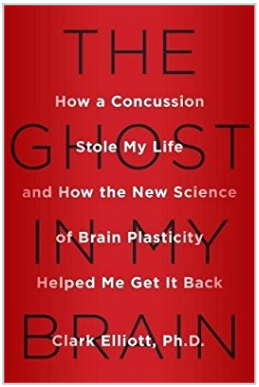

The Ghost in My Brain: How a Concussion Stole My Life and How the New Science of Brain Plasticity Helped Me Get It Back

By Clark Elliott

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The dramatic story of one man's recovery offers new hope to those suffering from concussions and other brain traumas

In 1999, Clark Elliott suffered a concussion when his car was rear-ended. Overnight his life changed from that of a rising professor with a research career in artificial intelligence to a humbled man struggling to get through a single day. At times he couldn't walk across a room, or even name his five children. Doctors told him he would never fully recover. After eight years, the cognitive demands of his job, and of being a single parent, finally became more than he could manage. As a result of one final effort to recover, he crossed paths with two brilliant Chicago-area research-clinicians—one an optometrist emphasizing neurodevelopmental techniques, the other a cognitive psychologist—working on the leading edge of brain plasticity. Within weeks the ghost of who he had been started to re-emerge.

Remarkably, Elliott kept detailed notes throughout his experience, from the moment of impact to the final stages of his recovery, astounding documentation that is the basis of this fascinating book. *The Ghost in My Brain* gives hope to the millions who suffer from head injuries each year, and provides a unique and informative window into the world's most complex computational device: the human brain.

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Editorial Review

Review

“This is a remarkable document, by a remarkable person, the most meticulous and informative account I have ever read of the effects of a traumatic brain injury on a single mind. It should be mined for years to come by all who care about the subject, and is filled with almost Proustian detail about how the brain and mind and heart respond to injury. It would have been just another tragedy, but instead, it turns into an exciting triumph, because of the tireless, ingenious, and utterly creative work of Clark Elliott and his healers—one inspired by the work of the Israeli pioneer, Reuven Feurstein, the other by a little known tradition of neuro-optometric rehabilitation, which can literally use light shone into the eyes, to treat and rewire the brain.”—**Norman Doidge, M.D., New York Times bestselling author of *The Brain That Changes Itself* and *The Brain’s Way of Healing***

“For anyone who has struggled to explain cognition or to understand what it feels like to suffer from traumatic brain injury, Clark Elliott’s fascinating account of his injury, diagnosis and then painstaking determination to heal himself reads like a how-to manual of how our brains work . . . His story gives hope to everyone out there and shines a light on the neuroplastic possibilities that exist for us all in the future."**—Bob Woodruff, ABC-TV News correspondent and Lee Woodruff, authors of *In an Instant***

"A remarkably informative discussion of brain injury.”—***Newsday***

"Elliott brings the words 'traumatic brain injury' to dizzying life."—***Chicago Tribune***

"Elliott's transformative tale will be invaluable for patients with traumatic brain injury, families, and caregivers."—***Publishers Weekly***

"Up-close view of living with the harrowing effects of a concussion... With concussions from sports injuries making the news, Elliott's easy-to-read account of his experiences is a valuable contribution to a better understanding of the condition."—***Kirkus***

“It is not often that one can gain some genuine insight into the soul-destroying and debilitating experiential world of victims of Mild Traumatic Brain Injury (MTBI). But through the brilliant descriptions that Clark Elliott provides, we can at least begin to grasp its devastating perceptual, cognitive, and behavioral consequences—its profound disruption of every aspect of normal daily life, of thinking and deciding, feeling and wanting, seeing and hearing, moving, and of our very sense of who we are. This is an extraordinary book about the brain and the mind—a book that is hard to stop reading.”—**Andrew Ortony, Ph.D., Professor Emeritus of Psychology, Computer Science, and Education, Northwestern University**

“Inspiring . . . Read it, first weep, then smile broadly!”—**Daniel Federman, Dean Emeritus, Harvard School of Medical Education, and past president of the American College of Physicians**

“A must-read for anyone in emergency medicine, trauma care, neurology, and primary care, as well as concussion sufferers and their families.”—**Ted C. Shieh, clinical instructor in emergency medicine, RUSH Medical College; chairman of emergency medicine and immediate care, DuPage Medical Group**

“I have diagnosed more than six hundred mild traumatic brain injury (MTBI) cases over thirty years of practice and know firsthand the devastating effects they can have on virtually any family. Dr. Clark Elliott’s comprehensive and creative analysis of this pathological epidemic is uniquely insightful, accurate, scary—and most importantly encouraging—for those who are afflicted with this disorder.”—**Michael P. Szatalowicz, D.C., A.O., whiplash trauma specialist**

About the Author
Clark Elliott, PhD, is an associate professor of artificial intelligence at DePaul University. He holds three teaching certificates for music, the B.M., M.M. (music), and M.S. (computer science) degrees, and a PhD from Northwestern’s Institute for the Learning Sciences with an emphasis on artificial intelligence. He lives in Evanston, Illinois.

FOREWORD

Clark Elliott was a mystery to me when we first met. Observing him through my glass front door, I saw that it took him two minutes just to find the doorknob with his hand. When I gave him the simplest of my assessment tests—copying a geometric line drawing—his body went into bizarre contortions as he struggled to complete it. It hurt me to watch this brilliant man put so much effort into such a trivial task. In my decades-long practice in clinically applied neuroscience (CAN), this case was striking. During the two-hour evaluation session, I kept asking myself, “What could have happened in the car accident eight years ago that all of these top medical doctors have missed?” In thinking over my plan for rewiring his brain, I realized that most of Clark’s cognitive and motor behaviors were likely tied to stress on his visual systems, and I wanted him to work in parallel with my highly esteemed colleague the optometrist Deborah Zelinsky, whom he went to see the following week.

Clark was an ideal client. He understood the complexity of the brain and the relationship between sensory input and behavior. And he was compliant, faithfully completing the rigorous cognitive exercises that I created for him—the brain puzzles he was to solve on a daily basis. Most important, he carefully documented his behavioral changes so that I could move him quickly through the exercises that would allow him to regain control of his personal and professional life.

Clark’s story is remarkable. Through his scrupulously documented recovery, he gives a voice and provides hope to millions of people, referred to as the *walking wounded*, with mild to moderate traumatic brain injury. The plasticity of the human brain is both its power and its weakness. Although the life-sustaining parts of the human brain are “hardwired,” the cognitive parts (located in the neocortex) are not. The part of the brain that allows people to think, to plan, to hope, to dream, to understand language and math, and to recognize themselves and others, is highly malleable.

This plasticity allows people to change their minds and to control their behavior, but it is also this part that suffers the greatest loss from brain injury. Much to the frustration of doctors and patients alike, cellular damage is microscopic and may be diffuse throughout the brain so that conventional scanning technologies cannot detect it.

By the time high-functioning individuals with post-traumatic head injury notice that their memories are not what they used to be, or that they have difficulty thinking through a problem they could once have easily solved, massive brain damage has occurred on a microscopic level. Because their symptoms are medically unverifiable and therefore untreatable, they are usually dismissed as the walking wounded, destined to suffer

the pain, frustration, and humiliation of not knowing how much longer their condition will last or how much worse it will become. The *Designs for Strong Minds* system I have developed to treat such clients who come to me is a program based on a neurocognitive model that relies on the brain's plastic, reconfigurable nature, and uses *attention, intention,* and *rehearsal* to implement learning and behavioral change.

It is important to give credit to two individuals who contributed to Clark's cognitive restructuring success. Professor Reuven Feuerstein in 1981 introduced me to the original theoretical framework and the system that are the basis of my work, where the tools are *context-free visual puzzles* organized by logical structure, and the technique is *mediation,* to change the structure of the brain. It is from Professor Feuerstein that I learned "Intelligence is plastic. . . . Cognition is modifiable at any age." And Christine Williams of NASA provided me with the opportunity to work with our top scientists, engineers, physicists—literally our rocket scientists—from 1998 to 2005. The tools, more than three thousand paper-and-pencil instruments that I created for NASA (joined by almost ten thousand instruments for children), became the framework, the structure, and the workbooks for Clark to regain his high-level cognitive functioning skills.

Warm regards,

Donalee Markus

www.designsforstrongminds.com

FOREWORD

After a car accident disrupted his brain function, Clark Elliott embarked on a long and difficult journey to regain mental and physical capacities. His recovery testifies to his own determination, and also to new therapeutic techniques developed by Dr. Markus and myself. At one level, Clark's story stands out because of his tenacity in pushing through successive phases of recuperation. At another, it supports the concept that visual inputs can affect brain function, which in turn can promote better coordination between brain and body systems. This theme that eyeglasses and mental activity can alter brain function, and brain function alters body function, remains at the forefront during the entire book and is very eye-opening to read.

Central eyesight, which allows us to "see" an object, is the last and slowest visual pathway to be activated during processing and yet, mistakenly, the most common way of evaluating visual function. Other pathways include peripheral eyesight that allows the brain to set a context for such objects, and many non-image-forming retinal pathways that link the external environment to internal systems that control sentience and metabolism. This last group of pathways is routed beneath conscious awareness directly from the retina to the body and affects such critical systems as balance, posture, hormones, neurotransmitters, circadian rhythms, etc. The interaction of all the non-image-forming signaling pathways modulates peripheral eyesight, and in turn the efficiency of central eyesight. Brain trauma such as that which Clark suffered often wreaks havoc on the balance of these three main visual systems.

My work in the field of neuro-optometric rehabilitation is based on the original ideas of Harry Riley Spitler and A. M. Skeffington, in the 1920s and '30s respectively. Spitler observed that specific color frequencies affected body function, and Skeffington noted that some people could see targets clearly, yet remained visually uncomfortable, often rejecting glasses and preferring to have blurry eyesight. This line of thinking that the eye has connections with both the body and the mind was advanced further by notable optometric contributors including Gerald Getman, who identified links between visual processing and motor development, and Harry Wachs, who used Piaget's concepts to link academic development in the mind with motor stimulation of the body. In the 1980s, optometrists Bruce Wolff and John Thomas used the image of

an eye being one of many doorways into brain function, having entrances and exits to synchronized, multisensory processing. In the 1990s my mentor, Albert A. Sutton, taught me never to think of the eye in isolation. A decade later, Selwyn Super's fascinating book on the differences between intention, attention, and inattention helped me to solidify rehabilitative concepts. As of 2014, more than 125 European doctors are expanding their thinking to include eye/ear interactions that can be affected by glasses, based on the ideas behind my patented Z-Bell™ diagnostic system.*

One outgrowth of these decades of clinical research has been the intentional use of therapeutic glasses to break old neurological habits, allowing new habits to develop beneath conscious awareness. Neuro-optometric rehabilitation, using customized lenses, can often help patients with different kinds of injuries recover from such lingering symptoms as difficulties with balance, motor control, seizure activity, and executive functioning. Thousands of articles on retinal circuitry—linking modern neuroscience with optometry—describe the pervasive integration of brain and body systems. At the heart of neuro-optometric rehabilitation is how such research can improve the lives of patients. Babak Kateb, M.D., another visionary, founded the World Brain Mapping Association based on the interdisciplinary concepts of translational medicine. At the association's international meeting this year, neuro-optometry will be one of the featured tracks, because contemporary retinal research has clearly demonstrated how optometry can profoundly affect brain and body functions.

Clark's amazing saga was written on the basis of his meticulous notes from the moment of his brain trauma until his remarkable recovery almost a decade later. He documents not only the intricate balance between visual/spatial processing and cognition that makes us human, but also the arduous passage from one stage of recuperation to another. As readers follow his story, it is hoped that they will gain a greater understanding of how the mind-eye connection is much more than meets the eye, and how people with many types of brain problems can be helped by carefully prescribed, nontraditional eyeglasses.

Deborah Zelinsky

www.mindeyeconnection.com

AUTHOR'S NOTE

This book is intended for those who have suffered from a brain injury and know it, for those who have suffered a brain injury and will not know it until they recognize aspects of their lives in these pages, for those who have family members or friends who have suffered a brain injury, and for those who are simply interested in the magnificent inner workings of the most powerful computing device on earth: the human brain.

Stories of my fellow concussion survivors have flooded the media in recent years: returning combat veterans who have suffered traumatic brain injury (TBI), professional athletes who are demanding accountability from sports leagues and helmet makers, and some of our country's youth who have suffered troubling sports concussions. Given the *millions* of TBIs that are even reported each year in the United States alone, this is, yes, a quiet plague of epidemic proportions. Yet our society is only grudgingly coming to recognize that concussions are serious and life-changing injuries that may have lingering, undiagnosed symptoms such as emotional difficulties, fatigue, learning problems, and social problems that can last a lifetime.

In my experience, the medical community's standard of care for certain classes of TBIs has not yet caught up with effective new treatments that are available. There are many excellent physicians who have been exposed to current research in "brain plasticity" (wherein parts of the brain can be trained to compensate for

other, injured parts), especially those physicians working with sports and military head injuries. However, it is unfortunately true that many M.D.s, including leading neurologists—as well as putative leading rehabilitation institutions—are as of the time of this writing unwittingly out of date when it comes to accurately diagnosing and treating concussion. This is unspeakably sad for those who are needlessly suffering and believe they have nowhere to turn.

The later chapters of this book that cover the science behind my recovery may also be highly revealing for those who suspect that they suffer from some form of attention difficulty, such as ADD, or suspect that a family member does. In the process of my recovery I realized that many of the features of such attention difficulties significantly overlap with those manifesting as concussion symptoms. From the many anecdotes I've heard from my university students, and others, I think we should be highly suspicious that some of these attention difficulties are rooted in prior, sometimes even mild, head injuries. How many times have I heard, "Oh, yes—now that you ask, I did start having this trouble last year after I had that [car accident / skiing mishap / skateboard fall / soccer concussion]. . . ."

The small changes that can occur in one's brain from even a quite forgettable bump on the head can masquerade in subtle ways such as personality oddities, trouble with multitasking, sleep disturbances, and even just growing old. Who would have thought to consider that slip on an icy doorstep five years ago as the culprit behind having a slight sense of being out of sync at unpredictable times, or having trouble managing appointments?

As a professor of artificial intelligence and cognitive science, I have shared some of the concepts covered in this book about how brains work with my classes, including the ideas behind several leading-edge cognitive restructuring, and neuro-optometric, treatments. It has been striking that I have never failed to have, in each such course, at least two students talk to me after class about their extreme interest in the material because of their own information-processing difficulties. This suggests to me that the kinds of brain difficulties experienced by *concussives* (as in, those who have suffered concussions)—albeit in much milder forms than my own—are far more widespread than we might traditionally suspect, especially among high-functioning, intelligent people who are very good at masking such problems.

One of the things concussives share is the feeling of having become an alien being. We still walk and talk and act as though we are part of the human race, but it doesn't feel that way inside. Essential parts of our brains that convey what it means to be fully human have disappeared—vanished in that moment of impact when we tripped on the stairs, or crashed into an arena wall. Instead there is a strange feeling of nostalgia, a longing for who we used to be.

Normals—those who haven't suffered from concussions—will take for granted the countless small operations their brains perform as they think and gracefully move their bodies through the day. But a concussive loses the ability to manage the staggering complexity of the systems that implement these operations, and as a result loses not only basic cognitive and motor functions, but also a larger sense of self-identity, and identity in relation to the world. This makes us odd beasts—a cross between what amputees may experience with phantom limb syndrome, and what *hemispatial neglect* patients have when they suddenly lose half of their world: On the one hand, with a phantom limb, amputees are constantly reminded of what they used to be, of being whole. On the other hand, neglect patients are missing part of themselves and their world, and while they feel a sense of loss, they can no longer even imagine what it is they are missing. For a long time I lived in such a dual-natured limbo.

This book captures my harrowing yet ultimately fascinating odyssey as a concussive. For almost a decade, and even while struggling mightily—sometimes just to get through a doorway, or down a flight of stairs—I was constantly observing, analyzing, and recording the events unfolding in my life, and the ways in which

my damaged brain was trying to make sense of them. I took twelve hundred pages of notes, and through them I became the subject of my own long-range experiment in cognition—exploring the relationship between mind and body, and the inner mind and outer world. Along the way I learned a great deal about how the *healthy* human brain works as well—leaving me in awe of this sublime and formidable computational device.

The book's title is a play on the phrase *the Ghost in the Machine*—and thus an indirect allusion to the seminal French philosopher René Descartes's idea of a mind-body dualism. Descartes believed these two agencies were separate—that the mind existed separate from the body. Oxford philosopher Gilbert Ryle disagreed, and in 1949 used the phrase to poke fun at Cartesian dualism. Although the jury is still out on this question, I know from personal experience—such as on a snowy night we'll soon see in downtown Chicago—that the mind and body are intricately intertwined. But the meaning of the title goes beyond this duality. Readers will come to understand that the ghost in my book is the sense of my true self—the "me" that was sent into exile in the moment of a car crash. Years later I underwent cognitive treatment based on the new principles of brain plasticity. Shortly thereafter, one evening outside my office at DePaul University, I felt the ghost return. My old self—the ghost of who I had been and who I so longed to be once more—had come back. I wept tears of joy that I was no longer sentenced to life as an alien living among real humans.

Above all, this is an illustrated tour through the odd, awe-inspiring, painful, scary, tragic, and fascinating world of brain injury, but one that in this case has the all-too-rare happy ending—an ending that is yet also likely to be possible for many thousands of those still exclusively locked into more traditional treatments (or nontreatments, as the case may be) for concussion.

As recently as four years ago I was told by local experts in the Chicago medical community that the only course of action I could take to deal with my symptoms was to learn to live with them. This would have entailed giving up my tenured position as a university professor, retiring into poverty from all forms of work, giving up the custodianship of my children, and perhaps becoming a ward of the state.

And yet today, through the courageous work of two brilliant Chicago-area researcher-clinicians, each of whom works at the leading edge of brain science relative to certain kinds of traumatic brain injury, I am almost without symptoms. The efforts of Donalee Markus, Ph.D., who rebuilds brains by using puzzles, and of Deborah Zelinsky, O.D., who accesses the visual cortex and regrows brain pathways using prescription eyeglasses, gave me back my life.

This is my story.

PART ONE

CONCUSSION

MIDNIGHT

Just before nine o'clock, on a frigid night in early 2002, I completed my three-hour lecture on artificial intelligence at DePaul University's downtown campus. I was exhausted, and ready to head for home, but it took me another two hours to make my way to the sixth floor of the building across the street, then crawl down the hall to my office and there rest in the dark and the quiet until I was able to attempt my journey north to Evanston. Finally, at eleven, I left the building again and headed off through the brutal wind,

intending to walk the five blocks to my car, parked near the lake on Columbus Drive.

Two and a half years earlier I had been rear-ended while waiting at a stoplight in nearby Morton Grove. It had been a relatively minor accident, but it had left me with brain damage from a concussion. Because of it, I found the scene now unfolding to be quite common: sitting behind the podium in my classroom until long after the students had left, surreptitiously crawling down the hallways when I could no longer walk, then later lying on the floor of my office doing absolutely nothing until I lost track of time. And now I had to face a bizarre gauntlet that would take me across nearby Grant Park to my car, before making the long drive home.

It was scary cold over by the lake at this late hour, but I thought: *I can make it*.

I was walking reasonably well—but quite slowly—when I left my building on Wabash next to the El tracks. As I rounded the first corner at Jackson Boulevard, snow flurries began swirling around my head, flickering in the streetlights. Cars carrying late-working professionals raced down the street next to me as they too headed for home. I started having trouble navigating through the visual chaos around me, and I began to lose my balance when the wind gusted around the corners of the skyscrapers. I shied away from the traffic, and reached out to hold on to the sides of the buildings as I walked. By the time I had gone only two short blocks my brain was already beginning to tire again from the effort.

I stopped to rest on the corner before crossing through the late Michigan Avenue traffic. But even then I only made it to the center island before having to pause for several more traffic-light cycles. I thought, *This is going to be tricky*, and considered turning back. But turning back would mean forming another plan for how to get home, or perhaps where to sleep, and I couldn't manage it. *Easier to go on*, I thought. *It's just across the park.*

By the next block, as I crossed over the Illinois Central tracks and headed up the slight incline, I was moving ever . . . more . . . slowly. I finally made it to the edge of the snow-encrusted park, and started diagonally across it toward my parking spot on the other side. I was by now shuffling along with a strange, slightly pigeon-toed gait and only managing a few inches with each step. My jaw hung down, and my head bobbed from side to side as I moved.

I felt the onset of a visual impairment similar to what cinematographers call the "Dolly Zoom Effect," famously used in the opening rooftop chase of Hitchcock's *Vertigo*: Jimmy Stewart is hanging from a rain gutter about to plunge to his death. As he looks down into the alley below, the background visual scene bends and the alley floor drops away, even though the foreground stays the same size. This was the scene playing out in front of me now, except in real life, and I couldn't stop it. With each step I took forward, the distant goal toward which I was walking appeared two steps farther away.

Despite the frightening challenges such breakdowns engendered, I often perversely experienced a kind of existential wonder during these episodes as well, as I watched the great machine disintegrating before my eyes. I became a rare observer of the fascinating structures from which the unfiltered world was actually formed. Simple relationships all around me deteriorated into an unfolding chaos of increasingly eccentric patterns. Time morphed into something hypnotically strange and disjoint. It was all spooky geometry linking one frozen moment to the next.

From within this dim labyrinth I was still just barely managing to power the engine of thought. As I progressed across the park, I had to carefully map out the *shape* of each step from within the shadowy white images, and force my legs to follow the path these shapes described: *left foot forward . . . right foot forward . . .* But my world was growing increasingly fragmented, and as I lost my ability to put the elusive fragments together to form visual goals, I simultaneously lost the ability to walk.

After *forty minutes*—three quarters of the way to my car but still less than four blocks from where I had started—I stopped moving altogether. My brain resources were used up. No crafty logic, no amount of physical strength, and not even an abundance of raw will could bridge the gap between my intention and my feet.

I had known the risks of getting stuck in the park when I went to work in the early afternoon, but I made my decisions from the most deeply felt sense of obligation. Not only did I love my work at the university, but keeping my job was not negotiable: ten people lived on my salary, including what would soon be five children. What other real choice did I have but to run the various gauntlets when I had to, including this one tonight? So now, once again, here I was. From long experience I knew there was not much for me to do but simply wait to find out how this particular scene in my life was going to end.

At this point my world had collapsed inward on itself: the concepts of *distance* and *left and right* had become dim memories. Every discrete event, independent of all context, slowly emerged from the ether and then receded into the void. My sensory filters had deserted me too, and within the great arc that was left I didn't even know where my body ended and the rest of the world began.

So now what? Despite the circumstances I was still at least the shell of a professor who worked at building artificial brains. It was my job to solve hard problems. I looked down at my feet and shouted at myself to walk, but I knew it was hopeless. I had lost the mysterious *initiative* that impels us all forward when we walk, and I knew that without brain rest I wouldn't be getting it back. I considered lying down in the snow—which would at least give my damaged vestibular system a rest—but because of the bitter cold it seemed unwise. I might never get up again.

In the end I just stood there staring into the distance, absolutely still: slowly and painfully freezing, my jaw hanging slack, my arms out to the side for balance, doing nothing at all. I was seeking a special kind of visual peace, a calming of the outward landscape that would give my brain the cognitive rest it needed. But I had to be careful not to slide into a meditative state—because meditation would require attention and the ability to sense some mystical structure in the nothingness. Each of these would require the forming of spatial images and further deplete the scant brain resources I had left. What I needed instead was a completely different kind of nothing: a run-of-the-mill, down-to-earth, completely, utterly boring nothing of the kind that tortures schoolchildren at 2:30 in the afternoon on beautiful warm days in June.

Midnight was approaching, and I started to shiver uncontrollably. After another twenty minutes—*an hour since leaving my office*—I had the vague thought that perhaps this was finally the end; I would become just another statistic of exposure, lost to the cruel Chicago winter. I reflected with some resignation—an internal shrugging of my shoulders—that this was going to be a lonely way to die, alone in the wind and the cold like this, unable to move. I felt ashamed of my helplessness—all I needed to do was start walking. But there was nothing I could do.

Because of a neurological quirk, I was holding my hands in an odd position, forefingers and thumbs sticking up and outward to form an "L," while my other fingers bent downward—apparently some elemental effort to help me keep my balance. With conscious effort I clenched my hands into fists inside my padded leather gloves to keep them warm. But going against my primal neural programming in even this minor way drained me of the last effort I could muster. My system was shutting down.

Be brilliant, Clark, and come up with a solution. But don't you dare use your brain—save every last mental resource to connect your body to the visual goal up ahead, and move your feet toward it. I wished for some magical solution that would float up out of the ether of my subconscious, one that I could conceive of without having to think at all. But I didn't know how to make this happen.

I was so tired—so bone-deep achingly tired. And somewhere in the cauldron of forbidden thoughts that I could not allow to form, I was also tired of being so tired—just like this—all the time, of having to struggle each day to perform the simplest of actions. But this was not a matter of emotional distress—most days my natural disposition was still upbeat, and I was often simply a careful observer, curious about what my obviously changed future would bring. My global fatigue was, instead, a deep exhaustion from the *physical* grind of thinking, and the resulting constant pain.

After a while an overwhelming desire came over me to lie down in the soft white blanket of snow covering the grass in front of me. The irony was that even though I was aware of the risk of dying, I was by this time no longer able to see what this meant. I couldn't conceive of it—something about time, something about calendars, something about endings, and the right-hand side of a timeline ending in nothing. The difference between life and death had lost its structure in the same way the line between my inner self and the world around me had vanished. It was too much, too hard, too fuzzy to try to understand. I just wanted to curl up with my back to the stinging wind, and disappear.

But in another twist of irony, *I didn't know how to lie down*. I couldn't see the relationships between the vertical and horizontal planes around me, or how my body fit into them either. My concussed brain couldn't make sense of motion, and the sequence of motion over time. It didn't "get" any of this in the geometric way that would have allowed me to move. Without *seeing*, I couldn't initiate, and without initiating I couldn't lie down in the snow to die. . . .

THE SIZE OF THE PROBLEM: THE MAGNIFICENCE OF THE HUMAN BRAIN

The human brain is a magnificent device, and the complexity of the human mind it supports is staggering to ponder. It is not possible for us fully to understand the enormity of the changes that take place when someone suffers a traumatic brain injury (TBI)—a concussion*—without first having some idea of the phenomenal (astronomical!) computational powers of the device we are considering.

Some supercomputer researchers estimate they'll need *exaflop* computing speeds (1,000,000,000,000,000,000 floating-point operations a second) to model a single human brain. Put in layman's terms, that's 50 *million* desktop computers all networked together—and a single such modern desktop is a pretty powerful device, far more sophisticated than the big boxes of the 1960s and '70s that might each support a company with thousands of employees. Another way to picture this is that 50 million desktop computers laid end-to-end would stretch halfway around the earth, with another three thousand miles to spare.

For those of us who are trying to mimic some of the brain's systems, these are not even the impressive numbers. Rather it is the *design* of the system—the organization of the software, so to speak, and the impregnated information—that is the truly extraordinary aspect of who we are.

Imagine for a second that you are back standing outside the front door of the place you lived when you were five years old. What color is the door? Does it have glass in it? Does it open outward or inward? Are there steps in front? A landing? Is there a doorknob or a latch? On which side are the hinges? Remember that door?

Estimates on the size of human memory vary widely. We are not even sure how to define it because, for example, retrieving information from memory also modifies it at the same time. But by almost all reckoning, it is very, very, large.

To get a handle on the numbers, let's imagine that we are writing everything we remember down on sheets of paper, in a 12-point font, on both sides of the paper (one byte per character). The more we have to remember, the more pieces of paper we put on our stack. The size of our memory is the height of the stack of paper. So how tall is the stack?

Harvard researchers have been able to store large amounts of information in DNA molecules, and if our brain were made of pure DNA, our memory-capacity stack of paper might stretch out into space for 2,485,795,454 miles—or circle the earth 100 million times. So we know that biological systems can store a great deal of information! Many estimates of actual human memory capacity have the pile of paper extending a much humbler distance—merely up to the moon and back.

But now we ask about the real magic—how did you get 238,000 miles up to the moon alongside that stack of paper, halfway back, another six hundred miles, twelve hundred feet, eight inches, fifty-eight pages, and two paragraphs along to find the exact location of the information about that front door you haven't seen in twenty years? How did you know to look there? How did you do that in less than a second? Because that is typically how long it takes us to retrieve that long-disused information . . .

What holds us in the greatest awe is not merely the hardware, but rather the design of the truly elegant system that runs on it, giving us the human mind.

And when we start talking about our *minds*—that which really makes us human—the numbers get even more staggering. At the University of Leicester, James Nelms, Declan Roberts, Suzanne Thomas, and David Starkey calculated that capturing everything that could contribute to a human's mental state would require 2.6 tredecillion bits (2.6 followed by 42 zeros).* In their fun paper, they note that to transmit that much information using a *Star Trek*–like teleporter, but at high-speed Internet bit rates, it would take . . . several hundred thousand times the current age of the universe.

To simulate concussion damage to a human brain then, we'll need to gather together those 50 million desktop computers, the 500,000-mile-high stack of paper, and the almost inconceivable amount of information it takes to construct a human *mind*, then loose a hurricane on the system, ripping out network lines, laying waste to vast sections of memory, and sending landslides to smash hundreds of thousands of computers.

In this way we can imagine the size of the problem we are trying to address: with a single blow to the head—in that moment of impact from concussion—we've caused staggering losses in computational power to the unimaginably complex systems that go such a long way in making us human.

Fortunately, this magnificent device is also largely plastic and able to reconfigure itself over time, borrowing a little here, and a little there, and in this way able to restore much of its lost functioning—though, as we will see, not always without a little clever jump-starting of the stalled processes.

THROUGH THE KALEIDOSCOPE

. . . My time was running out, but I was still stuck in the middle of Grant Park. And now, not only was my brain fatigued, but my mind was also growing dull from the onset of hypothermia. My body was giving up. I could not feel my toes or my fingers. I was fading away.

The question was, *How do I get moving before it is too late?*

Then magic happened. I swayed in the wind and tipped forward. My left foot moved on its own to keep me from falling, then my right foot, then my left again. *Stump, stump, stump.* I stared intently at the now inconceivably distant horizon where I knew my car was. *There is where I am going.* My jaw dropped farther, and my tongue hung down in my mouth. I could not feel the soles of my frozen feet. My index fingers popped out again, to help with balance, and I walked with a bent-kneed, shuffling gait—like a zombie. I willed myself toward my car a few inches at a time.

Within each unfolding moment, my world was made of fractured images: little scenes of blades of grass poking through the snow, of darkened tree branches, lights in the distance, and night shadows. Nothing was whole. The Dolly Zoom Effect was in full force, and though I knew, intuitively, that my car was just up ahead—thirty feet away—it still *looked* an impossible half mile distant. My feet were again coming . . . *to* . . . *a* . . . *stop.* . . . Out of desperation I changed tactics, and just *reached* for the car, let my feet walk toward the *feeling* of it, almost within my grasp. And then at last, from within the chaotic tunnel of my senses, my long journey—the first stage in the gauntlet—was finally over.

Now began the second stage. I still had to unlock the door, get in, and turn the car on. But I couldn't work it. I'd lost the concept of *center.* I had no internal representation, or visual understanding of *circle, target, middle, inside.* . . . Without these concepts I couldn't get my hand to move toward the lock, or put the key in the slot.

This situation may be a little difficult for nonconcussives— "normals"—to comprehend. There was nothing wrong with my eyes themselves, and I knew what I had to do: *put the key in the lock, open the door.* The problem was that I could not spatially or cognitively conceive of the *shape* of the problem. I stared at the door, the lock, my hand, the keys in my hand, wanting to get the door open but unable to form a physical plan to achieve my goal. I even knew the concept of *center* was still somewhere in my brain—I could feel it—but I just couldn't access it. I thought, *If I can't unlock the door, I'm going to have to walk back to my office and try again later.* I shuffled around to the front of the car and slipped down onto the frozen slush in the street, with my back against the car's front bumper. I knew I couldn't make it back to my office. I had no plan at all. No voice spoke. No thought came to me for a long time.

Then, from within the kaleidoscope, the magic rose up one last time. I pulled my stiff and cramping body to my feet. With a final extreme effort, my eyes saucer-wide and three inches from the door lock, my right hand waving around in random circles as though with no direction at all, I finally found the lock, pushed my key in, and opened the door.

I had passed through the second stage of the gauntlet.

Now came the third: maneuvering my body through the doorway in the side of the car. But once again, I couldn't *see* it. I couldn't make sense of the opening through which I was to pass. I pleaded with myself: *Get in the car, you idiot. Don't think about it—just get in and sit down.* But I couldn't do it. Instead I stood there staring off into the void, as I felt myself falling into the tunnel that reached out before me. My eyes grew wide with the effort.

Yet over time I'd developed strategies to compensate for doorways. When I couldn't propel myself in the usual way, I'd learned to spin, and dance myself through them. But now, in addition to not being able to *see* the opening, I could no longer *turn right* either. The right side of my world just tapered off into oblivion. So instead, I turned left, away from the door and away from the seat—all the way around in a full circle. I turned once, then again, and then again after that, using a strange-looking, index-fingers-out, head-turned-sideways, half-swinging motion. At last I was able to weave and bob myself into the car.

Thankfully, getting the key in the ignition was easier, and within five minutes I had the engine running. I

glanced at the clock on the dashboard. *Twelve-thirty*. It had taken me an hour and a half to make the five-block trip from my office.

I rested with the car idling until 2:00 A.M., staring at a tree in the park, completely still, completely exhausted, unaccountably hungry, but warm. A tricky moment came and went, as a suspicious cop came by, opened his window, and demanded to know why I was sitting there idling the engine. But in the end it was too cold to get out of his car, so after "rousting" me in this way, he drove away.

Soon after, sufficiently recovered, I headed for home. I never drove my car when I was under cognitive duress. But as long as my brain was sufficiently rested when I started out, then I would be okay to drive. In fact, if I was not too debilitated when I set out, the act of driving was itself restorative. Something about the staring straight ahead, and the regular motion along the sides of the road from the vanishing point past the periphery of my eyes, helped ease my impairment. Understanding directions could be tricky, as could making driving decisions, but on this night I was mindlessly following a well-worn path home, and I made the trip in about thirty minutes, without incident.

I had passed through the fourth stage of the gauntlet—but I was not done yet.

It took me another hour to get into my house from my car, though I was parked only forty feet from my front door. Finally, at 3:30 A.M., I dropped my belongings on the floor, removed my shoes, climbed the stairs to my bedroom, and lay down on my bed. In this state, sleep was still not possible. I knew that the visual processing required for dreaming would overload me when my brain was this tired. I would get sick. So, instead of sleeping, I lay in bed staring at the ice-covered branches outside my window for another hour. Then, with my brain sufficiently recovered, seven and a half hours after my class was over, I finally let myself drift off.

Another day in my life as a concussive had come to a close.

THE CRASH

On September 27th, 1999, my world as I had known it for forty-three years ended.

I was sitting at a stoplight at the intersection of Oakton and Gross Point Road in Morton Grove, Illinois, on my way to give a lecture at one of DePaul University's suburban campuses, waiting behind two other cars. A steady drizzle was falling.

Without warning, a Jeep Cherokee skidded on the wet pavement and slammed into the back of my Mazda sedan. My head bounced off the headrest behind me, and then was flung forward. I saw stars, and blacked out for a second. I was groggy, but pulled my car out of the busy intersection, around the corner, and parked on the side of Gross Point Road. I felt shaken up, but only in the way anyone who had been in a relatively minor car crash might.

A Morton Grove police officer arrived to take the accident report, and I got out of my car to meet him.

"Get back in your car and sit there until the ambulance comes!" he said, after he got a look at me. "I'm calling them now." This was puzzling to me. I couldn't understand why he was so concerned.

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