would likely mention other books and scientific papers that could provide more specific information about the topic, but there was no guarantee that the library would carry them. So, a trip to the bookstore would become necessary, or a (handwritten) begging letter to a

scientist on the other side of the world who, if I was lucky, would send back a copy of the scientific paper I was looking for. All this palaver could (and often did) take months and would dig into my yearly stipend. Nowadays, I can complete the same task in a matter of seconds and at a fraction of the cost using my laptop computer or my phone and the internet. But the advent of hardware and software that allows me to do that hasn't turned me into a mindless idiot; it has just given me more time to do what I enjoy doing—thinking about science! Perhaps the real challenge of technology isn't how to stop it from dumbing us down—it's learning how we can better integrate it as partners in our executive functioning.

For the most part, the existing neuroscientific evidence supports this view. It's true that keeping your notifications active on your phone will inevitably distract you, leading to poorer performance on whatever task you are supposed to be focusing on. But that doesn't mean that using the phone has affected your ability to attend per se; on the contrary, it reflects a choice you have made to divide your attention (between your current task and your phone notifications), and as a result, your performance takes a hit. Just as reading a book while talking with a friend doesn't work well, keeping your phone on and having it tap you on the shoulder every two minutes with another crucial piece of news is no different. Likewise, I know of no evidence that using your smartphone to store all your friends' phone numbers directly reduces your working memory capacity. It may mean that you come to rely too heavily on the device to the point that you can't even conjure up your wife's phone number without pulling out your phone (guilty!), but again, that is a choice you make, rather than a direct effect of technology on your brain's capacity to remember. The same is true when we examine most of the claims about the apparent detrimental effects of modern technology on our brains; whenever technology appears to get in the way, it's because we've made a conscious decision to let that happen.

I believe that the best way to make optimal use of modern technology in service of our executive functions is to think about the limitations of these all-important brain processes and to understand when they would benefit from some technological assistance. In doing so, we take control of our lives, which empowers us to be more productive, efficient, and successful. For me, the real power of our executive functions has always been in knowing exactly when and where we need them in order to maximize our behavioral choices. In the twenty-first century, this is not just about

considering what's going on in our brains; it's about thinking how to use technology to make the best use of it.

Ultimately, technology invites us to rethink the boundaries of our executive functions. While it can free us from boring, monotonous work so that we can devote our time and energy to more productive activities, its constant distractions and rapid gratifications also challenge us to think about how we can harness it to help us to maintain focus, regulate impulses, and engage in deep, sustained thinking. It challenges the old-school view that the brain is a stand-alone supercomputer, showing instead that our mental life is deeply intertwined with the world around us. So, the next time you find yourself leaning heavily on technology to get through the day, don't worry—you're not just being forgetful or lazy. You're embracing the full potential of your executive functions.

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9

Think Before You Think

It may be that we are puppets—puppets controlled by the strings of society. But at least we are puppets with perception, with awareness. And perhaps our awareness is the first step to our liberation.

—STANLEY MILGRAM

We began this journey by peeking under the hood of the human mind—not to marvel at neurons glowing in the dark, but to understand how we steer our lives through the everyday chaos of modern existence. We’ve seen how executive function is the quiet force behind everything from writing symphonies to resisting the second cookie. It’s not flashy, and it rarely announces itself, but it shapes nearly every decision we make—and many we don’t even realize we’re making.

So now the question naturally shifts from understanding *what* executive functions are to wondering *what we can do with them*. Can they be strengthened? Can we upgrade the internal systems that plan, prioritize, inhibit, reflect, and choose? Or are we simply passengers on a train that was mapped out by our genes, our early childhood, and our breakfast choices? This is not a self-help book, and I won’t bamboozle you with empty promises of mental makeovers. But I will give you a grounded look at what the neuroscience says, along with a quiet suggestion that perhaps the most powerful thing we can do isn’t to change our brains, but to *pay attention* to how we use them.

Let’s begin by reconsidering why it is that some people breeze through life with the mental clarity of a chess grandmaster, while others struggle to

organize their thoughts or even remember where they left their keys. I hope that by now you are persuaded that the answer lies in a thrillingly complex mosaic of genetic, biological, neurochemical, and environmental influences that come together to shape our executive functions. Genetically, some people hit the cognitive jackpot, inheriting versions of genes that enhance memory, attentional focus, or emotional resilience. Biologically, their brains might be wired with subtle differences in the size and connectivity of their frontal lobes, which we have seen are responsible for controlling most of our executive functions. On a chemical level, neurotransmitters like dopamine, acetylcholine, and norepinephrine play starring roles—a sprinkle here and a dash there can make the difference between a hyperfocused planner and a chronic procrastinator. Then there's neuroanatomy: Differences in the strength of white matter connections, which, as we have seen, are like the brain's "superhighways" of information, can impact how quickly each of us processes information and responds to unfolding events in the world around us. Environmental factors like early childhood stress, educational opportunities, and even diet can further mold these abilities. In other words, the path to robust executive functions isn't a straight line—it's a complex journey shaped by an intricate interplay of nature, nurture, and everything in between.

And then there's wear and tear. Few of us have lived the life of an NFL superstar, with its relentless barrage of blows to the head, and fortunately, many of us won't even experience a clinical concussion during our lifetimes. Yet life is full of small and large bumps on the head: that soccer ball that came out of nowhere as you were watching the match, or the door of the kitchen cabinet that you slammed your head against when it was carelessly left open (we've all done it). The cumulative effect of those bumps may lead to alterations in brain structure and function, affecting our capacity to use our executive functions effectively. Whether it's a single massive blow to the head or a series of small, minor blows, over time the effects might be just as bad.

Moreover, our ability to use our executive functions effectively may change from day to day and even from hour to hour, depending on a variety of factors. For example, when discussing emotional regulation, I described how our 2017 study of seventeen thousand people had shown that too little sleep can impair our executive functions. In the same chapter, we looked at "hanger" and how it can also affect executive functions if it goes

unchecked. But these are all temporary changes that can be reversed with a good night's sleep or a bite to eat. In that sense, our executive functions are a little like our blood pressure; how well they function is relatively stable over time, and factors such as stress, hunger, and sleep simply push them up or down a little around that baseline value.

Over the last twenty years or so, we have accumulated millions of executive function test results (more than twenty million, in fact), mostly from healthy participants, via our online cognitive assessment platform at Creyos.com. Some people performed better on these tests than others, and some people performed better when we first tested them than when we tested them a year later (or occasionally, vice versa). It's clear that some people have less effective executive functions than others or are simply worse at marshaling whatever executive powers they possess. I hesitate to say they are "impaired"; rather, this is just part of the rich diversity of human life and is not intended to be judgmental or derogatory. Executive functions vary between people, just as seeing, hearing, and most other abilities vary between people.

Executive Reboot: Can We Upgrade Our Mental Operating System?

Does that mean that we can't improve our executive capabilities? Is there really nothing we can do to take full advantage of that three-pound lump of gray and white matter inside our heads, to optimize our behavior, to make smarter decisions that lead to more productive, fulfilling, and creative lives? When our blood pressure is high, we take beta blockers to bring us back into the normal range. If we have diabetes, we take insulin and/or are encouraged to maintain a balanced diet to manage our blood sugar levels and keep to a healthy weight. Isn't there an equivalent way to maximize our executive functions or, for those of us who are struggling with ADHD, dementia, or Parkinson's disease, to at least get us back into the typical healthy range?

There are some options, but unfortunately, the gains you are likely to make are rather small, and you may notice no improvement at all. For example, some studies have shown that coffee, in moderation, can improve aspects of executive function, such as planning and attentional switching.

Caffeine is consumed daily by 87 percent of the world's population, making it the most frequently used drug on the planet. Caffeine increases the levels of several neurotransmitters in the brain, including dopamine and acetylcholine, which may affect mood, energy levels, and executive function. In the chapter on planning, we saw that prescription drugs like dextroamphetamine (Adderall), methylphenidate (Ritalin), and modafinil (Provigil) have also been shown to improve aspects of executive functioning, and they all affect levels of dopamine in the brain.

What you eat can also affect your executive function, although there is significant disagreement in the scientific literature about the size of those effects. In one study published in 2016, twenty-five adults drank grape juice every day for twelve weeks, and some improvements in attention, working memory, and planning were noted. More interestingly, these improvements on traditional cognitive tasks were accompanied by improvements in the participants' driving behavior, suggesting that the benefits of drinking grape juice translate into real-world differences in everyday behavior. A more recent study in 2023 from scientists at Kings College London, in the United Kingdom, found that attentional switching and working memory were also better in blueberry eaters than in participants who were fed a placebo. Both grapes and blueberries are rich in flavonoids, a natural compound found in many fruits and other plants. Flavonoids may help the brain in several ways. For example, some studies have suggested they can reduce inflammation, protecting brain cells from damage. Several animal studies have also shown that flavonoids can block beta-amyloid plaque buildup in the brain, a trademark of Alzheimer's. Finally, flavonoids may also increase blood flow to the brain. As we have seen, the brain's main fuel is glucose, which is delivered via the blood.

Physical exercise is another option to help ensure that your brain receives plenty of blood. Many believe that exercise is good for cognition and may be particularly beneficial for executive functions, although there is no overall consensus in the field. For example, several studies have reported improvements in performance on tests of executive function for aerobically trained participants relative to controls, while other studies report no such differences. One complicating factor is that exercise may indirectly improve cognition through its effects on other factors, like sleep. In general, exercise leads to better sleep, and as we have seen, better sleep can lead to better executive function.

But the main problem with all of these approaches is that the improvements (if they occur at all) are going to be incremental and are unlikely to change your life in any discernible way. In studies where people have changed their diet, the effects observed are generally tiny and spread over a whole group of people. It is unlikely that any single participant would have noticed an improvement in their executive function at all. Some drugs might give you that extra edge, just enough to get you through your exam, but as soon as the effects wear off, you are back where you started. We've all enjoyed the benefits of a caffeine high at 10 a.m., only to be plunged into a caffeine lull in the middle of the afternoon.

But surely, if we get the balance right and get all our ducks in a row, there must be some magic formula—a “design for life,” if you will—that will improve our executive functions enough to make a real difference to our lives?

In 2024, my team conducted one of the largest studies ever to examine the relationship between lifestyle choices and executive function. As we just discussed, optimizing cognitive capacity has been the target of many recent studies that have examined the influence of lifestyle choices such as exercise, diet, and sleeping habits. Many of these studies have focused on a single factor (diet, for example) and its effect on cognitive abilities; however, we make numerous lifestyle choices every single day, many of which interact with and influence each other (exercise and sleep, for example). Our study was designed to investigate whether combinations of lifestyle choices can predict better or worse executive function in the general population.

We examined twenty self-reported lifestyle choices, such as playing video games, alcohol consumption, diet, and the amount of exercise taken, in a sample of over ten thousand participants. We even asked them whether they believed in God on the off chance that that may affect cognitive performance! All participants also completed our battery of cognitive tests at Creyos.com, and using fancy AI techniques with names like “recursive feature elimination” and “random forest classification,” we set out to determine whether there was any relationship between the lifestyle choices people make and their executive functions.

The results were disappointing. While our AI algorithm performed a tiny bit above chance—that is, some combinations of lifestyle choices were (ever so slightly) related to better executive functioning—the effects were

minimal and were very unlikely to translate into any real-world differences for individual participants. As we said in our conclusions, regardless of how well you optimize your lifestyle choices, there exists no single “design for life.”

’Tain’t What You Do, It’s the Way That You Do It

I must confess, the results of our “design for life” study disappointed me. After more than thirty-five years working in this field, I had firmly come to believe that there must be choices that each of us could make to improve our executive function, even if knowing what those choices are was a fiendishly complicated problem that would likely only be solved when we had the statistical methods—and big data—available to us. By 2024, AI techniques like machine learning were everywhere, and we had amassed more than twenty million datasets at Creyos.com that we could use to solve the problem. But the results were clear. There was no secret combination of lifestyle choices—no magic bullet—that we could use to improve our executive functions.

But that can’t be the end of the story, can it? Surely, it can’t be that we are stuck with whatever executive functions we are born with and that determines the life that each of us will lead. History is full of rags to riches stories: tales of billionaires or Nobel Prize winners who came from humble beginnings yet went on to achieve remarkable success. What did those people know that twenty million data sets and some sophisticated AI algorithms can’t detect?

Maybe they just stopped to think for a second. One characteristic of successful people in any field of endeavor, from academia to art, is that they clearly think about what they’re doing and make deliberate choices about their decisions. We’ve seen that being able to make choices about when and where to use our executive functions is an incredibly powerful cognitive weapon, and one that may be uniquely human (at least in its most elaborate form). Granted, not everyone has the freedom to make any decision they wish, because they may be constrained by finances, geographical location, opportunity, and so on. But arguably most of us have the freedom to *think*. Could this be the answer? Could the origins of genius, creativity, and

curiosity lie not in the cognitive strengths we are born with, but in how we choose to use them?

I made the point at the beginning of this book that Einstein didn't just accumulate knowledge, he *thought about it*. Likewise, I don't think Andy Warhol just threw a few random pictures on a canvas and hoped for the best; he thought about exactly what he was constructing, why he was doing it, and the impact it would have on the world. The lyrics of great songwriters like Joni Mitchell, John Lennon, and Bob Dylan aren't just words on a page; they are infused with thought, consideration, and reflection, which is why they speak to so many millions of listeners. Hitchcock constructed his movies—his personal works of art—by thinking, carefully, about how every scene would impact the thoughts of his audience.

To take conscious control of our executive functions, we first have to think about them, and by thinking about (and controlling) them, we can make the best use of whatever cognitive abilities we possess. We are optimizing not only what brain capacities we have, but *what we do with what we have*. Let's return to Steve Faloan, the student of Swedish psychologist K. Anders Ericsson. How had Faloan increased his decidedly average memory of seven digits tenfold to a record-breaking eighty? He didn't just practice—mentally churning each series of digits through his working memory until it “stuck”—that might have increased his digit span by one or two items at most. No, Faloan made his phenomenal gains in working memory capacity by *thinking about it*. He came up with a strategy to optimize whatever executive functions he was born with to achieve amazing feats that most of us would assume were unachievable. By consciously deciding to lean on information that he already had lying around in his brain (in his case, running times and notable dates), Faloan had scaffolded his existing working memory to remarkable new heights. My point is, even if we work on our basic brain functions, like memory, and make gains, those gains are going to be relatively modest. But if we work on the executive functions that *control* those more basic functions, like Faloan, we could make gains that are ten times greater.

Likewise, in that tent at the Latitude Music Festival, memory champion Richard Bowdler taught me that the method of loci can also boost working memory significantly by optimizing how we think about, and control, the way we store and retrieve information. In his case, he was also consciously

using cues readily available to him (the layout of the tent) to bootstrap his working memory—in fact, he’d made a whole career out of doing just that.

The same is true of all our executive functions. For example, as we learned earlier, most of the time our attentional system runs on autopilot, tugged by bottom-up pulls; but when we consciously take the wheel and use our top-down selective attention system, we decide what gets in and what stays out. Translate that to real life: Tell your brain exactly where the spotlight goes for the next twenty-five minutes (finish the tax form, draft three emails), then wall off bottom-up intruders by muting your notifications, and you’ll find the jobs will get done. In other words, simply thinking about attention isn’t navel-gazing; it’s a deliberate control setting that lets the executive system do its job better.

Planning is no different. Good plans start by identifying the subgoals and putting them in order—mental “waypoints” you decide before you move, rather than as you go. When people rush in without that step, they become inefficient and impulsive, exactly what we saw in frontal lobe patients who took extra moves on the Tower of London test. In practice, that means taking sixty seconds to list the subgoals, order them, and decide what to ignore before you start. The small act of thinking about planning is actually what makes planning work.

These are some of the many reasons why I have come to think that the most important thing we can do to optimize our executive functions is to *think about how we use them*. In this book, we’ve covered a lot of information about our various executive functions, including planning, working memory, inhibition, and theory of mind. In every case, we have seen examples where simply thinking about what we are thinking is what really makes the difference.

We’ve all fired off a thoughtless email or an irate response to an internet post, only to regret it almost immediately afterward. Imagine how much easier life would be if we’d stopped and thought about it for two seconds instead of acting impulsively. Likewise, how many times have you taken your eye off the ball, only to miss whatever it is you were intending to experience in the first place? Whether it’s that critical final touchdown, a shooting star, or the birth of your first child, attending to what you are attending to (or what you intended to attend to) can ensure that you don’t miss out on the best moments in life. And the next time you get into a disagreement with a friend, try exerting a little theory of mind to try to

understand their point of view before things get too heated. Most arguments don't have an absolute right or wrong; they boil down to a matter of opinion, and understanding the opinions of others can prevent a minor disagreement from becoming a major feud. Finally, as we've seen, thinking about the plans you make, and making sure you stick with them, can get you a whole lot further than "playing things by ear." Whether it's a well-structured shopping list or a meticulously planned vacation, success comes to those who plan ahead and don't let themselves get distracted along the way.

It is tempting to go through life just living with our brains on autopilot and not think at all about who and what we are and what we can achieve by being here. In fact, it's the easy way to live because it requires less mental effort. But if we just start thinking more about what we do, take control of how we behave, and get more involved in the decisions we make, we can do much better in life. Put simply, the more we think about our executive functions, the more control we have over them.

This idea—that we can capitalize on our executive functions by simply thinking a little bit more about them—has much in common with the concept of metacognition. Metacognition refers to our awareness and understanding of our own thought processes—it's our ability to think about what we're thinking. On the face of it, that feels like an executive process itself, although returning to the criterion I set out earlier in the book, metacognition does not necessarily involve managing, regulating, or coordinating our thoughts and actions in order to achieve goals. For example, reflecting on whether our solution to a logical puzzle was in fact appropriate involves metacognition, but it wasn't part of solving the puzzle in the first place. In short, metacognition involves thinking *about* the thinking; executive functions *manage* the thinking.

Thinking about what we are thinking also has some things in common with what is often termed "mindfulness." Mindfulness refers to the practice of bringing our full attention to the present moment, tuning in to our thoughts, feelings, and sensations without judgment. While this needn't refer specifically to our executive functions, being mindful of what we are planning, whether we should inhibit our desire to grab the last piece of chocolate cake, or how our actions may be interpreted by others all seem like cognitive processes that would benefit from our being more mindful of them.

Whether we call it metacognition, mindfulness, or simply thinking about thinking, it's clear that taking some conscious responsibility for our thoughts and actions and intervening where necessary to take ourselves off behavioral autopilot imbues us with a tremendous amount of control over our lives. In some circumstances, that control might be directed toward greater creativity, increased curiosity, and productiveness. On other occasions, it might be more advantageous to just go with the flow. Crucially, however, it is our conscious experiences (and how we control them through our decisions and actions) that are at the heart of how we learn about the world, how we make plans, how we interact with those around us, and how we make every decision that forms the shape of our lives.

Evolution has given us humans the neural tools to think about our own executive functions, to consciously decide to deploy them as and when they are needed, to monitor how effective they have been in any particular situation, and to change them where necessary to optimize the path to our goals. This is no more mysterious than free will, and—like free will—it is the incredible outcome of packing eighty-six billion tiny processing units into a single human brain.

And that, to me, is what executive function is: the human brain's incredible way of navigating a turbulent world, of making split-second decisions or sticking resolutely to a long-term plan, of balancing ambition with adaptation. It's the silent strength behind our most impressive feats and the quiet restraint that prevents our worst mistakes. Whether grappling with our modern-day distractions or surviving life-altering challenges, it's a tool kit of mental superpowers that equips us for both the best, and the worst, that life can throw at us.

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Conor Wild deserves a very special mention because much of my lab's best science in the last ten years has been the product of his incredible frontal lobes.

The research described in this book would also not have been possible without the many wonderful colleagues I have collaborated with over the last thirty-five years; a comprehensive list would be impossible to compile, and so again, I only include those who worked closely with me on issues relating to executive function. With that in mind, I would like to extend my sincere thanks and appreciation to Trevor W. Robbins, Barbara J. Sahakian, Julien Doyon, Micheal Petrides, John Duncan, Roger Barker, Richard Swartz, David Menon, Rhodri Cusack, Angela Roberts, Merle James, Tim Hodgson, Rob Howard, Loretta Norton, and Laura Gonzalez. I would be remiss if I did not mention the special contribution of neurosurgeon Charles Polkey. Wittingly or not, he set me off on a path of discovery that would keep me fascinated (and busy) for several decades.

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